Identifying the Factors that Constrain and Facilitate the Adoption of Agroforestry Practices by Minnesota and Wisconsin Agricultural Producers

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Abstract

Agroforestry practices are agricultural and natural resource management systems in which trees are incorporated with agricultural crops and/or livestock. Agroforestry practices, particularly windbreaks, silvopasture, alley cropping, riparian forest buffers, forest farming, and living snow fences, provide a variety of environmental, economic, and social benefits to agricultural communities and landscapes. Despite the services these systems offer, only 1.9% of farmers in Minnesota and Wisconsin adopted at least one agroforestry practice by 2022. The purpose of this research was to identify the constraints to agroforestry adoption and opportunities to increase adoption by agricultural producers in Minnesota and Wisconsin.

Following producer interviews and a comprehensive review of the agroforestry adoption literature, three rounds of a mail survey were sent to producers in Minnesota and Wisconsin. The survey collected data regarding current adoption of agroforestry practices, information on acceptable incentives and limiting constraints, the likelihood of adopting each practice, and demographic information. Binary logistic regressions were performed to identify the constraints, opportunities, and demographic data that significantly influenced the likelihood of adoption for each practice.

The results indicate that windbreak adoption is enhanced by financial assistance programs, aesthetic values, and an alignment with producers' goals. Silvopasture adoption is enhanced by a minimization of competition between trees and forage, an alignment with producers' goals, and the lack of a woodlot on the farm. Alley cropping adoption is enhanced by technical assistance, aesthetic values, and a compatibility with the producers’ management and equipment and is likely to be adopted by younger producers and those with smaller farms. Riparian forest buffer adoption is enhanced by financial assistance programs and colleagues

adopting riparian forest buffers. Forest farming adoption is enhanced by technical assistance, a compatibility with the producers' management and equipment, and the presence of a woodlot. Finally, living snow fence adoption is enhanced by an alignment with producers' goals, the availability to manage trees, profit opportunities from the living snow fence, and colleagues adopting living snow fences. Natural resource technical assistance providers and policymakers can use these results to remove barriers and improve incentives for agroforestry practices, promoting agroforestry adoption among Minnesota and Wisconsin agricultural producers.

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INTRODUCTION

Agroforestry Practices and Services

Agroforestry is an agricultural and natural resource management system that intentionally integrates trees or shrubs with agricultural crops and/or livestock to provide specific benefits (Gold and Garrett 2021; USDA 2019). Five distinct agroforestry practices are commonly accepted and implemented in temperate agricultural areas: windbreaks, silvopasture, alley cropping, riparian forest buffers, and forest farming (Gold and Garrett 2021).

Windbreaks, also referred to as shelterbelts, are lines of trees included on agricultural landscapes to reduce wind speeds, protecting crops, livestock, or structures (Figure 1). Silvopasture is the intentional integration of rotationally grazed livestock in a forested environment, in which the overstory trees, forage crops, and livestock are managed collectively (Figure 1). Alley cropping incorporates strips of crops planted in the alleyways between parallel rows of trees (Figure 1). Riparian forest buffers are strips or areas of trees planted adjacent to waterways to filter runoff and stabilize banks (Figure 1). Forest farming is the active cultivation of specialty crops, such as ginseng, or other non-timber forest products, such as mushrooms or maple syrup, in woodlands (Figure 1).

Living snow fences can be considered a sixth agroforestry practice. Living snow fences are rows of trees planted parallel to roads and highways to minimize blowing snow that affects drivers (Figure 1). Living snow fences are often considered a type of windbreak, but due to differences in function and state-level investment and interest in living snow fences in Minnesota (Current et al. 2017; Wyatt et al. 2012), we discuss them as their own distinct practice.

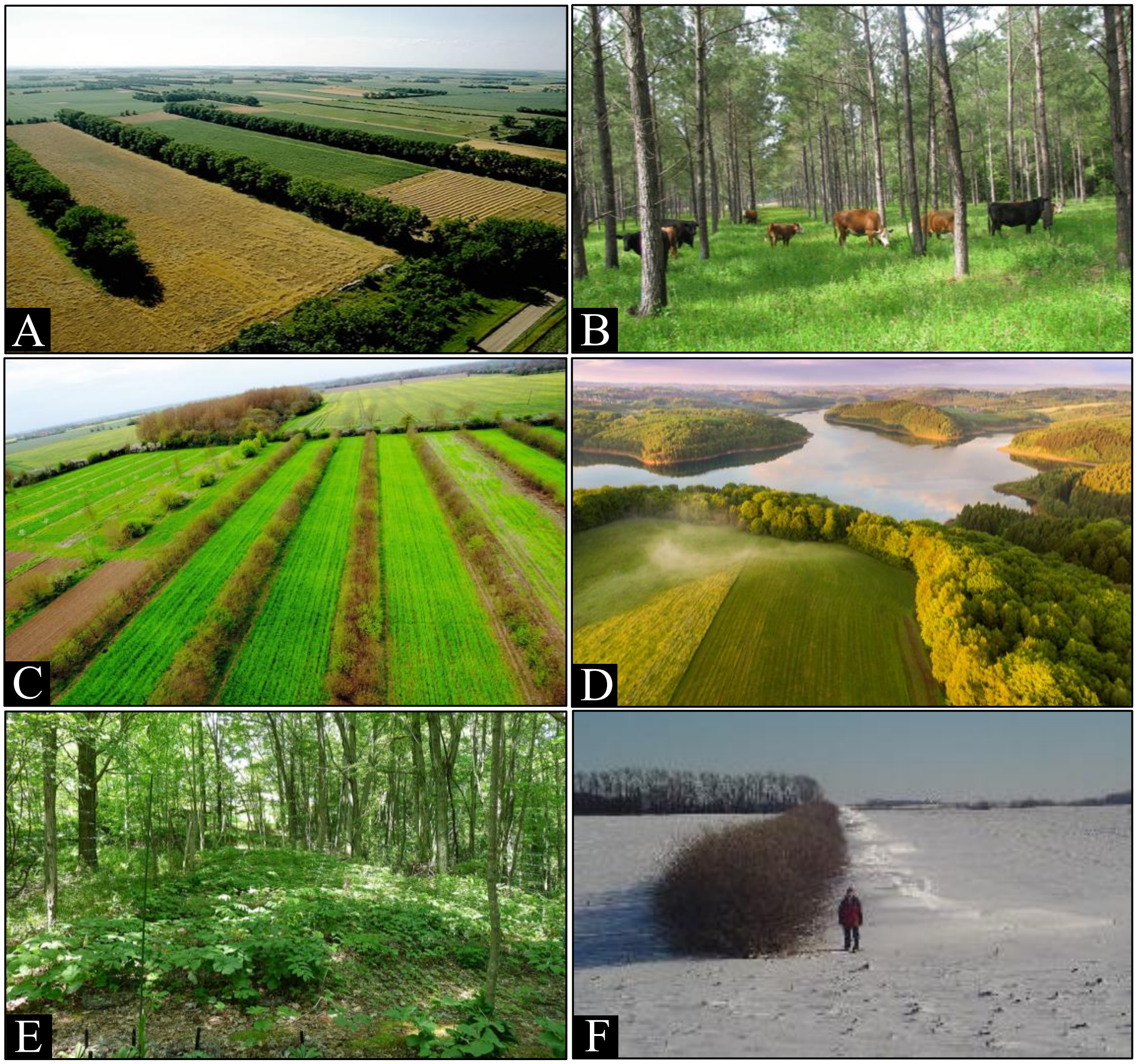

Figure 1: Photos of the six agroforestry practices included in this study. The agroforestry practices include: (A) windbreaks; (B) silvopasture; (C) alley cropping; (D) riparian forest buffers; (E) forest farming; and (F) living snow fences. *Sources: USFS National Agroforestry Center (A, B, D, E), Soil Association (C), and Association for Temperate Agroforestry (F).*

Trees in agroforestry systems can be cultivated for a variety of products: timber products, such as wood or fiber; commodity tree crops, such as fruits or nuts; and non-timber forest products, such as maple syrup or decorative nut husks (Gold and Garrett 2021). These trees often serve compounding benefits by providing important ecosystem services in addition to market products.

Previous research has demonstrated the environmental, economic, and social services that temperate agroforestry systems can provide to agricultural landscapes and communities. Compared to conventional row crop and livestock systems, the presence of agroforestry practices can reduce wind erosion of soil (van Ramshorst et al. 2022; Veldkamp et al. 2023), minimize nutrient leaching and runoff (Allen et al. 2004; Udawatta et al. 2002), minimize spray drift of agricultural chemicals (Lazzaro et al. 2008; Otto et al. 2015), provide pollinator and pest predator habitat (Graham and Nassauer 2019; Pywell et al. 2005), enhance microbial communities (Bainard et al. 2012; Beule and Karlovsky 2021) provide wildlife habitat and improve wildlife biodiversity (Assandri et al. 2016; Berges et al. 2010), enhance carbon sequestration (Peichl et al. 2006; Wotherspoon et al. 2014), and more. Agroforestry systems are economically important because they shelter crops and livestock (Bennell and Verbyla 2008; Veissier et al. 2018), reduce crop disease incidence (Behlau et al. 2021), reduce snow collection on roads (Heavey et al. 2015; Qi et al. 2021), and diversify farmer income (Cubbage et al. 2012) while remaining competitively profitable with conventional agriculture (Husak and Grado 2002; Wolz and DeLucia 2019) and maintaining long-term crop yields (Swieter et al. 2019). Socially, agroforestry systems can enhance personal well-being (MacDonald et al. 2020), cultural identity (Oreszczyn 2000), and perceptions of landscape aesthetics (Grala et al. 2010). In this way, temperate agroforestry systems are often considered an environmentally, economically, and socially sustainable alternative to conventional production agriculture.

Adoption of Agroforestry Practices

Widespread farmer adoption of agroforestry systems is a goal set by the United States Department of Agriculture (USDA) in its Agroforestry Strategic Framework (USDA 2019).

Many organizations in the Upper Midwest provide technical and financial assistance to landowners regarding the adoption of agroforestry practices, including local USDA Natural Resource Conservation Service (NRCS) offices, county Soil and Water Conservation Districts (SWCD), Minnesota Department of Transportation, University of Minnesota Extension, and various non-profits, such as the Savanna Institute, Minnesota Sustainable Farming Association, and Green Lands Blue Waters.

Despite the demonstrated benefits of agroforestry systems and institutional support in the Upper Midwest, only 1.9% of farmers in Minnesota and Wisconsin had implemented an agroforestry practice by 2022 (NASS 2024). This low adoption rate in the context of the benefits of agroforestry indicates underlying factors that inhibit adoption. The ability of agroforestry systems to conserve natural resources, mitigate climate change, and benefit rural communities cannot be realized if producers do not apply these practices. As such, it is necessary to understand the factors that constrain the adoption of agroforestry practices and identify opportunities to facilitate their adoption.

Windbreaks

Depending on their spatial arrangement, windbreaks can be categorized into those that shelter fields, livestock, or farmsteads (Smith et al. 2021). Adoption rates and reasons for adoption differ between these three windbreak types (Thompson et al. 2023). For example, a survey from Saskatchewan, Canada demonstrates that farmers appreciate different types of windbreaks for different benefits, in that they perceive the main benefit of field windbreaks to be a reduction in soil erosion, the main benefit of livestock windbreaks to be a general alteration of the microclimate, and the main benefit of farmstead windbreaks to be shelter for the house (Rempel et al. 2017).

One study demonstrated that 83% of Kansas farmers included in a survey found windbreaks to be desirable (Cable and Cook 1997), and many farmers agree that multifunctional windbreaks are more desirable than open fields (Kronenberg 2022). Particularly, in their review of windbreak adoption in the U.S., Smith and colleagues (2021) highlight the indirect economic benefits windbreaks in general provide. Farmers describe that windbreaks protect crops and livestock (Cable and Cook 1997; Hand and Tyndall 2018), reduce wind erosion of soil (Brodt et al. 2009; Cable and Cook 1997; Hand and Tyndall 2018; Howlader 2023; Matthews et al. 1993), improve soil moisture conditions (Hand and Tyndall 2018; Matthews et al. 1993), decrease pesticide use (Brodt et al. 2009), attract beneficial insects (Brodt et al. 2009), and increase land value (Matthews et al. 1993). Aside from economics, farmers report ecological and social benefits and reasons for adopting windbreaks, including improved water quality (Brodt et al. 2009), enhanced wildlife habitat (Cable and Cook 1997), enhanced landscape aesthetics (Brodt et al. 2009), and odor reduction (Tyndall 2009).

Windbreak adoption has been correlated with a variety of factors. Windbreak adoption increases with younger age (Dorr 2006; Matthews et al. 1993; Tyndall 2009), longer land tenure (Howlader 2023), larger parcel size (Matthews et al. 1993), less irrigation (Howlader 2023), more knowledge of windbreaks (Dorr 2006), more trees already on the landscape (Howlader 2023), advice from technical service providers (Dorr 2006), and the belief that wind erosion is an issue (Dorr 2006). Spatially, windbreak adoption increases in hilly areas, on organic or diversified farms, and on marginal land (Thompson et al. 2023). The diffusion of windbreak adoption has been debated, with some studies arguing that adoption of windbreaks is encouraged by other farmers adopting windbreaks (Brodt et al. 2009) and others showing that adoption by others does not influence personal adoption of windbreaks (Cable and Cook 1997).

Despite the benefits of windbreaks and these correlations, many factors constrain the adoption of windbreaks. These include the time and labor involved in establishment and maintenance (Brodt et al. 2009; Rempel et al. 2017; Tyndall 2009), the cost of establishment and maintenance (Brodt et al. 2009; Tyndall 2009), incompatibility between windbreaks and farm equipment (Brodt et al. 2009; Rempel et al. 2017), and the potential to provide habitat for pests and promote weed growth (Brodt et al. 2009). Loss of crop production is also a major barrier to adoption (Brodt et al. 2009), particularly when crop prices are high (Howlader 2023).

Silvopasture

Silvopasture may have more adoption potential than other agroforestry practices (Frey 2009). Farmers perceive silvopasture as more desirable than conventional open pasture (Kronenberg 2022), and a survey in Sweden found that 52% of respondents were willing to adopt silvopasture (Opdenbosch and Hansson 2023). Furthermore, over 40% of Alabama landowners included in a survey demonstrated an interest in learning more about silvopasture (Workman et al. 2003).

Silvopasture adoption likelihood has been correlated with personal and farm demographic factors. Men (Opdenbosch and Hansson 2023), younger farmers (Matthews et al. 1993), those with more income (Opdenbosch and Hansson 2023), those with higher levels of education (Dorr 2006; Opdenbosch and Hansson 2023), those with smaller farms (Matthews et al. 1993), and those with more acres of unmanaged timber (Dorr 2006) are more likely to be interested in or adopt silvopasture. Additionally, interest in silvopasture adoption increases with more knowledge of silvopasture (Dorr 2006), more concern over the loss of trees (Dorr 2006), more positive attitude toward silvopasture (Opdenbosch and Hansson 2023), and lower perceived maintenance costs (Opdenbosch and Hansson 2023).

Silvopasture benefits many farm characteristics. Particularly, silvopasture improves animal health and welfare (García de Jalón et al. 2017) by providing shade and shelter for livestock (Ford 2016; Mayerfeld et al. 2016; Mayerfeld et al. 2023). Farmers have also found that silvopasture systems control unwanted shrub growth (Mayerfeld et al. 2016; Mayerfeld et al. 2023), reduce soil erosion (Ford 2016), enhance biodiversity and wildlife habitat (García de Jalón et al. 2017), improve landscape aesthetics (García de Jalón et al. 2017), and diversify and increase income opportunities (Mayerfeld et al. 2023), particularly in marginal land (Mayerfeld et al. 2016). Additionally, silvopasture can be as profitable as conventional agricultural systems (Husak and Grado 2002). When compared to conventional forest management, silvopasture can be more profitable, though only when crops, such as fruit and nuts, are harvested from the trees (Randolph 2018).

Some of these benefits have incentivized producers to adopt silvopasture. Reported motivations for adoption include use of and profit from marginal land (Orefice et al. 2017; Rois-Díaz et al. 2018), expanding pasture acreage and forage availability (Orefice et al. 2017), shelter and shade for livestock (Orefice et al. 2017; Rois-Díaz et al. 2018), and expected increases in land value (Matthews et al. 1993). While silvopasture enrollment in carbon markets has been proposed, the returns from carbon offset trading may not be sufficient to incentivize adoption (Holderieath et al. 2012).

Many factors still constrain the adoption of silvopasture by producers. Increased intensity and complexity of labor (García de Jalón et al. 2017; Mayerfeld et al. 2016; Mayerfeld et al.

