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RESEARCH ARTICLE

Agroforestry in temperate-climate commercial agriculture: Feedback from agroforestry practitioners in the Mid-Atlantic United States

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Industrially managed annual monocultures are the primary agricultural system used to grow most crops in developed countries. These systems necessitate the destruction of natural ecological complexity for their management and contribute substantially to the environmental problems facing society in the 21st century, including climate change, biodiversity and habitat loss, water pollution, topsoil loss, and desertification. Agroforestry is a promising set of alternative practices that involve integrating trees into agricultural systems to optimize biophysical system interactions and achieve a range of environmental and economic benefits. Much of the agroforestry literature has focused on potential adopters rather than farmers who have implemented agroforestry, but researchers and farmers alike stand to gain from insights into farmer experiences. This study aims to address that gap through qualitative interviews with farmers in New York, Pennsylvania, and Maryland who utilize production-oriented agroforestry. Perceived benefits of agroforestry included: improved climate resilience; lifestyle and mental health benefits; improved water management; improved soil health; increased presence of wildlife; improved livestock wellbeing; improved business resilience; provision of food, fuel, or fiber; improved ecological connectivity; reduced need for purchased inputs; low labor requirements; improved yields; improved pasture or crop health; and high product quality. Perceived challenges included: early setbacks; negative interactions within agroforestry systems; high labor requirements; difficulty mechanizing; tree establishment work; delayed or uncertain yields; novel crop challenges; meat processing challenges; difficulty planning for the future; high startup costs; and high management complexity. Farmers identified the value of both farmer–farmer networking and government support in the form of flexible and context-specific grant funding, system examples, business planning, and technical assistance. Many of the challenges farmers face can be overcome with agroforestry system designs that optimize early cash flow, balance labor productivity and environmental outcomes, and allow for harmonious integration of animals and appropriate-scale machinery.

Keywords: Agroforestry, Agroecology, Agrobiodiversity, Diversified farming systems, Perennial agriculture, Permaculture

Introduction

In the past century, agricultural policies and economic conditions have encouraged the development of industrial agriculture, incentivizing farmers to maximize yields using manufactured inputs and mechanization, while at the same time discouraging more sustainable systems (Altieri, 1999; Foley et al., 2005). Simplifying agroecosystems into industrial operations made the substantial yield increases of the past century possible, but also caused the loss of ecological linkages, poor cycling of energy and nutrients, and increased dependence on external inputs (Altieri and Nicholls, 2005). Industrial agriculture is now a massive contributor to the environmental problems facing the world in the 21st century (Foley et al., 2005), including climate change (Edenhofer et al., 2014; Crippa et al., 2021), biodiversity and habitat loss (Scherr and McNeely, 2008; McNeely, 2016), nutrient pollution (Mekonnen and Hoekstra, 2015), topsoil loss, and desertification (Altieri, 1999; Sivakumar, 2007). Because these negative impacts are coupled with the food demands of a growing population, the need to reduce input use (McNeely, 2016), and the increasing effects of climate change worldwide (Luedeling et al., 2014; Burrell et al., 2020), a complex task arises: growing more food with less environmental impact, in a system that is resilient to extreme weather and a changing climate.

Fortunately, the ecological intensification of agricultural systems can help address many of these challenges. Ecological intensification is a variation on the earlier concept of "sustainable intensification" (Pretty, 1997) which emphasizes the orchestration of interactions among

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agroecosystem components to reduce farms' dependence on external inputs while maintaining or increasing system productivity (Bommarco et al., 2013; Kremen, 2020). Ecological intensification is achieved by increasing agrobiodiversity (Kremen and Miles, 2012) and positioning agroecosystem components in beneficial relationships, mimicking the structure of natural ecosystems (Scherr and McNeely, 2008). Agroforestry is one agricultural model for ecological intensification, and is defined as the integration of trees or shrubs with other crops and/or pasture to optimize the benefits arising from biophysical interactions among agroecosystem components (Brodt et al., 2020). The USDA promotes five common types of agroforestry, including alley cropping, silvopasture, forest farming, windbreaks, and riparian buffers (Schoeneberger et al., 2017); however, farmers also use systems outside these classifications, such as forest gardens or "food forests" used primarily in urban and peri-urban contexts (Kumar and Nair, 2004; Park et al., 2019) and entomoforestry, which combines insect and forest production (Brown et al., 2018).

Agroforestry systems foster agroecological health by increasing farm biodiversity (Schultz et al., 2004; Perfecto and Vandermeer, 2008), creating a heterogenous ecosystem matrix that facilitates the movement of forest species between patches of natural vegetation (Perfecto and Vandermeer, 2008; Moreira et al., 2015), and supporting healthy populations of insects and other wildlife (Asbjornsen et al., 2014; Moreira et al., 2015; Bentrup et al., 2019). They also increase soil infiltration capacity, reduce the potential for erosion, and improve soil structure, microbial activity, and nutrient cycling (Jose, 2009; Paudel et al., 2012; Asbjornsen et al., 2014; Cardinael et al., 2020). Agroforestry systems can offer economic advantages because they do not need to be replanted each year (Molnar et al., 2013) and often require fewer fertilizers, pesticides and other inputs than annual monocultures (Scherr and McNeely, 2008; Asbjornsen et al., 2014; Hatt et al., 2017; Cardinael et al., 2020). Agroforestry systems can help farmers utilize farmland marginal for other crops, making it more productive while improving soil quality (Molnar et al., 2013). They are also more resilient to flooding, drought, and severe weather events (Scherr and McNeely, 2008), and their agrobiodiversity helps mitigate risk for farmers (Ramírez et al., 2001; Asbjornsen et al., 2014; Fonteyne et al., 2022). Some agroforestry systems can have twice the return on labor (Armengot et al., 2016) and up to 80% more productivity per acre than monocultures (Fahmi et al., 2018; Santiago-Freijanes et al., 2021).

Although much of the world's agroforestry happens in the tropics (Nair et al., 2021), agroforestry has been used in temperate regions for millennia. The agroforestry systems of today resemble those used by indigenous people across the world and in North America, which are some of the oldest continuous forms of agriculture in existence (Berkes et al., 2000; Lovell et al., 2021), and are being used to inform agroforestry practices in temperate regions through various collaborations (Rossier and Lake, 2014; Bosco and Thomas, 2023). Agroforestry also has a long tradition in Europe (Herzog, 1998; Eichhorn et al., 2006; Nerlich et al., 2013; Bentrup et al., 2019), and some early 20th century precedents in the United States (Molnar et al., 2013). Worldwide, several large organizations work to research and promote agroforestry, including the World Agroforestry Center (ICRAF) in tropical areas and the European Agroforestry Federation (EURAF) in Europe. In North America, the Association for Temperate Agroforestry (AFTA) is a nonprofit focused on promoting the wider adoption of agroforestry in temperate zones; it is affiliated with the University of Missouri Center for Agroforestry and co-sponsors the biannual North American Agroforestry Conference (Association for Temperate Agroforestry, 2023). The USDA's National Agroforestry Center is a dedicated research and extension agency for agroforestry, with the stated mission of advancing the health, diversity, and productivity of working lands, waters, and communities through agroforestry (USDA National Agroforestry Center, 2023a). The Savanna Institute is an independent agroforestry research and outreach organization with a significant presence in the Midwest and a mission to lay the groundwork for a resilient, scalable agroforestry practice (Savanna Institute, 2023). The practice of agroforestry in the United States is heavily influenced by the Farm Bill and other policies, and a number of USDA programs exist with varying degrees of support for productive agroforestry systems, such as Sustainable Agriculture Research and Innovation (SARE) grants, the Farm Service Agency's Conservation Reserve Program (CRP), the Natural Resource Conservation Service's Environmental Quality Incentives Program (EQIP), and Conservation Stewardship Program (CSP), among others (Kreitzman et al., 2022).

Despite agroforestry's benefits and its history in temperate climates, only an estimated 1.5% (30,853) of U.S. farmers practice agroforestry (Smith et al., 2022). The factors leading to low agroforestry adoption in the United States include farmer age, social influences, limited farmer awareness of agroforestry, low performance expectations, high upfront costs, time required to manage agroforestry systems, limited equipment availability, and farmers' limited knowledge of tree management (Valdivia and Poulos, 2009; Valdivia et al., 2012; Trozzo et al., 2014; Mattia et al., 2018; Stanek et al., 2019). Agricultural incentives and programs designed to encourage conservation practices, such as CRP and EQIP, are oriented toward industrial monocultures and have demonstrated limited utility for fostering production-oriented agroforestry (Boody et al., 2005; Bowman and Zilberman, 2013; Schoeneberger et al., 2017). Such programs have historically prohibited harvesting as a condition of payment, causing farmers to see food production and conservation as competing interests rather than helping to integrate them together (Raedeke et al., 2003; Rhodes et al., 2018; Stanek and Lovell, 2020). Compounding these factors is the reality that the population of farmers in the United States is aging rapidly, because older farmers are risk-averse when considering unfamiliar practices (Valdivia and Paulos, 2009; Mattia et al., 2018). Researchers recognize the importance of understanding productive agroforestry systems (Lovell et al., 2017), yet most agroforestry knowledge comes from experimental research in a limited number of locations (Schoeneberger et al., 2017) and the adoption literature largely focuses on prospective adopters rather than agroforestry practitioners, leaving an incomplete picture of agroforestry as a growing practice.

Only a handful of studies have gathered experiential feedback from farmers using production-oriented agroforestry systems (Orefice et al., 2017; Brodt et al., 2020; Hastings et al., 2021; Kreitzman et al., 2022; Romanova et al., 2022). The body of experiential knowledge about operating agroforestry systems is still growing and farmers will benefit from continued documentation of replicable system examples and technical insights (Orefice et al., 2017; Brodt et al., 2020). Because most agroforestry knowledge is based in tropical areas and not directly transferrable to temperate climates (Smith et al., 2012a), continued on-farm research in temperate areas is critical to developing a robust temperate-climate practice. To date, very little experiential research has gathered feedback from farmers practicing production-oriented agroforestry in the Mid-Atlantic United States, and this study seeks to fill that gap.

In this study, I took a comparative case study approach to researching agroforestry in the Mid-Atlantic states of New York, Pennsylvania, and Maryland, using qualitative interviews with farmers to answer the following questions: Which production-oriented agroforestry systems are being used in these states and how do they work? What benefits and challenges are farmers experiencing from using agroforestry? What changes in agricultural policies, research, and farmer support are necessary to best support agroforestry practitioners? The resulting analysis reveals much that is useful for researchers, policymakers, and farmers wanting to implement temperate agroforestry.

Sampling and analysis methods

Between October and December 2021, I conducted remote interviews with eighteen commercial farmers practicing production-oriented agroforestry in New York, Pennsylvania, and Maryland. Given the scarcity of publicly known agroforestry practitioners in these areas, I started with contacts provided by agroforestry professionals in the Pennsylvania Department of Conservation and Natural Resources (DCNR), the Maryland Department of Natural Resources (DNR), and the Chesapeake Bay Foundation—organizations which knew about the farms from efforts to promote agroforestry through workshops, seminars, farm tours, and related grant programs. I obtained additional referrals from farmers until I reached thematic saturation in the data, following a snowball sampling method consistent with similar research (Orefice et al., 2017; Hastings et al., 2021; Kreitzman et al., 2022). The sample of farmers was screened to meet the following criteria: commercial status, determined by the current or intended future sale of an agricultural product, and the use of a clearly recognizable agroforestry system to grow the product. Farms were included even if they had not yet sold a product, because many agroforestry crops (e.g., tree nuts) take multiple years or even decades to bear. Nonproductive agroforestry systems, such as conventional windbreaks, were not targeted in the sample due to the focus on understanding agroforestry as a means of growing crops.

The farms were situated across 16 counties in New York, Pennsylvania, and Maryland, and represent diverse geographic regions on both sides of the Appalachian Mountains that range from USDA hardiness zone 5b in western New York to hardiness zone 7a in the Chesapeake Bay region (**Figure 1**). All farms were designed with an intent to sell produce, but farm 9 was also a demonstration site for the farmer's landscape design business, and farm 14 was maintained by a 501(c)(3) nonprofit organization. The farms varied in total size from 10 to 1,000 acres, with a median of 98.5 acres and a mean of 154.6 acres. For comparison, the PA mean farm size recorded in the 2017 Census of Agriculture was 137 acres (USDA National Agricultural Statistics Service, 2017). Acreage devoted to agroforestry ranged from 1.5 to 250 acres, with a mean of 34 acres. Weekly labor hours devoted to agroforestry varied widely, from 2 to 116 hours, with a mean of 34 hours. The farms' gross revenue varied from \$0 in some cases to \$500,000, although many of the high-grossing farms were grazing operations that used agroforestry only on part of their acreage; the highest gross revenue derived entirely from agroforestry was \$163,000. Of farms with planted agroforestry systems, the mean age was 5.3 years at the time of interviewing (the mean-representative system would have been planted in 2016), although several farms had added newer plantings since their initial planting date. Three silvopasture systems (farms 2, 5, and 12) had been created by thinning mature forests and sowing an understory pasture mix, and were several decades old. The farms produced a diversity of products in their agroforestry systems, including animal products, tree crops, and other produce (e.g., berries, mushrooms, flowers, herbs, vegetables). The number of products each farm sold from their agroforestry systems ranged from 0 (farms whose trees were still maturing) to 25 products, with a mean of 5.3 products. Many farms sold products grown outside their agroforestry systems. Twelve out of the eighteen farmers had supplemental income sources other than farming. Fourteen farmers reported owning the land they farmed, two reported leasing, and two reported a mix of owning and leasing their land (Table S1).

