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Silvopasture in the USA: A systematic review of natural resource professional and producer-reported benefits, challenges, and management activities

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ABSTRACT

Silvopasture is the deliberate integration of trees, forage, and grazing livestock on the same piece of land. These agroecosystems are intensively managed for multiple benefits, providing both short- and long-term income. Research suggests that silvopasture systems can increase systemwide productivity, while providing multiple ecosystem services. Due to these benefits, silvopasture adoption is increasing across the United States of America (USA), as described in regional case studies exploring silvopasture adoption. However, most of these case studies have a limited sample size, making it difficult to assess broader trends that help or hinder silvopasture adoption. To address this issue, we conducted a systematic review of silvopasture adoption studies in the USA. Our key objectives were to understand the primary benefits and challenges reported by producers using silvopasture, assess how satisfied producers are with their silvopasture systems, and understand how agricultural and natural resource professionals view silvopasture management. In total, 53 studies from 1983 to 2021 related to silvopasture adoption were included. When analyzed collectively, diversification of farm income and shade for livestock were the primary benefits of implementing silvopasture. This was similar to benefits reported from international studies that were compared. Regarding challenges, lack of information was identified as a primary concern by producers. Producers reported using a wide range of livestock that included cattle, goats, sheep, chickens, turkeys, horses, bison, pigs, geese, and ducks. Results indicate that producers almost exclusively use some form of rotational or management intensive grazing in their silvopasture systems, with 98% using one of these practices. Furthermore, 96% of producers reported using silvopasture in combination with paddocks in open pasture, suggesting that silvopastures are primarily used as a complementary component of their pasture rotation system. Silvopasture retention was also found to be high across studies, with 88% of producers indicating they would continue the practice into the future. With increasing interest to diversify agricultural management under the uncertainty of a changing climate and the need for agricultural landscapes to sequester more carbon, silvopasture may be an effective strategy for some livestock operators to diversify farm income, enhance animal productivity and wellbeing, and increase ecosystem resilience.

1. Introduction

Silvopasture is an agroforestry practice that integrates tree, livestock, and forage management on the same piece of land to diversify production, increase animal wellbeing, and enhance ecosystem services. Fig. 1 provides a brief overview of key effects of temperate silvopasture systems based on the research literature.

While benefits exist, silvopasture systems are also associated with management challenges and costs. Integrating tree, livestock, and forage management requires considerable planning and technical expertise to

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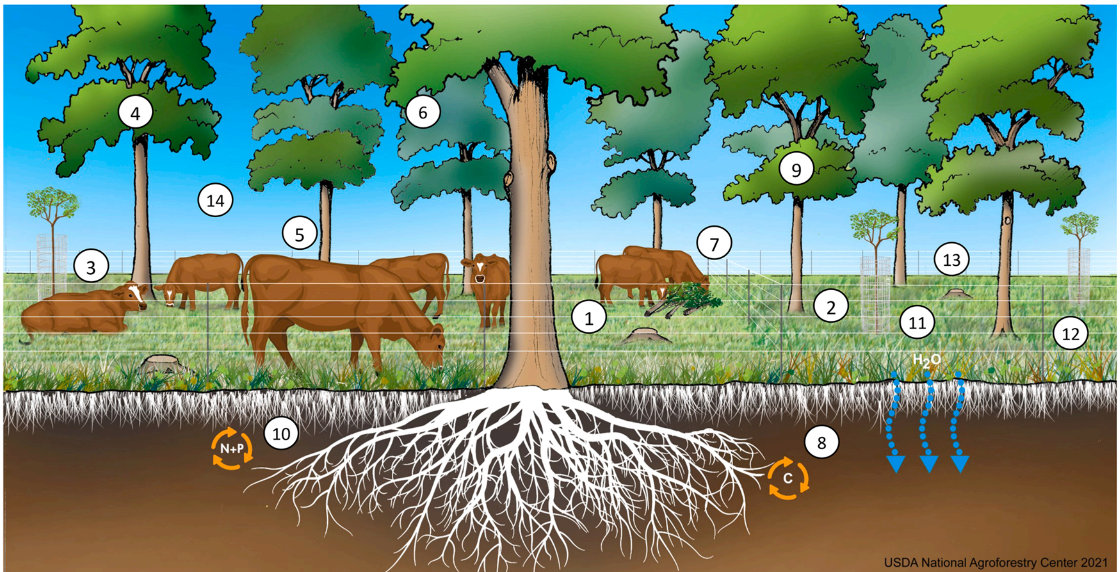

Key	Component	Summarized primary effects	Key references
1	Forage	Microclimate modification can maintain or enhance forage yield and quality compared to open pasture depending on species and management.	Buergler et al. (2006), Ford et al. (2019b), Fannon et al. (2019), Orefice et al. (2019), Pang et al. (2019a, 2019b)
2	Forage	Potential for extending forage growing season and yields due to microclimatic modification in droughty summer months and reducing radiation frosts in early and late season.	Frost and McDougald (1989), Feldhake (2002), Kallenbach et al. (2006), Coble et al. (2020)
3	Livestock	Shade reduces solar radiation and heat stress which can enhance animal productivity.	Karki and Goodman (2010), Schütz et al. (2014), Van laer et al. (2014), Pent et al. (2020b, 2021)
4	Livestock	Shelter from trees can offer thermal protection for livestock during winter by reducing wind and precipitation reaching sheltering animals.	Van laer et al. (2014, 2015), He et al. (2017)
5	Livestock	Livestock weight gain in silvopastures can be comparable to that of livestock grazed in open pastures depending on species and management.	Kallenbach et al. (2006), Ford et al. (2019b), Pent et al. (2020a)
6	Tree	Trees in silvopasture can produce products to increase enterprise diversification. Tree growth can benefit from nutrient input but may be negatively impacted by livestock if not adequately managed.	Ares et al. (2006), Broughton et al. (2012), Bruck et al. (2019), Pent 2020
7	Tree	Leaf fodder and mast (e.g., acorns, honey locust pods, apples) can augment livestock diets and offer nutritional value depending on species.	Moreno et al. (2018), Vandermeulen et al. (2018), Pent and Fike (2019), Hassan et al. (2020), Seidavi et al. (2020)
8	Ecosystem service	Soil carbon storage is increased at various soil horizons and depths when converting from open pasture to silvopasture but may decrease when converting from forest.	Haile et al. (2008, 2010), Baah-Acheamfour et al. (2014, 2015), De Stefano and Jacobson (2018)
9	Ecosystem service	Soil and biomass carbon sequestration is generally higher in silvopasture than open pasture but may be lower than forests.	De Stefano and Jacobson (2018), Lal et al. (2018)
10	Ecosystem service	Silvopasture can enhance nutrient recycling and reduce phosphorus loss and nitrate leaching when compared to open pasture.	Michel et al. (2007), Bambo et al. (2009), Boyer and Neel (2010), Nyakatawa et al. (2012)
11	Ecosystem service	Infiltration rates are similar or slightly higher in silvopasture than open pasture but lower than forests.	Sharrow (2007), Moreno et al. (2018) Stewart et al. (2020)
12	Ecosystem service	Silvopasture can increase biodiversity compared to open pastures but may be less than diverse natural forests.	Burgess (1999), Mcadam et al. (2007) Torralba et al. (2016), Moreno et al. (2018)
13	Ecosystem service	Grazing and woodland management in silvopasture systems may reduce fuel load and wildlife risk.	Ruiz-Mirazo and Robles et al. (2012), Palaiologou et al. (2020), Damianidis et al. (2021)
14	Ecosystem service	Silvopasture may provide cultural ecosystem services including sense of place, aesthetic value, recreation and ecotourism, and cultural heritage value.	Fagerholm et al. (2016), Moreno et al. (2018)

Fig. 1. Summary of primary effects of temperate silvopasture systems. (Buergler et al.(2006); Ford et al.(2019b); Fannon et al. (2019); Orefice et al. (2019); Pang et al., 2019a,b; Frost and McDougald (1989); Feldhake (2002); Kallenbach et al.(2006); Coble et al.(2020); Karki and Goodman 2010; Schütz et al.(2014); Van laer et al.(2014); Pent et al. 2020b, 2021; Van laer et al.(2014, 2015); He et al.(2017); Kallenbach et al. (2006); Ford et al., 2019b; Pent et al., 2020a; Ares et al.(2006); Broughton et al.(2012); Bruck et al.(2019); Pent 2020; Moreno et al.(2018); Vandermeulen et al.(2018); Pent and Fike (2019); Hassan et al. (2020); Seidavi et al. (2020); Haile et al. (2008,2010), Baah-Acheamfour et al. (2014,2015); De Stefano and Jacobson (2018); Lal et al. (2018); Michel et al. (2007); Bambo et al. (2009); Boyer and Neel (2010); Nyakatawa et al. (2012); Sharrow (2007); Moreno et al. (2018); Stewart et al. (2020); Burgess (1999); Mcadam et al. (2007); Torralba et al. (2006); Moreno et al. (2018); Ruiz-Mirazo and Robles et al. (2012); Palaiologou et al. (2020); Damianidis et al. (2021); Fagerholm et al.(2016); Moreno et al. (2018)).

ensure that system components complement one another and do not compete. For example, knowledge of rotational grazing is considered a prerequisite to silvopasture management, due to the damage livestock can cause to trees and soil if not moved frequently (Lehmkuhler et al., 1999; Garrett et al., 2004; Gabriel, 2018). Knowledge of forest management is also necessary, since too few trees can result in concentrated grazing and uneven forage utilization (Karki and Goodman, 2010; Frey and Fike, 2018), in addition to increased disease pressure caused by concentrated animal waste around a limited number of trees (Brantly, 2014; Mayerfeld et al., 2016). Conversely, a tree canopy that is too dense will reduce forage growth, which can increase the likelihood of livestock browsing the trees if they are too densely stocked or not rotated quickly enough to a new paddock (Gabriel, 2018). Consequently, silvopastures require periodic management of the tree component to ensure adequate light availability for forages as the trees mature and create more shade (Garrett et al., 2004).