2023; Orefice et al. 2017; Wilkens et al. 2022a), increased infrastructure complexity (Orefice et al. 2017), lack of knowledge regarding silvopasture and its management (Ford 2016; Orefice et al. 2017), uncertainty regarding the benefits of silvopasture (Davis and Rausser 2020), potential for damage to trees and soil (Mayerfeld et al. 2016; Mayerfeld et al. 2023), access to land (Mayerfeld et al. 2016), the cost of establishment and maintenance (Ford 2016), and the belief that silvopasture is unprofitable (Davis and Rausser 2020) have been found to constrain silvopasture adoption.

However, two factors may confound silvopasture adoption studies. First, many producers confuse active silvopasture with passive forest grazing (Matthews et al. 1993; Mayerfeld et al. 2016), yet the two management systems are not synonymous. Additionally, silvopasture can be created either by planting trees in open pasture or thinning and planting forage crops in forest, and producers prefer different methods (Wilkens et al. 2022b). As such, producer preferences regarding silvopasture adoption may be muddied by these variables.

Alley Cropping

Much of the literature regarding the adoption of alley cropping has focused on economic potential. Economic barriers to alley cropping adoption include a belief that alley cropping is unprofitable (Borremans et al. 2016; Mary et al. 1998), competition between trees and crops (Borremans et al. 2016; Mary et al. 1998), and reduced crop production (Borremans et al. 2016). In a survey of German farmers, only 7% of respondents described being interested in adopting alley cropping, but after being instructed to assume they were in a situation in which they are guaranteed to be profitable, the percent of German farmers interested in alley cropping increased to 48%, demonstrating profitability as a significant barrier (Beer and Theuvsen 2020). Interest in adopting alley cropping is correlated with the perception of increasing economic advantages for the farm operation (Beer and Theuvsen 2020), fewer economic risks (Beer and Theuvsen 2020), and more income from off-farm sources (Dorr 2006). Furthermore, alley cropping can be successful at diversifying income (Cubbage et al. 2012; Dunn et al. 2021) and can generate similar profits to conventional agricultural systems (Wolz and DeLucia 2019), though it is economically optimal in many circumstances to not transition from conventional agriculture to alley cropping (Frey et al. 2013). Carbon markets have been disputed as a potential economic incentive for alley cropping adoption, with research from Canada suggesting carbon offset trading provides viable economic returns in alley cropping systems (Winans et al. 2016) and research from the U.S. that the returns may not be sufficient to incentivize adoption (Holderieath et al. 2012).

Technical considerations also exist for alley cropping adoption. Technical constraints to adoption include the incompatibility between alley cropping and the current farming method (Borremans et al. 2016; Frey 2009; Mary et al. 1998), labor intensity of alley cropping (Mary et al. 1998; Laroche et al. 2019), and a lack of understanding regarding alley cropping (Matthews et al. 1993). These impediments to adoption can be solved through advice from conservation professionals and other farmers and increased knowledge of alley cropping systems (Dorr 2006), though adoption of alley cropping may also be more likely when farmers possess less agricultural training (Beer and Theuvsen 2020). Alley cropping's ability to provide more products from the same land area is also an attractive benefit to farmers (Mary et al. 1998).

Ecological, social, and demographic consideration also influence alley cropping adoption. Alley cropping adoption has been correlated with enhanced ecological benefits and by farmers who experience less precipitation (Beer and Theuvsen 2020), and farmers perceive the ecological benefits of alley cropping adoption to be a reduction of soil erosion (Borremans et al. 2016), improved soil fertility (Mary et al. 1998), improved pest and weed control (Mary et al. 1998), increased biodiversity (Borremans et al. 2016), and enhanced air quality (Borremans et al. 2016). Socially, interest in alley cropping adoption increases with more concern regarding loss of trees on agricultural landscapes (Dorr 2006) and the belief that alley cropping would be supported by the farmer's family (Beer and Theuvsen 2020). Additionally, further social acceptability of alley cropping and an interest in landscape aesthetics may encourage adoption (Laroche et al. 2019). Finally, younger demographics are more likely to adopt alley cropping than older farmers (Dorr 2006; Matthews et al. 1993).

Riparian Forest Buffers

Adoption of riparian forest buffers can occur as part of or independent of government conservation programs. For example, the Minnesota State Legislature passed Minnesota's "Buffer Law" in 2015, directing landowners in the state to plant filter strips, of which riparian forest buffers are an option, adjacent to public ditches and waterways (*Buffer Law* 2023). Voluntary conservation programs exist in other states encouraging landowners to adopt riparian forest buffers (MDA n.d.). Landowner adoption of riparian forest buffers can be increased when landowners have more education regarding these programs (Roberts 2011; Shelton et al. 2009) or view them positively (Skelton 2004; Skelton et al. 2005). In one European study, however, 53% of survey respondents denied participation in a conservation buffer program (Buckley et al. 2012), and an unwillingness to participate in these programs may constrain the adoption of riparian forest buffers (Skelton 2004).

Voluntary buffer programs, such as the Maryland Department of Agriculture's (MDA n.d.), aim to remove economic barriers to riparian forest buffer adoption, including loss of crop production and loss of income (Buckley et al. 2012; Lynch and Brown 2000). Indeed, financial assistance is a key incentive for riparian forest buffer adoption (Lynch and Brown 2000; Matthews et al. 1993; Rhodes et al. 2018; Skelton et al. 2005), and higher discretionary income has been linked to increased interest in riparian forest buffer adoption (Trozzo et al. 2014a). The source of this income, however, has been debated between the farm operation (Kim et al. 2005) and off-farm revenue (Dorr 2006).

Other constraints to riparian forest buffer adoption include labor intensity (Matthews et al. 1993) and a lack of awareness of the benefits of riparian forest buffers (Rhodes et al. 2018), highlighting opportunities for technical assistance (Rhodes et al. 2018; Roberts 2011; Shelton et al. 2009; Skelton et al. 2005) and education regarding riparian forest buffers and their benefits (Dorr 2006; Matthews et al. 1993; Rhodes et al. 2018; Roberts 2011; Skelton et al. 2005) to enhance riparian forest buffer adoption. Particularly, interest in riparian forest buffer adoption increases with increasing knowledge of riparian forest buffers (Valdivia and Poulos 2009) and more planting experience (Trozzo et al. 2014a).

Almost 50% of Alabama landowners included in a survey demonstrated an interest in learning more about riparian forest buffers (Workman et al. 2003), and in another study, farmers found riparian forest buffers more desirable than grass filter strips (Kronenberg 2022). Despite this interest, many farmers still hold unfavorable opinions of trees on their landscape (Rhodes et al. 2018) or do not believe that riparian forest buffers align with their objectives (Trozzo et al. 2014b). While many farmers are interested in adopting riparian forest buffers for the productive, economically important ecosystem services they provide (Barbieri and Valdivia 2009), others may be interested for a variety of other reasons. Personal, abstract reasons include the perception that riparian forest buffers positively impacted the environment (Skelton 2004), the belief that trees are important for future generations (Valdivia and Poulos 2009), and the belief that trees are important for aesthetic purposes (Valdivia and Poulos 2009). Physical impetus to adopt is related to issues with streambank erosion (Valdivia and Poulos 2009), hilly farm landscapes (Kim et al. 2005), and higher crop diversity (Kim et al. 2005).

Demographic predictors of adoption include age, farm size, and land ownership. Those more likely to be interested in adopting riparian forest buffers are of younger age (Skelton 2004; Valdivia and Poulos 2009), possess smaller farms (Lynch and Brown 2000; Skelton 2004; Trozzo et al. 2014a), own more land than they rent (Kim et al. 2005), and have come into land ownership more recently (Trozzo et al. 2014a).

Forest Farming

Most of the studies concerning the adoption of forest farming in the United States occur in three locales: Appalachia, Pennsylvania, and Missouri. In Appalachia, almost 50% of the family forest landowners included in a survey demonstrated an interest in forest farming (Trozzo et al. 2021). Of these respondents, newcomers to the area were most interested in forest farming, followed by established farmers and then established non-farming landowners. Similarly, over 40% of Alabama landowners included in a survey demonstrated an interest in learning more about forest farming (Workman et al. 2003). Significant barriers to the adoption of forest farming in North Carolina include lack of access to land and lack of education on forest farming (Kwiatek 2022).

Similarly, in Pennsylvania, lack of information regarding forest farming has been found to constrain forest farming adoption (Strong and Jacobson 2006). Additionally, many common non-timber forest products cultivated in Pennsylvania forest farming systems are not profitable, which may also constrain forest farming adoption in the state (Burkhart and Jacobson 2009). Many opportunities exist to increase the adoption of Pennsylvania ginseng forest farming, specifically, including the implementation of quality certification programs, the ability to produce multiple products from forest farming systems, and an increased understanding of ginseng habitat suitability (Burkhart 2011).

In Missouri, interest in forest farming has ranged from 18% to 26% of farmer and landowner respondents (Dorr 2006; Stubblefield 2021). Despite the relatively little interest, farmers have found forest farming scenes to be more desirable than natural forest stands and managed timber stands (Kronenberg 2022), as well as more desirable than other agroforestry practices (Kronenberg 2022; Stubblefield 2021). Interest in forest farming in Missouri has primarily been correlated with better knowledge of forest farming and younger age (Dorr 2006; Valdivia and Poulos 2009). In addition, Dorr (2006) found that interest in forest farming increased with increasing acres of managed timber, advice from natural resource professionals, concern for the loss of trees on the landscape, and the percent of income from non-farm sources. Valdivia and Poulos (2009) also found that interest in Missouri forest farming increased with the belief that trees are important for future generations, the belief that trees are important for aesthetics, and more prior trees on the land.

Living Snow Fences

Adoption of living snow fences has been encouraged at the state level. In recent years, state transportation agencies have launched programs to incentivize landowners bordering highways to implement snow fences, which include living snow fences, structural snow fences, and standing corn rows (Iowa DOT n.d., MnDOT n.d.). For example, the Minnesota Department of Transportation will cover the establishment costs of living snow fences on private land adjacent to highways (MnDOT n.d.). Studies in Minnesota and Illinois have assessed farmer and landowner perspectives of, constraints to, and opportunities for adopting living snow fences as part of these state programs.

Some farmers and landowners have found living snow fences to be more intrusive and less desirable than other snow fence options, namely structural snow fences and standing corn rows (Baral et al. 2023). Factors that constrain the adoption of living snow fences and enrollment in state living snow fence programs include the potential for agricultural chemicals to harm trees (Motschke 2020; Qi et al. 2020; Wyatt et al. 2012), the maintenance of the trees (Qi et al. 2020; Wyatt et al. 2012), the cost of implementation and maintenance (Baral et al. 2023; Qi et al. 2020), the loss of crop revenue (Baral et al. 2023; Qi et al. 2020), making a long-term agreement with the state (Qi et al. 2020; Wyatt et al. 2012), the long-term risk of trees dying (Wyatt et al. 2012), competition between trees and crops (Qi et al. 2020), and trees shading crops (Qi et al. 2020).

Opportunities to increase the adoption of living snow fences through state programs include the financial assistance these programs may award, spreading awareness of the program, promoting the benefits of the program, the perception that the program advances the landowner's objectives, potential hunting opportunities around the living snow fence, and the aesthetics of the living snow fence (Wyatt et al. 2012). Additional opportunities for landowners include allowing landowners to engage with the design of the living snow fence (Qi et al. 2020), particularly encouraging them to select species from which they can harvest alternative products, such as berries or ornamentals (Current et al. 2017). Benefits of living snow fences that previous adopters have experienced, such as increased wildlife abundance, reduced soil erosion, and enhanced appreciation for improved driver safety, can also incentivize others to adopt living snow fences (Wyatt et al. 2012).

General Agroforestry

Stubblefield (2021) demonstrated that producers are more familiar with the individual agroforestry practices than the term "agroforestry." Nevertheless, some studies analyze the adoption of agroforestry, broadly defined, as opposed to a set of implementable practices. These studies either did not measure or report factors influencing adoption per practice and instead referred to agroforestry systems broadly, so they will be synthesized collectively.

Many factors have been found that constrain the adoption of agroforestry systems in general, particularly the cost of establishing and maintaining trees in agroforestry systems (Fregene 2007; García de Jalón et al. 2018; Hand and Tyndall 2018; Kronenberg 2022; Rois-Díaz et al. 2018; Romanova et al. 2022; Strong and Jacobson 2005; Valdivia et al. 2012; Workman et al. 2003). Other barriers to agroforestry adoption include: the time or labor involved in managing trees in agroforestry systems (Fregene 2007; García de Jalón et al. 2018; Rois-Díaz et al. 2018; Romanova et al. 2022; Valdivia et al. 2012), lack of knowledge or experience regarding agroforestry systems and their management (Fregene 2007; Kronenberg 2022; Rois-Díaz et al. 2018; Valdivia et al. 2012; Workman et al. 2003), incompatibility between mechanical equipment and agroforestry systems (Rois-Díaz et al. 2018; Graves et al. 2017; Romanova et al. 2022; Workman et al. 2003), the belief that agroforestry systems are unprofitable (Fregene 2007; Kronenberg 2022; Rois-Díaz et al. 2018; Sereke et al. 2015), difficulty or complexity in managing agroforestry systems (Rois-Díaz et al. 2018; García de Jalón et al. 2018; Graves et al. 2017), lack of available markets for agroforestry products (Kronenberg 2022; Mattia et al. 2018; Workman et al. 2003), social norms for crops or against trees in agricultural areas (Hand and Tyndall 2018; Rois-Díaz et al. 2018; Sereke et al. 2015), lack of access to land ownership (Rois-Díaz et al. 2018; Romanova et al. 2022), lack of knowledge regarding marketing agroforestry products (Strong and Jacobson 2005), perceived risk in committing to an agroforestry system (Hand and Tyndall 2018), reduced cash crop production with trees present (Rois-Díaz et al. 2018), competition between trees and crops or animals (Workman et al. 2003), lack of agroforestry demonstration sites (Workman et al. 2003), and government regulations (Mattia et al. 2018).

Despite these barriers, producers remain interested in agroforestry systems or have implemented them because they: provide wildlife habitat (Fregene 2007; Gao et al. 2014; García de Jalón et al. 2018; Kronenberg 2022; Rois-Díaz et al. 2018; Romanova et al. 2022; Sereke et al. 2015; Valdivia et al. 2012; Workman et al. 2003), conserve soil and improve soil quality (Fregene 2007; García de Jalón et al. 2018; Hand and Tyndall 2018; Kronenberg 2022; Mattia et al. 2018; Romanova et al. 2022; Workman et al. 2003), enhance landscape aesthetics (Fregene 2007; García de Jalón et al. 2018; Rois-Díaz et al. 2018; Romanova et al. 2022; Valdivia et al. 2012; Workman et al. 2003), diversify farm products and income (Hand and Tyndall 2018; Rois-Díaz et al. 2018; García de Jalón et al. 2018; Graves et al. 2017), enhance on-farm biodiversity (García de Jalón et al. 2018; Graves et al. 2017; Romanova et al. 2022; Sereke et al. 2015), protect crops and livestock from weather (Hand and Tyndall 2018; García de Jalón et al. 2018; Rois-Díaz et al. 2018; Sereke et al. 2015), improve farm profitability (Graves et al. 2017; Romanova et al. 2022), enhance carbon sequestration (Gao et al. 2014; Valdivia et al. 2012), protect water quality (Fregene 2007; Mattia et al. 2018), provide profit opportunities in marginal lands (Rois-Díaz et al. 2018), provide shade (Workman et al. 2003), protect natural habitats (Gao et al. 2014), enhance the producer's reputation (Graves et al. 2017), facilitate knowledge transfer and engagement with the local community (Romanova et al. 2022), and benefit future generations of the farmer's family (Fregene 2007). Additional reasons that farmers adopt agroforestry systems include the farmer's family or friends have implemented an agroforestry system (Rois-Díaz et al. 2018) or the farmer is motivated to cultivate crops more sustainably, improve their land stewardship, or practice agroforestry (Romanova et al. 2022).

Socioeconomic characteristics of producers significantly influence patterns of agroforestry adoption and interest. Younger farmers are likely to be more interested in adopting agroforestry systems than older farmers (Rois-Díaz et al. 2018), particularly young, educated farmers (Mattia et al. 2018). Additionally, when residents from Missouri, Pennsylvania, and Texas were asked to compare farms using agroforestry systems and farms using conventional agricultural systems, females were more likely to find agroforestry farms as socioeconomically important, while females, individuals with higher levels of education, and rural residents were more likely to find agroforestry farms as ecologically important (Gao et al. 2014). Finally, interest in agroforestry increases with higher income and smaller farm size (Stubblefield 2021).

Many opportunities to increase the adoption of agroforestry systems have been identified, and financial assistance and cost-share programs are the most frequently cited (Hand and Tyndall 2018; Rois-Díaz et al. 2018; Graves et al. 2017; Romanova et al. 2022; Valdivia et al. 2012).