I used semi-structured interviews and a hybrid deductive–inductive qualitative analysis process based on grounded theory (Tie et al., 2019), a social science methodology that has been used to study farmers' prioritization of biodiversity (Farmar-Bowers and Lane, 2009), the practice of forest gardening for ecological restoration (Park et al., 2018), farmers' perceptions of trees on their farms (Fleming et al., 2019), and political dimensions of agroforestry adoption (Hastings et al., 2021). Interview questions were based on desired informational targets, inspired partially by similar research conducted by Brodt et al. (2020), and approved by the Allegheny College Institutional Review Board (Text S1). Initial questions were formulated to elicit characteristics of the farm enterprise (e.g., "What is the farm's annual gross revenue?"), as well as detailed descriptions of each system and its ecological context (e.g., "How did the regional climate and site characteristics inform the design of the agroforestry system?"). Subsequent questions targeted the benefits and

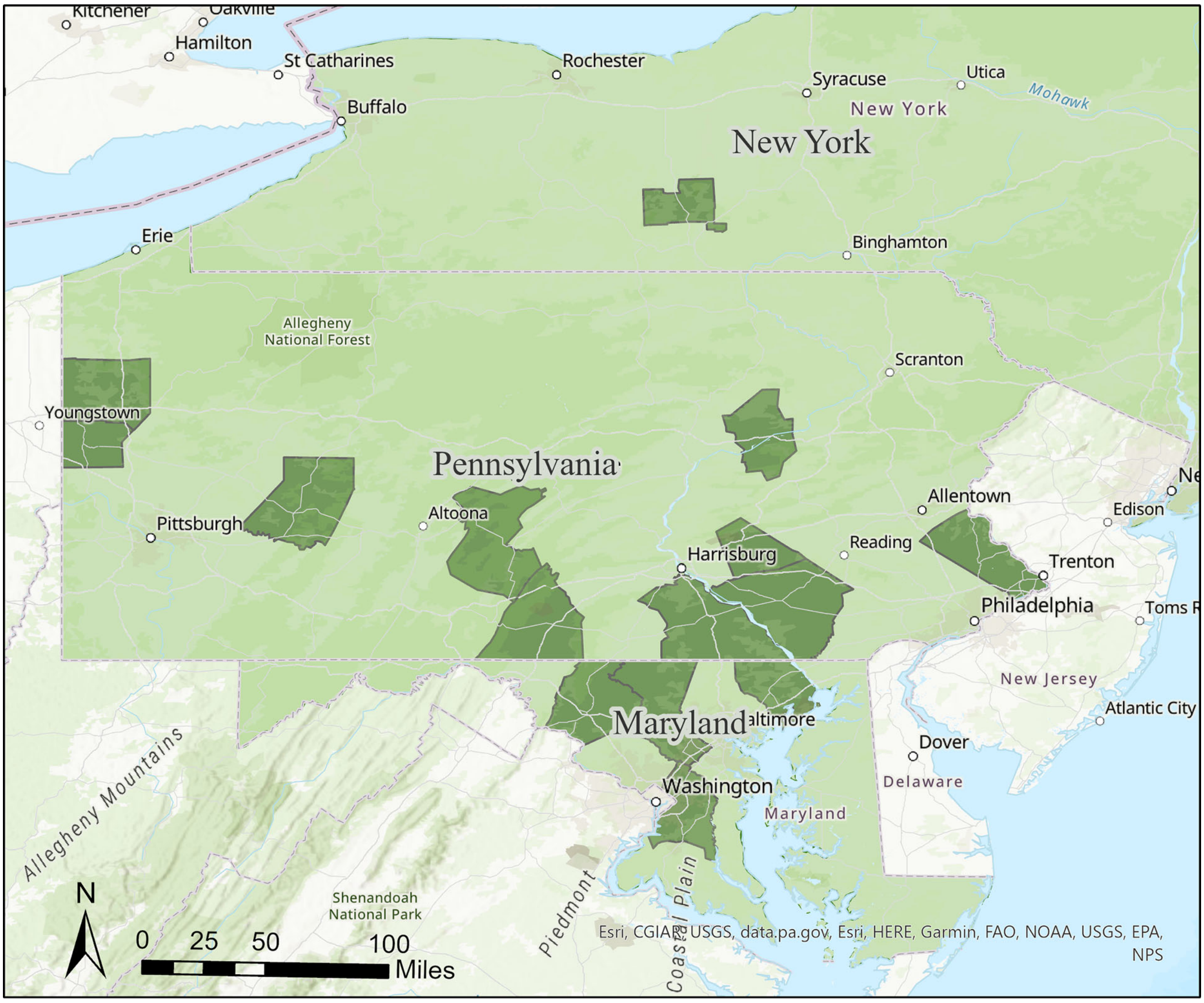

Figure 1. The geographic distribution of counties where interviewed farmers practice agroforestry. Farmers practiced agroforestry in 16 counties across a diverse spread of ecoregions in the Mid-Atlantic on both sides of the Appalachian Mountain range, varying from USDA hardiness zone 5b in western New York to hardiness zone 7a near Chesapeake Bay. Data collected via remote interviews from October to December 2021.

challenges of using agroforestry (e.g., "Have you seen any specific benefits from using agroforestry—positive impacts on crop yields, pest management, water management, soil health, labor needs, or production-related expenses?"), including the impacts of agroforestry on farm resilience to climate change and market fluctuations. Additionally, I asked farmers about their pathways for learning about agroforestry, knowledge gaps they had, and motivations for implementing agroforestry. Informed consent was obtained via email correspondence and reiterated verbally before the interviews. Each interview lasted from 40 minutes to almost 2 hours and was conducted and recorded using Zoom meeting software, with a phone recorder as backup. Questions were open-ended and interviewing was viewed as an iterative process, so I repeated or rephrased questions until all necessary information was provided. The farmers' responses constitute an exploratory account—not a complete record—of their experience with agroforestry.

Audio recordings were anonymously transcribed and quality-checked using online transcription software (Trint), and transcripts were analyzed qualitatively using a hybrid deductive–inductive coding process in NVivo (v. 1.5.2). The deductive portion of the analysis involved coding the interviewees' responses into the following initial codes, which were elicited directly from interview questions: agroforestry system description, benefits, challenges, climate resilience, market resilience, learning pathways, knowledge gaps, and motivations for using agroforestry. However, the final code structure contained many emergent codes and sub-codes that were generated inductively from what farmers said: additional codes for farmers' advice, innovative practices, the use of swales, the use of tree tubes, examples of external income, and the use of agrotourism, as well as each of the sub-coded marketing strategies, benefits, challenges, learning pathways, knowledge gaps, assistance needs, and motivations for using agroforestry. These themes were ranked by the number of respondents, and the group of respondents for each theme was analyzed to yield relationships between the practices farmers used and the experiences they had. To ensure that the data reflect all aspects of agroforestry practitioners' experience, farmers' comments were included even if the issue could have been encountered by farmers not practicing agroforestry (e.g., issues with grazing animals).

Results

Agroforestry system designs

Farmers utilized agroforestry practices in six broad categories: silvopastures, forest gardens (also known as "food forests" or "home gardens"—the term "forest gardens" is used here because that is what farmers called them), riparian buffers, forest farming, entomoforestry, and alley cropping (**Table 1**). Eleven farmers had just one type of system; of these, nine were silvopastures and the other two were an alley cropping system and a forest farming system. The other seven farms were more diverse and utilized multiple different practices, and all seven had forest garden systems. Three farmers had systems that integrated multiple agroforestry practices together: farmer 14 integrated bees in a forest garden, creating an entomoforestry system, and farmers 15 and 16 both integrated forest garden systems into multifunctional riparian buffers (Table S2).

Eleven farms had silvopasture systems: four were simple rotational grazing operations with cows only (farms 1, 4, 7, and 12), while seven exhibited more complex multispecies rotational grazing where primary grazers (cows or sheep) were followed by poultry (chickens or turkeys) to reduce parasite populations for the grazers and provide a high-protein food source for the poultry (farms 2, 3, 5, 6, 8, 10, and 13). Five farms in the latter category also incorporated pigs, which were sometimes used to help clean up and make use of fallen fruit and nuts after harvest (farms 2, 5, 6, 8, and 10). None of the farms with livestock practiced set-stocking management. Of the eleven farms using silvopasture, eight had only one silvopasture system. Three farms had more than one silvopasture system (farms 8, 10, and 13), and these farms all had three or more silvopasture systems with differing species compositions and management objectives. For example, farmer 13 had three separate silvopasture systems—one with planted fruit trees, one with planted nut trees, and one resulting from forest thinning—that together formed an integrated grazing area. Two of these farms (10 and 13) also had forest garden systems.

Seven farmers had forest gardens, which varied in scale from half-acre plantings consisting of a diverse selection of berry bushes to 7.5-acre plantings replete with nut trees, fruit trees, herbaceous crops, and supporting species. Three farmers had riparian buffers, and all were actively harvested: farmers 15 and 16 had multifunctional riparian buffers with productive forest garden plantings, and farmer 10 harvested tree hay from their riparian buffer for animal feed. Three farmers practiced forest farming of mushrooms: farmers 9 and 11 grew shiitake mushrooms in a section of their forest, and farmer 18 had a planted truffle orchard. Farmer 13 also grew shiitakes, but the logs were not harvested from their woods, and thus were not counted as a forest farming system. Only two farmers had alley cropping systems: farmer 11 had a small section of cider apple trees interplanted with chestnuts and grew cut flowers in the alleys, and farmer 17 grew chestnuts with mowed hay in the alleys. Farmers 14 and 15 had entomoforestry systems featuring bee forage plants in their systems and honey as a primary product (Table S2).

Marketing strategies

Farmers utilized a variety of marketing strategies to sell their produce, and fifteen out of eighteen farmers utilized more than one strategy (Table S3). Direct marketing was the most common strategy overall (ten farms), followed closely by restaurant/retail sales (nine farms). Marketing strategies varied significantly among farmers based on their primary products, which reflected their agroforestry practices. Most prominent was the grouping of farmers with silvopasture systems, who primarily used direct marketing in combination with restaurant/retail sales (nine out of eleven silvopasture farms), whereas only two out of seven non-silvopasture farmers used direct marketing or restaurant/retail sales, and were more likely to utilize CSA memberships, tree crop cooperatives, and some form

Table 1. Agroforestry practices utilized by interviewed farmers

Agroforestry Practice	Code	# of Farms	Description[a]
Silvopasture	SP	11	Trees integrated with grazing pasture. Can be food-bearing trees (i.e., apple), fodder trees (i.e., oak, mulberry), or trees with other functional benefits (i.e., nitrogen fixation, shade).
Forest garden	FG	7	Multistory planting with a diverse selection of fruit trees and berries in a polyculture arrangement. Animals may or may not be integrated periodically.
Riparian buffer	RB	3	Planting of productive and/or native trees along a stream, designed to intercept and infiltrate water flowing off pasture and crop land.
Forest farming	FF	3	Forested areas used for production or harvest of naturally standing specialty crops for medicinal, ornamental or culinary uses.
Entomoforestry	EN	2	Production combining trees and insect-supporting species (e.g., bee forage plants).
Alley cropping	AC	2	Trees planted in rows with an annual or perennial intercrop between the rows.

[a]Agroforestry practice descriptions adapted from Schoeneberger et al. (2017) and Brown et al. (2018).

of agrotourism. Among farms utilizing silvopasture, those using multispecies grazing were more likely to utilize marketing strategies other than direct marketing and restaurant/retail sales (three out of seven farms), compared with only one of four farms grazing cows only (farm 12).

Agrotourism

Besides growing and selling food, four farmers hosted some form of agrotourism, such as on-farm education or recreation opportunities for their customers. Sometimes it simply provided supplemental income, as for farmer 16: "It was a pretty tough year and I sold very little out of the market garden . . . if you're looking for what income streams the farm is bringing in, it is more through events right now than from any other product." The other three farmers identified the appeal of agroforestry to members of their community, and used agrotourism to grow a farm-centered network of loyal customers that helped them market their products and sometimes even provided supplemental labor. Farmer 2 told me, "We have a recreational side to the farm . . . we use our hunters as our labor source [to manage our deer herd]. We have a campground on the farm. We bring people on to the farm to camp from our buying clubs. And we use that as an educational venue to give them tours of the farm and educate them about what we're doing and how we're doing it and have them become farm cheerleaders and customers." Farmer 14 was unable to sell all their products directly, but could sell them by offering classes: "The cherries have just started. It's not enough for market sales yet. We've basically incorporated it into, again, classes and events, which we make money through selling tickets." People visiting the forest garden offered a source of labor in a u-pick model: "We put out a social media blast to say the chestnuts are in and . . . if you want to come up and help harvest, you can pay to take some of it . . . And so, you know, I'm getting the free labor that way." Farmer 9 offered farm-to-table dining experiences for customers: "One of the attractions of a forest garden, one of its strengths, economically speaking, is it being a good habitat for people . . . People are excited and willing to pay $200 a person to come to a dinner here. Chefs are excited to be out here. They've called it a chef's playground where you walk around and you can try lots of different flavors that you haven't ever encountered before." An urban setting contributed to farmer 9's success: "Marketing-wise, this is something that seems suited to being near the city. We have sold out every dinner event that we've ever offered here. So clearly, there is an appetite for that."

Farmer innovations

Several farmers revealed innovations they discovered while practicing agroforestry. Farmer 5 used dog leashes to tether their goats to a wire on the outside of a fence, which allowed the goats to graze down vegetation in the roadside ditch. Farmer 9 buried water tanks in a pile of composting horse manure to prevent them from freezing—a system they used to supply water to their ducks throughout the winter. They also practiced a labor-saving strategy of purposeful neglect with parts of their forest garden, planting a great diversity of trees and identifying individuals and varieties that could "grow pretty carefree and start to produce a good yield without too much input." Farmer 10 had a silvopasture system organized into long alleys, with trees in tree tubes planted on contour; to facilitate grazing, they wrapped electrical wires around the plastic tree tubes as they stretched the wire down the tree row, utilizing the tubes themselves as makeshift insulators that saved them from having to set up a separate fence. They also implemented a coppice-based riparian buffer system in a wet spot on their farm: cutting the vegetation back every 2 years and storing it as tree hay (for winter feed), which made an otherwise unusable site productive while simultaneously protecting it from animals. Farmer 12 designed a water reticulation system for their cows that flowed in a gravity-fed sequence, keeping the water moving year-round to prevent freezing. Farmer 16 laid out their forest garden system in four zones with different species compositions patterned on their proximity to the center of farm activity and decreasing in management requirements as the distance from the house increased. Farmer 18 custom-built a mechanical device for mixing and "planting" truffle inoculum in their tree rows. Such innovations allowed farmers to save time and energy, and to make better use of available resources, revealing a high degree of creativity in their engagement with agroforestry.