While there is a solid foundation of research documenting the effects of silvopasture, there is less understanding on how producers perceive this agroforestry practice. Information related to producer-reported silvopasture management, benefits, challenges, or overall satisfaction is limited internationally (Frey et al., 2012; de Jalón et al., 2018, Kagiraneza, 2019; Lee et al., 2020). In the United States of America (USA) most information reported in the literature is from experimental sites, a few regional producer case studies, or natural resource professionals (NRPs) who have assisted producers with their silvopastures. Critical knowledge gaps exist in our understanding of how producers manage silvopastures, the benefits they value most, and potential challenges or barriers to establishing or maintaining these integrated systems. This is problematic, since producers are more likely to adopt a new farming practice if there is evidence that other farmers have done so successfully (Rogers, 1995; Fregene, 2007). Furthermore, there continues to be uncertainty about what silvopasture management entails, with some landowners and NRPs mistaking the practice for unmanaged grazing in woodland or forest (Brantly, 2014; Orefice et al., 2017). Unfortunately, this confusion has resulted in some forestry professionals being unwilling to consider silvopasture as a valid management practice in the USA, due to a checkered history of overgrazing in forests and woodlands (Hardesty et al., 1993; Mayerfeld et al., 2016).

To address some of these knowledge gaps and misconceptions, we conducted a systematic review of the silvopasture adoption literature in the USA. We focused this study on the USA because national context is a key variable in adoption research (Mozzato et al., 2018). Our goal was to identify barriers to silvopasture adoption as well as research gaps, educational needs, and policies or programs that could help or hinder adoption. Our research questions were:

1. What are the primary benefits and challenges being reported by agricultural producers using silvopasture in the USA and how do those compare to producers from other countries?
2. What silvopasture establishment and management activities are producers reporting?
3. Are producers in the USA satisfied with their silvopasture systems?
4. What are the primary drivers affecting willingness or intent to adopt silvopasture in the USA?
5. What level of knowledge and support do NRPs have for silvopasture management?

Addressing these knowledge gaps will help connect information from landowners and NRPs experienced with silvopasture management to those that may consider the practice in the future. Given that 326,279 farm operations in the USA reported pastured woodland on 10.5 million hectares of land (USDA, 2019), there is great potential for expansion of silvopasture by targeting these landowners, along with those considering adding trees to pastures. This type of transition could be a strategic approach to increase income diversification, forage production, livestock wellbeing, and environmental integrity on grazing lands across the USA and abroad.

2. Methods

2.1. Eligibility criteria

This study followed the PRISMA guidelines for systematic reviews described in Moher et al. (2015) and used the same methodology described in Smith et al. (2021). The review included all U.S-based studies providing information obtained from producers, natural resource professionals and other stakeholders on silvopasture management, perceptions, and drivers of adoption. The literature search was completed in October 2020. The databases used to find relevant studies included Web of Science, Scopus, AGRIS, ProQuest, and CAB Direct. We also screened the first 100 results from Google Scholar per search term. Search terms included agroforestry, and various ways silvopasture is described in the USA (silvopasture, orchard grazing) and terms more commonly used internationally (silvopastoral, silvipasture, silvopastoralism, agrosilvopasture, agrosilvipasture, agro-pastoralist). We also included search terms that are often confused with silvopasture (forest grazing, forest pasture, wooded pasture, woodland grazing), since these terms were often used to describe silvopasture systems pre-1990 and are still used incorrectly in the present day. Each search was further refined to include only studies conducted in the USA and published in English. No date range or other exclusionary filters were used. The final database of studies was created using a three step-process: (1) screening each title, abstract and set of keywords (N = 1888), (2) reading full text of potentially relevant articles (N = 86) and (3) analyzing references from included studies to find literature not present in the six databases used during Step 1. To augment this synthesis, silvopasture case studies were also included from the USDA National Agroforestry Center's *Inside Agroforestry* Article Library.

2.2. Data analysis

Data from each study were input and summarized using Microsoft Excel. From here, the feasibility of conducting a meta-analysis was investigated. Due to the variability in study design and small sample size of like-studies, a meta-analysis was not feasible when the essential rules required for that type of analysis were considered (Borenstein et al., 2009). Instead, a comprehensive synthesis approach was used (Pullin and Stewart, 2006). Data were also aggregated across studies to assess percent silvopasture retention, percent of producers using rotational or management intensive grazing, and percent of producers who use silvopasture exclusively with no land base in open pasture. Following initial data analysis, authors from several studies were contacted for supplemental data. Through this request, additional data were obtained from Schattman et al. (2020), Stutzman et al. (2020), Ford et al., 2019a, Frey et al. (2016), and Workman et al. (2003).

2.3. Statistical analysis

Statistical analyses were conducted on three of the new data sets (Workman et al., 2003; (Ford et al., 2019a); Schattman et al., 2020). For Schattman et al. (2020), a Pearson's chi-square test with post-hoc Cramer's V was used to compare livestock producers to producers without livestock for opinions on whether they believe silvopasture will work as a best management practice. Using data from (Ford et al., 2019a), a Pearson's chi-square test with post-hoc Cramer's V was used to compare silvopasture establishment preference methods between farmers and NRPs. A Mann-Whitney *U*-Test was also used to compare the level of silvopasture knowledge between farmers and NRPs. Using data from Workman et al. (2003), a Mann-Whitney *U*-Test was used to compare producers who graze livestock to non-grazers for how likely they are to use silvopasture in the next ten years, and how interested they are in learning more about silvopasture. A Mann-Whitney *U*-Test was also used to compare silvopasture adopters to non-adopters for silvopasture retention, age, farm size, years farming, and hours farmed per week. A Pearson's chi-square test with post-hoc Cramer's V was also used to compare producers who graze to non-grazers for whether they knew the definition of silvopasture. All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 27 (IBM Corp., Armonk, N.Y., USA). All tests used a level of significance of $p < 0.05$.

3. Results/Discussion

3.1. Summary of silvopasture adoption studies in the USA

This synthesis includes 35 silvopasture studies (Table 1), and an additional 18 silvopasture case studies from the USDA National Agroforestry Center Inside Agroforestry database. Collectively, 32 studies provided practice-specific information from producers, 10 provided information from producers who are yet to adopt silvopasture, and 17 studies covered information from NRPs.

Based on this review, most studies focused on producers from the Northeast, Southeast and Midwestern portions of the USA, representing three primary Köppen-Geiger climate zones (Dfb, Dfa, and Cfa) (Fig. 2). Studies from the Western and far Southeastern corner of the country represent another eight climate zones (Af, Aw, Am, Csa, Csb, Bsk, Dsb, Dsc). However, as evident in Fig. 2, there was an absence of producer-focused studies from the Great Plains, Rocky Mountain, and Southwestern portions of the country. Furthermore, we did not find a study fitting our criteria from Hawaii or from any USA territory. This represents a tremendous gap in our understanding of how producers use silvopasture on these lands.

3.2. Reasons why producers adopt silvopasture in the USA

Out of the 53 studies, 32 investigated why producers practice silvopasture, with a majority using a case study approach. Despite small sample sizes, case studies can provide a greater understanding of the interconnections and nuances found in silvopasture systems. A prime example of the interconnections between system components in a silvopasture is utilizing trees to provide shade for livestock to reduce stress, increase livestock comfort, and in some cases enhance livestock productivity. Studies of producers using silvopasture in the Northeast (Orefice et al., 2017), and Southeast (Workman et al., 2003, Raw Data) identified these beneficial functions from shade as a top priority. A case study of silvopasture adopters in Virginia and North Carolina also reported the importance of shade, with one producer citing that the value of shade in the silvopasture justified a longer than normal timber rotation for their loblolly pine (*Pinus taeda* L.) plantation (Frey and Fike, 2018). Shade was also identified as a top priority for silvopasture adopters in Missouri (Kidwell, 2013; Keeley et al., 2019), Wisconsin (Keeley et al., 2019), Texas (Moseley, 2012) and Minnesota (Luhman, 2021). Producers in Minnesota (Luhman, 2021) and Missouri (Kidwell, 2013) also cited that the shade found in their silvopasture systems provided a safer place for their cows to calve during the summer. Interestingly, the benefits of shade were identified by producers from across Köppen-Geiger climate regions, ranging from tropical savannah (Aw) in the most southeastern portion of the country to northern portions characterized by a much cooler climate (Dfb) (Fig. 2). Looking to the future, the beneficial functions of shade found in silvopastures will only increase as climate warms and there is an increase in high heat days. In many regions across the world, increased temperatures will result in reduced livestock weight gain, pregnancy rates, milk production and overall animal health (Dosskey et al., 2017). As identified in Fig. 1, biophysical studies have found that silvopasture can alleviate some of these issues.