Other opportunities include technical assistance (Barbieri and Valdivia 2009; Hand and Tyndall 2018; Stubblefield 2021), education and knowledge regarding agroforestry practices (Mattia et al. 2018; Strong and Jacobson 2005; Stubblefield 2021), highlighting the benefits of agroforestry practices (Mattia et al. 2018; Stubblefield 2021), highlighting the implementation of agroforestry on marginal lands (Graves et al. 2017; Mattia et al. 2018), payments for agroforestry adoption (Stubblefield 2021), printed informational materials (Barbieri and Valdivia 2009), and government regulations (Rois-Díaz et al. 2018).

Research Objective and Application

This research aims to identify and qualify the major constraints, opportunities, and demographic factors that inhibit and facilitate the adoption of agroforestry practices by Minnesota and Wisconsin farmers. The purpose of this study is to better understand patterns of agroforestry adoption among farmers to improve and/or promote the implementation of programs that increase the adoption of agroforestry practices in the Upper Midwest.

Many agricultural service providers (i.e., local USDA NRCS, SWCD, Extension, and non-profit staff) lack substantial training in agroforestry systems, reducing their effectiveness in providing informed conservation recommendations to farmers interested in implementing agroforestry systems (Kronenberg et al. 2023; Stutzman et al. 2019). Technical service providers have the capacity to benefit their area's natural resources and their community's well-being by supporting the adoption of agroforestry practices. If more farmers are to implement agroforestry practices, it is critical that service providers recognize barriers and opportunities associated with agroforestry adoption and are equipped with the resources to provide assistance. This research, then, is framed in a way to be directly applicable to the work of agricultural service providers.

Particularly, we study factors influencing adoption by each agroforestry practice as opposed to agroforestry in general. This practice-specific approach allows farmers unfamiliar with agroforestry systems to clearly define and imagine their arrangement on the landscape, thereby facilitating more effective communication between technical service providers and farmers.

METHODS

Survey Design and Data Collection

A comprehensive literature review of North American agroforestry adoption studies and a series of interviews with Minnesota farmers informed the survey design. Seven semi-structured interviews were conducted prior to designing the survey – four with farmers that maintain edagroforestry practices at the time ("adopters") and three with farmers that had not adopted an agroforestry practice ("non-adopters"). At the time of the interviews, adopters collectively maintained windbreaks, silvopasture, alley cropping, forest farming, and living snow fences. Adopters were identified for interviews through membership in the Sustainable Farming Association (https://sfa-mn.org/) and connections through the Center for Integrated Natural Resource and Agricultural Management at the University of Minnesota (https://cinram.umn.edu/). Non-adopters were identified for interviews through the soil health case studies on Farmmaps (https://farmmaps.umn.edu/), meaning that they implemented another conservation agriculture practice, such as cover crops or no-till, and may be likely to have heard about agroforestry but decided not to adopt.

Adopters were asked about: their reasoning for adopting agroforestry practices; the barriers to the implementation of agroforestry practices that they experienced; any factors that may have encouraged them to adopt agroforestry practices; the impact that agroforestry practices have had on farm operations, management, and profitability; and how and from where they received information regarding the adoption or management of agroforestry practices. Non-adopters were asked about: their reasoning for adopting non-agroforestry conservation practices, such as cover crops; their familiarity with agroforestry practices; the barriers to the implementation of agroforestry practices that they experience; factors that might encourage them to adopt agroforestry practices; their perception of the impact that agroforestry practices may have on farm operations, management, and profitability; and preferred sources of information for agricultural management. The answers to these questions, in addition to reported constraints and opportunities from the agroforestry adoption literature review, were used to create a list of constraints to agroforestry adoption (Table 1) and a list of opportunities for agroforestry adoption (Table 2).

Table 1: Constraints to the adoption of agroforestry practices used in this study.

Category	Constraints
Economic	Cost of establishing trees
	[Practice] is unprofitable
	Marketing - lack of markets, finding markets, etc.
Technical	Long time to production (timber, nuts, etc.)
	Lack of knowledge on how to manage
	Amount of time or work to manage trees
	Lack of labor to help manage trees
	Lack of a demonstration of a real [practice]
	Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and [practice]
	Loss of land available for row crops or pasture
	Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)
Environmental	Soils or hydrology would not support trees
	Trees compete too much with crops
	Risk or uncertainty with climate change
Political	Loss of acres eligible for government subsidies
Social	[Practice] does not align with my goals

To conduct the survey, farmer addresses were purchased from Dynata (https://www.dynata.com/), a private company that maintains mailing lists and databases for surveys and marketing. The mailing list included the names and addresses of 3,000 farmers, 1,500 of whom reside in Minnesota, and the other half of whom reside in Wisconsin. The sample within each state was proportionately weighted by county, meaning that counties with more farmers received more surveys than counties with fewer farmers. The sample was randomly generated from all farmer addresses in Dynata's database using these criteria. Each address was given an identification number to identify the state to which it was mailed, maintain anonymity of individual responses, and avoid repetitive mailings to participants that already responded.

The survey packet delivered to each farmer in the mailing list included a cover letter, questionnaire, and pre-paid return envelope. The cover letter described the purpose of the study, the research rights of the participants, and the contact information for the principal investigators. The cover letter also provided a URL to an online, web-based version of the questionnaire, developed through the survey company Qualtrics (https://www.qualtrics.com/), and offered one of five $50 gift cards as an incentive to those participants that fully complete and return the physical or online survey. In the cover letter, the primary producer, or the producer who more regularly conducts the farm work, was asked to complete the questionnaire.

Table 2: Opportunities for the adoption of agroforestry practices used in this study.

Category	Opportunities
Economic	Cost-share or financial assistance/incentive programs
	Diversification of income sources
	Information about wood or tree crop marketing
Technical	Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)
	Information about [practice] management
	Demonstrations of successful [practice] on farms
	Information about the benefits of [practice]
Political	Enrolling the land in a carbon market program
Social	[Practice] may make an area more visually appealing
	Friends or neighbors implementing [practice]

The questionnaire was structured into eight sections. The first six each highlighted one of the six agroforestry practices included in this study. In each of the practice-specific sections, participants were provided with a short description and graphic of each practice (Figure 2). Participants were then asked if the practice currently exists on the land that they farm, to which they could respond: “yes”; “no, I’ve never had a [practice]”; or “no, I used to have a [practice] but not anymore.” Following the question regarding current adoption, participants were presented with the lists of constraints and opportunities and were asked to classify them on a Likert scale. Participants rated the degree to which each constraint limits their willingness to adopt new practices on a five-point Likert scale from “not limiting” to “extremely limiting.” Additionally, participants rated their likelihood of being incentivized by each opportunity on a four-point Likert scale from “very unlikely” to “very likely,” in which there was not a neutral option. The questions regarding constraints and opportunities were included for each practice to allow for the comparison of these factors between practices.

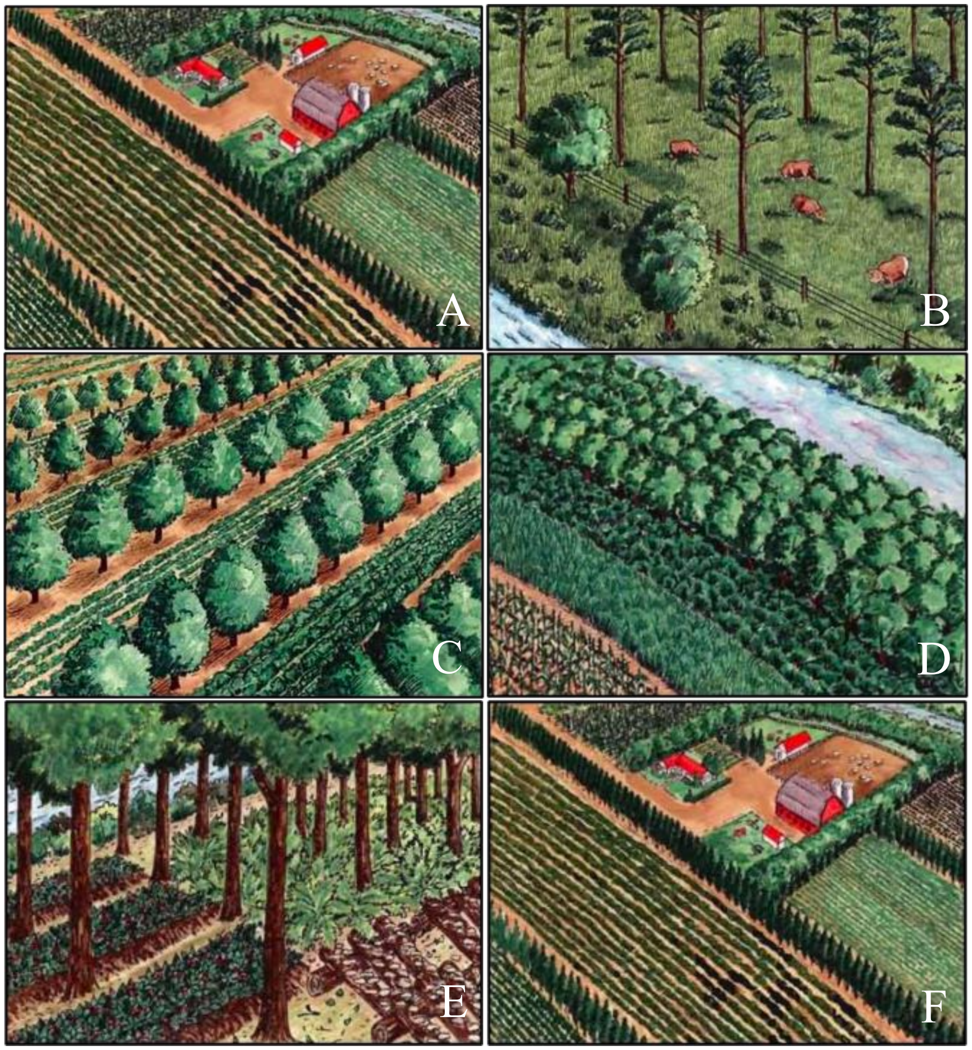

Figure 2: Illustrations of the six agroforestry practices included in the survey. The practices include: (A) windbreaks; (B) silvopasture; (C) alley cropping; (D) riparian forest buffers; (E) forest farming; and (F) living snow fences. *Source: USFS National Agroforestry Center in Josiah 2000*.

The silvopasture, riparian forest buffer, and living snow fence sections included an initial question to filter participants. A riparian forest buffer cannot be implemented on land that lacks a waterway, so participants were first asked if a waterway is present on or adjacent to their land. If not, they were directed to skip the riparian buffer section. Similar questions were included for the silvopasture and living snow fence sections to filter out participants that do not produce livestock or have a road adjacent to their land, respectively.

The seventh survey section focused on adoption potential and information preference. First, participants were asked to rate their likelihood of adopting each of the six agroforestry practices on a six-point Likert scale from "very unlikely" to "very likely," in which there was not a neutral option. Additionally, participants were asked to describe their preferred method of receiving information (e.g., visiting a website, receiving an email newsletter, asking another farmer) on a five-point Likert scale from "not preferred" to "extremely preferred."

The final section gathered farm and socioeconomic demographic information. Specifically, questions solicited total acres farmed in 2022, owned acres farmed in 2022, rented acres farmed in 2022, acres of each crop farmed in 2022, if farming is the primary source of income, net farm income in 2022, age, gender, race, and highest education level.

Data were collected using a modified Tailored Design Method (Dillman et al. 2014). The survey was conducted in two waves. In the first wave, the survey packet was mailed in mid-July 2023 following guidance from University of Minnesota Extension educators familiar with the timing of farmers' summer activities. A follow-up postcard reminding participants to complete the survey was delivered two weeks later. Responses were accepted through September 2023. The second wave constituted another survey packet delivered in early January 2024 to members of the sample population that had not responded to the first wave. Responses to the second wave were accepted through February 2024. In total, three mailings were sent to the sample population.

Data Analysis

Following data collection, physical and online surveys were entered into a Microsoft Excel file. Data was cleaned and formatted before being imported into IBM SPSS Statistics (https://www.ibm.com/products/spss-statistics). Data was analyzed in IBM SPSS Statistics to gather descriptive statistics, such as the frequency of responses and mean values of age and acre variables, and conduct binary logistic regressions.

Binary logistic regression is a statistical tool used to measure the effect of independent variables on a binary dependent variable. The independent variables included in this regression analysis were the degree to which each constraint is limiting, the likelihood of accepting each opportunity, total acres farmed, the proportion of acres farmed that are owned, acres of corn and soybean, acres of pastured cattle, income source, age, gender, and highest education level. Additionally, the presence of a woodlot on the farm was included for silvopasture and forest farming because these systems may be created using an existing woodland in addition to planting trees. Race was not included because the sample was highly skewed white, so the model did not have adequate variability in race by which it could make predictions. Additionally, income was not included as an independent variable because very few respondents offered their income and including it would have lessened the number of cases entered into the model.

The dependent variable being impacted by the independent variables was the likelihood of adoption for each practice. As the likelihood of adoption was measured on a six-point Likert scale, dummy variables were created to allow for binary analysis. In this way, all levels of unlikely ("very unlikely," "moderately unlikely," and "slightly unlikely") were recoded to 0, and all levels of likely ("very likely," "moderately likely," and "slightly likely") were recoded to 1. A binary logistic regression was conducted in SPSS for each practice, measuring the effect of the independent variables on that practice's binary likelihood of adoption. The results were scanned for the independent variables that demonstrated a statistically significant effect on the likelihood of adoption. Producers were expected to be likely to adopt agroforestry practices as the constraints become less limiting and the opportunities become more available.

Collinearity, in which independent variables are correlated instead of remaining separate, may misrepresent regression results. To ensure independent variables were not collinear, binary logistic regressions were conducted as linear regressions in SPSS to identify the variance inflation factor (VIF) for each independent variable. A VIF value under five indicates low to moderate correlation and is not concerning, while a VIF value over five demonstrates moderate to substantial correlation and may interfere with regression results. The independent variables with a VIF over five were investigated to identify the other variables with which they were correlated, and some were deleted to ensure all independent variables were under a value of five. As a result, the following independent variables were deleted from the logistic regressions: lack of labor to help manage trees, lack of a real-life demonstration, loss of acres eligible for government subsidies, diversification of income sources, information about wood or tree crop marketing, information about the management of the practice, information about the benefits of the practice, demonstrations of successful practices on a farm, acres of corn and soybean, and acres of pastured cattle.

Finally, the descriptive statistics gathered from the demographic variables, such as mean age and proportion of male and female farmers, were compared against 2022 U.S. Census of Agriculture data for Minnesota and Wisconsin (NASS 2024) to assess if the sample studied is representative of Minnesota and Wisconsin farmers. Additionally, t-tests were conducted in SPSS to identify potential differences in respondents' demographic data between survey waves.

RESULTS

Sample Demographics

The survey received 345 responses. Forty-four of the 3,000 mailed surveys were returned undeliverable, resulting in a 11.7% actualized response rate. Of the 345 responses received, 295 were usable. It should be noted, though, that because the regressions were conducted for each practice and respondents were able to skip questions, the different regressions incorporated variable numbers of responses. Mean and proportional socioeconomic demographic (e.g., age and education) and farm demographic (e.g., farm size and acres of crop type) information are presented in Table 3.

Table 3: Frequency results for demographic survey variables.

Variable	Description	Mean / Proportion	N	SD	Min	Max
State	1 = Minnesota 2 = Wisconsin	56.9% 43.1%	295	0.496	1	2
Farm size	Farmed acres, total Farmed acres, owned Farmed acres, rented Proportion of owned acres	781.3 412.3 369.6 0.72	277	1,311.1 639.5 892.9 0.33	2 0 0 0	10,000 5,000 7,000 1
Production acreage	Corn/soybean acres Other crop acres Cattle pasture acres Other livestock pasture acres Specialty product acres	557.8 96.5 54.5 84.9 3.2	288	1,168.2 275.8 144.5 998.2 32.1	0 0 0 0 0	10,000 3,000 1,600 2,000 520
Production type*	Corn/soybean (0=no, 1=yes) Other crop (0=no, 1=yes) Cattle (0=no, 1=yes) Other livestock (0=no, 1=yes)	75.0% 51.4% 35.2% 6.7%	284	0.43 0.50 0.48 0.25	0 0 0 0	1 1 1 1
Income source	0 = Not primary income 1 = Primary income	36.2% 63.8%	287	0.48	0	1
Income	Net income ($)	105,745	90	330,653	-24,000	3,000,000
Age	Respondent age	64.2	266	11.8	25	85

Table 3 continued.

Education	1 = Did not graduate high school 2 = High school diploma 3 = Associate's/vocational degree 4 = Bachelor's degree 5 = Graduate degree	0.02% 30.5% 30.9% 28% 8.7%	290	1.17	1	5
Gender	1 = Man 2 = Woman 3 = Other gender	86.4% 13.6% 0%	287	0.58	1	2
Race	1 = White 2 = Asian 3 = Black/African American 4 = Native Hawaiian/Pacific Islander 5 = American Indian/Alaska Native 6 = Middle Eastern/North African	98.5% 0% 0.4% 0.4% 0.7% 0%	286	1.69	1	5
Hispanic	0 = No 1 = Yes	98.8% 1.2%	284	0.66	0	1

*Percentages do not add to 100 because one farmer may produce multiple types of products.