Perceived benefits of agroforestry

Improved climate resilience

Each farmer identified a range of benefits resulting from their use of agroforestry (Table S4). Sixteen farmers across all system types felt that agroforestry has made their farms more resilient to extreme weather events and climate change, or anticipated it would in the future. Farmer 11 said, "Yes and yes, and very much so to the individual crazy weather events. It's definitely more resilient to them . . . We had an awful drought this summer and then all of a sudden, transition to Hurricane Ida and then Elsa, the tropical storm before it. And we got slammed with so much rain and it's like nothing happened. You know, the system was really resilient to it . . . Part of that is the swaling we did and the fact that we changed to perennials." Similarly, farmer 9 said, "Yeah, you could throw a number of shocks at this place, and it'll still be producing some amount of food, and it will certainly hold on to its soil a whole lot better in the case of flooding or extreme rain . . . If you had a big fire go through here, there's going to be some fire adapted things. It's just diversity. Diversity is more resilient than monocultures." Farmer 4 had not seen a direct benefit yet, but anticipated several benefits as their silvopasture developed: "Oh, more resilient. Maybe not yet, but within five years? Definitely. To have the tree cover in a rainstorm. To have the shade, not just for the cows or for the grasses too, but in the summer, you have the trees available as feed if it's super dry. Yeah, definitely more resilient." It was challenging for many farmers to gauge the long-term resilience of recently planted systems, but most were confident that their farms would be more resilient to yearly extremes.

Two farmers felt agroforestry was less beneficial in the context of climate change than the other farmers did. Farmer 12 said, "The trees can handle the water and help use up water, if there's too much in the pasture, they won't be soupy. But if you have a super drought, the pastures that have trees in it, the grass loses to the tree because the tree will pull the moisture first and then your grasses die quicker." Farmer 17 truly felt that agroforestry made their farm less resilient. They had an alley cropping system with 6 acres of chestnuts in hay pasture and felt that the trees' long lifetimes and slow maturation made the farm enterprise less adaptable: "So a chestnut tree over its lifetime will . . . potentially experience 40 catastrophic hurricanes, and each of those events have the capacity to break limbs, to blow the entire tree over, to have a catastrophic impact on my farm enterprise."

Lifestyle and mental health benefits

Thirteen farmers across all system types said they enjoyed an agroforestry lifestyle, finding personal enjoyment, fulfillment, beauty, or stress relief from working in an agroforestry system. As farmer 13 put it, "I would say the biggest benefit of all is one that's sort of intangible, which is just the lifestyle component. You know, just living in these systems is really enjoyable." Farmer 14 spoke similarly: "It's a very pleasing place to work. It helps my mental health to work in that space, because it's a lush, beautiful garden and it's a great place to appreciate nature." Farmer 9 found that their forest garden attracted people to form a pleasant social atmosphere: "There's a lot of social life there. You know, if it's a really nice day, I'll find various neighbors, like whenever neighbors have their family in, if it's Thanksgiving weekend or something, they all like to take people out to the forest garden and show them around. And it's just fun to be out there and run into neighbors doing that." Farmer 16 felt that having a diverse agroforestry system created a "deepened relationship with the land," and described this connection in spiritual terms.

Improved water management

Twelve farmers across all system types reported that agroforestry improved water management and reduced erosion on their farms. Farmer 9 compared the water flows on their farm to those of a neighboring conventional farm: "It's as clear as day when you look at the field immediately adjacent . . . it's a hay field, but the guy will disk it in the fall . . . and you can just watch the soil coming off of that field. No soil is leaving the forest garden area. It's so densely vegetated." For farmer 2, water filtration and reduced erosion were closely linked in their silvopasture: "When we have thick grass in the understory and we get a heavy rain . . . we don't have runoff or erosion issues on this farm. And I believe by having a thick understory and a well-stocked over story, I mean, everybody knows that a forest is the ultimate in water filtration." Three farmers used water-harvesting swales in their systems, which helped mitigate extremes by preventing runoff during heavy rains and storing water in the soil during drought. While the use of swales is not an agroforestry practice, for these farmers, it was combined with the use of trees in a comprehensive water management strategy. For example, farmer 11 made a pass along each of their contoured tree rows with a moldboard plow, turning the soil downhill to create one-foot-deep swales. They reflected on the benefits of swales during hurricane Ida: "With Ida and everything coming in September, I mean, we just got so much rain, so fast. If we didn't have even the little bit of swales that we do in that section, all of my soil would have just gone away. I mean, it was torrential."

Improved soil health

Eleven farmers across all system types said that agroforestry nourished the health of their soil. Improvements in soil health were strongly correlated with improvements in water management, with ten farmers noting both benefits together. Farmer 14 found soil and water to be closely intertwined in their management strategy: "I don't have water up there. Irrigation is not an option, so a lot of those holistic organic elements of management are around the idea that the only water these trees are going to get is what rain falls on them. I want to foster all of the aspects of an ecosystem that I know in the world around me actively work to slow water down and hold it in place, whether that is perennial roots that are physically holding the ground in place and absorbing that water or it's good biology that is ensuring that there are pore spaces in the soil . . . that when it does rain can be filled up and that water can be held in place instead of compacted ground created by excessive tilling." Other farmers noted visible improvements in their soil's quality, such as farmer 11: "It was pale, chalky, like it was a light brown color. Now it's like chocolate. It's beautiful . . . I'm sure the organic matter in the soil has bumped up by a percentage point or two. And the water thing is important, it just holds water better, which is good."

Increased presence of wildlife

Eleven farmers across all system types observed more wildlife on their farms. Farmer 13 noticed an increase in bird species and their overall numbers resulting from the additional niches created: "Since we started the farm, we've seen the bird life just grow exponentially in terms of both quantity of individual birds, but also . . . the different species we're seeing has increased . . . The more we've created all these different little niches and spaces on the farm . . . we're just seeing all these different types of birds that we never saw before." Farmer 8 noticed an increase in bird life along with a host of other organisms: "We get a lot of turtles. We're on a hill and the turtles will actually come up from the wetland area down below for their nesting. We have snakes, we have deer. We have foxes, raccoons, coyotes. We've got great horned owls, hawks, and eagles. We've got salamanders, we get tons of frogs . . . So, we get a lot of good, ecologically healthy indicators here. We've got dung beetles; we've got more than the 25 earthworms per square foot they recommend." Nine out of eleven farmers who observed more wildlife on their farms also cited environmental improvements as a primary motivation for using agroforestry.

Improved livestock well-being

Ten farmers saw that their agroforestry systems offered health benefits to their animals, including diet diversification and shade during hot summer weather—benefits that were noted exclusively by farmers practicing silvopasture. Farmer 8 described how the diversity of plants in their system forms a healthy diet for their animals: "The pastures have between 75 and 100 species of plants. Then we have . . . the woody species with the trees and the brush . . . it's a good diet for them." Farmer 7 emphasized their animals' nutritional preferences and observed that their cows always browsed on woody vegetation before grazing pasture. Several farmers intentionally used willow trees in their systems because their sheep browsed the willow to "self-medicate" against parasites. Farmer 10 noted the importance of having shade in their pasture, especially given temperature increases driven by climate change: "We have big honey locusts that are casting enough shade for the cows and the sheep . . . Shade's critical for health, because it's 90 to 100° in July, most days here, now. It seems like every year is hotter, so shade is really critical."

Enterprise diversity and business resilience

Ten farmers across a range of system types found their farm businesses more resilient and attributed this to having a diversity of enterprises. Farmer 11 observed that crop diversity helped buffer against natural variation in productivity: "We grow enough different things that if one thing is having not so good of a year, then something else will be having a good year . . . this year, elderberries didn't have quite as good of a year as they did the prior year, but we had a really great pawpaw year . . . And so that's a good example of the diversity coming in and giving you some resiliency." Farmer 6 described how diversity made their business nimbler in the market: "We're kind of just trying to see where the market is at this point, and until that happens, you know, we can scale down. But that's why we also have a diversified livestock operation, we still have the sheep. So, you know, if something's not selling, then we can then focus on something else."

In contrast, two farmers specifically said the permanence of trees made their farm businesses less resilient. Farmer 17 said, "There's not a huge amount of opportunity to pivot to a new crop when you commit to a tree." Farmer 1 felt the same way about the trees as physical obstacles in their silvopasture: "If I would feel the need to grow any type of crop other than pasture or hay, it would be a problem. I'd have to take them out."

Provision of food, fuel, or fiber

Nine farmers across all system types benefited from food, heating fuel, and even clothing fiber derived from their agroforestry systems. Many harvested firewood and ate produce from their agroforestry systems, reducing their expenditures on products from outside the farm. Farmer 11 said, "We don't calculate the economic benefits of this, but we grow, you know, the vast majority of our own food," and added, "We never have to go into the woods to get firewood, you know, because we have enough black locust interplanted in our agroforestry system." Farmer 13 had sheep and described the satisfaction of having clothing made from their own wool: "So we'll give [local weavers] our wool and in exchange, we'll ask that they make us a hat or something, you know? It's very minor that we get anything back from it in terms of economic yield, but you know, that hat is super special to me, because it's made from our own sheep's wool and it's actually pretty soft and pretty nice, so we're getting some sweaters and other stuff made. It's a little economic yield; that's a hat I don't have to buy or a sweater I don't need to buy because we're getting it for free."

Improved ecological connectivity

Eight farmers across all system types related improvements in ecological system functions, such as pest regulation and pollination—changes that resulted partially from additional habitat for beneficial wild species, and partially from farmers' intentional fostering of agroforestry systems with ecological control mechanisms. Farmer 14 described how beneficial insect habitat helped reduce pest issues in their forest garden: "I get aphids every year like any other orchardist, but between the populations of ladybugs, assassin bugs, mantises and other things, braconid wasps that I keep in the orchard . . . I notice them every year, but their populations never explode." Farmer 11 grew cut flowers in alleys between rows of fruit trees and said, "It's really neat to have cut flower annual production in between rows of trees that are flowering because the pollinator activity is insane." Farmer 13 grazed chickens in their orchard to clean up fallen fruit and disrupt the life cycles of flies that would otherwise bother their sheep: "So the chickens are really more like disease control in the orchard, or rather insect control . . . Anything that falls on the ground, that's fruit I'm going to throw in to my chickens . . . and they'll make use of the fruit that . . . we can't make use of. And in the process, they'll kill those bugs that are inside." Seven farmers used poultry in multispecies rotational grazing as a form of integrated pest management.

Reduced need for purchased inputs

Eight farmers, seven of whom had silvopastures, identified the reduced input requirements of agroforestry systems that can supply most of their own needs. Farmer 14 described how pesticide spraying became unnecessary: "The more that I foster the polyculture and create that biodiversity of checks and balances, particularly with predator and prey, the less product that I have to buy. You know, it only took one year of me buying products that I then didn't end up using because the system took care of itself . . . I just don't buy nearly as much product now." However, the most commonly reduced input was animal feed, because many silvopasture farmers had systems designed to provide forage for their animals. As farmer 5 put it, "Honestly, the feed costs drop when the apples start falling and again when the hazelnuts start dropping." Farmer 4 had trees that they pollarded to provide forage for their animals: "Already, I'm getting a little more feed, by pollarding some of the trees, cutting a few branches off and the leaves off of the branches. So that's something I'm excited to continue."

Low labor requirements

Five farmers with a range of system types recounted that their agroforestry systems had low labor requirements, either because maintenance needs declined with maturation or because they were designed to operate with little human intervention. Farmer 10 described how using swales in their silvopasture allowed them to let trees grow with little concern for watering: "We did a little swale and berm system, just to make sure we are catching water, and to water our trees since we planted them and forgot about them—we weren't going to give them any care. We didn't have time." Farmers 2 and 13 noted that trees reduced the need to move shade structures around their silvopastures. Farmer 13 said, "I think the great thing about these systems is as these systems grow, like silvopasture especially, the labor requirements go down, which is awesome. The initial work is in the setup, and once the systems are set up, they're very self-sustaining in many regards, so they don't take a lot of labor to keep them going." Farmer 14 used a low-intensity maintenance regime that allowed for natural diversity and resulted in lower pest management needs: "I have a large variety of different native wildflower species . . . that volunteered themselves and, you know, benefit me in a huge way, whether it's feeding my honeybees and other pollinators or creating year-long habitat for a lot of those beneficial insects . . . It's been the best thing in terms of less labor on my part, leading to greater benefits and a better system that can manage itself." They explained that after 4 years of letting the forest garden grow wilder, their need to spray foliar insecticides decreased by 10 hours per week. Farmer 16 mentioned that trees do not need constant attention, allowing them to leave the farm without worrying about losing their crop.

Improved yields

Five farmers across a range of systems saw augmented yields due to agroforestry management. Farmer 2 had converted a mature forest into silvopasture and found that it increased their farm's carrying capacity: "If we have 86 acres on the farm, and only 35 of it's really good grass but we can add another 20 acres of silvopasture, then that's a benefit." Farmer 13 described how their sheep grazed more throughout the day under the continuous dappled shade of trees versus a mobile shade structure. Farmer 14 took advantage of canopy gaps between their trees to produce an early stage yield while the long-term fruit trees matured: "While the orchard is still young enough, there's plenty of light coming in . . . so in these interim years, while we can, we've started doing intercropping. We have a large number of rows in between the trees [with which] my coworker has been able to expand production for the urban CSA."