In addition to livestock benefits, producers have reported integrating silvopasture into grazing systems to enhance forage production and quality (Huntsinger et al., 1997; Mills, 2000; Moseley, 2012; Fike, 2016a; Zamora, 2016; Orefice et al., 2017; Keeley et al., 2019). Because of the partially shaded and modified microclimate, forage production can be enhanced, particularly during the early spring and late fall (Feldhake, 2002) and times of drought (Frost and McDougald, 1989; Kallenbach et al., 2006; Ford et al., 2019b; Alley and Marsh, 2021). A producer in Virginia described being able to produce forage during the coldest and hottest months of the year in the silvopasture, allowing for almost year-long grazing (Frey and Fike, 2018). The producer also reported that overall forage production in the silvopasture was probably lower than in an adjacent treeless pasture, but the growth patterns in the silvopasture differed and balanced farm-wide forage availability throughout the year. This in turn reduced supplemental hay purchases (Frey and Fike, 2018). Similar findings were reported in Missouri and Wisconsin (Keeley et al., 2019). Silvopasture adopters in the Northeast (Orefice et al., 2017), Minnesota (Luhman, 2021) and Texas (Moseley, 2012) cited increased forage production during the summer and times of drought as one of the primary benefits. Producers also discussed the nutritional benefits to livestock when they browse a more diversified diet, especially woody shrubs in silvopastures (Orefice et al., 2017; Keeley et al., 2019).

The positive interactions that flow between system components in a silvopasture can also optimize the growth and production of the tree crop. Because of the importance of light on forage growth, trees in silvopasture systems require periodic thinning, pruning, and control of understory vegetation. Through these silvicultural treatments, producers can optimize production of both forage and tree crops (Johnson and Davis, 1983). For producers managing trees for timber, these silvicultural treatments can increase the quality and size of sawlogs, which was reported across studies and bioclimatic zones (Townsend and Wight, 2007; Kidwell, 2013; Frey and Fike, 2018; Keeley et al., 2019). Producers also reported increased tree growth associated with fertilizer applications used to increase forage production, and naturally deposited fertilizer provided by the grazing livestock (Smith, 2002; Ellison, 2006; Kidwell, 2013; Luhman, 2021). Furthermore, producers in the Northeast reported using silvopasture in orchard systems for tree fertilization, grass management, livestock nutrition, and reduction of rodent habitat (Orefice et al., 2017).

Across studies and bioclimatic zones, producers identified farm wide economic benefits from their silvopasture systems (Marcelina, 2000; Smith, 2002; Ellison, 2006; Townsend and Wight, 2007; Brantly, 2012; Orefice et al., 2017; Frey and Fike, 2018; Brodt et al., 2019; Luhman, 2021). In particular, producers mentioned the benefit of converting marginal pasture, forest, or woodland into silvopasture to increase the utility and value of their land. A producer in Luhman (2021) described how the establishment of their silvopasture resulted in more contiguous grazing land, which was less costly than a new land purchase that would also increase annual property taxes. Furthermore, a farmer in Mayerfeld et al. (2016) described how he and other beginning farmers were not able to purchase prime farmland and instead could only afford land currently in marginal pasture or wooded pasture. Consequently, stacking multiple enterprises through a practice like silvopasture is necessary to turn a profit on these marginal acreages.

Producers also expressed the benefit of using silvopasture to generate short- and long-term income. In Frey and Fike (2018), a producer in North Carolina adopted silvopasture to generate annual income from his cow-calf operation, while his pine plantations matured. The producer described how the annual revenue allows for increased flexibility for the timing of timber harvests, which can be delayed depending on markets. In Ellison (2006), a producer in Mississippi was using silvopasture for horses (brood mares) and described the system as a cashflow pasture with the trees contributing to his planned retirement income. Silvopasture adopters in several studies mentioned improved hunting within their silvopastures, due to a reduction in understory vegetation (Johnson and Davis, 1983; Kidwell, 2013), with some producers even leasing hunting rights to generate income (Smith, 2002; Frey and Fike, 2018). Silvopasture adopters also described using livestock to reduce costs

Table 1
Summary of studies addressing behaviors, attitudes, perceptions, and intentions regarding silvopasture in the USA (N = 35).

Authors	State/Region	Respondent Type and Sample Size	Study description
Alavalapati et al. (2004)	FL	Landowners (152)Farmers (421)	Assessed if landowners would be willing to pay for nonmarket goods and services originating from silvopasture. Also assessed ranchers' willingness to accept a price premium for silvopasture adoption.
Arbuckle et al. (2009)	MO	NOLs[b] (239)	Survey of non-operator landowners to explore the factors that affect interest in agroforestry.
Barbieri and Valdivia (2010)	MO	Farmers (118)NOLs[b] (229)	Explored the relationship between recreational multifunctionality and the practice of agroforestry.
Beacom (2016)	National	NRPs[a] (3000)	Survey of conservation district staff across the USA to assess their level of engagement assisting landowners with agroforestry.
Brodt et al. (2019)	CA	Farmers (16)NRPs[a] (10)	Used interviews to assess the benefits and constraints of agroforestry practices, which included silvopasture.
Davis and Rausser (2020)	AL	Farmers (294)	Survey of producers to assess their knowledge of silvopasture and their willingness to accept payments to adopt the practice.
Dorr (2006)	MO	Farmers (364)NOLs[b] (239)	Survey to assess how farmer and non-operator landowner opinions, demographics, and site characteristics affect interest in agroforestry.
Fike (2017)	VA	Farmers (43)	Survey of limited-resource agricultural producers to assess their understanding of silvopasture.
(Ford et al., 2019a)	MN	Farmers (202)NRPs[a] (41)	Survey of farmers to identify how many practice silvopasture and understand the extent of NRP support for silvopasture.
Frey et al. (2016)	Southeast	NRPs[a] (138)	Survey to gauge attitudes toward and knowledge of silvopasture by natural resource professionals in MD, WV, VA, NC, SC, GA.
Frey and Fike (2018)	NC, VA	Farmers (4)	Case studies of farmers using silvopasture to assess how they established and manage their silvopasture systems.
Hardesty et al. (1993)	WA	Landowners (296)	Survey of landowners to assess how they perceive forest grazing as a means of meeting their land management objectives.
(Huntsinger et al., 1997)	CA	Landowners (121)	Survey of landowners to assess demographic characteristics, attitudes, management practices and uses for hardwood rangeland.
Johnson and Davis (1983)	AL, FL, MS, GA	Landowners (12)	Interviews with forest owners who are using silvopasture.
Keeley et al. (2019)	IA, IL, MN, MO, WI	Farmers (11)	Interviews with producers to explore their multi-party agroforestry land tenure arrangements, including those with silvopasture.
Lawrence and Hardesty (1992)	WA	NRPs[a] (75)	Survey to assess awareness and perceived opportunities and challenges of agroforestry, including silvopasture.
Lawrence et al. (1992)	WA	Landowners (296)	Survey to investigate the extent of agroforestry use by nonindustrial private forest landowners.
Luhman (2021)	MN	Farmers (5)	Detailed case studies of farmers using silvopasture.
Mayerfeld et al. (2016)	WI	Farmers (7)NRPs[a] (10)	Focus groups of farmers and resource professionals to assess their attitudes toward silvopasture.
(NACD, 2012)	National	NRPs[a] (490)	Survey of conservation district staff to gauge the rangeland and silvopasture outreach activities occurring in each district.
(Orefice et al., 2017)	Northeast	Farmers (20)	Interviews of farmers practicing silvopasture in NY, VT, NH, ME, MA, RI, and CT to gather data on silvopasture management.
Rietveld et al. (1997)	National	NRPs[a] (43)	Survey of NRPs to assess agroforestry extension activities across the USA.
Rule et al. (1994)	Midwest	Farmers (155)	Survey of farmers in IL, IN, IA, MI, MN, MO, OH, WI to inventory agroforestry use, including silvopasture.
Schattman et al. (2020)	National	Farmers (72)NRPs[a] (28)Other (33)	Survey of farmers, farm advisors, and landowners regarding their climate change knowledge and their intentions to adopt or recommend best management practices, including silvopasture.
Shrestha and Alavalapati (2004)	FL	Landowners (152)	Assessed if landowners would pay for nonmarket goods and services originating from silvopasture.
Shrestha and Alavalapati (2003)	FL	Farmers (421)	Survey to assess ranchers' willingness to accept a price premium for silvopasture adoption.
Stutzman et al. (2019)	AL, GA, MS, FL	NRPs[a] (389)	Survey to assess how familiar NRPs are with silvopasture, and their perceptions of the practice.
Stutzman et al. (2020)	AL, GA, MS, FL	NRPs[a] (389)	Survey of NRPs perceptions of silvopasture and methods they use for information exchange to landowners.
Teel and Lassoie (1991)	NY	Farmers (230)	Survey of dairy farmers to evaluate the types of woodland and agroforestry practices they are using.
(USDA, 2000)	National	NRPs[a] (222)	Survey of NRPs to assess the extent and geographic location of agroforestry throughout the USA.
Wilkens (2019)	VA	Farmers (139)	Survey of producers enrolled in cost-share initiatives to gauge interest in varying forms of silvopasture establishment.
Workman et al. (2003)	AL, FL, GA	Farmers (742)NRPs[a] (297)	Survey of farmers and NRPs to gain insight into the perceived benefits and challenges of agroforestry.
Workman et al. (2005)	AL, FL, GA	NRPs[a] (278)	Survey of NRPs to understand motives, barriers and needs for agroforestry extension and training.
Zinkhan (1996)	South/ Southeast	NRPs[a] (218)	Survey of natural resource professionals' perceptions of agroforestry in AL, AR, FL, GA, LA, MS, NC, OK, SC, TN, TX, VA.
Zinkhan and Mercer (1997)	South/ Southeast	NRPs[a] (218)	Survey of natural resource professionals' perceptions of agroforestry in AL, AR, FL, GA, LA, MS, NC, OK, SC, TN, TX, VA.