Of the 295 surveys used for analysis, 54.6% were returned during the first wave of the survey in summer 2023, and the remaining 45.4% were returned during the second survey wave in the winter of 2024. The results of the independent T-tests indicate that the two waves differ significantly in acres farmed, gender, and race, whereby the second wave is skewed to more acres farmed, more men, more producers who identify as white, and more producers who do not identify as Hispanic (Table 4).

Table 4: T-test comparison of demographic means between the survey waves.

Variable	Description	Wave 1 N	Wave 1 Mean	Wave 1 Std. Dev.	Wave 2 N	Wave 2 Mean	Wave 2 Std. Dev.	Sig.
Farm size	Farmed acres, total	153	623.2	1,018.0	128	954.3	1,573.6	0.034**
Land ownership	Proportion of acres owned	151	0.73	0.33	127	0.69	0.34	0.266
Income source	0 = Not primary income 1 = Primary income	156	0.62	0.49	131	0.66	0.48	0.544
Age	Respondent age	144	63.7	12.5	122	64.8	11.0	0.443
Gender	1 = Man 2 = Woman 3 = Other gender	160	1.27	0.68	127	1.14	0.41	0.054*
Race	1 = White 2 = Asian 3 = Black/African American 4 = Native Hawaiian/Pacific Islander 5 = American Indian/Alaska Native 6 = Middle Eastern/North African	160	1.67	2.01	126	1.20	1.12	0.019**
Hispanic	0 = No 1 = Yes	160	0.34	0.74	124	0.15	0.53	0.020**
Education	1 = Did not graduate high school 2 = High school diploma 3 = Associate's/vocational degree 4 = Bachelor's degree 5 = Graduate degree	160	3.36	1.22	130	3.14	1.11	0.116

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Factors Influencing Adoption

This section presents the results of the logistic regressions conducted for each practice, which identify the major constraints to, opportunities for, and demographic predictors of agroforestry adoption by practice.

Windbreaks

Table 5 demonstrates the factors influencing the adoption of windbreaks by the survey sample. The relationship between the dependent and independent variables in the binary logistic regression model for windbreaks was moderate, and the model was correctly able to predict 83.1% of the cases. The statistically significant constraints to adoption include the amount of time or work to manage trees, trees compete with crops, and windbreaks do not align with producers' goals. Statistically significant opportunities for adoption include financial assistance programs and the visual appeal of windbreaks. None of the demographic factors were statistically significant.

Consistent with regression expectations, the statistically significant constraints demonstrate that windbreak adoption is expected to be unlikely as windbreaks not aligning with producers' goals becomes more limiting. Furthermore, the statistically significant opportunities demonstrate that windbreak adoption is expected to be likely as financial assistance programs are provided and producers have a positive perception of the visual appeal of windbreaks. In contrast to expectations, the regression predicted that windbreak adoption is also likely as the amount of time or work to manage trees and trees competing with crops becomes more limiting.

Table 5: Binary logistic regression results for windbreaks.

Independent Variables	Coefficient	p-value	Sig.	VIF
Constraints				
Cost of establishing trees	-0.096	0.628		1.659
Windbreaks are unprofitable	-0.153	0.449		2.437
Marketing - lack of markets, finding markets, etc.	-0.267	0.189		2.542
Long time to production (timber, nuts, etc.)	-0.353	0.110		2.505
Lack of knowledge on how to manage	-0.079	0.753		2.298
Amount of time or work to manage trees	0.429	0.088	*	2.389

Table 5 continued.

Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and windbreaks	0.047	0.798		2.219
Loss of land available for row crops or pasture	-0.322	0.150		3.104
Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)	0.322	0.218		2.761
Soils or hydrology would not support trees	-0.045	0.862		1.819
Trees compete too much with crops	0.486	0.024	**	2.459
Risk or uncertainty with climate change	-0.159	0.536		2.044
Windbreaks do not align with my goals	-0.530	0.022	**	2.549
Opportunities				
Cost-share or financial assistance/incentive programs	0.496	0.027	**	1.788
Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)	0.265	0.269		1.974
Enrolling the land in a carbon market program	-0.351	0.119		1.505
Windbreaks may make an area more visually appealing	0.621	0.026	**	2.498
Friends or neighbors implementing windbreaks	0.416	0.107		2.031
Demographics				
Total acres	0.000	0.574		1.397
Proportion of owned acres	-0.629	0.357		1.509
Primary income source	-0.069	0.875		1.275
Age	-0.017	0.396		1.460
Gender	-0.518	0.474		1.335
Highest education level	0.315	0.113		1.174
Nagelkerke R-squared	0.547			
Prediction statistics (correctly classified)	82.8%			
Number of observations used in model (n)	221			

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Silvopasture

Table 6 demonstrates the factors influencing the adoption of silvopasture by the survey sample. The relationship between the dependent and independent variables in the binary logistic regression model for silvopasture was strong, and the model was correctly able to predict 82.6% of the cases. The statistically significant constraints to adoption were trees competing with crops and silvopasture not aligning with producers' goals, indicating that producers are unlikely to consider adopting silvopasture systems when there is competition between trees and crops and silvopasture does not align with producers' goals. The only statistically significant demographic variable was the presence of a woodlot, in that producers who do not have a woodlot are likely to adopt silvopasture systems. None of the opportunities were statistically significant.

Table 6: Binary logistic regression results for silvopasture.

Independent Variables	Coefficient	p-value	Sig.	VIF
Constraints				
Cost of establishing trees	-0.065	0.871		2.396
Silvopasture is unprofitable	-0.050	0.914		3.285
Marketing - lack of markets, finding markets, etc.	0.256	0.578		3.049
Long time to production (timber, nuts, etc.)	0.037	0.924		2.561
Lack of knowledge on how to manage	0.566	0.130		2.440
Amount of time or work to manage trees	0.227	0.565		2.891
Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and silvopasture	-0.087	0.878		3.929
Loss of land available for row crops or pasture	-0.150	0.734		3.568
Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)	-0.005	0.991		2.824
Soils or hydrology would not support trees	-0.231	0.603		1.841
Trees compete too much with crops	-0.895	0.043	**	3.244
Risk or uncertainty with climate change	0.358	0.457		1.830
Silvopasture does not align with my goals	-1.340	0.012	**	3.824
Opportunities				
Cost-share or financial assistance/incentive programs	0.584	0.220		2.885
Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)	-0.435	0.439		3.218
Enrolling the land in a carbon market program	0.099	0.813		2.035
Silvopasture may make an area more visually appealing	0.538	0.191		2.226
Friends or neighbors implementing silvopasture	0.164	0.739		2.164
Demographics				
Presence of woodlot	-1.527	0.091	*	1.349
Total acres	0.000	0.775		1.396
Proportion of owned acres	-0.625	0.585		1.612

Table 6 continued.

Primary income source	0.085	0.905	1.343
Age	0.018	0.613	1.759
Gender	-0.683	0.521	1.670
Highest education level	0.353	0.264	1.396
Nagelkerke R-squared	0.669		
Prediction statistics (correctly classified)	82.6%		
Number of observations used in model (n)	115		

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Alley Cropping

Table 7 demonstrates the factors influencing the adoption of alley cropping by the survey sample. The relationship between the dependent and independent variables in the binary logistic regression model for alley cropping was strong, and the model was correctly able to predict 92.7% of the cases. The only statistically significant constraint was an incompatibility between alley cropping and producers' equipment or management, in that producers whose management or equipment are incompatible with alley cropping are unlikely to adopt alley cropping.

The significant opportunities for adoption were technical assistance from a natural resource professional, the visual appeal of alley cropping, and friends and neighbors adopting alley cropping. Consistent with expectations, the opportunities demonstrate that alley cropping adoption is expected to be likely as technical assistance becomes more available and as farmers value the visual appeal of alley cropping. In contrast to expectations, the regression predicted that alley cropping adoption is also likely when friends or neighbors do not adopt alley cropping.

The demographic factors of total acres and age significantly influenced adoption likelihood. Producers who farm less acres and younger producers are expected to be likely to adopt alley cropping systems.

Table 7: Binary logistic regression results for alley cropping.

Independent Variables	Coefficient	p-value	Sig.	VIF
Constraints				
Cost of establishing trees	0.405	0.238		1.827
Alley cropping is unprofitable	0.382	0.525		4.258
Marketing - lack of markets, finding markets, etc.	-0.125	0.784		2.903
Long time to production (timber, nuts, etc.)	-0.170	0.741		3.299
Lack of knowledge on how to manage	-0.746	0.204		2.536
Amount of time or work to manage trees	-0.369	0.518		2.872
Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and alley cropping	-0.569	0.098	*	2.015
Loss of land available for row crops or pasture	-0.545	0.243		3.711
Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)	0.395	0.350		3.105
Soils or hydrology would not support trees	0.042	0.919		2.486
Trees compete too much with crops	0.121	0.784		3.856
Risk or uncertainty with climate change	0.416	0.243		2.189
Alley cropping does not align with my goals	-0.338	0.340		2.373
Opportunities				
Cost-share or financial assistance/incentive programs	-0.428	0.469		2.721
Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)	1.915	0.023	**	3.604
Enrolling the land in a carbon market program	0.227	0.534		2.030
Alley cropping may make an area more visually appealing	1.005	0.062	*	2.993
Friends or neighbors implementing alley cropping	-1.286	0.031	**	2.622
Demographics				
Total acres	-0.003	0.038	**	1.386
Proportion of owned acres	1.198	0.365		1.499
Primary income source	0.798	0.335		1.174
Age	-0.074	0.098	*	1.557
Gender	1.097	0.432		1.279
Highest education level	0.120	0.691		1.147
Nagelkerke R-squared	0.594			
Prediction statistics (correctly classified)	92.7%			
Number of observations used in model (n)	218			

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Riparian Forest Buffers

Table 8 demonstrates the factors influencing the adoption of riparian forest buffers by the survey sample. The relationship between the dependent and independent variables in the binary logistic regression model for riparian forest buffers was moderate, and the model was correctly able to predict 82.5% of the cases. Financial assistance programs, enrolling the land in a carbon market, and friends or neighbors implementing riparian forest buffers were statistically significant opportunities.

Consistent with expectations, riparian forest buffer adoption is expected to be likely as financial assistance programs are more available and when friends or neighbors implement riparian forest buffers. Contrary to expectations, the regression model predicted that riparian forest buffer adoption is also expected to be likely as producers are less likely to enroll the land in a carbon market. None of the constraints or demographic factors were statistically significant.

Table 8: Binary logistic regression results for riparian forest buffers.

Independent Variables	Coefficient	p-value	Sig.	VIF
Constraints				
Cost of establishing trees	-0.102	0.749		2.552
Riparian forest buffers are unprofitable	0.324	0.354		3.838
Marketing - lack of markets, finding markets, etc.	0.449	0.271		4.633
Long time to production (timber, nuts, etc.)	-0.317	0.384		4.133
Lack of knowledge on how to manage	-0.309	0.357		3.428
Amount of time or work to manage trees	-0.005	0.987		3.005
Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and riparian forest buffers	-0.209	0.484		2.985
Loss of land available for row crops or pasture	-0.166	0.592		4.331
Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)	-0.047	0.898		4.446
Soils or hydrology would not support trees	0.486	0.215		3.297
Trees compete too much with crops	-0.338	0.323		4.336
Risk or uncertainty with climate change	0.135	0.748		3.009
Riparian forest buffers do not align with my goals	-0.326	0.345		3.415

Table 8 continued.

Opportunities				
Cost-share or financial assistance/incentive programs	0.873	0.034	**	3.381
Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)	0.378	0.319		3.025
Enrolling the land in a carbon market program	-0.620	0.053	*	1.927
Riparian forest buffers may make an area more visually appealing	0.028	0.943		2.867
Friends or neighbors implementing riparian forest buffers	0.676	0.068	*	2.039
Demographics				
Total acres	0.000	0.383		1.517
Proportion of owned acres	0.236	0.824		1.847
Primary income source	-0.795	0.198		1.385
Age	-0.026	0.368		1.798
Gender	0.101	0.904		1.315
Highest education level	0.068	0.780		1.402
Nagelkerke R-squared	0.471			
Prediction statistics (correctly classified)	82.5%			
Number of observations used in model (n)	126			

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Forest Farming

Table 9 demonstrates the factors influencing the adoption of forest farming by the survey sample. The relationship between the dependent and independent variables in the binary logistic regression model for forest farming was moderate, and the model was correctly able to predict 81.4% of the cases. The statistically significant constraints to adoption include the incompatibility between forest farming and current equipment or management and risk or uncertainty with climate change. The only statistically significant opportunity for forest farming adoption was technical assistance.

Consistent with expectations, forest farming adoption is expected to be unlikely as the incompatibility between forest farming and current equipment or management becomes more limiting, while adoption is likely when technical assistance becomes more available. Contrary to expectations, the regression model predicted that forest farming adoption is expected to be likely when producers' risk or uncertainty with climate change becomes more limiting. The only statistically significant demographic variable is the presence of a woodlot, in that producers who possess a woodlot are likely to adopt forest farming, while producers that do not possess a woodlot are unlikely to adopt a forest farming system.

Table 9: Binary logistic regression results for forest farming.

Independent Variables	Coefficient	p-value	Sig.	VIF
Constraints				
Cost of establishing trees	0.378	0.127		2.430
Forest farming is unprofitable	0.356	0.194		3.089
Marketing - lack of markets, finding markets, etc.	-0.254	0.380		3.759
Long time to production (timber, nuts, etc.)	0.046	0.863		3.308
Lack of knowledge on how to manage	-0.117	0.703		3.358
Amount of time or work to manage trees	-0.108	0.715		2.668
Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and forest farming	-0.499	0.057	*	2.148
Loss of land available for row crops or pasture	0.010	0.971		4.037
Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)	-0.419	0.185		3.921
Soils or hydrology would not support trees	-0.174	0.518		2.950
Trees compete too much with crops	-0.053	0.837		3.676
Risk or uncertainty with climate change	0.526	0.094	*	2.744
Forest farming does not align with my goals	-0.287	0.203		2.707
Opportunities				
Cost-share or financial assistance/incentive programs	0.000	0.999		3.829
Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)	0.649	0.080	*	3.764
Enrolling the land in a carbon market program	-0.050	0.834		1.716
Forest farming may make an area more visually appealing	0.312	0.380		3.067
Friends or neighbors implementing forest farming	-0.072	0.819		2.379
Demographics				
Presence of woodlot	1.358	0.033	**	1.512
Total acres	0.000	0.595		1.332

Table 9 continued.

Proportion of owned acres	-0.393	0.608	1.541
Primary income source	-0.563	0.255	1.272
Age	-0.023	0.268	1.480
Gender	0.637	0.375	1.295
Highest education level	0.227	0.250	1.191
Nagelkerke R-squared	0.449		
Prediction statistics (correctly classified)	81.4%		
Number of observations used in model (n)	215		

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Living Snow Fences

Table 10 demonstrates the factors influencing the adoption of living snow fences by the survey sample. The relationship between the dependent and independent variables in the binary logistic regression model for living snow fences was strong, and the model was correctly able to predict 81.3% of the cases. The statistically significant constraints to adoption include the opinion that living snow fences are unprofitable, a lack of knowledge on how to manage living snow fences, the amount of time or work to manage trees, and living snow fences not aligning with producers' goals. The only statistically significant opportunity for adoption is friends or neighbors implementing living snow fences.

Consistent with expectations, living snow fence adoption is expected to be unlikely when the unprofitability of living snow fences, the amount of time or work to manage trees, and living snow fences not aligning with producers' goals becomes more limiting, while adoption is likely when friends and neighbors adopt living snow fences. Contrary to expectations, the regression model predicted that living snow fence adoption is expected to be likely when the lack of knowledge on how to manage a living snow fence becomes more limiting. Demographic factors did not affect living snow fence adoption.

Table 10: Binary logistic regression results for living snow fences.