Improved pasture or crop health

Four farmers noted shading, nutrient and water-related benefits for their pastures and understory crops. Farmer 11 said, "From the point of view of . . . you know, annual production, having the more mature tree rows is great . . . wind protection is huge, partial shade . . . " Farmer 10 described the functions of trees for their pasture: "Black locust trees in particular put nitrogen in the ground and make every other plant around them grow better . . . There are even trees that harbor both kinds of mycorrhizal fungi that bridge the gap between grass plants and forest trees . . . That allows for more nutrient swapping between the grass and trees." They went on to observe that the pasture grew better underneath a light canopy: "[We have] bigger root systems holding more water, less evaporation with the trees in the pasture. All of the grass growing underneath our trees is healthier than the grass out in the middle of the field, because of the light shade that's cast in the summer, and that tree just sucking water, pulling water and nutrients up."

High product quality

Four farmers noted the quality of their agroforestry produce, especially with regard to nutritional content. Farmer 14 was excited to produce shelf-quality apples organically. They said, "With all the pests and disease . . . it is kind of the standard belief in the industry of orchardists that it is, if not impossible, it is so difficult to grow good quality fruit organically that it is not worth doing . . . And so, I took this job as kind of like challenge accepted . . . I am excited as the apples start coming in that they are, you know, it's not just that we're making fruit . . . in all the desirable aspects—size, look, quality of flavor and texture—it is high quality fruit." They attributed the unique flavor profiles of the fruit to better soil nutrition from the biological diversity surrounding the apple trees in the forest garden. The other three farmers all sold meat grown on silvopasture and pointed out the distinct improvements in nutrition and flavor when animals are raised on a diverse diet that includes tree nuts and fruits.

Perceived challenges of agroforestry

Early setbacks

Farmers recalled a wide array of challenges that arose when implementing agroforestry (Table S5). Seven farmers across all system types reported experiencing setbacks early on, either because of poor planning, poor system design, or a lack of experience. Farmer 10 described losing most of the initial trees when they were girdled by voles: "We had heavy vole pressure in the first year and we planted trees without tubes . . . A lot of trees got hit, and a lot of them resprouted. And then we got a grant and we filled in a bunch more trees, doubled the number of lanes, put all those in tubes. It was a little more standardized the second time. The first time was just like trees everywhere diversity, because we weren't sure what was going to stick." Farmer 6 had similar losses: "The first year we got here, so that was six or seven years ago . . . there were some pretty heavy losses, because I would say that I had no idea what I was doing back then. I probably lost about 50 percent of what I planted." Several other farmers had damages from wildlife, including voles, deer, yellowjackets and beetles, during system establishment.

Negative interactions within agroforestry systems

Seven farmers, all of whom had silvopastures, experienced negative interactions within their systems. The most common negative interaction was livestock damaging trees, as farmer 13 described: "Our ram, when he's bored, he'll just ram tree tubes with young trees . . . or the sheep will just rub up against things." Farmer 4 also found this to be the case with cows: "As long as I keep the fence hot . . . it's okay. If I don't, the cows will just be like, oh, here's something nice to rub on, and like all of a sudden, there's 10 broken trees and tree tubes overnight. So that's not so great." Cows and sheep were particularly damaging to young trees, but mature trees proved susceptible to damage as well, as farmer 5 discovered: "We left pigs around a pair of walnuts that have been here since we bought the place . . . And one of them was fine with pigs being around it. The other one died . . . the biggest challenge is keeping everybody moving to the point where they're not doing damage." Farmer 12 found that mature trees encouraged a "loafing area" where cows concentrated nutrients too much and could be struck by lightning, and found it annoying when tree branches fell on their fence. Farmer 8 practiced multispecies grazing and observed tensions between different livestock species during breeding: "We tried running the sheep and goats and the cows together during birthing, but it's just a very stressful situation . . . We had a cow kick one of the sheep or one of the goats and break its leg one time . . . So, we found in our system it was better to separate everybody out when it was time to have a baby."

High labor requirements

Seven farmers, six of whom had forest gardens, noticed high labor requirements in their agroforestry systems. Farmer 15 mentioned: "Well, we have a lot of shrubs intermixed with the trees, so some of the maintenance . . . you have to be careful with these little shrubs. So that makes it slower." Farmer 10 reflected: "Labor is difficult—these systems just require more labor. They require more people farming. They require a different economy than what we have . . . We, in our little farm, our little version of what we're trying to bring to the world, we just have to do more labor for smaller yields . . . Per unit of food, there's more labor that goes into it." Sometimes this increased labor was truly a challenge, but sometimes it was simply a tradeoff of labor over other, more environmentally damaging inputs, as farmer 13 described: "I think the gains that we gain in other ways . . . not having inputs of whatever . . . it's worth, you know, a little bit of extra labor we need to maintain the system."

Difficulty mechanizing

Seven farmers across a range of system types acknowledged that agroforestry systems present obstacles for farm machinery. Farmer 14 had a forest garden and said, "You know, with that rich diversity of plants and all of those unmowed spaces that I maintain for wildlife, it's not feasible to run large equipment through the space . . . Even as it is with the trees not mature, it would be challenging for me . . . to get a large tractor with a tank to drive between the rows to spray them, and the more mature the trees will get, the harder it will be to run equipment like that through there." Farmers with larger-acreage silvopasture systems found difficulty as well, even if their systems were intended for mechanization. Farmer 4 had a silvopasture laid out in short rows spanning the width of a long, narrow pasture, and was no longer able to spread manure because of the sheer number of turns required to navigate all the rows: "[We] used to spread usually the long way across the field . . . We did the spacing so that [we] could drive between, but it's just so many short rows." Farmer 17 explained the problem with a comparison: "When you mow an open field, you just start from the outside and . . . you mow in a circle and it gets tighter and tighter and tighter . . . Whereas when you have an orchard or you have an obstacle, all of a sudden you have to go up and back, which means that you have to be making a really tight turning radius at the end. So that adds a huge amount of time, and it also makes mowing hay completely inefficient." This problem prevented farmer 17 from harvesting the hay crop from their alleys. Farmers who use heavy equipment emphasized the need to minimize operation time because the equipment is so expensive to run.

Delayed or uncertain yields

Seven farmers across a range of system types found the delay between planting trees and having a marketable yield to be problematic. Farmer 17 said, "There's such a big lag time between planting chestnuts and having a product that you bring to market. So right now, the market is their cows great and people are getting maybe $6 a pound for chestnuts . . . in 10 years' time, am I actually going to be getting $6 a pound for my nuts or am I going to be getting $3 a pound for my product? Which impacts all of my profitability projections." Farmer 10 had trouble paying their family members and employees for their work: "Because we're not making a lot of money yet, we don't have the money to pay people the way we want to, so all that labor has to come from within the family structure." Farmer 11 described relying on off-farm income sources while their chestnut trees mature: "We wouldn't be able to grow our agroforestry systems the way we're doing it right now without having that source of income, essentially because we just don't have production. Chestnuts are the real backbone of our agroforestry system in terms of trees we're planting and we don't have production from them yet." They found pawpaws, elderberries, and cut flowers to be useful interim crops.

Novel crop challenges

Five farmers had issues related to the novelty of their agroforestry crops. Farmer 10 described the challenge of educating customers on how to eat persimmons and other uncommon tree fruits, and expressed concern that bad experiences could result in lost customers. Farmer 14 had built a drying facility for processing herbs from their forest garden, but ran into trouble when acquiring permits because, "The health department was basically at a loss just because nobody had approached them about processing herbs before . . . and so to a large extent, they were like, 'we don't really have standards for this'." Farmer 18 expressed frustration that no one could understand their needs, including creating the hyper-alkaline soil conditions that truffles require: "Nobody knows what I'm doing and when I don't know what I'm doing, I can't find anybody else to help me . . . and just in preparing the soil, [it's challenging] finding someone who's willing to do the things that are necessary, that are strange and so far out of most people's comfort zone that they think you're just nuts." Crop processing, especially acquiring all the necessary equipment, was a challenge for farmer 9, who maintains a diverse forest garden and harvests over 25 different crops. In the end, they felt that aggregated, cooperative processing might solve the issue: "It's hard to justify having like a hundred different pieces of equipment to support a polyculture . . . I'd like to see a facility where you have just a whole lot of these different tools, presses and whatnot. Nut shellers, sorters, winnowing stuff, maybe even a conveyor belt like, just moving material around takes so much time . . . So, a processing hub to support local forest gardens could, in theory, be very useful." Lastly, farmer 17 expressed concern in harvesting and finding markets for their chestnuts, and was not familiar with regional tree crop cooperatives.

Difficulty planning for the future

Five farmers across a range of system types spoke of difficulties planning or adapting for the future. Several of them were uncertain of what they could sustainably manage as they aged. Farmer 14 wondered how they would make up lost revenues when the main understory cash crops get shaded out by maturing trees: "I know that they're thriving right now, but when the apple and other fruit trees really mature, the canopy is really going to shade some things out . . . That's just an interesting challenge of anticipating, you know, particularly for the cash crops that way . . . How are we going to make up that money in the future?" Another farmer was leasing their farm and concerned about investing in property they did not own.

High management complexity

Five farmers, four of whom were silvopasture practitioners, said the management complexity of their agroforestry systems was a challenge. For farmer 8, the interconnected nature of their silvopasture made decision making more complicated: "Everything you do, you have to think about it in 15 different ways. You know, OK, this I want to do. How is it going to affect this? How's it going to affect that? How are those going to affect each other, you know? So, it's a lot more complicated of a system." Likewise, farmer 11 said, "Ease of management has been a challenge because we've had to learn how to manage the system over time, and that has been challenging. And that's a challenging step for anybody adopting these types of practices or planting trees in something they've managed very differently for a long time."

Meat processing challenges

Four farmers, all of whom practiced silvopasture, faced issues related to meat processing. Two of them found the cost untenably high, and the other two were unable to find available processors, both factors threating to economic viability. Farmer 8 related (in 2021), "Last month, when I was reaching out to places within an hour radius of me, the earliest I could find anybody that had any dates was the end of 2022. Well, if I got to wait a year to process an animal that I've got ready to go now, you know, customers are just going to go to the grocery store . . . Our farm system works phenomenally, but the piece that I can't control is the processing, and that's the piece that kills us." Farmer 2 faced a similar issue, although their frustration was directed at prohibitions for on-farm processing: "I don't understand why I can process a chicken safely on my farm and sell you a piece of that chicken or the whole chicken legally, but I can't do that with a cow or a lamb or a hog . . . Probably the biggest weak link that we are experiencing as grass farmers is the processing end because we are required to go through inspected facilities . . . And because those guys are strapped, we're booking animals that aren't even born for slaughter . . . All of our dates for 2022 are already on the calendar. And with COVID, when we had a surge in orders, we had the animals, we had the grass, we had the market, but we couldn't increase our production because all the butcher shops were completely booked. So, with poultry, I could add another thousand chickens, just have the crew come in another day a week and we could do that . . . The system is not stacked for success for someone in this niche, and to me, that's irresponsible and contrary to the way it should be." Insufficient processing capacity is a bottleneck on the economic viability of silvopastures, even when they work well in other respects.

Tree establishment work

Four farmers identified a significant challenge in managing grass around trees during their establishment years. This challenge had significant crossover with several other challenges: three farmers also reported higher labor requirements, and three farmers also reported early setbacks, which largely involved losing trees to rodents. Farmer 11 said, "It was challenging in the first couple of years to keep the trees alive and to keep things mowed around them, and there were a lot of inputs of time and money in terms of fuel and equipment use in those first couple of years . . . You know, if you keep them alive past year three or four, then things really start to take off and really start to thrive . . . But the first couple of years, the establishment years is what I would call them. They were more difficult and much more labor intensive, and they were not economically viable." Farmer 17 described the effort it took to adapt to various animal pressures: "Deer are one of the biggest [challenges], and we started using tree tubes, which is kind of the standard. They grew their first year in tree tubes and then going into the winter, tons of the tree tubes, just all of a sudden had little vole nests in them, and so the tree tubes just functioned as the perfect little habitat for [harmful] rodents."

Eleven farmers used tree tubes to protect young trees from browsing deer and livestock. Most farmers found tubes protected saplings well and could even provide a beneficial microclimate, but they also required maintenance. Farmer 8 wanted to use untreated wooden stakes to support their tree tubes, but had trouble keeping up with their decay: "The problem is, I didn't want to use pressure treated stakes because we're trying so hard not to put toxins and stuff in the soil . . . The problem is you got 7500 stakes out there and over time they break down because now you got this super healthy soil . . . It's a constant battle to keep enough stakes in the ground that you're, you know, not having to be out there constantly replacing them." Weeding inside the tubes is also necessary, as farmer 13 described: "When the trees are young and before we can take the guards off . . . we have to do some weeding inside of those tree tubes, like, lift them up every now and then and kind of pull the grass that's growing inside of them out. That's kind of annoying."

High startup costs

Four farmers, all silvopasture practitioners, remarked on the high startup costs for their agroforestry enterprises. Farmer 10 said, "The challenge is that the inputs are really high to start, you know, planting hundreds of trees is expensive and you don't get a yield, a significant yield, probably for seven years for something like a nut crop. That doesn't really work in our financial system, to wait seven years." For farmer 12, it was tree protection—not the trees themselves—that proved cost prohibitive: "I would love to be able to put more trees in places, but it's the cost of protecting those trees versus the gain."