[a] NRPs = natural resource professionals,
[b] NOLs = non-operator landowners

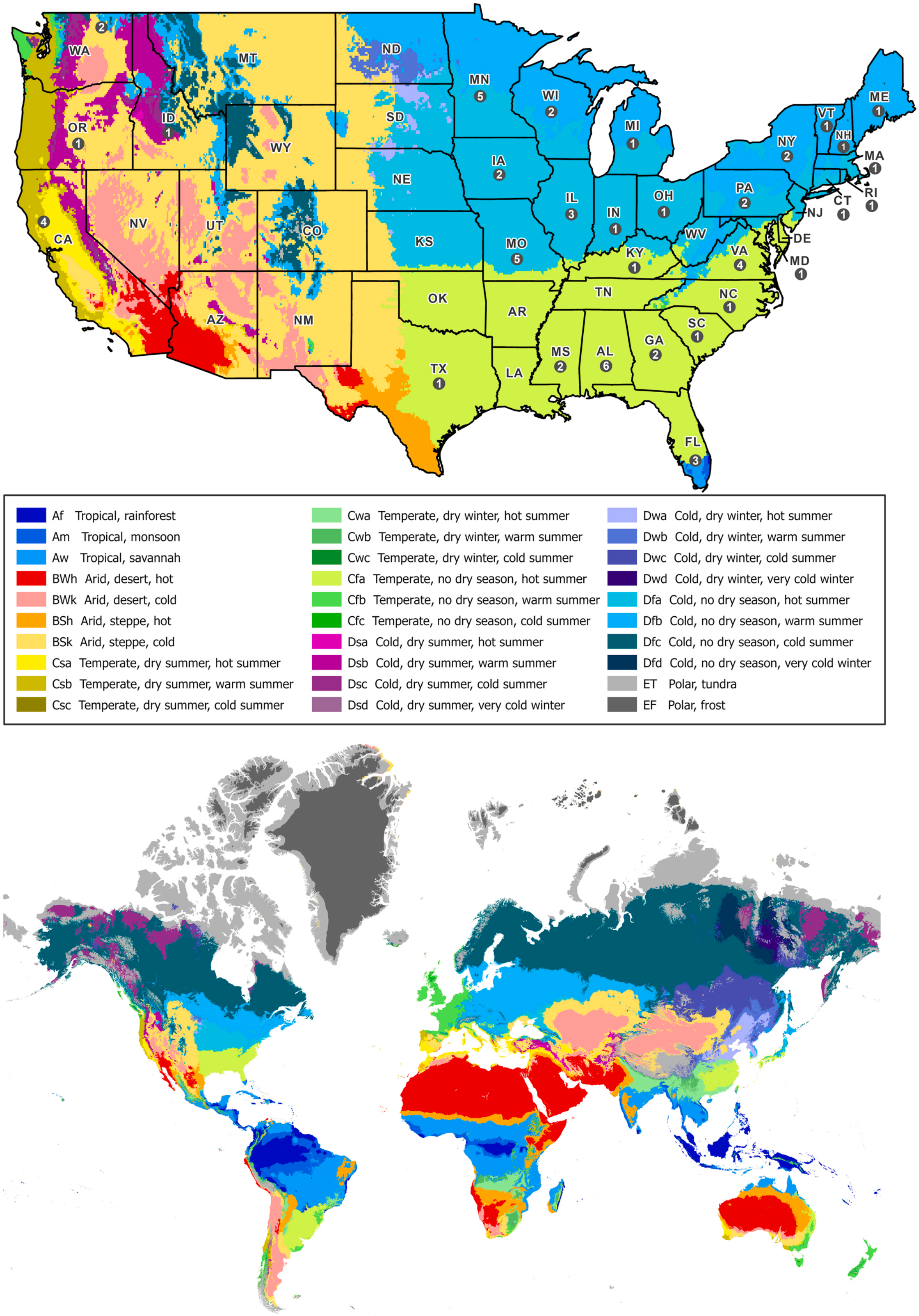

Fig. 2. Number of studies providing information from silvopasture adopters in the USA. Map overlaid with Köppen-Geiger climate classification zones from Beck et al. (2018).

associated with fertilizer applications and weed management (herbicides and labor) in vineyards (Brodt et al., 2019), Christmas tree plantations (Marcelina, 2000), and orchards (Orefice et al., 2017; CAFF, 2021).

Interestingly, the aesthetic benefits of a silvopasture were occasionally viewed from an economic perspective. In Frey and Fike (2018) a producer in Virginia believed that the aesthetics of the silvopasture improved the marketability of a rental house on the property, while a second producer in North Carolina reported that the aesthetics of the silvopasture may be beneficial if selling or leasing land in the future. Workman et al. (2003) reported similar findings, with aesthetics and increased land value being tied for the second highest ranked benefit reported by silvopasture adopters in the Southeast.

In addition to financial and animal welfare benefits, silvopasture adopters reported using the practice for ecosystem services. For example, producers across several studies reported using silvopasture to restore a threatened ecosystem type, such as oak savanna in Wisconsin (Mayerfeld et al., 2016) and Minnesota (Luhman, 2021), oak rangelands in California (Huntsinger et al., 1997), and longleaf pine (*Pinus palustris*) in Alabama (Mallach et al., 2020). Producers also reported using silvopasture to knock down brush and weeds in areas inaccessible to machinery (Luhman, 2021), and to control invasive species, such as kudzu (*Pueraria montana* var. *lobata* (Wild.)) (Frey and Fike, 2018) and multiflora rose (*Rosa multiflora* Thunb) (Rossier, 2014). Producers also described using silvopasture for soil erosion control (Smith, 2002; Workman et al., 2003, Raw Data; Ellison, 2006; Zamora, 2016), wildlife habitat enhancement (Ellison, 2006; Moseley, 2012; Luhman, 2021) and wildfire risk reduction by removing hazardous fuel loads (Johnson and Davis, 1983; Gariglio, 2002; Townsend and Wight, 2007; NACD, 2012; Wight, 2013). For example, a California producer described how using goats to reduce fuel loads became a new revenue stream and the fuels treatment was easier for them to manage than using prescribed fire (Wight, 2013).

In addition to economic and environmental benefits, a few producers described the importance of stewardship, especially as a strategy to encourage their children to carry on the family farm (Wight, 2013; Fike, 2016b; Zamora, 2016;). In Fike (2016b) a Virginia producer described the importance of increasing the value of his land, adding infrastructure for farming, and increasing the value of future timber harvests to create a more valuable and workable asset for his children. A producer in California had a similar sentiment, describing the importance of finding ways to keep his children on the land, so it is not converted to housing developments (Wight, 2013).

3.3. Challenges producers encounter when establishing or managing a silvopasture system in the USA

Although the studies describing producer-reported challenges of establishing and managing silvopasture systems are limited, some broad themes emerge. Table 2 synthesizes some of the primary concerns, which included external and internal factors. External factors include lack of information and knowledge, lack of technical assistance, lack of demonstration, lack of support from agricultural extension organizations and lack of markets. Lack of information was one of the top-reported challenges by producers despite the availability of existing information on silvopasture and silvopasture management. For instance, information is available on fencing and forage management for silvopasture systems (Fike et al., 2004; Hamilton, 2008; Karki, 2015; Gabriel, 2018). However, this information may not be reaching producers. Another barrier to accessing information may be that producers practicing silvopasture are not familiar with the term (Orefice et al., 2017).

Producers also noted challenges in seeking technical assistance from local NRPs. Johnson and Davis (1983) reported that some landowners were unable to obtain silvopasture information from consulting foresters, since they did not have training in that discipline. Furthermore, foresters and other NRPs have been found to have negative perceptions of silvopasture and advised producers against multi-use management (Mayerfeld et al., 2016; Orefice et al., 2017; Frey and Fike, 2018; Brodt et al., 2019; Ford et al., 2019a). NRPs also tended to associate silvopasture with unmanaged grazing in woodlands or forest, without understanding the definition and principles of silvopasture (Rietveld et al., 1997; Frey et al., 2016; Mayerfeld et al., 2016; Orefice et al., 2017). Some NRPs also believe that promoting silvopasture could be viewed as an endorsement of unmanaged woodland grazing, which may increase the practice and the associated negative impacts (Mayerfeld et al., 2016). This misconception suggests a need for continued information sharing and training to NRPs on silvopasture. This will likely require a multi-pronged approach, including targeted outreach materials, technical workshops, and demonstration sites.