Independent Variables	Coefficient	p-value	Sig.	VIF
Constraints				
Cost of establishing trees	0.328	0.277		2.973
Living snow fences are unprofitable	-0.505	0.079	*	4.147
Marketing - lack of markets, finding markets, etc.	-0.322	0.298		4.369
Long time to production (timber, nuts, etc.)	0.227	0.463		4.001
Lack of knowledge on how to manage	0.580	0.088	*	3.605
Amount of time or work to manage trees	-0.408	0.091	*	2.375
Incompatibility between current equipment/management (vehicles, herbicides, drainage, etc.) and living snow fences	0.163	0.480		2.959
Permanence of trees (affecting ability to sell land, plant trees while leasing land, etc.)	-0.011	0.965		3.367
Soils or hydrology would not support trees	0.183	0.518		2.792
Trees compete too much with crops	-0.072	0.767		3.160
Risk or uncertainty with climate change	-0.124	0.684		3.075
Living snow fences do not align with my goals	-0.951	<0.001	***	2.707
Opportunities				
Cost-share or financial assistance/incentive programs	0.579	0.112		2.807
Technical assistance from a natural resource professional (e.g., Extension, private agricultural consultant)	-0.529	0.111		2.831
Enrolling the land in a carbon market program	0.040	0.871		1.552
Living snow fences may make an area more visually appealing	0.333	0.426		3.998
Friends or neighbors implementing living snow fences	1.107	0.002	***	2.600
Demographics				
Total acres	0.000	0.638		1.480
Proportion of owned acres	-0.479	0.556		1.539
Primary income source	-0.532	0.291		1.406
Age	-0.035	0.182		1.611
Gender	-0.715	0.355		1.451
Highest education level	0.269	0.208		1.152
Nagelkerke R-squared	0.632			
Prediction statistics (correctly classified)	81.3%			
Number of observations used in model (n)	198			

*** Significant at $p < 0.01$ (99%); ** Significant at $p < 0.05$ (95%); * Significant at $p < 0.1$ (90%).

Frequency and Distribution of Responses

This section presents descriptive statistics, such as the proportions of responses, for each question of the survey.

Current Adoption

Figure 3 demonstrates the current adoption rate of agroforestry practices in Minnesota and Wisconsin. Of the 295 responses received, 202 respondents (68.5%) indicated that they currently have at least one agroforestry practice on the land they farm. Ninety-seven respondents (32.9%) currently have multiple agroforestry practices on the land they farm.

Windbreaks demonstrate the highest adoption rate of the six agroforestry practices studied with 58.9% of respondents indicating that they possess a windbreak on the area they farm. Riparian forest buffers exhibit the next highest adoption rate at 19.9%, followed by living snow fences at 19.1%, silvopasture at 14.6%, and forest farming at 7.3%. Alley cropping demonstrates the lowest adoption rate at 1.7%.

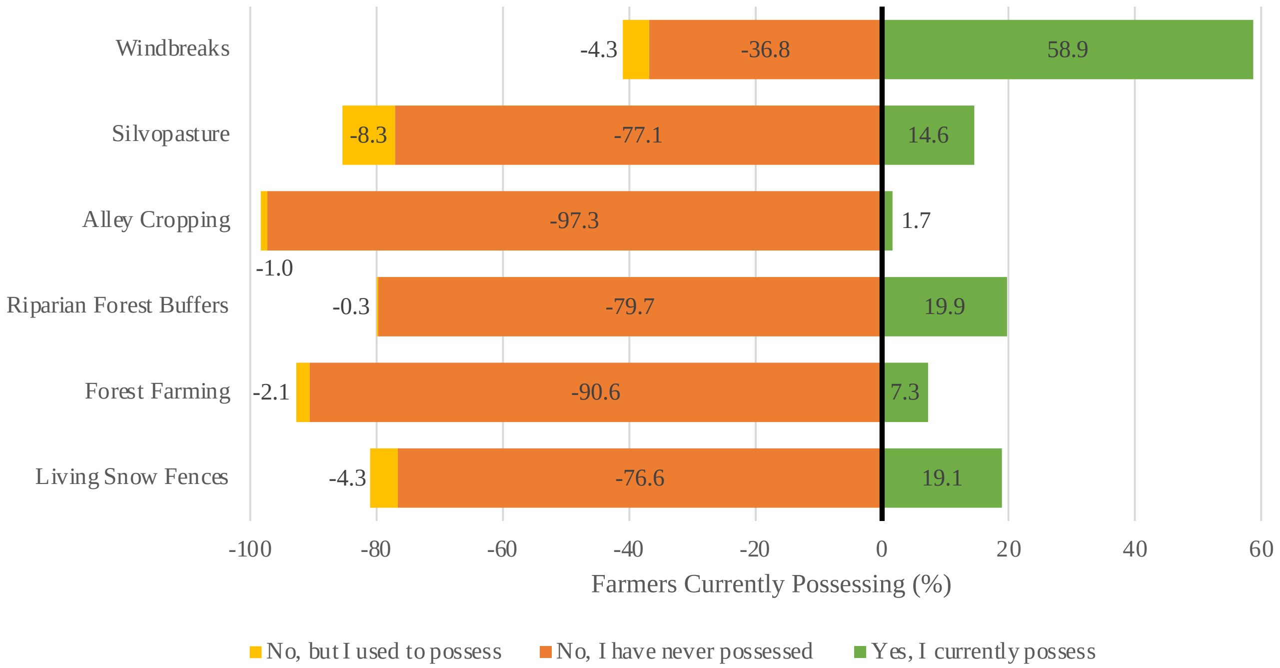

Figure 3: Current adoption of agroforestry practices in the producer sample.

Likelihood of Adoption

The frequency of the likelihood of adoption of each agroforestry practice is consistent with the current adoption of each practice (Figure 4). Windbreaks are the only practice to which respondents were more likely to consider adopting than not with 59.8% of respondents selecting that they are likely to consider adopting. Windbreaks also exhibit the highest proportion of respondents that selected “very likely” at 18.1%. Following windbreaks, 38.2% of respondents are likely to consider adopting living snow fences, 23.3% for riparian forest buffers, 21.6% for silvopasture, and 19.8% for forest farming. Alley cropping demonstrates the lowest interest with 9.5% of respondents likely to consider adopting and the highest frequency of respondents who selected “very unlikely” at 73.3%.

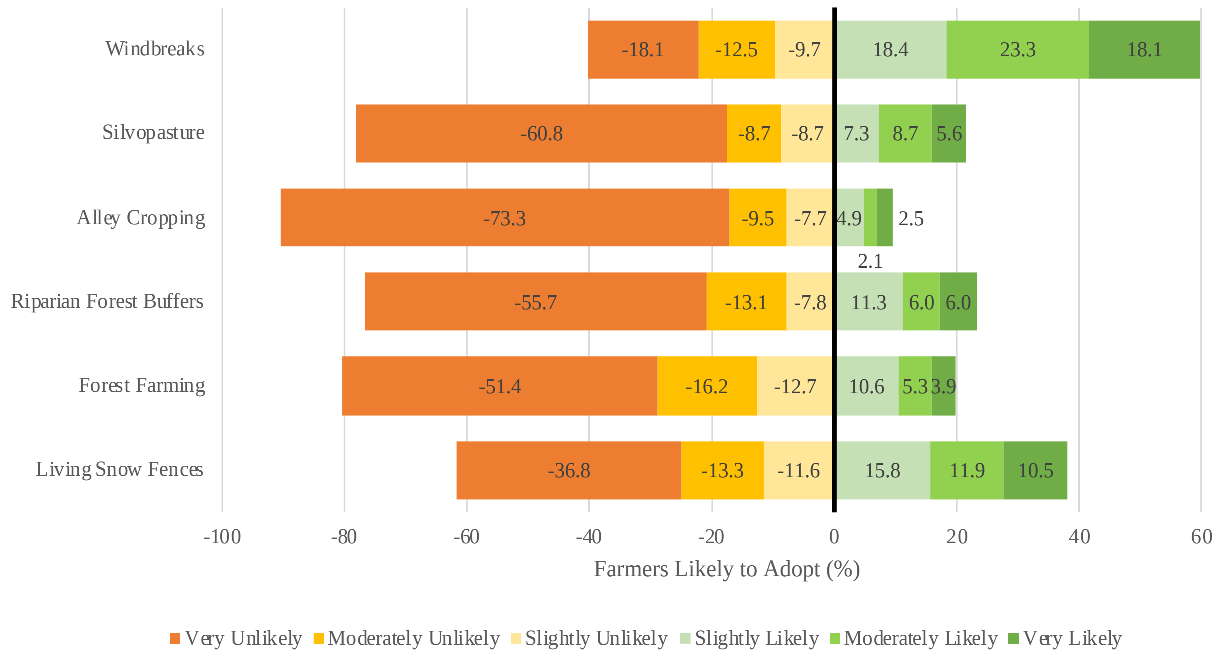

Figure 4: Farmers likely to adopt each agroforestry practice.

Constraints

Across the sample, most farmers found the cost of establishing trees, the time or work to manage trees, and the lack of labor to help manage trees as the most frequently limiting. Oppositely, risk and uncertainty with climate change was frequently cited as a less limiting constraint or not limiting at all.

Farmers found most constraints related to windbreaks more limiting than not (Figure 5). The time or work to manage trees (83.9%), the lack of labor to help manage trees (82.8%), and the cost of establishing trees (82.4%) were the most frequently cited limiting constraints in the sample. Most farmers reported that risk or uncertainty with climate change, soils and hydrology not supporting trees, and windbreaks not aligning with producers' goals were not limiting.

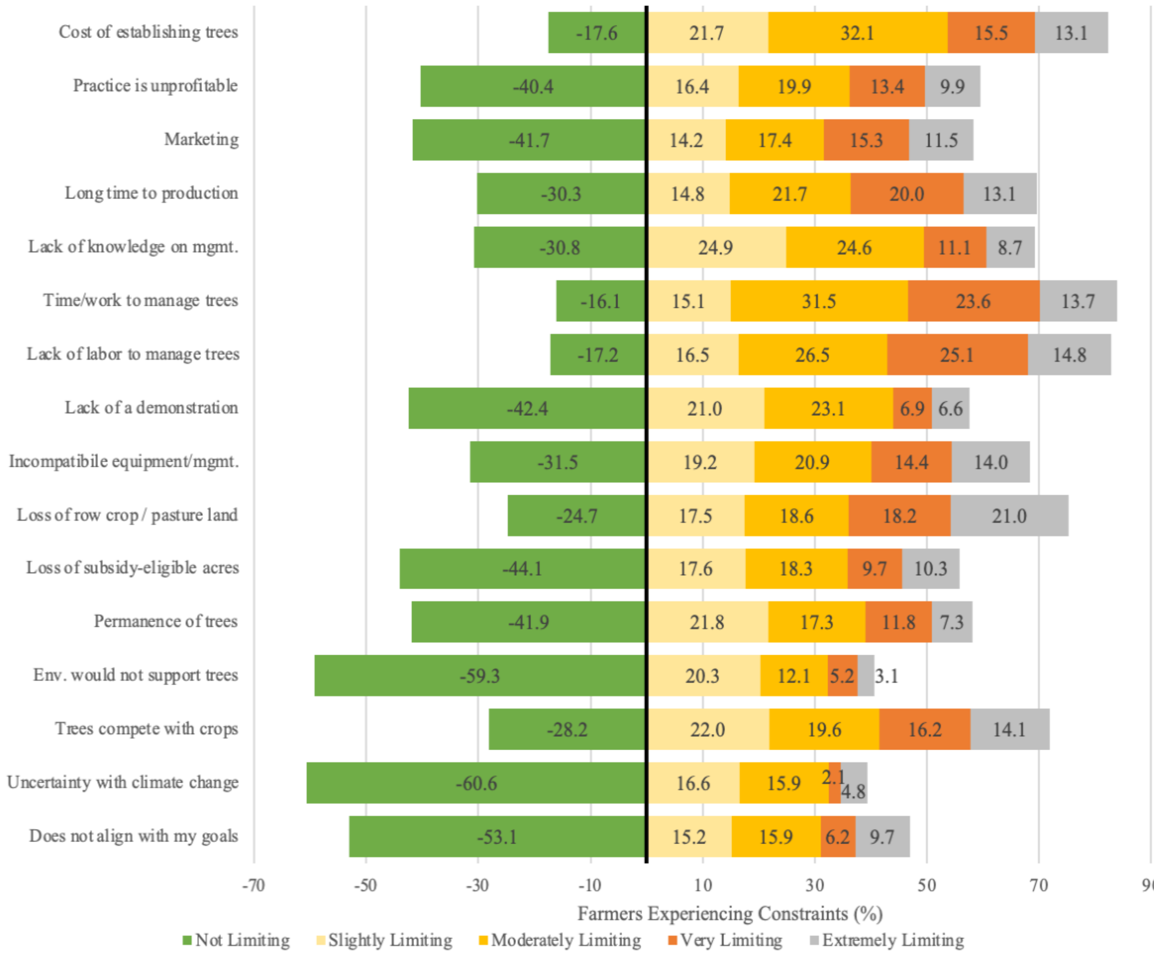

Figure 5: Farmers limited by each constraint for windbreaks.

Similarly, regarding silvopasture, most farmers only cited risk or uncertainty with climate change and soils and hydrology not supporting trees as not limiting (Figure 6). Otherwise, all other constraints related to silvopasture were some level of limiting, with the cost of establishing trees (85.1%), the lack of labor to help manage trees (84.6%), and the time or work to manage trees (84.5%) being the most frequently cited as limiting.

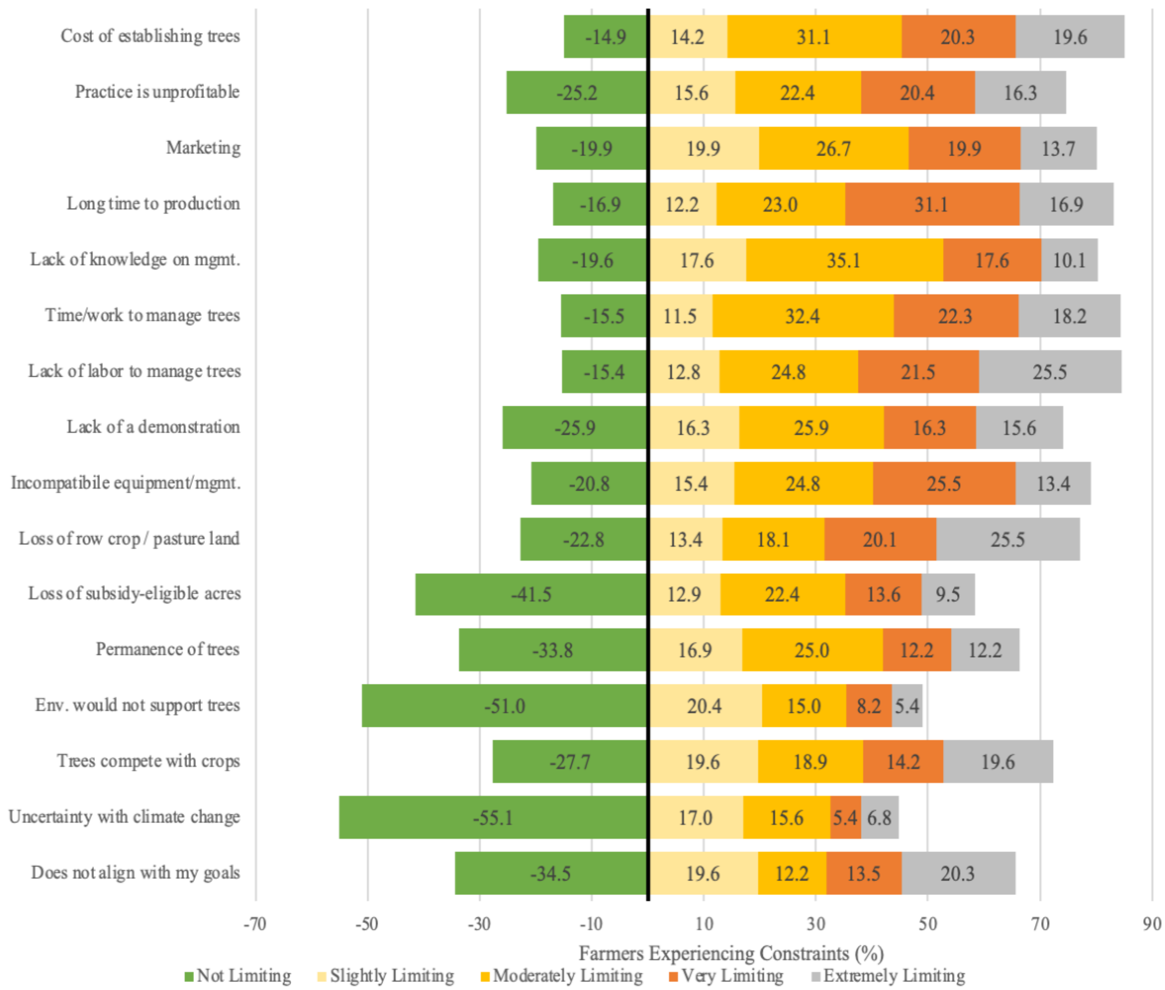

Figure 6: Farmers limited by each constraint for silvopasture.

Farmers found all constraints related to alley cropping more limiting than not (Figure 7). Most of the constraints were seen as limiting by around 90% of farmers in the sample. While still seen as limiting, risk or uncertainty with climate change and soils and hydrology not supporting trees were the least limiting.