Several farmers offered advice to others thinking about implementing agroforestry on their farm. Farmer 6 said, "Figure out exactly what you want to grow. Don't move them around, put tree tubes on them . . . I wish we had a better plan when we had started the farm because we basically went through everything and lost a lot of money for the first few odd years." Farmer 11 echoed the need for planning: "You're talking about, you know, something you're planting that's going to live for potentially 200, 250 or 300 years. So, you want to get it right from the beginning . . . Planning is really important." Farmer 15 emphasized soil preparation and restoration prior to planting because they had to rehabilitate a field that bore the residual effects of pesticide use.

Farmer assistance needs and knowledge gaps

Agroforestry system examples

Several needs for farmer assistance became apparent (Table S6). Seven farmers across all system types wished they could see better examples of working agroforestry systems. Farmer 10 said, "I don't fully know how every part of the farm is going to work and I don't have a business plan for every part of the farm. It's a lot of guesses at this point, because there's not a lot of people who have a 20-year agroforestry farm, who you can just go to and you're like, 'this is how it works'." Other farmers showed interest in learning from farmers with similar systems. Farmer 11 was interested in networking with other agroforestry practitioners to facilitate knowledge exchange: "I would like to learn more from other people that are doing similar stuff, and that's hard to find at times because some of that is few and far between." Farmer 18 was particularly in want of examples, since there are few farmers growing truffles in North America: "For anybody growing truffles, it's always going to be a challenge until we have more local information . . . that's really appropriate to interpret directly." They added that the documentation of "clearly defined agricultural practices" on truffle farms in Australia was a major deciding factor in being willing to plant the system on their farm.

Grant funding

Grant funding is another important need, expressed through farmers' use of grants and desire for more funding directly applicable to productive agroforestry systems. Six farmers received various grants, including NRCS EQIP grants, grants through the Pennsylvania DCNR, and financial support from the Alliance for the Chesapeake Bay, both to cover initial installation costs and replace lost trees. Four farmers expressed frustration with current funding avenues, lamenting the scarcity of public support for agroforestry compared to the funding directed at commodity farming and pointing out that one-time grants fail to account for the multiyear or decade-long delay between planting and harvesting tree crops. Farmer 8 said, "In order for a farm to be able to do this, it has to be profitable. Well, many of the farms aren't profitable . . . you might give them a grant to put the stuff up, but then there's no money there to maintain it, and that farmer has to use their profit then to maintain it. Well, they're going to put their profit into things that are actually making money for the farm." Farmer 8 also described the link between grant funding, which allows farmers to install agroforestry systems without incurring debt, and their ability to experiment and set up a well-functioning system without the pressure of an economic return: "One of the things that my family kind of drove into my head is, stay out of debt. Well, a lot of farms use their land equity to help fund the operation . . . We don't have any debt, so I could take chances and make mistakes . . . I wasn't one mortgage payment away from losing the farm. And that's one of the challenges that I see with a lot of these farms, is that a lot of this stuff has a much longer horizon for payout."

Business planning assistance

Three farmers using various practices indicated a need for better business planning prior to planting their agroforestry systems, to help ensure economic viability. Farmer 6 said, "If we would have started out with livestock, we would have just started with pigs, [and] we would have been in a very good position right now. But it probably took us till about year four to break even, [and in] year five and six, we started making money." Farmer 15 wanted to learn "really how to reach into markets, really how to set up a business plan to take something that looks different and is managed differently and still make it viable, in terms of providing income." Similarly, farmer 16 described the gap between their farm and relevant markets: "There is a gap between where I sit and where these agencies sit and where the market is . . . connecting with those folks who understand either the restaurant market or the wholesale market and the retail market would be beneficial."

Technical advising

Three farmers with a range of practices saw a need for technical advising specific to agroforestry, because its interdisciplinary nature makes siloed extension expertise less useful. Farmer 8 spoke from their experience: "If I go to extension and I talk to the forage expert . . . They can tell me anything I want to know about a particular monoculture forage: orchard grass, timothy, alfalfa, whatever. But you ask them how it works with grazing native wildflowers and grasses; they haven't got the faintest idea. So, then you go to a wildflower expert at the extension . . . they tell you anything you want to know about a black-eyed Susan, but they don't know anything about how it responds to grazing from a cow, grazing from a sheep . . . our knowledge is so siloed in these different disciplines." Another farmer echoed this idea, saying, "Especially for sheep and fruit trees, there's not a lot of information out there on how to do it right, so like, how do you put sheep in your orchard? . . . There are books on orchards and books on silvopasture, but there's no book that really tells you how to set up an orchard that you graze animals through."

Knowledge gaps

Farmers described 14 widely varying knowledge gaps (Table S7). Five farmers had no reported knowledge gaps, and two farmers had as many as three or four separate gaps, but most had only one or two. The most common gap was general agroforestry system knowledge or knowledge of agroforestry systems other than those farmers had implemented, which five farmers utilizing a range of system types reported. For example, farmer 15 had read published agroforestry literature and expressed the concern that system designs for the larger-scale Midwestern operations weren't directly transferrable to the Mid-Atlantic, and hoped to see more research focusing on this area. The next most common gap was how to effectively maintain young trees, especially in the deployment of tree tubes, which three farmers reported. The other gaps pertained mostly to the technical aspects of agroforestry system operation, such as controlling pests, building soil fertility, and processing tree crops, although one farmer also wanted to learn more about effectively managing their employees.

Complaints about government agencies and regulations

Four farmers also made complaints about agencies and regulations they had trouble with. Two farmers felt constrained by the Food Safety Modernization Act's stipulations for grazing in orchards. Farmer 13 said, "The food safety regulations are moving away from animals in the orchard, which is very frustrating because it's a really great system and it's quite safe when you're picking that fruit off the branches of the tree several feet in the air . . . but still, they're out of overabundance of safety or precaution, just eliminating that as a valid form for large farms to graze animals in the orchard unless you get them out . . . months before you're going to harvest the crop, which isn't really practical." The same farmer also found the NRCS to be inflexible, making it challenging for them to benefit from its programs: "To them, it has to be orchard or pasture, and then depending on what you pick, you're only eligible for certain things . . . I think our orchard is only considered an orchard, so we're not eligible for fencing or anything like that because they don't see it as a silvopasture system; they only see it as an orchard . . . There is a regulatory disconnect there where they want to encourage this stuff, but they also discourage it in the way they categorize." Farmer 6 had to call their silvopasture plantings "windbreaks" to receive grant funding from the NRCS: "We actually got a big EQIP grant through NRCS and I wanted to use some of that grant for silvopasture, but . . . I don't even think that's a word in their vocabulary at this point . . . we have a pretty good agent who worked with us and she's like, 'Well, how about we put in windbreaks instead?'" These classification rules and regulations make agencies like the NRCS less effective in helping farmers implement agroforestry—even farmers eager to use conservation practices.

Farmers' learning pathways and motivations to use agroforestry

Learning pathways

Farmers described a number of ways they first learned about, and continued to learn about, the practice of agroforestry (Table S8). Most farmers described multiple modes of learning in progressive stages that culminated in their decision to start farming, as exemplified by farmer 14: "Probably initially, just through books. I really started getting into small scale and sustainable farming in college. And from there, it was a combination of, you know, getting my hands on whatever books and research I could find, going to farm days and other events and working on farms . . . I worked a number of years, kind of transiently moving from one farm to the next just to get the hands-on experience to learn how different people do different things . . . I did take the permaculture design certification course . . . you know, that's where I got the core curriculum for permaculture, which I use a lot. But also at this point, I'm pulling from anybody I can learn from." The permaculture network, including authors Joel Salatin and Mark Shepard, was the most common way farmers had learned about agroforestry, with twelve farmers mentioning it as a core part of their learning. Reading books was a pathway used by eight farmers, seven of whom had also learned from the permaculture community. Eight farmers had learned about agroforestry from connections with the organic farming community, either via working on a farm or visiting farms. College education in the environmental sciences was another common learning pathway for seven farmers. Four farmers mentioned learning about agroforestry from time spent abroad, in England, Germany, Costa Rica, and Argentina.

There were a number of relationships between farmers' sources of learning and the practices they chose to implement. The permaculture network was utilized by farmers with all system types, but among silvopasture practitioners, it was correlated with a higher degree of complexity in grazing systems. All of the farms practicing multispecies rotational grazing cited the permaculture network (including authors Mark Shepard and Joel Salatin) as a key source of their learning about agroforestry and utilized multiple learning pathways together; in contrast, none of the farmers grazing only cows in their silvopastures learned from the permaculture network, and each mentioned only one source of learning about agroforestry. Farm visits and the organic farming community were utilized by farmers using a range of agroforestry practices, but most used more than one practice (five out of eight farmers). An environmentally focused college education was most prevalent for non-silvopasture farmers; only one of the farmers practicing silvopasture was educated in environmental science (farmer 10), compared with five out of seven farmers using forest gardens, and all farmers using forest farming, alley cropping, and entomoforestry. Four out of the five farmers who cited international travel as a source of learning were silvopasture operators, and internet searching and workplace influences were mentioned by a variety of farmers.

Motivations for using agroforestry

Farmers' motivations for implementing agroforestry were diverse, but the most common motivation was to have a positive environmental impact in some way, including sequestering carbon, restoring wildlife habitat, minimizing downstream pollution, and returning the landscape to a more natural forested state—a motivation shared by thirteen farmers across all system types and often mentioned in conjunction with other motivations (Table S9). Farmer 10 used a commonly-known environmental nonprofit as a metaphor for their vision, saying "It should look more like a Nature Conservancy property than a conventional farm, but still be producing tons and tons of food." Farmer 11 grew most of their family's food and described their thinking this way: "You know, eating is the land use activity that you do three times a day . . . So, if you're thinking about what you're eating and . . . what systems it was growing in, you're essentially making a land use decision every time you purchase a product." A few farmers in this group saw their farm as a force for positive change in the farming world, comparing their agroforestry practices to industrial farming practices they perceived to be harmful. Farmer 5 mentioned carefully observing, and farming with, nature rather than trying to bend it to their will, contrasting this philosophy with the "fencerow to fencerow" attitude of industrial agriculture. Farmer 17 viewed their farm as a means of repairing damages caused by previous farming generations: "[They cut] down all the trees to plant corn or wheat . . . This was the great Eastern woodland, you know? I don't know if we should be growing corn here at all. Or I mean, at least not on the scale that it is . . . I see planting trees, on one level as an act of repentance for the sins of my ancestors." Similarly, farmer 16 viewed their agroforestry system as "a reclamation, or a rematriation, to help return the region to a system that is more ecologically thriving than what's happening [on other farms]."

Nine farmers, seven of whom used silvopasture, were motivated by agroforestry's perceived usefulness in helping farms to be more self-maintaining, resilient, and productive, or to need fewer inputs. Many silvopasture operators expressed the desire to "better utilize the whole farm" (farmer 7) and benefit from the increased resilience of agroforestry systems. Farmer 13 had a mix of motivations: "It's so many different reasons, but I think it's just the enjoyment of it, the lifestyle aspects and just the efficiency of getting multiple yields off the same system. So instead of just having sheep grazing in a field, I'm able to have sheep and an orchard, you know, two yields off of one piece of land, basically." Farmer 14 sought a self-maintaining system: "My choice in how I manage comes from a place of personal choice and ethics, but it also comes from a practical place . . . I want to create an ecosystem that can take care of itself as much as possible because my time is limited and I can't be up there all day, every day, spraying for every single pest that comes by, you know. I'd much rather create habitat for their natural predators and let them take care of as much of it as possible."

Three farmers were motivated to leave their farms or the planet in a better state for future generations, as exemplified by farmer 11: "My goal in life is to, you know, make the planet better for my kid, and for everybody else too . . . " Three farmers saw the economy and industrial farming as convoluted, and emphasized the need to be prepared for economic collapse, as exemplified by farmer 10: "As our money system learns about reality and, you know—the Earth, feedback loops, human health—just like all the systems that are sort of sorry, this is philosophical, but falling apart. That is going to make all these systems a lot more appealing and make a lot more sense." Three farmers were motivated by an aesthetic of "quality of life" or growing "real food" in comparison to industrial farming, as exemplified by farmer 16: "I'm surrounded by corn and dairy for the most part. There's a little bit of wheat, a little bit of pig, you know, a little bit of soybean, but none of it is really accessible as like food . . . , it's all things that have to be heavily processed, and for the most part, a lot of [my crops] don't—they're immediate food sources. I think that's a really good thing." Two farmers were motivated by agroforestry's abilities to provide a high quality of life for their animals, as exemplified by farmer 6: "I like the mix of grassland to support pasture and . . . mainly for the animals, I mean, just providing more natural feed for them." Two farmers were motivated to prove the effectiveness of agroforestry, as exemplified by farmer 14: "I am hoping that putting a little more effort in creating a rich polyculture that I'll be able to foster that better looking fruit . . . that'll kind of be my ultimate goal to say, 'look, conventional growers, I can make an apple to your standard of beauty that is maybe even arguably tastier, if not certainly healthier'." Farmer 18 had a personal interest in truffles from studying horticulture in college.

Discussion

Agroforestry system designs

The farmers documented in this study can be divided into two distinct cohorts: those who embraced complexity in their agroforestry systems, and those who preferred simpler systems. The farms featuring forest gardens—the system with the greatest spatial, temporal, and ecological complexity—exhibited greater overall complexity than farms without forest gardens. Only farmers with forest gardens utilized more than one type of agroforestry system, including the three farms that utilized combined systems (e.g., multifunctional riparian buffers). Those with forest gardens and silvopastures were more likely to have multiple silvopastures instead of just one, and to utilize multispecies grazing instead of using cows alone. Broadly speaking, farmers who embraced greater complexity in their farms had subtly different learning pathways and motivations, faced slightly different challenges, and tended to have less income from agroforestry than those with simpler systems, which were primarily silvopastures. Research has documented the values and motivations of farmers using production-oriented agroforestry (Kreitzman et al., 2022), but little research has connected farmers' educational background or motivations to their design thinking, or linked their experiences back to their agroforestry practices, making this an important focus for post-adoption research.