In (Workman et al., 2003, Raw Data) respondents identified lack of markets for products as a concern. This was also noted by a producer in Frey and Fike (2018) who described how current timber markets in his area were more favorable toward clear cutting small diameter stands of pine (*Pinus* spp.) for pulpwood rather than sawtimber, reducing the attractiveness of silvopasture. A producer using silvopasture in Pennsylvania described the issue of bringing products to market because of bottlenecks associated with access to slaughter for their specialized grass-fed and grass-finished livestock products (Rossier, 2014). Another market-related concern was the issue of producing a long-term crop that could be susceptible to pests in the future. Orefice et al. (2017) described

Table 2
Top ranked concerns or obstacles related to silvopasture establishment and management reported by producers in the USA.

	Rank						
Authors	1st	2nd	3rd	4th	5th	6th	7th
(Ford et al., 2019a)	Lack of information and knowledge	Expense of management	Lack of technical assistance	Lack of equipment	Lack of financial incentives	Lack of demonstration	Property too small
(Orefice et al., 2017)	Fencing establishment and maintenance	Lack of information and knowledge	Lack of time for management	Unknown forage quality and management techniques	Reduced mobility of machinery	Lack of support from agricultural organizations	Undesirable vegetation
Stutzman et al. (2020) b1	Length of time from tree planting to livestock grazing	Lack of familiarity	Lack of information AND Length of time from tree planting to timber harvest	Livestock damage AND Expense of management	Lack of financial incentives	Component competition	Lack of demonstration AND Lack of technical assistance
Workman et al. (2003) (Raw Data)	Lack of land	Lack of markets for products	Lack of information and knowledge AND Lack of demonstration	Lack of equipment AND Have not seen trees used successfully	Lack of financial incentives	Time Consuming	Component competition AND Lack of technical assistance

[1]Survey of natural resource professionals who also indicated that they practice silvopasture on their personal property (Stutzman et al., 2020, Raw Data)

how 45% of silvopasture adopters were concerned with forest pests (i.e., emerald ash borer (*Agrilus planipennis*) and hemlock wooly adelgid (*Adelges tsugae*) that could impact the viability of tree-based products.

Internal factors centered on lack of land, management expenses, increased labor requirements, lack of time for management, tree regeneration, and lack of equipment (Orefice et al., 2017; Frey and Fike, 2018; Brodt et al., 2019; (Ford et al., 2019a)). Economies of scale can also be a challenge. For example, a producer described in Fike (2016b) had trouble finding a logger willing to help establish a silvopasture by thinning a one-hectare lot, while also leaving some of the higher-valued trees. However, in Frey and Fike (2018) producers overcame this challenge by combining timber harvests from their small silvopasture parcels with that of other timber stands on their property to achieve economies of scale. The challenge of thinning trees to create a silvopasture was also identified in Hall et al. (2007), where a producer described that thinned stands were susceptible to windthrow and ice damage for a few years following harvest.

Another internal factor included the possibility of needing new or modified equipment. For example, a producer in California had to design their own grape trellises to keep vines away from browsing sheep in a vineyard (Brodt et al., 2019), while a hazelnut (*Corylus avellana* L.) producer had to develop a special harvester to avoid contamination from grazing livestock (MacFarland, 2019), and a producer described in Orefice et al. (2017) had to modify the height of sugar maple (*Acer saccharum* Marsh.) sap lines to be above the reach of his cattle in his hardwood silvopasture sugarbush. A final concern discussed in two studies was livestock poisoning from plants. Orefice et al. (2017) reported this concern for silvopasture adopters in the Northeast and Luhman (2021) reported that a producer in Minnesota lost a few livestock due to poisoning from plants. However, the producer indicated that management and education were an effective means to prevent this risk.

3.4. Silvopasture establishment and management activities reported by producers in the USA

The complex nature of establishing and managing a silvopasture is important to recognize; however, producer-reported experiences are seldom included in the literature. In most cases, information about silvopasture establishment and management comes from anecdotal evidence or a limited number of studies. The following section synthesizes information from a series of producer case studies on silvopasture establishment and management within the USA. It is not meant to be a "how-to" on establishing and managing a silvopasture, but more to highlight key considerations and areas needing further investigation regarding adoption and retention.

3.4.1. Producer-reported silvopasture establishment

Across studies in this review, producers described six methods for establishing silvopastures:

1) Thinning trees in an existing tree plantation (Moseley, 2012; Orefice et al., 2017; Frey and Fike, 2018),
2) Thinning trees in an existing woodlot or forest (Rossier, 2014; Zamora, 2016; Orefice et al., 2017; Luhman, 2021),
3) Thinning trees on the edge of an existing pasture (Kidwell, 2013; Orefice et al., 2017),
4) Planting trees into a field or pasture (Mills, 2000; Ellison, 2006; Brantly, 2012; Orefice et al., 2017; Alley and Marsh, 2021; Luhman, 2021)
5) Incorporating livestock into an existing orchard (Orefice et al., 2017; Brodt et al., 2019;CAFF, 2021) or
6) Incorporating livestock into an existing savanna (Luhman, 2021).

While multiple transition pathways exist, there was strong preference for creating a silvopasture by thinning established trees, either within a plantation, forested area, or on the edge of an existing pasture, and less interest in establishing silvopasture by planting trees into open pastures or fields (Mayerfeld et al., 2016; Orefice et al., 2017; Frey and Fike, 2018; Ford et al., 2019a). A likely explanation is that trees, even fast growing, take years to provide shade benefits to livestock, and the expense and time required to protect them from animal browse during the initial establishment phase may not be appealing to producers. Furthermore, planting trees into pasture requires capital investments, while thinning trees in an existing forest or woodlot has the potential to generate revenue from timber sales, which reduces the financial risk to the producer. Across studies, several producers described generating money from this type of thinning operation as they transitioned to silvopasture (Orefice et al., 2017; Luhman, 2021). However, increased emphasis and potential financial incentives for planting trees on marginal agricultural lands for climate mitigation may encourage increased silvopasture adoption through tree planting.

For producers establishing silvopastures in an existing tree plantation, the dominant strategy was to remove several adjacent rows of trees to create 3 – 15 m (10–50 ft) alleys for grazing (Moseley, 2012; Frey and Fike, 2018). This strategy was also used by producers planting trees into an existing pasture (Mills, 2000; Smith, 2002; Ellison, 2006; Luhman, 2021). Utilization of herbicides prior to planting trees and fencing around young trees were also common practices for this conversion pathway. Producers transitioning to silvopasture by thinning trees in an existing forest or trees on the edge of an existing pasture also seemed to prefer uniform spacing (Kidwell, 2013; Orefice et al., 2017). The strategy of using uniform spacing across the various establishment pathways is not surprising, given that it allows for easier and more predictable access for farm machinery and fencing (boundary and cross fencing). Furthermore, tree seedling protection during establishment is often easier since perimeter fencing can be used vs protecting individual trees, which is more expensive and time consuming. Uniform spacing also allows for more consistent light patterns across the silvopasture, which is beneficial for having more predictable forage growth and shade for livestock. However, one notable exception to uniform spacing preference were producers interested in using silvopasture to reestablish savanna ecosystems with scattered trees (Luhman, 2021).

Beyond thinning or planting trees, producers also described preparing sites for forage establishment, which involved removing debris and stumps, disking the soil, testing the soil, and adding fertilizer and lime to correct any deficiencies (Ellison, 2006; Karki, 2012; Kidwell, 2013; Zamora, 2016; Frey and Fike, 2018). In some cases, producers also described using pigs to turn up the soil and help root out stumps (Rossier, 2014; Orefice et al., 2017). Installation of fencing and water infrastructure for the livestock were also reported across studies.

3.4.2. Producer-reported silvopasture management

The management of a silvopasture is incredibly site specific, with activities dependent on system scale, geographic region, species mix (livestock, trees, and forage) and their associated products, and the overall goals and objectives of the producer. While variability exists, some general trends were apparent in the limited number of studies addressing producer-reported silvopasture management.