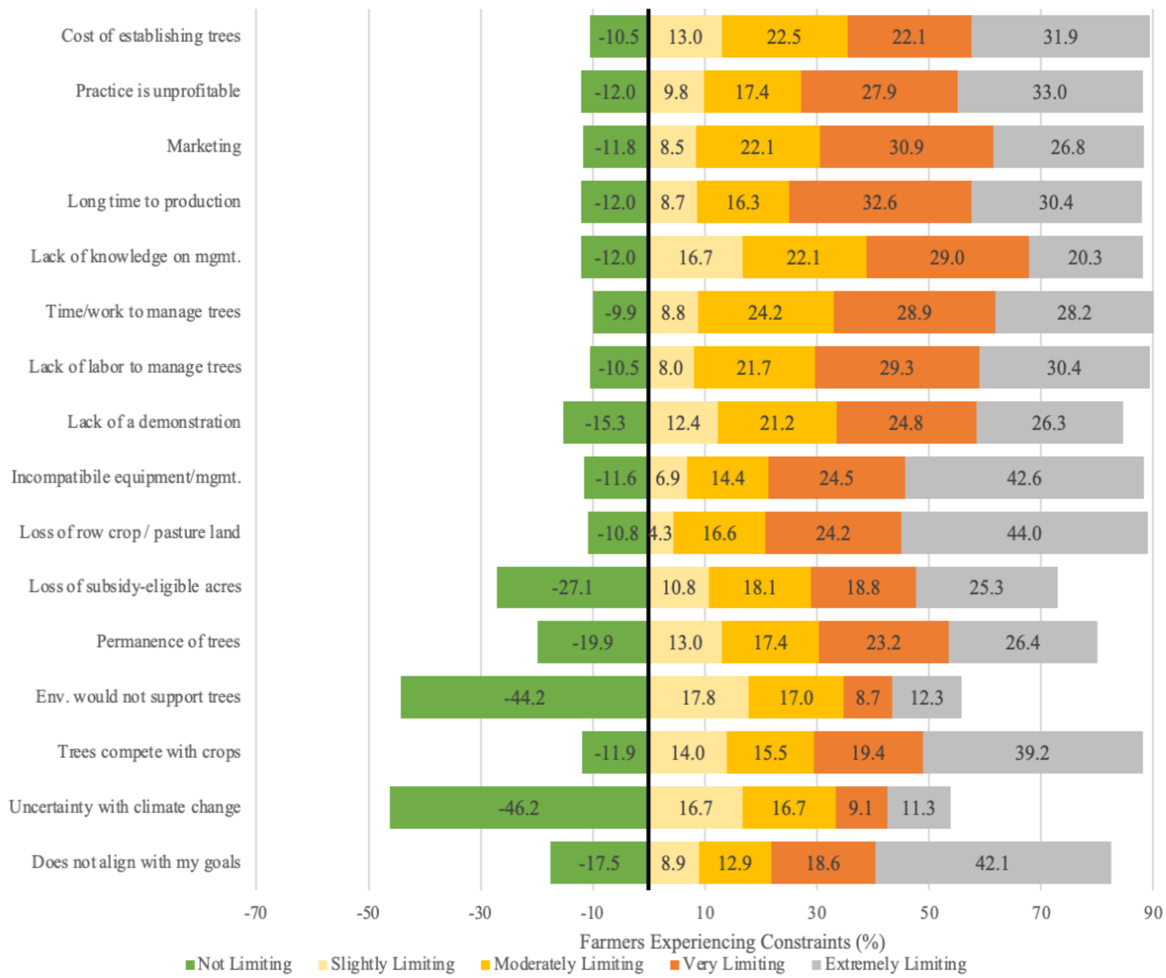

Figure 7: Farmers limited by each constraint for alley cropping.

All constraints related to riparian forest buffers were found to be some level of limiting except risk or uncertainty with climate change (Figure 8). Particularly, 88.2% of farmers found the lack of labor to help manage trees to be limiting, 87% saw the cost of establishing trees as limiting, and 86.4% reported that the time or work to manage trees was limiting.

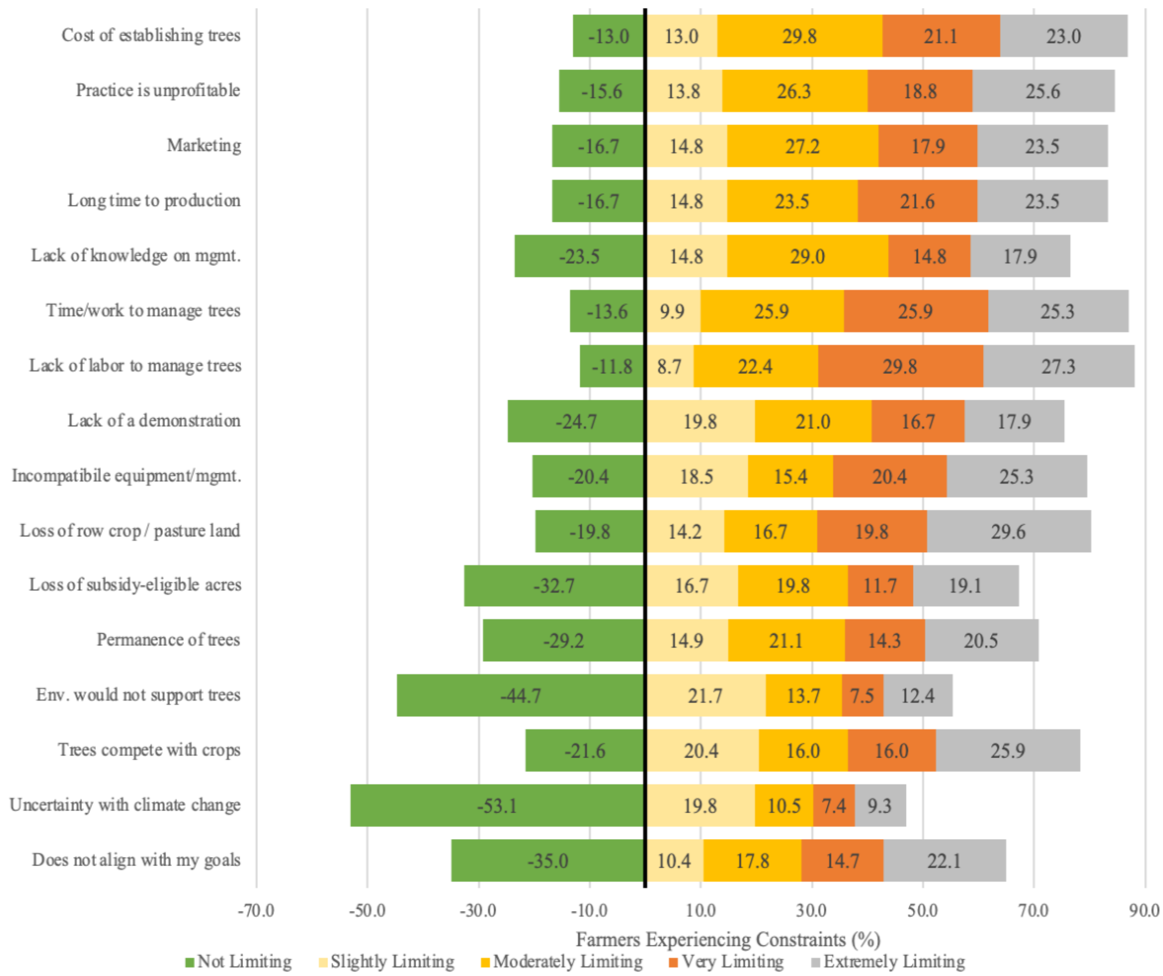

Figure 8: Farmers limited by each constraint for riparian forest buffers.

As with alley cropping, farmers considered all constraints related to forest farming to be limiting (Figure 9). Of these constraints, risk or uncertainty with climate change and soils and hydrology not supporting trees were equally the least limiting.

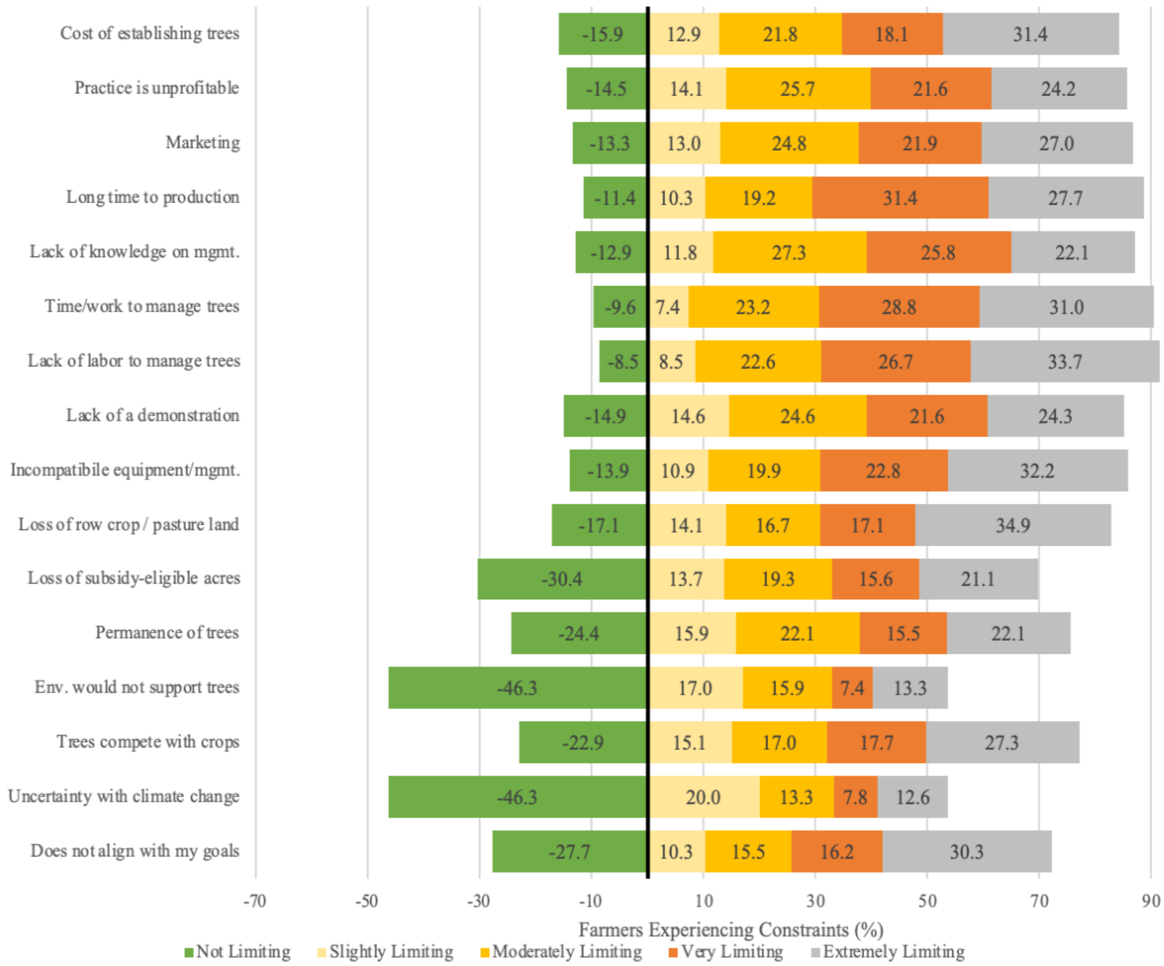

Figure 9: Farmers limited by each constraint for forest farming.

Finally, farmers reported most constraints related to living snow fences as more limiting than not except for risk or uncertainty with climate change. Additionally, farmers were equally likely to cite the environment as limiting versus not limiting (Figure 10).

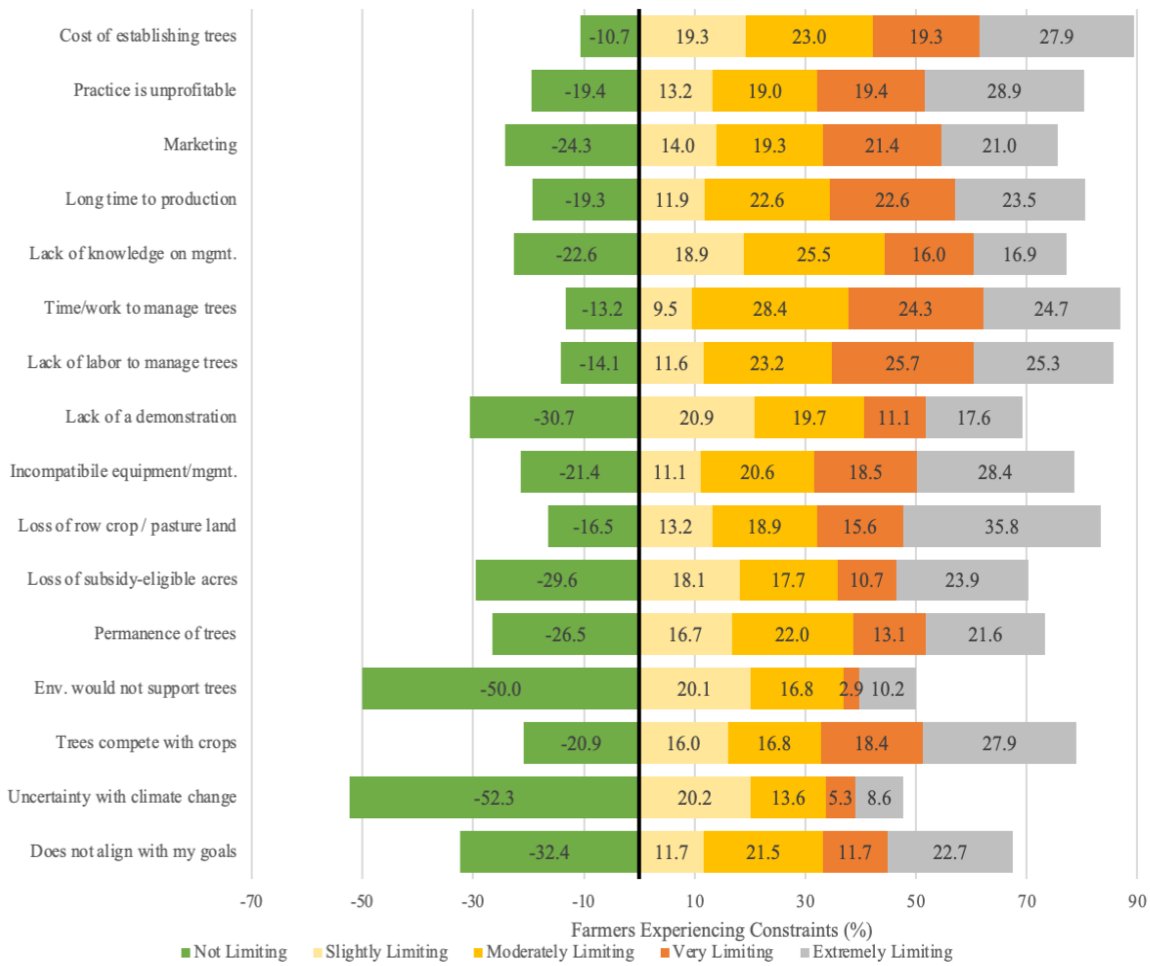

Figure 10: Farmers limited by each constraint for living snow fences.

Opportunities

Across the sample, most farmers are unlikely to consider friends and neighbors adopting as an opportunity for each practice. Oppositely, cost-share or financial assistance programs are most frequently considered most likely of the opportunities. Across the six practices, financial assistance demonstrates the highest proportion of "very likely" to accept, while friends or neighbors adopting shows the highest proportion of "very unlikely."

Farmers described that they are more likely than not to accept financial assistance, technical assistance, information about management, information benefits, real-life demonstrations, and visual aesthetics as opportunities for windbreaks (Figure 11). Most farmers are not likely to accept income diversification, information about marketing, enrolling in a carbon market, or friends or neighbors adopting as opportunities.