The large number of silvopasture systems in this sample is not unusual, given that other research in the eastern United States has focused on silvopasture as a practice (Orefice et al., 2017), although most studies find a smaller proportion of farms incorporating animals (Brodt et al., 2020; Kreitzman et al., 2022). Possible explanations include the conceptual simplicity and clear benefits of planting shade trees on pasture, and the fact that animals can provide revenue long before trees begin bearing. The ubiquitous preference for rotational grazing instead of set-stocking aligns with similar research, but the large proportion of farms using planted systems over thinned forests does not (Orefice et al., 2017). The USDA literature speaks of both approaches and their benefits (Schoeneberger et al., 2017), but the adoption literature has documented livestock producers' preference for establishing silvopastures by thinning forests (Wilkens et al., 2022b), leaving the incidence of plantation silvopasture in this sample unexplained. The silvopasture practitioners in this study can be categorized by their use of single or multispecies grazing, two groups that differed significantly in how they learned about agroforestry, which has not been discussed by similar research (Orefice et al., 2017). Subsequent post-adoption studies incorporating silvopasture should elucidate farmers' choice of either planted or thinned-forest silvopastures, as well as their reasons for using single or multispecies grazing.

Many of the tree crop systems, such as the forest gardens, alley cropping systems, and silvopastures that utilized fruit and nut trees, align with system descriptions from similar research (Orefice et al., 2017; Kreitzman et al., 2022). However, while the proportion of farms using alley cropping is similar to that found in previous post-adoption studies documenting a range of practices, forest gardens were much more common in this sample (Brodt et al., 2020), and stand out as an example of farmers adapting the traditionally urban practice of forest gardens or "food forests" (Park et al., 2018) to a more rural, production-oriented context (Kreitzman et al., 2022). Forest gardens are more typically employed in noncommercial, urban settings due to their need for intensive management and their alignment with environmental and social values driving alternative land use in urban areas (Park et al., 2018; 2019). The use of multistoried agroforestry systems like forest gardens in agricultural contexts has been documented primarily in the Midwest, often bearing the name "woody perennial polycultures" (Kreitzman et al., 2022; Roeder and Harmon-Threatt, 2022), although such systems sometimes resemble those used in urban contexts (Park et al., 2019). The practice of "forest gardens" or "food forests" appears in USDA agroforestry publications as an urban adaptation of forest farming (Schoeneberger et al., 2017), primarily in resources targeting suburban homeowners (USDA National Agroforestry Center, 2023b). Such resources present forest gardens as a solution to urban food security and ecosystem service provisioning challenges, not as a broad-acre agricultural practice the way they were used by farmers in this study.

All three riparian buffer systems were managed for harvest, and align with theoretical descriptions of multifunctional riparian buffers (USDA National Agroforestry Center, 2015), although farmer 16's system, at 16 acres, was significantly larger than most riparian buffers. These systems demonstrate farmers' eagerness to simultaneously foster productivity and ecological value, which has contributed to the success of working-land programs in lieu of land retirement (Reimer et al., 2018; Chapman et al., 2019). The only forest farming practices documented in this sample were log-based mushroom cultivation and orchard-based truffle cultivation. Growing high-value shiitake mushrooms using forest management byproducts (i.e., oak trees from forest thinning) is relatively simple compared to other forest farming practices, and can be an easy additional enterprise for small farms (Baker and Saha, 2018). The documentation of a commercial truffle orchard in this study is interesting, given the rarity of the practice in the United States, but there are a growing number of truffle orchards across the country (North American Truffle Growers' Association, 2020). The structure of truffle orchards in many ways qualifies them as an agroforestry system that may garner more attention as they increase in number. The instances of entomoforestry (i.e., honeybee integration) in this study fall outside the scope of USDA-recognized agroforestry systems, although they are recognized as an agroforestry system by some researchers (Brown et al., 2018), and typical for small-scale apiculture in the United States (Tubene et al., 2023).

Marketing strategies

The majority of farmers used multiple marketing strategies for their products, which is common among small agroforestry producers, as well as the prevalence of direct marketing and small-scale retail outlets (Kreitzman et al., 2022), a pattern that holds true for small farms in general (LeRoux et al., 2010; Dong et al., 2019). However, the marketing decisions of small farms are complex, being based on highly variable characteristics of farm size, employment status, labor resources and risk preferences (LeRoux et al., 2010), so a deeper analysis is needed. The data supporting variation in marketing preferences between silvopasture practitioners and tree-crop producers in this study is superficial at best, but remains important due to the differences in primary products between the two groups (i.e., meat vs. fruit and nuts) and the implications of their marketing preferences for further development of the practice, making this another focus area for future research. Alternative marketing strategies like values-based supply chains may also benefit agroforestry practitioners hoping to connect with like-minded consumers (Peterson et al., 2022).

Agrotourism

The utilization of agrotourism among several farmers in this study, mostly located near urban areas, aligns with the literature on income diversification and agrotourism in small-scale farming. Agrotourism has garnered increased attention in recent years for its ability to provide small farms with increased income and financial stability (Little and Blau, 2020; Holland et al., 2022). Studies have also documented its benefits for marketing and customer relations, especially for farms showcasing sustainable production methods and those located near urban centers (Tew and Barbieri, 2012; Khanal et al., 2019), which lines up with several farmers' use of agroforestry to build a customer base and promote their products. The forms of agrotourism farmers utilized, including on-farm camping and hunting, farm to table dinners, classes, and U-pick, are standard forms of agrotourism in the literature (Holland et al., 2022). However, agrotourism was not used by several farms that may have benefited from increased revenue and marketing support, which suggests that not all farmers may know about agrotourism's benefits or have the capacity to implement it.

Perceived benefits of agroforestry

Environmental benefits

Farmers associated a range of environmental benefits with their use of agroforestry, all of which have substantial backing in the experimental and post-adoption literature. The climate resilience of agroforestry systems due to their biological diversity and ability to withstand weather extremes is touted as one of their key advantages over monocultures (Kremen and Miles, 2012; Schoeneberger et al., 2012; Cardinael et al., 2021; van Noordwijk et al., 2021). Farmer 17's concern about wind damage to trees is not generally reflected in the literature on diverse agroforestry systems, which have demonstrated a high resilience to hurricanes and other extreme weather (Altieri et al., 2015), although this resilience may be greatly reduced in lower-diversity systems. The concern posed by farmer 12 about trees competing with pasture for water during summer drought has occasioned a significant amount of research, some of which has corroborated this concern, and some of which has found that trees increase surface water availability through hydraulic lift—the balance between these effects depends on the root structures of all plants involved, amid a myriad of other factors (Bayala and Prieto, 2020; Jacobs et al., 2022).

There is also ample evidence confirming improved water management, erosion control, and soil health with agroforestry (Kremen and Miles, 2012; Paudel et al., 2012; Asbjornsen et al., 2014; García de Jolón et al., 2018; Romanova et al., 2022). Brodt et al. (2020) found that nine out of sixteen farmers reported improved soil health, and seven reported improved water management, as a result of using agroforestry. As in this study, farmers also frequently mentioned soil health and water management together due to their interrelation in landscape function (Brodt et al., 2020). Several farmers in this study who identified the water management benefits of agroforestry also demonstrated a mental shift toward whole-farm water and ecosystem management (Kreitzman et al., 2022), including the use of water harvesting swales, which is consistent with research finding the co-benefits of agroforestry and water harvesting for climate resilience (Altieri et al., 2015). These findings bode well for the future of agroforestry in the Mid-Atlantic, with resilience to both increased rainfall and temperature extremes becoming increasingly important in coming decades as Pennsylvania and surrounding states undergo projected climatic changes (Pennsylvania Department of Environmental Protection, 2021).

Agroforestry's ability to provide high-quality habitat for many species, resulting in increased abundance and diversity of on-farm wildlife, is well documented (Perfecto and Vandermeer, 2008; Scherr and McNeely, 2008; Ferreira et al., 2018; Kletty et al., 2023). Farmers in other post-adoption studies have reported satisfaction with improving wildlife habitat and seeing more wildlife on their farms as primary benefits of using agroforestry, both in the United States (Kreitzman et al., 2022; Romanova et al., 2022) and in Europe (García de Jolón et al., 2018). Farmers in this study also showed a significant correlation between environmental motivations to use agroforestry and satisfaction with seeing more wildlife, which has been corroborated by relational values research in the Midwest (Kreitzman et al., 2022).

Practical and business-related benefits

Farmers also described a number of practical and business-related benefits of agroforestry, which largely consisted of beneficial system characteristics or provisioning services. Chief among these was the enjoyment and satisfaction farmers reported from living and working in their systems, which was frequently couched in comparison with more industrial forms of agriculture; this benefit is corroborated by research finding spiritual, emotional, and psychological wellness resulting from living and working with agroforestry (Hastings et al., 2021; Romanova et al., 2022) and high farmer satisfaction with agroforestry in both commercial and diversified home garden contexts (Cardozo et al., 2015). More generally, the ability of green, vibrant, and diverse landscapes to support mental health is well documented in the green-space literature (Kemper, 2019; Wendelboe-Nelson et al., 2019; Beute et al., 2023).

The health benefits of agroforestry systems for livestock, especially the provision of shade, are supported in the experimental literature (Schoeneberger et al., 2012; Jordon et al., 2020) and show up in the post-adoption literature as common motivations for, and benefits of, using silvopasture (García de Jolón et al., 2018; Orefice et al., 2017; Romanova et al., 2022). Aside from shading benefits, several farmers hypothesized the forage diversity and availability of woody browse in their silvopasture led to better nutrient intake for their livestock, particularly because they observed preferential browsing of woody vegetation. The preference for woody vegetation under certain conditions has been mentioned by other silvopasture practitioners (Orefice et al., 2017) and demonstrated in experimental research (Vandermeulen et al., 2018). Certain trees common in silvopastures, such as black locust (*Robinia pseudoacacia* L.), can have more than double the crude protein of pasture forages (Papachristou et al., 2020), and other common temperate agroforestry plants have substantial nutritive benefits (Mahieu et al., 2021). Research suggests that shading in silvopasture systems may also increase crude protein and decrease crude fiber percentages in pasture forages, with significant utilization benefits for livestock (Kallenbach et al., 2006). Other farmers mentioned using fruit and nut trees to provide forage for pigs, which is a long-standing traditional practice that can provide more calories and nutrients than pasturage alone (Stavi et al., 2022). The inclusion of high-tannin browse plants such as willow (*Salix* sp.) as an animal-regulated dietary supplement is supported by evidence for the benefits of tannins at low concentrations for the digestibility of other forages (Patra and Saxena, 2011) and the control of gastrointestinal parasites (Zeineldin et al., 2020).

The business resilience and income security afforded by a diversity of commercial enterprises have been supported by other post-adoption studies in agroforestry (García de Jolón et al., 2018; Brodt et al., 2020; Hastings et al., 2021), and in diversified agricultural systems more broadly (Lin, 2011; Bowman and Zilberman, 2013). Research in tropical areas suggests that the reduction in financial risks occurs more strongly with higher diversity (Cardozo et al., 2015), but this may differ in developed economies where labor is often more costly and farmers often rely on mechanization (Bowman and Zilberman, 2013). As with the question of climate resilience, farmers who expressed concerns about the lack of business resilience in agroforestry systems were focused on the permanent nature of trees and the physical work of removing them if they were to switch to a different enterprise. This has not been mentioned by other post-adoption studies and remains an interesting question for subsequent research.

The benefit of having agroforestry systems that yield food, fuel, or fiber for personal use has been documented among agroforestry practitioners (Hastings et al., 2021), and such forms of nonmonetary income can have a significant economic impact (Cardozo et al., 2015). The benefits farmers realized from eating some of the food they grew, both for income and nutritional outcomes, are similar to other studies connecting on-farm production to farmer nourishment (Deaconu et al., 2019) and the benefits of growing one's own produce in general (Algert et al., 2016). However, because very few farmers in industrialized countries consume their own produce, documentation of this benefit in temperate contexts is lacking, making it an important topic for other post-adoption studies.

The regulating services of pest control and pollination made possible by improved wildlife habitat are a known benefit documented in the post-adoption literature (Brodt et al., 2020; Hastings et al., 2021) and the experimental research (Kremen and Miles, 2012; Asbjornsen et al., 2014; Moreira et al., 2015; Bentrup et al., 2019). The use of poultry in multispecies grazing systems as a form of integrated pest management can been seen in other studies (Kreitzman et al., 2022), and the use of small livestock in tree systems has documented pest management, weed control, and fertilization benefits (Paolotti et al., 2016).

The reduction of purchased inputs resulting from agroforestry systems' ability to meet some of their own needs has been mentioned by other agroforestry practitioners (Brodt et al., 2020; Hastings et al., 2021), and line up with the literature on reductions in both pesticides (Hatt et al., 2017) and fertilizers (Jose, 2009; Molnar et al., 2013; Pardon et al., 2018). The majority of farmers who mentioned reduced inputs had silvopasture systems that reduced their purchased feed requirements, which aligns with the post-adoption literature (Orefice et al., 2017; Romanova et al., 2022) especially in the context of mid-summer declines in pasture productivity. For farmers who want to feed tree foliage to their animals as a supplemental forage, many tree species meet the nutritional requirements for grazing livestock (Kendall et al., 2021), and can exceed the nutritional content of pasture forages in late summer (Ryan et al., 2022). Additionally, feed production for animals as an emergent property of agroforestry systems is one of the largest reasons for their reduced environmental impact compared to conventional agriculture (Paolotti et al., 2016).