Regarding livestock, most producers reported grazing cattle (dairy or beef) in their silvopasture system. Producers also reported using goats (meat and/or dairy), sheep (meat and/or fiber), turkeys (meat), chickens (meat and/or eggs), geese (meat), horses (brood mares), pigs (meat), and bison (meat), with varying stocking rates (Ellison, 2006; Hall et al., 2007; Karki, 2012; Kidwell, 2013; Rossier, 2014; (Orefice et al., 2017); Frey and Fike, 2018; Keeley et al., 2019; Luhman, 2021). Across studies, it was clear that several livestock-specific management practices were being considered. For example, producers described using pigs only on a limited basis in their silvopastures, due to the severe damage they can cause to the site and tree crop if left unmanaged even for a short duration (Rossier, 2014; Orefice et al., 2017). A producer in Florida also described the importance of protecting newly planted seedlings from adult cattle, who may trample or bite the tops off the trees (Mills, 2000). To reduce this risk, the producer allows only calves into the silvopasture during the first 3–4 years. Larger animals are not allowed until the trees are too tall to be trampled or have the tops browsed. Producers across the Northeast described keeping goats and pigs out of the silvopasture during the spring when tree sap is flowing, due to bark stripping concerns (Orefice et al., 2017). However, this issue was not reported for other species of livestock. Producers also described utilizing specific breeds of livestock that were well-suited for a silvopasture system. Examples included Shropshire sheep for grazing in Christmas tree plantations (Marcelina, 2000), Tamworth pigs for their ability to thrive outside without shelter (Rossier, 2014), Longhorn cattle for their hardiness (Mills, 2000), and freedom ranger chickens for being good foragers and having few health issues in a grazing environment (Luhman, 2021).

The management of forages in a silvopasture is a critical element, as it relates directly to stocking rate. Across studies, most producers reported planting a mix of cool-season grasses and legumes, with fescues (*Festuca* spp.) and clovers (*Trifolium* spp.) being the most common choices. A few producers reported using novel-endophyte tall fescue, specifically MaxQ™ (Ellison, 2006; Karki, 2012; Frey and Fike, 2018), to reduce the risk of toxicity associated with traditional tall fescue (*Festuca arundinacea*) pasture grass. Other cool-season grasses included timothy (*Phleum pratense*), Virginia wild rye (*Elymus virginicus*), orchardgrass (*Dactylis glomerata*), bentgrasses, (*Agrostis* spp.) and bluegrasses (*Poa* spp.) (Orefice et al., 2017; Zamora, 2016; Frey and Fike, 2018). A few producers in the Southeastern USA reported using warm-season grasses, which included Bahiagrass (*Paspalum notatum*), big bluestem (*Andropogon gerardii*) and switchgrass (*Panicum virgatum*) (Johnson and Davis, 1983; Mills, 2000; Smith, 2002; Frey and Fike, 2018). A producer in Minnesota reported using a mix of warm and cool-season grasses in different paddocks to balance farm-wide forage production (Luhman, 2021). In contrast, a producer in Alabama was managing specifically for native forage species, including endangered American Chaffseed (*Schwalbea americana*), to restore the longleaf pine ecosystem (Mallach et al., 2020). Regardless of species selected, nearly all producers from across studies and bioclimatic zones were using rotational or management intensive grazing (98%), suggesting the importance of moving livestock to new paddocks, while previously grazed paddocks are rested and allowed to recover. Furthermore, 96% of producers reported using silvopasture in combination with paddocks in open pasture, suggesting that silvopastures are primarily used to complement their pasture rotation system. Producers also described applying fertilizer and lime periodically to increase forage production (Mills, 2000; Ellison, 2006; Frey and Fike, 2018) and clipping/mowing after livestock grazing to reduce competition from weeds (Brantly, 2012; Frey and Fike, 2018). A producer in Florida was also using prescribed fire every three years to remove excess pine straw that was smothering the forages (Mills, 2000). Producers also described the use of herbicides to control weeds (Ellison, 2006; Frey and Fike, 2018).

Across studies, information was limited on how trees were being managed following silvopasture establishment. Producers reported managing trees primarily for sawtimber, with species selection being regionally specific. For example, producers in the Northeast were predominantly managing for oaks (*Quercus* spp.) and maples (*Acer* spp.) (Orefice et al., 2017), while those in the Southeast were predominantly managing for loblolly pine (*Pinus taeda*) (Smith, 2002; Ellison, 2006; Hall et al., 2007; Frey and Fike, 2018). Other tree-related products included pulp, firewood, fruits or nuts, fence posts, pine straw, fodder, and maple syrup (Mills, 2000; Townsend and Wight, 2007; Orefice et al., 2017; Frey and Fike, 2018; Brodt et al., 2019; Keeley et al., 2019). Regarding nut trees, producers reported using various types of walnuts (*Juglans* spp.), hickories (*Carya* spp.) including pecans (*Carya illinoinensis*), common hazelnut (*Corylus avellana* L.), and chestnuts (*Castanea* spp.) (Brantly, 2012; Orefice et al., 2017; Brodt et al., 2019; Keeley et al., 2019; MacFarland, 2019; Luhman, 2021). Fruit trees included olives (*Olea europaea*) and apples (*Malus* spp.) (Orefice et al., 2017; Brodt et al., 2019).

Across studies, there was a lack of information on how producers intended to regrow trees in their silvopasture systems following harvest or removal associated with another management purpose. Orefice et al. (2017) investigated this issue and found that 70% of the case study farmers were not actively regenerating trees in their silvopastures. Producers in Frey and Fike (2018) also expressed concern about regenerating trees in their silvopasture pine plantations. One potential reason for this relates to timber management and the importance of crop trees to self-prune. In most cases, pruning trees is not economical, requiring denser planting spacing, which may not be desirable from a forage management perspective (Johnson and Davis, 1983). While only a few studies addressed regenerating trees in active silvopastures, it is an area of management needing further investigation and research.

3.5. How satisfied are producers with their silvopasture systems in the USA?

The success and potential expansion of a novel farming practice can be judged by the retention of that practice by initial adopters. While few studies have assessed satisfaction and retention of silvopasture systems in the USA, those that did reported that producers are highly satisfied with their systems. In a study of silvopasture adoption in the Northeast, ($N = 20$) 95% of producers said they were satisfied with the practice, with 70% saying they intended on increasing the amount of land they had in silvopasture (Orefice et al., 2017). In a survey of landowners in Minnesota, 87% of those practicing silvopasture ($N = 61$) indicated that they would continue to do so (Ford et al., 2019a). Frey and Fike (2018) reported similar findings, with three of the four landowners providing positive reviews of their silvopasture systems. Taken together, 88% of silvopasture adopters from across these studies indicated that they plan to continue using silvopasture into the future. This finding was also supported when analyzing raw data from Workman et al. (2003). When silvopasture adopters were asked how likely they would use silvopasture over the next ten years on a scale of 1–5, with 1 = Not Likely and 5 = Very Likely, the average was 4.6/5 (Workman et al., 2003, Raw Data).

3.6. Information sources silvopasture adopters are using

As discussed in Section 3.3, lack of information about establishing and managing a silvopasture system was identified as a key challenge to adoption. Understanding the information sources that producers prefer and are using can be critical to addressing this barrier. Unfortunately, few studies surveyed producers about their preferences for learning about silvopasture or investigated the ways in which NRPs share information about silvopasture with producers. In a national survey of conservation districts, NRPs indicated using presentations, workshops, tours, brochures, and websites to inform producers about silvopasture. However, the frequency or effectiveness of these communications was not specified (NACD, 2012). Orefice et al. (2017) found mixed and conflicting responses among farmers in the Northeast when asked about the resources they utilize to learn about silvopasture. Farmers were divided on their preference for online resources (webinars and webpages) and printed material. However, most respondents reported that farm tours were an important learning opportunity, but the timing of those tours was a challenge. Farmers also reported seeking advice from extension personnel, conferences and other farmers for information related to silvopasture (Orefice et al., 2017).

3.7. Drivers affecting silvopasture adoption in the USA

One key method used to assess drivers of adopting an agricultural practice is to compare those using the practice to a similar population of non-adopters. Unfortunately, few silvopasture studies have investigated this topic in the USA. Across the studies in our review, only raw data from Workman et al. (2003) could be used for this type of analysis. This analysis indicated that silvopasture adopters were more likely to be full-time farmers than part-time ($p < 0.000$) and have more land in farming (800 acres) than non-adopters (449 acres) ($p < 0.000$). Age was also significant, with those adopting silvopasture being younger (56 years old) than non-adopters (67 years old) ($p < 0.000$). Length of time farming was not significant (Workman et al., 2003, Raw Data).

For silvopasture adoption to increase, there needs to be more research investigating demographic, socioeconomic, and farm operational variables between adopters and non-adopters. Historically, this type of research has been difficult to conduct in the USA, as no database exists of producers who are using silvopasture from which to draw samples. Instead, most studies either focus on a few silvopasture adopters in depth or survey a large population of producers in general, who may or may not practice silvopasture or even graze livestock. Future research needs to compare a sufficiently large sample of silvopasture adopters to a similar population of non-adopters (i.e., producers actively grazing livestock). Furthermore, there needs to be a clearer definition of what qualifies a producer as being a silvopasture adopter. This issue was apparent in Hardesty et al. (1993) and Lawrence et al. (1992), where those practicing silvopasture were combined with forest and woodland grazers. While forest and woodland grazing have some similarities to silvopasture, they should not be combined in most analyses. Uncertainty also exists regarding studies investigating producers grazing native savannas. This was apparent in Huntsinger et al. (2010), which described landowners in California's hardwood rangeland. While the word silvopasture was not mentioned, several of the producer reported management practices, along with site descriptions, fit the definition of silvopasture.