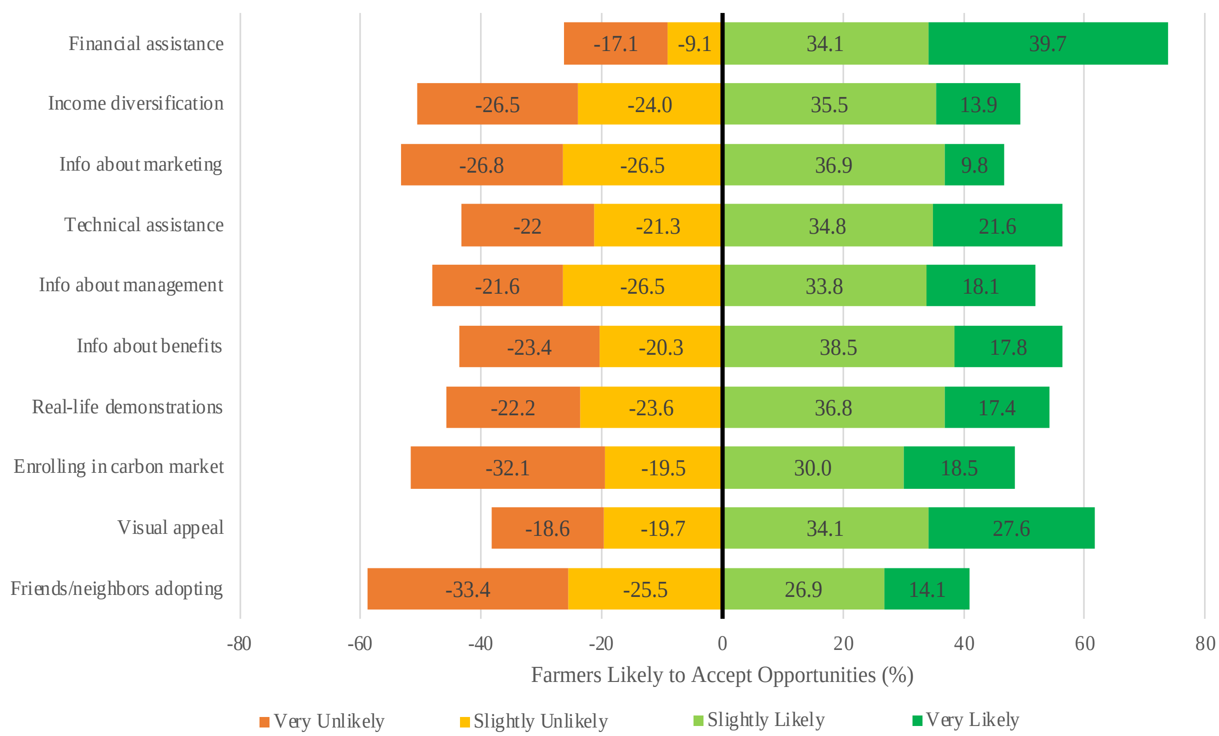

Figure 11: Farmers likely to accept opportunities for windbreaks.

Farmers are more likely than not to accept most opportunities for silvopasture, though information about management, enrolling in a carbon market, and friends or neighbors adopting were more frequently considered unlikely (Figure 12). Financial assistance was the most frequently cited as likely with 62.5% of farmers agreeing that they would accept financial assistance for silvopasture.

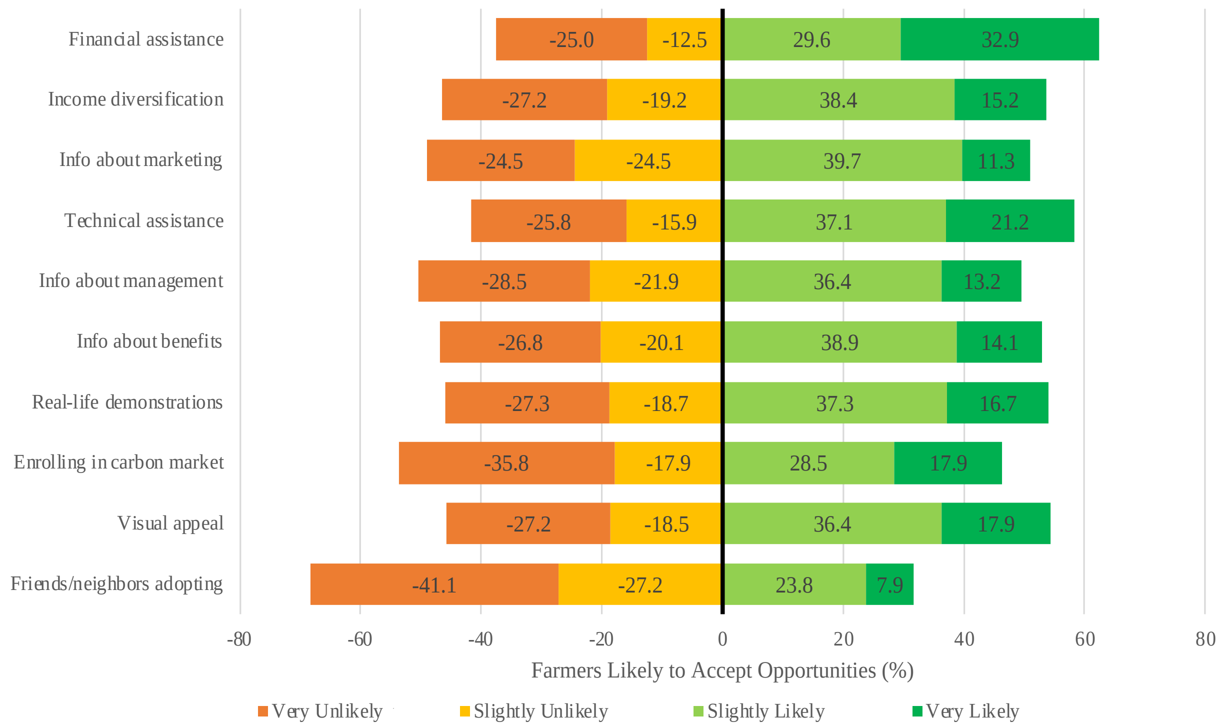

Figure 12: Farmers likely to accept opportunities for silvopasture.

As with the likelihood of adoption and constraints, farmers reinforced negative attitudes toward alley cropping, with most farmers demonstrating that they are unlikely to accept all of the opportunities related to alley cropping (Figure 13). Of these, financial assistance is most frequently cited as the least unlikely, followed by technical assistance.

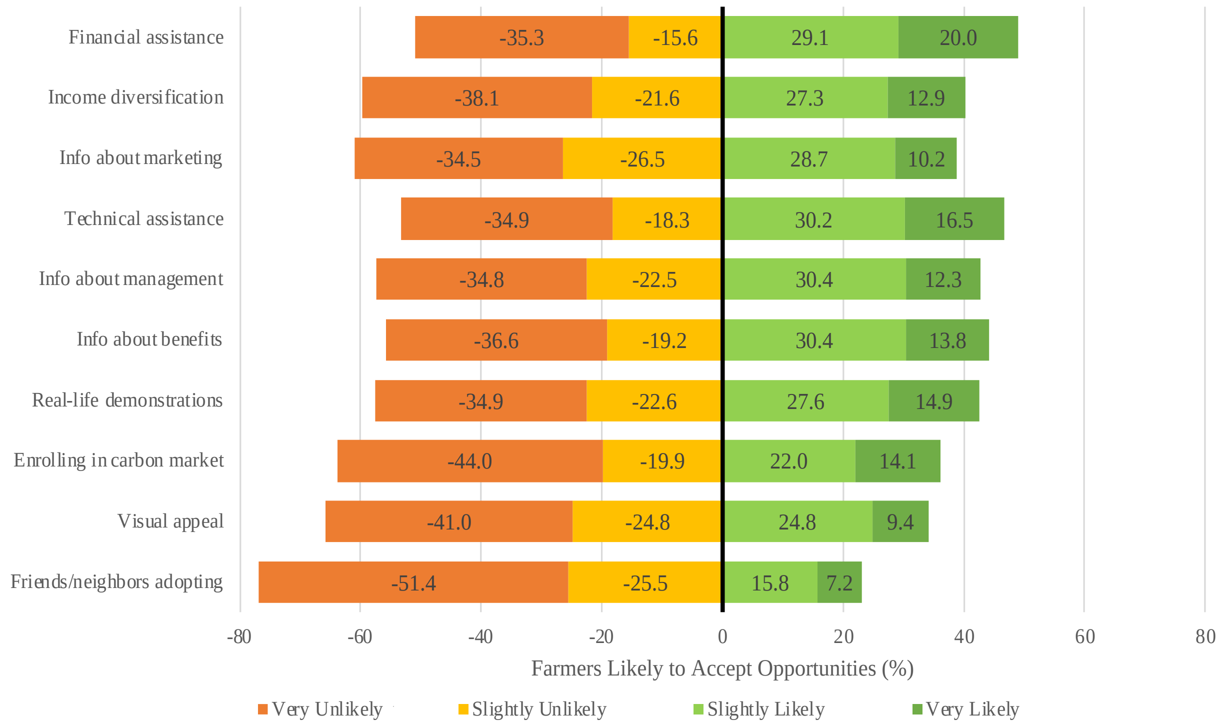

Figure 13: Farmers likely to accept opportunities for alley cropping.

For riparian forest buffers, 64% and 50.3% of farmers were likely to accept financial assistance and technical assistance, respectively (Figure 14). However, farmers were unlikely to accept all other opportunities.

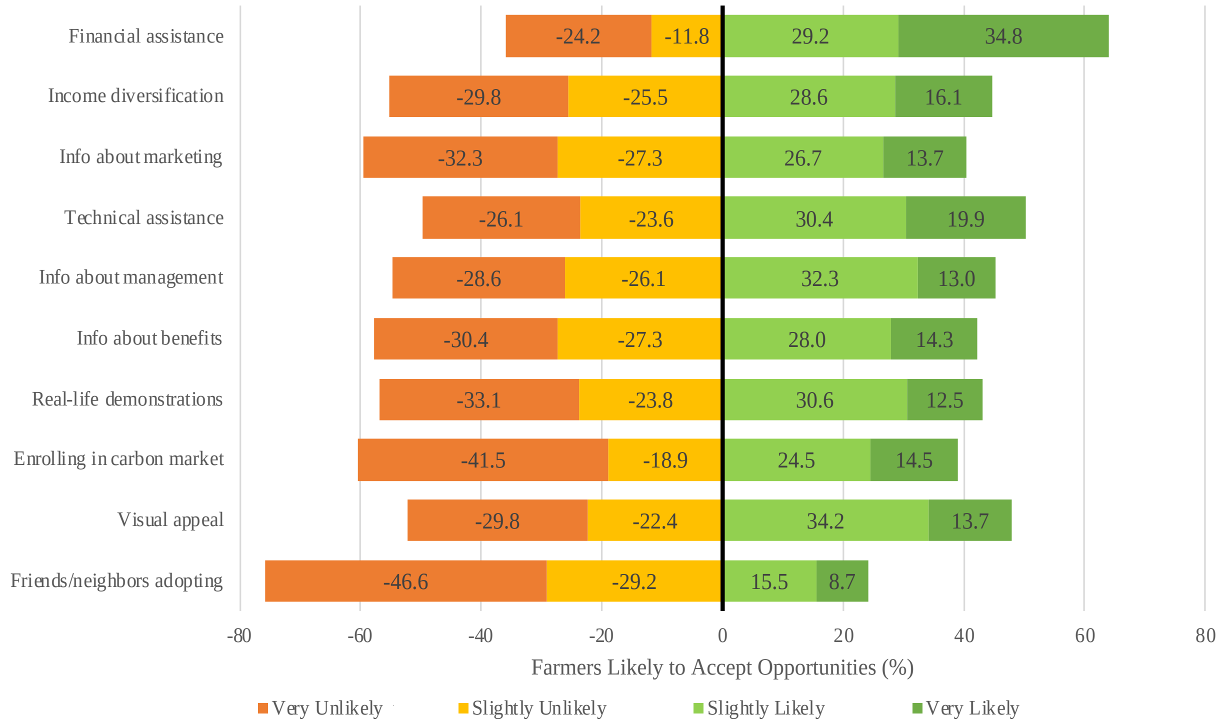

Figure 14: Farmers likely to accept opportunities for riparian forest buffers.

Forest farming demonstrates very similar results to riparian forest buffers. Most farmers were more likely than not to accept financial assistance followed by technical assistance and were unlikely to accept the remaining opportunities (Figure 15).

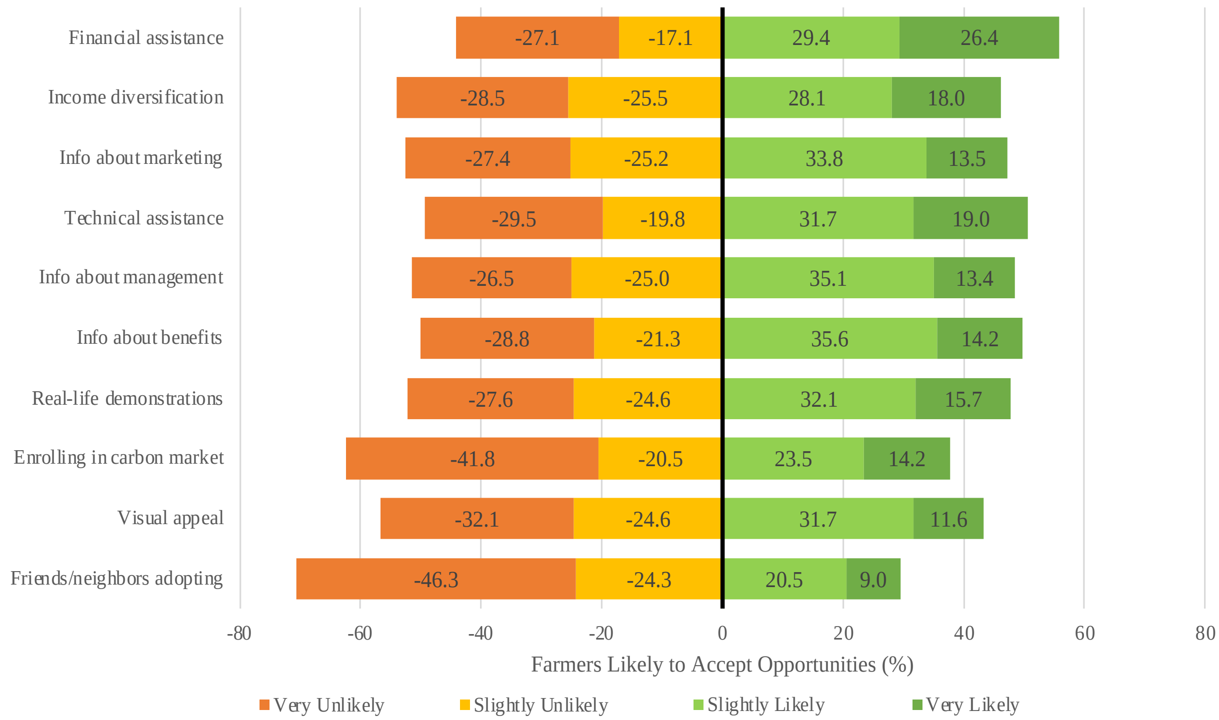

Figure 15: Farmers likely to accept opportunities for forest farming.

Most farmers are unlikely to accept many opportunities for living snow fences (Figure 16). However, 68.1%, 53.5%, and 50.2% of farmers are likely to accept financial assistance, technical assistance, and information about management, respectively.

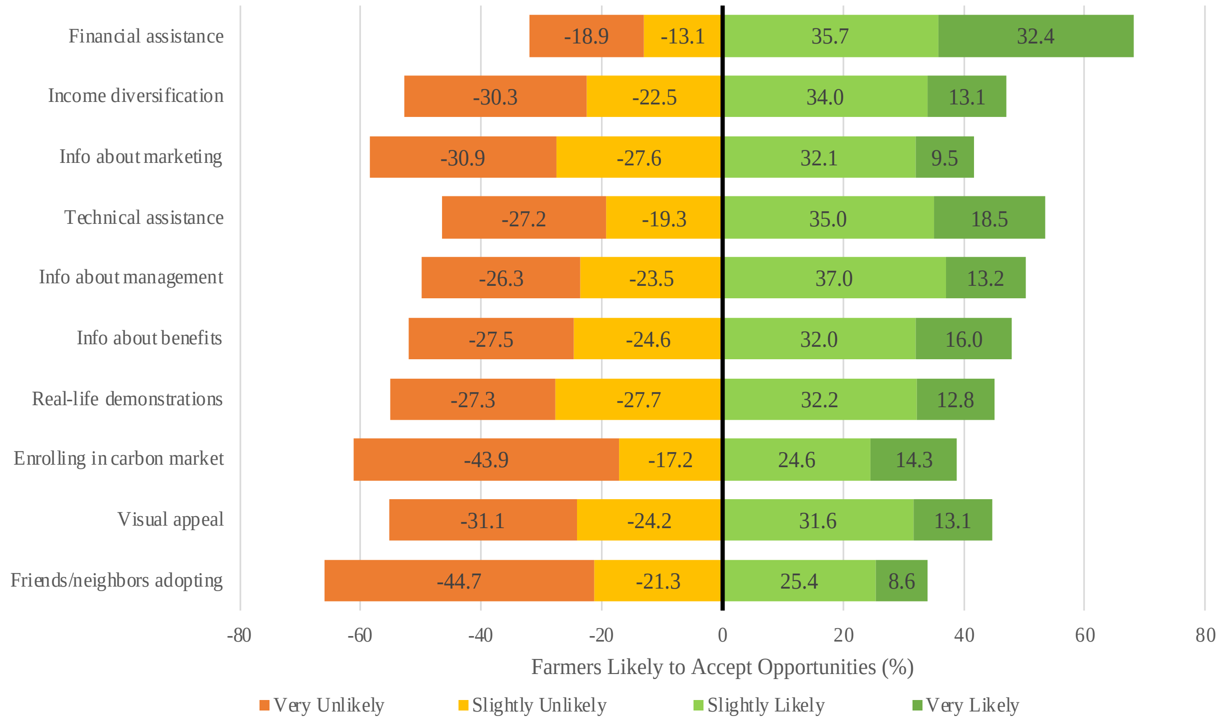

Figure 16: Farmers likely to accept opportunities for living snow fences.