The possibility of having higher yields as a result of using agroforestry has been documented by other studies, but it is usually a small proportion of farmers (Brodt et al., 2020), with the exception of silvopasture systems, in which the phenomenon of increased grazeable acreage from the conversion of forests to silvopasture is common (Orefice et al., 2017). Post-adoption research by Hastings et al. (2021) confirms that increased yields can come in two ways: the use of agroforestry to utilize previously neglected areas of the farm, and by stacking enterprises in the same physical space, which can result in higher total yields, even if yields of individual crops are reduced (Martins et al., 2011; Armengot et al., 2016; Fannon et al., 2019; Staton et al., 2022). An additional pathway for higher yields hinted at by farmer 13 is livestock gaining weight faster with the presence of shade in silvopasture systems, for which there is mixed evidence in the literature (de-Sousa et al., 2023).

The positive effects of agroforestry on pasture and crop health that farmers mentioned, such as the regulation of ground-level microclimate, protection from wind, and fertilization from nitrogen fixing trees, have been broadly supported by the agroforestry literature (Jose et al., 2004; Hastings et al., 2021; Jacobs et al., 2022). These are promoted as primary reasons farmers should utilize agroforestry, and the use of trees to provide a beneficial microclimate for crops has been identified in the post-adoption literature (Hastings et al., 2021). In a review, Jacobs et al. (2022) found studies supporting in-field reductions in light intensity, wind speed, and surface runoff, as well as some moderation of temperature and humidity. Research has also found nutrient facilitation effects in agroforestry systems that support the concept of tree-based fertilization (Munroe and Isaac, 2014; Isaac and Borden, 2019).

Several farmers postulated that their products (apples and meat) were more nutritious than those grown in conventional settings, but this is hard to verify. For example, farmer 14 anecdotally said that their apples tasted better than they would outside a forest garden, and attributed this to the diversity of plants—and thus, microbes and fungi supplying nutrients—in the forest garden where they were grown. Experimental evidence comparing the abundance of soil microbes between grass and forest garden understory treatments in an apple orchard found little difference (Wartman et al., 2017), so this hypothesis may be unsupported. There is little research comparing the taste and nutrition profile of produce from agroforestry systems with that from conventional settings, and studies have reported farmers' curiosity about the nutrition effects of agroforestry (Brodt et al., 2020), so research in this area would be a substantial contribution.

Challenges of temperate agroforestry, and overcoming them

The challenges that farmers encountered were generally consistent with those encountered in other studies, and fortunately, there are potential solutions for most of them. Early setbacks were largely a result of poor planning prior to implementation and issues with wildlife (e.g., rodents), problems which were echoed elsewhere in discussions of the need for planning assistance, advice for prospective agroforestry adopters, and knowledge gaps related to planting and maintaining trees. However, learning experiences are a normal part of the innovation process, and ultimately not a determinant of success (Romanova et al., 2022). The post-adoption literature has documented issues with rodents being a common problem, although not necessarily in the establishment years (Brodt et al., 2020; Hastings et al., 2021), making this an ongoing area of technical research. Better planning assistance and technical mitigations for rodents would help to alleviate these challenges.

Negative interactions within agroforestry systems were largely caused by livestock, and it was a challenge primarily mentioned by silvopasture practitioners. Orefice et al. (2017) found that protecting trees from livestock was a concern for some silvopasture practitioners in the Northeast, although the majority of the farmers in their study had thinned-forest systems. However, they found that damage from pigs was a concern, as it was for some farmers in this study (Orefice et al., 2017). Livestock are known to be damaging to trees when unmitigated (Karki et al., 2019), making appropriate tree protection an important measure (Lehmkuhler et al., 2003). Concerns about integrating animals and trees for the viability and optimization of silvopasture have spurred research into these interactions (Nicodemo and Porfírio-da-Silva, 2019), which is ongoing and would be well-supported by increased farmer participation in extension research for silvopasture.

Difficulties with integrating machinery largely had to do with either the physical complexity of the involved systems or the inefficiency of using large machinery when trees are introduced as obstacles. These challenges are often cited as core issues preventing the scalability of agroforestry (Wolz et al., 2018), and have spurred research into agroforestry-appropriate mechanized technologies (de Morais et al., 2023). The range of mechanization in agroforestry systems varies, as it did in this study, and farmers opting for the integration of machinery can simplify their systems to accommodate machines while retaining diversity (Wolz et al., 2018; Kreitzman et al., 2022). Further research into the feasibility and benefits of structurally simplified but biologically diverse arrangements, such as within-row diversification or between-row diversification (Wolz et al., 2018) may make such concepts more accessible to farmers working to design a system that strikes this balance.

Delayed yields and high startup costs were reported as separate challenges by two groups of farmers with very little overlap, but both challenges relate to the issue of cash flow in agroforestry enterprises. Most agroforestry systems had high installation costs, but these were frequently covered by grants—it was the lack of income in subsequent years that posed a challenge. Studies of varying scope have identified poor cash flow during establishment as a common problem (Bowman and Zilberman, 2013; Hastings et al., 2021; Kreitzman et al., 2022; Staton et al., 2022). However, agroforestry systems can also be designed to produce yields while trees mature, allowing farmers to recoup the cost of their initial investment (Smith et al., 2012b); this is one possible explanation for the large proportion of farmers in this sample using silvopasture, which can yield high-value meat products in the first year. High upfront costs can also be lessened by grants and payments for positive externalities, such as carbon sequestration (Bowman and Zilberman, 2013; García de Jolón et al., 2018; Staton et al., 2022). Many farmers in this study also utilized external income sources, which is common in similar studies (Kreitzman et al., 2022).

The novel crop challenges farmers encountered were diverse, but there are solutions. Little research has looked into the challenge farmers face in educating their customers on how to utilize unfamiliar produce, making this a useful area for future research. The case of farmer 14 being unable to receive a permit for an herb drying facility demonstrates permitting procedures may need to evolve with the innovations present on small, integrated commercial farms. The issues posed by processing a diverse spread of crops have been mentioned in post-adoption studies (Kreitzman et al., 2022), and solutions include spatial arrangements that optimize harvesting efficiency while retaining diversity (concomitant with optimizing other spatially dependent management tasks), and the use of processing and distribution cooperatives that reduce the burden on small, diverse farms. A small number of regional cooperatives have sprung up in recent years in response to this need, including the Keystone Tree Crops Cooperative in Pennsylvania (Keystone Tree Crops Cooperative, 2023) and the Route 9 Cooperative in Ohio (Route 9 Cooperative, 2023). While the agricultural cooperative model has been around for over a century and has many benefits, other forms of small-scale aggregation may also be useful for agroforestry enterprises (Abraham et al., 2022).

Several farmers reported challenges related to anticipating the future, including the question of who would maintain the farm as they got older, the uncertainty of how system succession would impact income streams, and a reluctance to invest in rented land. The aging farmer population has been pointed out in numerous studies (Valdivia and Paulos, 2009; Mattia et al., 2018), and although agroforestry practitioners tend to be younger than farmers in general (Kreitzman et al., 2022), their use of long-term crops may heighten awareness of such issues. With regard to the impacts of succession on income streams, the developmental character of agroforestry systems is largely inherent (Kreitzman et al., 2022), but business planning may alleviate such concerns. The issues posed by rented land for perennial and innovative farming practices have been documented in a variety of contexts (Caulfield et al., 2020; Bruce et al., 2022), but longer leases and alternative tenure agreements may help with this problem.

The system complexity mentioned by farmers in this study describes the challenge of understanding the interconnected nature of agroforestry systems and predicting the effects of human interventions, which other post-adoption studies have documented (Brodt et al., 2020; Kreitzman et al., 2022). Brodt et al. (2020) found farmers were challenged with coordinating irrigation for different crops, the timing of different management activities, and learning how to manage their systems overall. Kreitzman et al. (2022) discuss how farmers mitigated complexity by limiting the scale of their systems and finding ways to optimize labor. In this study, management complexity was something farmers faced whether they had one silvopasture or three, or even multiple different system types with a greater number of enterprises, which suggests that even relatively simple agroforestry systems can exhibit ecological complexity.

The meat processing challenges farmers mentioned, namely a lack of local processing capacity, is a known constraint for small-scale meat producers (Lewis et al., 2012). Interestingly, silvopasture practitioners interviewed by Orefice et al. (2017) did not bring up processing concerns, but this was not the focus of their research. Legislation permitting small-scale meat producers to process and sell their own meats may be beneficial, as this would allow each farm to scale their enterprise adaptively and reduce dependence on centralized facilities.

The tree establishment work farmers encountered entailed protecting trees from livestock and mowing to reduce rodent pressure, and made up a large portion of labor requirements during the early years. The pattern of large up-front investment in time rings true for most agroforestry systems (Park et al., 2018; Kreitzman et al., 2022; Romanova et al., 2022). Careful design planning and proactive management practices, such as the use of competitive groundcovers to suppress grass in the tree rows, might reduce tree maintenance needs early on (Alley et al., 1998), and numerous tree protection technologies exist. In the context of silvopasture, recent research has demonstrated farmers' preference for thinning a forest rather than planting into a pasture, as this method avoids many of the challenges of tree establishment (Wilkens et al., 2022b).

Labor in agroforestry systems

High labor requirements are often cited as a challenge in the literature on agroforestry and diversified farming systems (Brownlow et al., 2005; Bowman and Zilberman, 2013). The post-adoption literature has found that high labor requirements and management complexity are frequently mentioned by agroforestry practitioners, regardless of the agroforestry system used (García de Jolón et al., 2018; Orefice et al., 2017; Brodt et al., 2020). In this study, the majority of farmers reporting high labor requirements had forest gardens, and research in forest garden systems has found labor to be a core challenge in their management due to their great system complexity and reliance on manual labor (Björklund et al., 2019). This pattern of low mechanization and high reliance on labor is generally seen in most temperate agroforestry contexts (Brodt et al., 2020; Kreitzman et al., 2022), making increased labor productivity an important goal in enabling more farmers to use agroforestry and avoid excessive simplification (Ferguson and Lovell, 2017). However, several farmers also mentioned the benefits of agroforestry for reducing maintenance needs, having designed systems that needed less active management. For example, farmer 10 included swales along their tree rows to concentrate runoff where trees could access it, reducing the work of watering their trees. Farmer 14 let the native wildflowers grow wild in their forest garden, fostering biological pest control and reducing the amount of time needed to apply foliar sprays to the fruit trees. The post-adoption literature has documented similar applications of agroforestry to reduce the need for mowing, fertilization, and disease prevention (Brodt et al., 2020), as well as aiding in weed management (Hastings et al., 2021). It is possible for diverse, interconnected systems to exhibit synergies that increase productivity (Ferguson and Lovell, 2017; Kreitzman et al., 2022), which can arise due to facilitation and/or resource partitioning effects among system components (Picasso et al., 2011; Brooker et al., 2015). Several farmers in this study also practiced purposeful neglect, such as farmer 9, who propagated many plants from seed and allowed natural selection to take its course; this approach has been documented as a "judicial withholding of active management" among some Midwestern agroforestry practitioners

(Kreitzman et al., 2022) and written about extensively by Shepard (2013).

Interestingly, four out of five farmers who articulated a labor-saving component to their agroforestry system also mentioned the challenge of agroforestry systems' high labor requirements, suggesting that labor in agroforestry is not governed by a straightforward causal relationship. Instead, the farmers in this study exemplify a balancing act: labor is an expensive input in an industrialized economy, so agroforestry adopters design systems that make efficient use of their time while still achieving the environmental benefits that underpin their efforts, and find satisfaction in their systems despite never approaching the labor efficiency of industrial agriculture. Both sides of the relationship appear to be mediated by the way agroforestry systems are designed, as systems with greater complexity (i.e., forest gardens) can require more labor but also offer increased possibility for labor-saving emergent properties, such as self-regulation. While labor is not preventing agroforestry adopters from being successful, farmers would benefit from labor-saving innovations across a spectrum of system configurations. Additionally, farmers found that labor requirements were high during establishment years but lessened over time, especially if their systems could "outgrow" some management needs, so it may be best to understand agroforestry systems as developmental processes (Kreitzman et al., 2022; Romanova et al., 2022). More research into the relationship between agrobiodiversity, structural arrangements, and labor productivity in production-oriented agroforestry systems is needed.

Addressing farmer assistance needs and knowledge gaps

Farmers generally reported struggling on their own, without nearly the visible examples, funding resources, planning assistance, and knowledge available to conventional farmers. The post-adoption literature confirms the need for examples of what successful agroforestry systems and businesses look like (García de Jolón et al., 2018; Orefice et al., 2017; Park et al., 2018; Hastings et al., 2021), and eight farmers in this study learned from other farmers before or during the process of implementing agroforestry. The availability of applicable system examples is important, both for adoption and throughout the design process (Orefice et al., 2017; Hastings et al., 2021). The impression among farmers that there are few examples of agroforestry systems, despite the concentration of agroforestry practitioners represented in this study, indicates the unrealized potential of a farmer–farmer regional knowledge-sharing network in the Mid-Atlantic. Farmers in this study and others have shown interest in networking with other farmers in their region to learn directly from each other (Hastings et al., 2021; Kreitzman et al., 2022), and research has demonstrated the value of such networks for facilitating a growing agroforestry practice (Ferguson and Lovell, 2017; Asprooth et al., 2023; White et al., 2023). There is a role for both centralized, government extension support networks and decentralized farmer–farmer networks in facilitating agroforestry, as these networks are dominated by different types of expertise (Sutherland et al., 2017), and farmer–farmer networks would be best equipped to provide relevant system examples. Concurrently, the traditional ecological knowledge of North American indigenous people remains a largely underutilized resource in the design of agroforestry systems (Rossier and Lake, 2014).