3.8. Pre-adoption studies of willingness to accept, pay, or participate

3.8.1. Willingness to accept and willingness to pay

Pre-adoption studies of willingness to pay and willingness to accept can help to monetize non-market benefits of silvopasture and provide insight into the motivations behind decision making. Unfortunately, few studies have investigated this topic related to silvopasture management, with most coming from the Southeastern USA. In a willingness to adopt study, Florida cattle ranchers indicated that the environmental benefits of silvopasture (e.g., carbon sequestration, pollution runoff control and wildlife habitat improvement) were not sufficient to compensate for the added costs of production (Shrestha and Alavalapati, 2003). However, ranchers indicated that a price premium of $0.15/lb. of beef or a direct payment of $9.32/acre/year would be a sufficient incentive to adopt silvopasture. A similar finding was reported by Davis and Rausser (2020), who investigated Alabama producers' willingness to accept silvopasture. Producers initially required $61.47 per acre/yr. to adopt silvopasture. However, through a bid revision process, where they were presented with information related to the non-market benefits of silvopasture, bids were lowered to an average of $37.52 per acre/yr. This suggests that producer's value non-market benefits and were considering them in their bids. Davis and Rausser (2020) added that the successful adoption and implementation of policies that promote silvopasture (i.e., the Conservation Reserve Program) hinge heavily on a well-informed producer base.

While the previous willingness to accept studies relate to the incentives required to adopt silvopasture from the producer side, Shrestha and Alavalapati (2004) investigated how much the public would be willing to pay to help support silvopasture adoption for the purpose of improving the environment. The study revealed a strong willingness to pay by the public for environmental services associated with silvopasture that could potentially offset the cost of adoption. Specifically, an average household in south-central Florida would be willing to pay between $30.24 – $71.17 per year for five years for environmental services associated with silvopasture. The authors concluded that efforts should focus on strategic and effective means of compensation for ecosystem services provided by land in silvopasture, since these non-market goods and services are shared with the public (Shrestha and Alavalapati, 2004).

3.8.2. Willingness to participate

Willingness to participate studies involving silvopasture have investigated producer socio-demographics, on-farm operational variables, and producer knowledge, opinions, and motivations. Through these pre-adoption studies of farmers not currently using silvopasture, key factors can be identified that help or hinder silvopasture implementation.

When looking at the willingness to participate studies in this synthesis, some general trends become apparent. Producers who have not adopted silvopasture are most concerned with lack of information and technical assistance (Dorr, 2006; Mayerfeld et al., 2016; Wilkens, 2019), which was a similar finding to silvopasture adopters described in Section 3.3. Non-adopters were also concerned with the extra time and investment required to manage and maintain a silvopasture system. However, it should be noted that a handful of studies investigating willingness to participate or interest in silvopasture (Arbuckle et al., 2009; Barbieri and Valdivia, 2010; Dyer, 2012) used a sampling frame that was not specifically targeted to producers with livestock or landowners with land in pasture. While this is not a critique of those studies, which prioritized other research questions, it is not surprising that they reported low interest levels in silvopasture, since many of the respondents were not livestock producers or those with lands in pasture. Strong and Jacobson (2006) also identified this issue in a survey of residents in Pennsylvania, which was used to assess agroforestry adoption potential. In their analysis, market segmentation was used to separate the heterogeneous population into distinct clusters for the purpose of narrowing outreach to each specific group. When the population was segmented into those with and without livestock, interest in silvopasture increased. Similarly, when we analyzed raw data from (Workman et al. (2003), Raw Data) and segmented producers into those with and without land in grazing/pasture, significant differences existed between the two populations. Those with land in pasture/grazing were more likely to use silvopasture in the next ten years ($p < 0.001$), were more interested in learning about silvopasture ($p < 0.001$) and were more familiar with the definition of silvopasture ($p < 0.001$) when compared to those without land in pasture/grazing. These examples illustrate the importance of clearly defining and possibly segmenting populations when conducting future silvopasture adoption research. This conclusion was also made by Smith et al. (2021) in a synthesis of windbreak adoption in the USA, further suggesting the importance of using distinct clusters in agroforestry adoption research.

3.9. Opinions about silvopasture from natural resource professionals

3.9.1. Natural resource professional awareness, knowledge, and support of silvopasture

Understanding the attitudes of natural resource professionals is key to understanding producer adoption for any agricultural practice. Studies suggest that farmers and landowners turn to NRPs to learn about farming practices that are new to them (Rogers, 1995; Stutzman et al., 2020). However, the interdisciplinary nature of silvopasture poses a potential challenge, as information and insight most relevant to the topic may be siloed in various professional fields (forestry, agronomy, and animal science). In many cases, these professionals may work for different organizations and may not provide technical assistance outside of their area of expertise (Zinkhan, 1996; Workman et al., 2005; Stutzman et al., 2020). This challenge is compounded by the fact that NRPs in different professional fields have been found to have varying knowledge, training, and attitudes toward silvopasture. A study of NRPs in the Southeast found that registered and state-employed foresters were much more cautious about silvopasture than Natural Resources Conservation

Service or Cooperative Extension agents (Stutzman et al., 2020). There are also regional differences in NRP awareness of and attitudes toward silvopasture, with greater familiarity and positive perception among NRPs in the Southeastern USA (Zinkhan, 1996; Zinkhan and Mercer, 1997; Workman et al., 2005; Stutzman et al., 2019, 2020). This reflects the longer research and practice history of silvopasture in this region. For example, Stutzman et al. (2019) reported that 64% of surveyed NRPs in the Southeast were somewhat or very familiar with silvopasture and 46% had been asked to assist with establishing or managing a silvopasture. In contrast, a survey of NRPs in the Mid-Atlantic states found that only 25% of NRPs had attended a silvopasture training event and only 16% had been involved with a silvopasture project (Mize et al., 2017). Frey et al. (2016) also reported that NRPs in the Mid-Atlantic states generally had negative opinions of silvopasture, perhaps because of their past experiences with unmanaged livestock grazing in the woods. In Minnesota, opinions of silvopasture were generally positive. When asked about promoting silvopasture, 32% said they would continue, 8% said they would start, 52% would consider and 8% said they would not promote silvopasture (Ford et al., 2019a). However, knowledge about the practice was low, with only 2% knowing "a lot" and 39% knowing "some" about the practice. A majority of NRPs knew "a little" (44%) or knew "nothing" about the practice (15%). From a national perspective, Beacom (2016) surveyed NRPs from 3000 conservation districts and found that only 10% of the surveyed staff reported helping producers with silvopasture.

3.9.2. Natural resource professional perceptions of silvopasture benefits and challenges

Similar to silvopasture adopters (Section 3.2), NRPs from across studies and geographic region often ranked improving and diversifying farm economics or increasing shade for livestock as the most important silvopasture benefits (Zinkhan and Mercer, 1997; (USDA, 2000); Mayerfeld et al., 2016; (Ford et al., 2019a); Stutzman et al., 2020, Raw Data). Other silvopasture benefits cited by NRPs included: brush control for invasive species, savanna restoration, erosion control, improvement of water quality, improved soil health, improved livestock health, improved forage production and quality, increased land value, winter shelter, and enhancement of wildlife habitat (Zinkhan and Mercer, 1997; (USDA, 2000); Mayerfeld et al., 2016; (Ford et al., 2019a)).

Regarding challenges associated with silvopasture, there was less consistency between studies than with perceived benefits. This inconsistency was primarily due to the way in which survey questions were structured. In one case, NRPs were asked to rank perceived barriers/obstacles to the promotion of silvopasture (Ford et al., 2019a), while others investigated operational challenges and logistics associated with managing a silvopasture system (Zinkhan and Mercer, 1997; Mayerfeld et al., 2016; Stutzman et al., 2020). For studies addressing barriers more generally, some of the key concerns identified were lack of information, lack of familiarity, additional expense of management, lack of financial incentives, lack of demonstration sites, and feasibility of managing small landowner projects (NACD, 2012; Ford et al., 2019a; Stutzman et al., 2020). Financial considerations and lack of information were also key barriers identified by producers using silvopasture discussed in Section 3.3. Regarding operational challenges, key concerns identified by NRPs included damage to trees and soil by livestock, difficulty regenerating trees in established silvopastures, quality of forage, management challenges, and the length of time from planting trees until livestock can graze (Zinkhan, 1996; Zinkhan and Mercer, 1997; Mayerfeld et al., 2016; Stutzman et al., 2020, Raw Data).

3.9.3. What is needed to increase natural resource professional awareness and support for silvopasture?

NRPs generally felt that technical information and demonstration sites for silvopasture were lacking, with this challenge being identified in studies of NRPs over a wide range of years, occupational categories, and geographic regions (Zinkhan, 1996; Workman et al., 2005; Mize et al., 2017; (Ford et al., 2019a); Stutzman et al., 2019; Stutzman et al., 2020). NRPs also stressed the importance of having locally specific training materials, field tours, and demonstration sites that reflect regional needs and climatic conditions (Mayerfeld et al., 2016; Mize et al., 2017; (Ford et al., 2019a)). NRPs described the importance of targeted outreach to producers who have operations and physiographic conditions well-suited for a successful silvopasture system (Zinkhan, 1996; Mayerfeld et al., 2016; Stutzman et al., 2019, 2020).