Information Preference

Figure 17 demonstrates respondents' preferences for receiving information regarding agricultural practices. Overall, farmers primarily prefer to consult a natural resource professional (83%), followed by asking another farmer (82.3%) and visiting a website (79.7%). Visiting a website demonstrated the highest number of farmers selecting "very preferred," with 40.2% of respondents indicating they most prefer receiving information by visiting a website. Joining an online webinar was the least preferred source of information by farmers with 43.4% of respondents indicating they did not prefer to receive agricultural information through webinars.

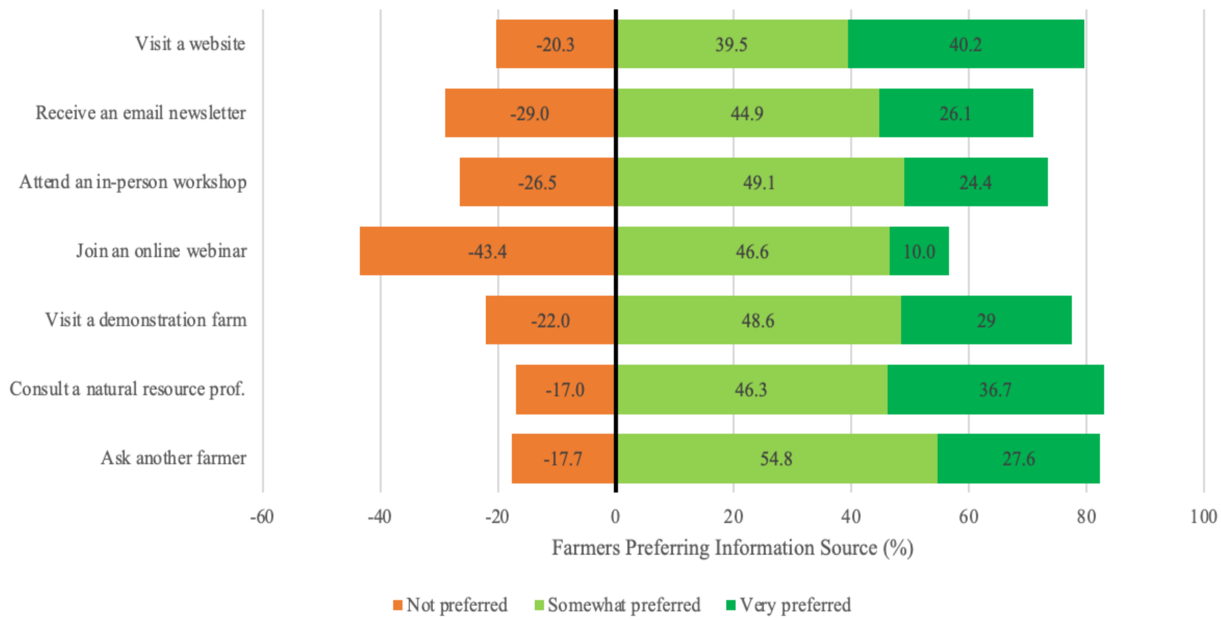

Figure 17: Farmer preferences for receiving information on agricultural practices.

DISCUSSION

Sample Demographics

The sample included in this study and the U.S. Census of Agriculture data for Minnesota and Wisconsin demonstrate an almost identical distribution in producer race, with about 99% of producers self-reporting as white. This sample demonstrates an average of slightly older individuals (64.2 years versus 56.9 years) and a significantly higher proportion of male farmers (86.4% versus 66.8%). Finally, the average farm size in this sample (781 acres) is over double the Minnesota and Wisconsin average (312 acres). These comparisons indicate that our study sample significantly under-represents female farmers and smaller farms.

The misalignment related to farm size may be the result of differences in survey methodologies. While the U.S. Census of Agriculture is sent to all U.S. farms regardless of geography (NASS 2024), mailings for this study were weighted proportionate by county, such that surveys were concentrated in counties with more farms. More farms operate in the southern regions of Minnesota and Wisconsin, and farms in these areas tend to be larger (NASS 2024). As such, the survey design for this study may have facilitated a larger average farm size than the U.S. Census of Agriculture. When using the results to inform agroforestry outreach with smaller farms across Minnesota and Wisconsin, natural resource professionals should be careful to verify small farms' alignment with the results presented here.

The comparison between the two survey wave populations demonstrates that the second survey wave has a significantly higher proportion of large farms, male farmers, white farmers, and non-Hispanic farmers. The difference in farm size and gender may indicate non-response bias in the first survey wave that was eliminated by sending a second wave. Considering that the proportion of non-white farmers in Minnesota and Wisconsin is very low, the significant difference in farmer race between the waves is most likely the result of farmers of color happening to respond in the first wave as opposed to the second, which had an outsized impact when included in the T-test. As a result, the difference in race is most likely insubstantial and not a consequence of non-response bias.

Factors Influencing Adoption

Few of the demographic variables were statistically significant for any of the agroforestry practices. Only alley cropping was influenced by age and farm size, with younger farmers likely to adopt being consistent with previous research (Dorr 2006; Matthews at al. 1993), though no previous studies have found that smaller farm sizes are likely to adopt alley cropping systems. Furthermore, silvopasture and forest farming were influenced by the presence of a woodlot on the farm, which is also consistent with previous silovpasture (Wilkens et al. 2022b) and forest farming (Dorr 2006; Valdivia and Poulos 2009) research.

Other agroforestry studies have found that more demographic variables, including education and income, influence agroforestry adoption patterns (Mattia et al. 2018; Rois-Díaz et al. 2018; Stubblefield 2021). In most cases in the present study, attitudinal data related to perceived constraints and opportunities comprised most of the factors significantly influencing adoption of each practice. Other studies have demonstrated the importance and utility of attitudinal data as opposed to farm and producer characteristics to inform the adoption of agricultural conservation practices (Pradhananga and Davenport 2019). Ultimately, different groups of farmers hold different opinions, perceptions, and values related to agroforestry practices (Barbieri and Valdivia 2009; Mattia et al. 2018; Wilkens et al. 2022a). As such, demographic factors not commonly influencing adoption may reinforce that farmers are a diverse community with variable preferences that are not dependent on their personal characteristics.

Many of the significant predictors of adoption aligned with the expectation that adoption likelihood increases as constraints become less limiting and producers become more likely to accept opportunities. Agroforestry practices not aligning with producers' goals was found to be a significant constraint to windbreak, silvopasture, and living snow fence adoption. While no studies found a similar pattern for windbreaks or silvopasture, Wyatt and colleagues (2012) proposed that a misalignment with producers' goals may limit adoption of living snow fences. This misalignment presents a unique challenge to natural resource professionals, who must work with farmers to design windbreaks, silvopastures. and living snow fences that align with producers' goals or shift producers' perspectives to demonstrate how these practices may already align with their goals.

The incompatibility with equipment or management was a significant constraint to alley cropping and forest farming adoption. While multiple studies have demonstrated that this incompatibility is a barrier to alley cropping (Borremans et al. 2016; Frey 2009; Mary et al. 1998), no known studies have identified this constraint specifically for forest farming, though adopters of forest farming in the interviews described the difficulty in accessing specialty equipment.

Other constraints that decrease the likelihood of living snow fence adoption include the amount of time or work to manage trees and the belief that living snow fences are unprofitable. Previous studies have found tree maintenance to constrain living snow fence adoption (Qi et al. 2020; Wyatt et al. 2012). No known studies have found unprofitability of living snow fences to be a constraint, and research has instead focused on reducing establishment costs through state programs (Baral et al. 2023; Qi et al. 2020), though selecting species that provide profit opportunities is a potential opportunity for living snow fences (Current et al. 2017).

Finally, silvopasture is also constrained by potential competition between trees and crops. While no known studies have explicitly found this same result, Mayerfield and colleagues (2016; 2023) have previously described the potential for silvopasture systems to facilitate damage to trees and soil as a constraint to its adoption, and other practices have been confirmed to be constrained by potential competition between trees and crops (Borremans et al. 2016; Mary et al. 1998; Gi et al. 2020). This finding highlights the need for technical assistance related to nutrient management or species selection to minimize competition in silvopasture systems.

Many opportunities also followed expected trends. Technical assistance for alley cropping and forest farming are likely to increase adoption of those practices. This finding is consistent with previous research in Missouri, in which interest in these practices was correlated with advice from natural resource professionals (Dorr 2006).

Financial assistance programs were found to be likely to increase adoption of windbreaks and riparian forest buffers. This finding is consistent with other studies demonstrating that financial assistance is an important adoption incentive for riparian forest buffers (Lynch and Brown 2000; Matthews et al. 1993; Rhodes et al. 2018; Skelton et al. 2005). While no studies have shown a similar pattern for windbreaks, the cost of establishment and maintenance of windbreaks is a barrier to their adoption (Brodt et al. 2009; Tyndall 2009). These practices are also among the most currently adopted and most likely to be adopted, indicating that producers may have already taken advantage of financial assistance programs to adopt these practices, and improving or publicizing these programs may further enhance adoption.

Aesthetics and visual appeal is a significant opportunity for windbreak and alley cropping adoption. While Brodt and colleagues (2009) found that farmers realize benefits from the visual appeal of windbreaks, no studies have found this to impact windbreak adoption. Meanwhile, interest in landscape aesthetics may directly encourage adoption of alley cropping (Laroche et al. 2019). Farmers have found illustrated scenes of multifunctional windbreaks on field edges to be more desirable than scenes solely of open fields (Kronenberg 2022), which is consistent with our results that farmers may be incentivized to adopt these practices because of their visual appeal.

Finally, adoption by fellow farmers is expected to encourage the adoption of riparian forest buffers and living snow fences. This finding is consistent with a robust field of literature demonstrating that adopters of agricultural conservation practices can be change agents, promoting further adoption of these practices within their communities (Abdulai et al. 2021; Díaz-José et al. 2015; Nyantakyi-Frimpong et al. 2019). No previous known studies have demonstrated a similar farmer-to-farmer network effect on riparian forest buffer and living snow fence adoption, though a farmer adopting a windbreak may promote further diffusion of windbreak adoption (Brodt et al. 2009).

Some constraints and opportunities that were found to be significant are the opposite of the expected regression results. We expected that adoption was likely as constraints became less limiting and opportunities became more available. However, the regression model predicted that windbreak adoption is likely as the amount of time or work to manage trees and the competition between trees and crops becomes more limiting, not less. Similar patterns were found for forest farming and living snow fences regarding risk or uncertainty with climate change and a lack of knowledge of management, respectively. For the opportunities, the model predicted that alley cropping and riparian forest buffer adoption is likely when friends and neighbors do not adopt alley cropping and when farmers are not interested in enrolling riparian forest buffers in carbon markets. These constraint and opportunity findings are unusual and counterintuitive.

The counterintuitive constraint results may indicate perseverance, in that despite experiencing constraints such as competition and climate change, producers remain interested in adopting agroforestry practices. Additionally, the unusual opportunity result for alley cropping may be the result of familiarity, in that a producer who has a neighbor that practices alley cropping may decide not to pursue its adoption once learning of it and its challenges from their neighbor. The unusual opportunity result for riparian forest buffers may indicate a dislike of carbon market programs, in that a producer who may want to pursue a riparian forest buffer is not incentivized by or does not wish to participate in a carbon market program.

Frequency and Distribution of Responses

The adoption rate of 68.5% of farmers reporting that they have at least one of the six agroforestry practices is significantly higher than the U.S. Census of Agriculture's finding of 1.9% between Minnesota and Wisconsin (NASS 2024). The discrepancy may be due to a number of factors. First, the 2022 U.S. Census of Agriculture did not specify living snow fences, while the present study separated living snow fences from windbreaks, potentially garnering more responses from farmers who practice living snow fences. Second, the U.S. Census of Agriculture did not include a description or illustration of the agroforestry practices, while the present study included these resources to differentiate and define the practices to inform farmers' responses. A lack of description in the Census of Agriculture may have caused confusion among adopters, and the description and illustration in this study may have resulted in more farmers being able to identify the land use practices in which they participate. Finally, the discrepancy in current adoption may again be the result of survey mailing methodology. In the present study, there is a higher proportion of southern counties compared to northern counties, and the lack of natural forest cover in these prairie counties may necessitate the adoption of windbreaks. As such, windbreaks and living snow fences may be over-represented in this sample, culminating in a high adoption rate for these practices. The 68.5% adoption rate found here aligns more closely with other studies conducted in the lower Midwest (Fregene 2007; Stubblefield 2021; Valdivia et al. 2012), though ours is still twice as high.

Few other studies have measured likelihood to adopt agroforestry practices. Beer and Theuvsen (2020) found that 7% of German farmers included in a survey were interested in adopting alley cropping, which is similar to our finding of 9.5% of producers likely to consider alley cropping adoption. Opdenbosch and Hansson (2023) found that 52% of Swedish farmers in a survey were willing to adopt silvopasture, which is more than double our finding of 21.6%.

Most other studies focus on interest in these practices and learning about them as opposed to willingness or likelihood to consider adoption. Yet, our distribution in adoption likelihood is generally consistent with other studies tracking interest. Dorr (2006) similarly found interest in windbreaks to be highest and interest in alley cropping to be lowest, and the proportion of farmers interested in the practices are very similar to our data. An exception is windbreaks, in which the proportion of farmers likely to adopt windbreaks in this research is double the proportion of farmers interested in windbreaks in Dorr's (2006) survey in Missouri.

The high likelihood of adoption of windbreaks is consistent with their high adoption rate, indicating that producers may be willing to adopt and expand windbreaks because they are familiar. Producers have preferred practices that are less disruptive (Baral et al. 2023), and by being placed along edges of fields and pastures, windbreaks also may be more compatible with the current farming method than other practices, such as alley cropping. Additionally, unlike other practices which increase in adoption potential as farm size decreases, windbreak adoption has been correlated with larger parcel sizes (Matthews et al. 1993). Considering that our sample over-represents larger farms compared to the typical Minnesota and Wisconsin farm, this may help explain why the adoption likelihood of windbreaks is not only the highest, but also the only practice with more farmers likely to adopt than not.

CONCLUSION

Agroforestry practices can conserve natural resources in agricultural landscapes while economically and socially benefitting the communities that work and live there. This research takes a holistic approach to identify practical, promising, and farmer-informed recommendations that natural resource technical assistance providers and policymakers can use to promote agroforestry adoption among Minnesota and Wisconsin producers.

Specifically, natural resource professionals could connect farmers to or develop financial assistance programs to enhance the adoption of windbreaks and riparian forest buffers. Providing and strengthening technical assistance programs for alley cropping and forest farming is likely to increase adoption of those practices. Centering the ability of agroforestry practices to beautify an area may enhance windbreak and alley cropping adoption. Collaborating with farmers to identify how windbreaks, silvopasture, and living snow fences may help them achieve their goals can promote adoption. Facilitating connections between adopters and non-adopters is likely to increase riparian forest buffer and living snow fence adoption. Directing producers to specialty equipment for alley cropping and forest farming, recommending profitable species for living snow fences, and employing management techniques to minimize competition in silvopastures can enhance adoption of those practices. By pursuing these avenues to remove barriers and enhance incentives for the adoption of agroforestry practices, natural resource professionals would be improving farmland natural resources and invigorating farming communities in Minnesota and Wisconsin.

It is critical that agroforestry outreach efforts with farmers distinguish between agroforestry practices. The practice-specific approach taken in this study was validated by differences between constraints and opportunities for each practice. For example, the regression results demonstrate that the effect of the constraints and opportunities on adoption likelihood varies widely between practices, and the descriptive statistics results indicate that producers experience constraints and opportunities at different magnitudes for each practice. There is variability in attitudes toward practices, so lumping practices together as agroforestry, broadly defined, loses accuracy when applying the information.

In addition to our practice-specific approach, another contribution of this research is its holism. Many previous agroforestry adoption studies have focused on a single practice over a large geographic area (Smith et al. 2021) or multiple practices in a few counties (Dorr 2006). This research covers all six farmland agroforestry practices on a relatively large scale, encompassing two Midwest states. Additionally, we include many possible constraints and opportunities to adoption experienced by farmers and allow regression modeling to identify the few major predictors per practice.

Further research should pursue areas in which this study was limited. Particularly, we do not consider the products gained from adopting agroforestry practices. For example, we do not analyze motivations regarding whether an agroforestry practice would be created using trees with harvestable products, such as wood or nuts, or trees solely for environmental purposes, regardless of the species. This information is important for farmers' adoption preferences and may influence adoption likelihood (Kronenberg 2022; Wilkens et al. 2022b). Future studies should also work to receive a higher response rate or a larger sample size. Doing so for the present study may have improved accuracy in the regression models and resulted in a more representative survey sample.

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