The significant need for agroforestry-appropriate grant funding featured prominently in many interviews, due to the high up-front costs and long negative cash flow period in agroforestry. The importance of grant funding for alleviating the cash flow problem has been corroborated by other research (Brodt et al., 2020; Hastings et al., 2021; Staton et al., 2022), especially because it takes time to experiment and learn from mistakes (Kreitzman et al., 2022; Romanova et al., 2022). Additionally, just because farmers receive grants does not mean the grant system is set up to best serve their needs; even farmers in this sample who had received grants were frustrated with the grant system for its use of strict system classifications, which in some cases meant they had to misrepresent their systems to receive funding (i.e., farmer 6 had to call silvopasture plantings windbreaks because silvopasture was not eligible for funding). For grants to meet the needs of agroforestry practitioners, they must be flexible enough to fund highly variable systems, allow for harvest of interim crops, and persist until tree crops can provide income (Hastings et al., 2021). Farmers may also be unaware of newer and less broadly known incentive programs that allow for harvesting, indicating that additional outreach is necessary (Kreitzman et al., 2022).

Several farmers in this study specifically said that they would have benefited from business planning assistance, and pointed out the importance of this step for any farmer considering agroforestry. The importance of planning for realizing the benefits of agroforestry and minimizing tradeoffs shows up in the post-adoption literature (Kreitzman et al., 2022), and strategic whole-farm planning is known to be beneficial, both for agriculture in general (Muleke et al., 2022) and in the context of conservation practices (Reimer et al., 2018). Extension professionals who are well-versed in the types of productive agroforestry being employed by farmers in this study should be able to provide comprehensive business planning assistance in such systems, in addition to technical advice.

The lack of agroforestry-specific technical advice is another key challenge that several studies have mentioned (Orefice et al., 2017; Brodt et al., 2020). Farmers in other post-adoption studies have also expressed concern that knowledge is siloed, and thus, less applicable to the highly interdisciplinary practice of agroforestry (Hastings et al., 2021). The challenges that farmers ran into and the knowledge gaps they described give a thorough overview of the kinds of information that agroforestry-specific extension agents should be versed in. Farmers in this study most commonly wanted to know about other agroforestry practices, and other post-adoption studies have found that farmers want to know how to design and manage systems that improve crop production and minimize negative tradeoffs (Brodt et al., 2020; Hastings et al., 2021). Fortunately, while the knowledge base is still growing and agroforestry practitioners are few and far between, each farm represents an opportunity to expound on successes and learn from failures with collaboration across farmer–researcher networks (Kreitzman et al., 2022). In the meantime, farmer–farmer knowledge exchange remains an important tool to facilitate the growth of agroforestry (Romanova et al., 2022; Asprooth et al., 2023; White et al., 2023).

Discussion of assistance needs brought out the frustration among farmers in this study that government policies are structured around commodity farming and not designed to serve agroforestry practitioners—something identified across the post-adoption literature (Hastings et al., 2021; Kreitzman et al., 2022). The farmers in this study and others largely work to overcome technical challenges through experimentation and adaptive management, whereas systemic challenges related to inadequate government support are perceived as insurmountable barriers (Kreitzman et al., 2022). Government programs intersecting with diversified farming systems like agroforestry can be receptive to change, as in the Food Safety Modernization Act, which was a frustration for farmers in this study and others (Brodt et al., 2020; Kreitzman et al., 2022), but now gives farmers the ability to determine the timing of animal management at their own discretion (U.S. Food & Drug Administration, 2023). However, the problems farmers encountered in finding relevant system examples, being eligible for funding, and seeking business planning and technical advice point to a fundamental disconnect between government structures and the needs of agroforestry adopters.

Government policies are tightly bound to specific agroforestry practices, such as windbreaks or alley cropping, but the implementation of agroforestry practices on the ground has not aligned with such rigorously-defined categories. Instead, it is characterized by an extensive use of combined systems and a high degree of context-dependent variability as farmers engage in a ground-up process to design the best system for their ecological and economic context. For example, farmer 16 had a system that exhibits all the characteristics of both a forest garden and a riparian buffer. Farmer 10 had a forest garden system in which ducks foraged occasionally, but which was best understood as a forest garden rather than a silvopasture. Farmer 13 had a system they called a "silvopasture orchard" because it could be described as either an orchard or a silvopasture system. Even within a defined agroforestry practice, such as silvopasture, variation between systems limits the extent to which the label of "silvopasture" can fully encapsulate individual systems, such as the difference between silvopastures featuring tree crops as the primary enterprise and those built around animals. The two farmers with multiple silvopastures (10 and 13) were distinct from other silvopasture practitioners in that tree crops were a core enterprise, and animals were used for integrated pest management and to better utilize the planting area through spatial stacking. In most other cases, silvopastures were designed with a mix of trees—sometimes even fruit- and mast-producing trees—intended to support animals, and the tree crops available in such systems were not harvested or sold. Both silvopasture configurations involved animals grazing under fruit trees, but the structure, management requirements, and business models involved were quite different—a dynamic other studies have documented (Orefice et al., 2017). Research into farmers' thinking about agroforestry systems has revealed that modifying or adapting known practices to the farm context is a normal, if not necessary, part of the process (Romanova et al., 2022), but the inflexibility of current policies makes it challenging for farmers to receive support while making such modifications.

An alternative norm in government assistance for agroforestry would be to conceptualize agroforestry systems as the evolving product of a complex developmental process of engagement between each individual farmer and their unique context—and assist farmers throughout this process. Farmers considering agroforestry are more likely to participate in a collaborative design process characterized by in-person farm visits and thorough consideration of farm context and personal preferences (Stanek and Lovell, 2020). Incentive programs could reward farmers for implementing and maintaining systems that provide ecological service outcomes, regardless of their configuration or whether farmers harvest a product from the system (Kreitzman et al., 2022). The tasks that farmers face in optimizing their systems for their context, avoiding tradeoffs, and adapting management over time are best encapsulated as a design challenge rather than a choice between codified practices, so government policies that incorporate this idea may be more successful at facilitating agroforestry adoption.

Learning pathways, motivations to use agroforestry, and implications for agroforestry adoption

Learning pathways

Most farmers in this study used multiple learning pathways in combination, and the literature has documented how agroforestry practitioners generate knowledge for their context by piecing it together from multiple sources, often simultaneously building on existing network-available knowledge and experimenting with their own ideas (Park et al., 2018; Hastings et al., 2021; Kreitzman et al., 2022; Romanova et al., 2022). Hastings et al. (2021) called this process a "triangulation of knowledge" including seeing agroforestry examples firsthand, accessing ancestral knowledge, connecting with practitioner networks, and learning through experience. Romanova et al. (2022) found that some farmers spend considerable amounts of time researching agroforestry prior to implementation, and others adopt agroforestry based on limited knowledge and spend time learning after implementation.

The significance of the permaculture network as a source of learning for this sample of farmers aligns with the findings of Kreitzman et al. (2022), although other studies have found a smaller proportion of farmers using it (Hastings et al., 2021). While the USDA National

Agroforestry Center and other research organizations are shifting to provide more resources for production-oriented systems, their focus until recent years was more simplified agroforestry systems. In light of this, the permaculture design principles, web resources, and associated authors have long filled a need for tree-crop-related knowledge and an organizing framework for creating and managing systems of great agroecological complexity (Kreitzman et al., 2022). Permaculture is controversial in the academic realm for its evangelical approach and promotion of sometimes-unsubstantiated information, but a large portion of its teachings are derived from traditional practices and supported by agroecological research (Ferguson and Lovell, 2014; Krebs and Bach, 2018), and its prevalence among the farmers using productive agroforestry systems suggests it will remain a part of the agroecology movement (Kreitzman et al., 2022)—at least until mainstream agricultural research can match the depth and applicability of its available information. Other learning pathways that were identified, including books, the organic farming community, environmentally focused college education, international travel, web resources, and workplace exposure are not unusual (Orefice et al., 2017; Hastings et al., 2021; Romanova et al., 2022).

The potential influence of farmers' learning pathways on the systems they implemented is challenging to corroborate given the scarcity of studies that have explicitly focused on the sources of learning prevalent for agroforestry practitioners and how they influence farmers' system preferences. There was overlap between farmers using the permaculture network and reading books, but these were also the most common learning pathways. Silvopasture practitioners who utilized the permaculture network were more likely to use multispecies grazing than those who did not, which may be attributable to permaculture's emphasis on diversity as a design principle (Krebs and Bach, 2018). Perhaps the most direct relationship was the fact that only one of eleven silvopasture practitioners had an environmentally focused college education, compared with five of seven farmers with forest gardens and all farmers using forest farming, alley cropping, and entomoforestry. Further research into how farmers learn about agroforestry and implement their knowledge would help clarify these relationships.

Motivations for using agroforestry

The motivation to have a positive environmental impact through the use of agroforestry—often in comparison to the damage caused by previous generations' agriculture or modern industrial agriculture—was prevalent for the majority of farmers in this study and others in the post-adoption literature (Hastings et al., 2021; Kreitzman et al., 2022). Farmers often mention environmental and practical motivations together (Kreitzman et al., 2022), and for some groups of farmers, practical motivations are secondary to values-based motivations (Hastings et al., 2021). Kreitzman et al. (2022) found that 90% of agroforestry practitioners had environmental motivations, which were interwoven with the related values of land stewardship, connection to nature, learning and sharing knowledge, long-termism, and diversity. Like some in this study, farmers emphasized "farming with nature" rather than trying to conform their land to a specific practice (Kreitzman et al., 2022). Similarly, the primary motivations of Hawaiian agroforestry practitioners interviewed in Hastings et al. (2021) included reversing the damage caused by plantation agriculture, prioritizing responsibility to the land over profit, counteracting the social injustices of capitalism, and using native practices as a means of connecting with ancestors.

Half the farmers in this study, most of whom had silvopastures, also had more practical motivations for using agroforestry. Some farmers are more profit-motivated than others (Kreitzman et al., 2022), and the silvopasture practitioners in Orefice et al. (2017) almost exclusively held practical motivations for using silvopasture, such as providing shade for livestock, expanding pasture acreage, and increasing summer forage growth. However, additional research into the relationship between farmers' motivations and the agroforestry systems they choose is needed to clarify this difference. The literature shows parallels for other motivations, including improving the land for future generations and paving the way for future agroforestry practitioners (Hastings et al., 2021; Kreitzman et al., 2022), "growing real food" instead of "feeding the world" (Kreitzman et al., 2022), maintaining quality of life for animals (Orefice et al., 2017), and demonstrating the viability of agroforestry (Kreitzman et al., 2022). Concerns about economic collapse do not show up as a distinct motivation in the literature, but this is closely related to farmers' desire to differentiate themselves from mainstream farming practices they perceive to be harmful.

Implications for agroforestry adoption

Very few of the farmers interviewed had switched from conventional management to agroforestry—most were first-time farm owners who chose to practice agroforestry over conventional farming because of their educational background, personal values, and interest in alternative agricultural practices, which closely matches profiles of potential agroforestry adopters (Trozzo et al., 2014; Mattia et al., 2018) and farmers who have adopted agroforestry (Hastings et al., 2021; Romanova et al., 2022). The adoption literature confirms the importance of farmers' attitude and farming philosophy for their interest in agroforestry (Valdivia and Poulos, 2009; Wilkens et al., 2022a), and that farmers who implement agroforestry demonstrate deep philosophical connections to their work, sometimes regardless of financial outcomes (Kreitzman et al., 2022). With the average age of American farmers climbing steadily and a large portion of farmland expected to change hands in the coming decades (Leonard and Gutmann, 2006), facilitating the transition of land from current owners to younger, prospective farmers with an inclination toward agroecological methods may speed up the rate of agroforestry adoption.

Conclusions

- The perceived benefits of agroforestry included: improved climate resilience; lifestyle and mental health benefits; improved water management; improved soil health; increased presence of wildlife; improved livestock well-being; improved business resilience; provision of food, fuel, or fiber; improved ecological connectivity; reduced need for purchased inputs; low labor requirements; improved yields; improved pasture or crop health; and high product quality.
- The perceived challenges of agroforestry included: early setbacks; negative interactions within agroforestry systems; high labor requirements; difficulty mechanizing; delayed or uncertain yields; novel crop challenges; difficulty planning for the future; high management complexity; meat processing challenges; tree establishment work; and high startup costs. Many of these challenges can be overcome with the development of agroforestry systems that minimize early costs, ensure early yields, balance environmental outcomes with labor productivity, and enable the harmonious integration of animals and appropriate-scale machinery. Farmers with high levels of diversity and processing-intensive crops would benefit from regional cooperative processing and marketing hubs for agroforestry crops.
- Labor is a key variable in the development of economically viable agroforestry systems. Some farmers found that their agroforestry systems had high labor requirements, and others found that their agroforestry systems had relatively low labor requirements. Labor requirements were generally high during establishment years but lessened over time, especially if the agroforestry system needed less intervention. Mechanization may be a valuable tool for reducing labor needs, but careful planning is necessary to make it operable in a polyculture setting.
- This research supports the conceptualization of agroforestry not simply as a set of system configurations but as a developmental practice. The pattern of development and change reflects how benefits accrue and challenges abate over longer time spans than in conventional systems, and characterizations of a ground-up design process, rather than categorically-defined "practice adoption," more accurately match why and how farmers design an agroforestry practice. This understanding is crucial for shaping government support for agroforestry that is flexible enough to serve each farmer's unique situation, which will enable increased agroforestry adoption.
- Farmers have a range of motivations for using agroforestry, but environmental and practical benefits are the most common reasons. Farmers learn about agroforestry from a range of resources, most commonly from the permaculture network, reading books, and connecting with the organic farming community. Farmers in this study closely align with the background and values that characterize potential agroforestry adopters described in the adoption literature.

Data accessibility statement

The interview guide is viewable in supplementary file Text S1. Two tables containing useful descriptive information about each farm and its agroforestry systems have been submitted as supplementary table files: farm characteristics (Table S1) and detailed descriptions of agroforestry systems (Table S2). Interview transcripts cannot be provided for reasons of confidentiality. The seven tables containing farmers' responses are also included as supplemental tables (Tables S3–S9).

Supplemental files

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

Text S1. Interview questions used in farmer interviews. (DOC)

Tables S1–S9. PDF

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