Across studies, NRPs suggested that multi-disciplinary research is needed to help support and promote silvopasture. Areas of research requested by NRPs included profitability and productivity of silvopasture systems, producer benefits and concerns, detailed methods on silvopasture establishment and management, approaches to reducing tree damage and soil compaction by livestock, information on addressing food safety concerns and regulations associated with integrating livestock with other crops, and advice on how to best engage producers (Zinkhan, 1996; Zinkhan and Mercer, 1997; Mayerfeld et al., 2016; Brodt et al., 2019; Ford et al., 2019a; Stutzman et al., 2020). In addition, Frey et al. (2016) noted an important research dilemma, where increased silvopasture adoption requires more information being provided to producers, yet researchers and NRPs face challenges in justifying research without a significant pool of adopters. One potential strategy was described by Brodt et al. (2019), who suggested that farmer-researcher networks could be an effective strategy to monitor and document new and existing agroforestry systems, including silvopasture.

3.10. Perceptions of silvopasture in other countries

Despite differences in geography, climate, and socio-economic context, many of the perceived benefits and challenges of silvopasture identified in the USA were commonly shared by producers in other countries (Table 3). Increased shade and animal wellbeing were some of the most identified benefits (Pérez, 2006; Calle et al., 2009; Frey et al., 2012; de Jalón et al., 2018; Jara-Rojas et al., 2020; Lee et al., 2020). Economic benefits that centered around diversification of farm income and products, reduction of inputs, and meeting household needs were also frequently cited (Pérez, 2006; Calle et al., 2009; Frey et al., 2012; de Jalón et al., 2018; Kagiraneza, 2019; Gosling et al., 2020; Jara-Rojas et al., 2020; Opdenbosch, 2021). While ecosystem goods and services, such as soil conservation, water quality enhancement, and biodiversity were cited in several studies, these benefits were infrequently acknowledged by producers in our study. Perceived economic challenges were identified across all studies, which included concerns about capital investments, establishment costs, and increased labor (Pérez, 2006; Calle et al., 2009; Frey et al., 2012; de Jalón et al., 2018; Kagiraneza, 2019; Gosling et al., 2020; Jara-Rojas et al., 2020; Lee et al., 2020; Opdenbosch, 2021). Lack of information and lack of technical assistance was a primary challenge identified by producers in the USA; however, this was a much less common issue in studies from other parts of the world.

While there are globally shared benefits and challenges, these studies also indicate that unique but important perceptions can arise based on specific context. For instance, silvopasture is often viewed as a tool to adapt to climate change and yet Columbian producers in Lee et al. (2020) considered silvopasture as increasing risk. Farmers mostly showed a pessimistic attitude toward integrating trees into their farming system due to the risk associated with the low survival rates of planted trees, as well as slow growth rates under climate change. Our study of producers also differed in that restoration of savanna or other ecosystem types was identified as a key benefit to some producers, yet this was not identified as a primary benefit by producers in studies outside of the USA. Furthermore, our study differed in that perceptions of silvopasture by NRPs were commonly identified, which was a topic infrequently discussed in silvopasture adoption studies from other countries.

Table 3
Comparison of key benefits and challenges of silvopasture systems perceived by producers across the world.

Study	Location	Key perceived benefits	Key perceived challenges
Our systematic review	USA[a]	Increased shade for animal wellbeing, calving, and production; diversification of farm income; short– and long–term cash flow; enhanced forage quality; enhanced forage production during shoulder seasons, mid-summer, and times of drought; increased quality and size of trees for timber; and restoration of savanna habitat	Lack of information; lack of assistance from resource professionals; increased time required for management; expense of management; lack of land; tree regeneration in established systems; and possible need for new or modified equipment
Calle et al. (2009)	Columbia	Reduced use of inputs; improved conditions for cattle; and increased wildlife diversity	High capital investment; and lack of information and knowledge
(de Jalón et al., 2018)	Europe[b]	Animal health and welfare; animal production; biodiversity and wildlife habitats; income diversity, diversity of products; rural development; soil conservation; general environment; and landscape aesthetics	Increased labor; added administrative burden and regulation; higher complexity of work; mechanization; tree regeneration survival; losses by predation; and disease and weed control
Frey et al. (2012)	Argentina	Joint production of two outputs; less heat stress on livestock; quick income from livestock; reduced quantity of weeds; and lower forest fire risk	Not enough light for good pasture growth; compatibility of trees and pasture; high capital investment; and difficulty of managing trees to allow light
Gosling et al. (2020)	Panama	Meet household needs; enhance economic stability; and long–term income	Compatibility with operation; and establishment costs
Jara-Rojas et al. (2020)	Colombia	Joint production of two outputs; low–cost forage for improving animal performance; fulfillment of forage–demand in the dry season; and source of shade for cattle	Costs related to seeds; materials for propagation; and labor required for planting and tending
Kagiraneza (2019)	Rwanda	Use as fencing; control of soil erosion; and trees for selling	Insufficient funds; perceived damage to trees by grazing cattle, and the availability of seedlings
Lee et al. (2020)	Columbia	More humidity on farm; shade effect for cattle; improved soil quality; provision of additional animal feed; animal (cattle) well–being; and more birds and insects in the farm	Land tenure status; risky due to climate conditions; long–term investment required to obtain benefits; and highly perceived complexity
Opdenbosch (2021)	Sweden	Source of alternative income	Higher management costs; and lack of knowledge of the practice
Pérez (2006)	Honduras	Shade for livestock; economic products (timber, firewood, posts); and ecological (water quality) goods and services	Lack of cheap seeds/ seedlings; lack of support from institutions; high labor investment; and tree mortality

[a] See Table 1 for specific locations across the USA
[b] Multiple locations across Europe. See de Jalón et al. (2017) for more detail

4. Conclusions and recommendations

This synthesis investigated silvopasture adoption studies in the USA to identify barriers to implementation, as well as research gaps, educational needs, and policies or programs that could help or hinder adoption. In total, 53 silvopasture studies from 1983 to 2021 were evaluated. Based on this synthesis, the following conclusions were made:

- Diversification of farm income and shade for livestock were the primary benefits of implementing silvopasture according to producers using the practice and NRPs.
- Lack of information was the primary obstacle when managing a silvopasture according to producers using the practice and NRPs.
- Rotational or management intensive grazing is a fundamental aspect of silvopasture, with 98% of producers using one of these management practices.
- 96% of producers reported using silvopasture in combination with paddocks in open pasture, suggesting that silvopastures are primarily used as a complementary component of their pasture rotation system.
- 88% of producers using silvopasture indicate they will continue the practice into the future.
- Producers reported that NRPs, especially foresters, often confuse silvopasture with unmanaged grazing in woodland or forest, resulting in a negative perception and lack of support for the practice.
- Producers established their silvopastures primarily by thinning an existing plantation, forest, woodlot, or trees on the edge of an existing pasture.
- Producers used a wide range of livestock including cattle, goats, sheep, chickens, turkeys, horses, bison, pigs, geese, and ducks.
- Producers and NRPs identified a need for financial incentives to increase silvopasture adoption.
- Producers thinking about adopting silvopasture (non-adopters) were most concerned with lack of information and technical assistance, followed by the extra time and investment required to manage and maintain the system.
- NRP opinions of silvopasture vary by geographic region and by professional category.
- NRPs desire locally-specific training materials, field tours, and demonstration sites.

Through this synthesis, we also identified key research gaps and methodological issues that should be considered when designing future research studies investigating silvopasture adoption.

- A majority of silvopasture adoption studies involve case studies with limited sample size (< 20 respondents). More research using larger sample sizes is needed to better identify trends and nuances.
- Studies are needed to better understand producers' decision-making and plans regarding products produced from their silvopasture systems and which markets they are utilizing.
- More studies investigating the drivers affecting silvopasture adoption are needed by comparing silvopasture adopters to an appropriate pool of non-adopters (i.e., producers grazing livestock) to ensure results are not skewed.
- Future surveys should clearly define what qualifies as silvopasture, as several past studies were unclear and could have included those using unmanaged woodland or forest grazing, which are different management practices.
- Information is lacking on producers' decision-making regarding livestock breeds well suited for grazing in silvopastures.
- Longitudinal studies assessing long-term silvopasture management, retention, and reasons for maintaining or stopping the practice are needed.
- More research on NRP awareness, knowledge, and opinions of silvopasture are needed on a regional level, where many of the relevant

policy boundaries occur. Studies should separate NRPs into distinct clusters by professional category since it has been shown to affect opinion and support for silvopasture.

Based on this review, additional research, education, and outreach are needed to support informed and appropriate adoption of silvopasture in the USA. With over 300,000 farm operations reporting woodland pasturing on 10.5 million hectares of land in the country (USDA, 2019), there is great potential for silvopasture expansion. Likewise, producers already using rotational grazing in treeless pastures may find benefit by adding trees to their systems, especially under changing climate conditions. As such, more deliberate management in the form of silvopasture may be a strategic approach for producers looking to improve forage availability throughout the year, produce forest products, enhance livestock wellbeing and production, and improve the ecological integrity and resiliency of the land they graze.

Declaration of Competing Interest

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

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