Silvopasture: integrating livestock in land restoration and reforestation

By

Keefe O. Keeley

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The dissertation is approved by the following members of the Final Oral Committee:
Stephen J. Ventura, Professor, Soil Science & Environmental Studies
John A. Harrington, Professor, Landscape Architecture
Randall D. Jackson, Professor, Agronomy
Adena R. Rissman, Associate Professor, Forest & Wildlife Ecology
Valentín D. Picasso Risso, Assistant Professor, Agronomy

Abstract

This dissertation describes a research program investigating ecological processes, appropriate management practices, and social dynamics at play in silvopasture. Specifically, we examined applications of silvopasture in oak ecosystems, which in the eastern US generally lack disturbance needed for their persistence, as well as in reforestation of open pastureland, which represents a globally important carbon sequestration strategy. We also studied knowledge exchange and land tenure as key factors for adoption of silvopasture.

In *Silvopasture establishment shifts plant community and soil properties in oak woodlands in the Driftless Area of the Midwest USA*, we tested the influence of tree and shrub canopy thinning, forage establishment, and rotational grazing on environmental outcomes in on-farm experiments in Crawford County, Wisconsin. Grazing reduced shrub cover only where initial thinning occurred and more so with native than introduced shrub species. Planting agricultural forages reduced floristic diversity but did not increase forage quality. Grazing increased soil exposure and compaction in the upper 10 cm of the soil; the former effect was moderated by canopy thinning. Impacts of grazing and vegetation management on soil microbial community composition were mixed.

Protecting seedling trees and managing competing vegetation in silvopasture establishment presents research conducted with four farmers adapting silvopasture practices on their land. Our experimental trials tested the efficacy of various methods for establishing trees in pastures with various livestock. Tube protectors with electrified fencing generally worked best.

Evolving conceptions of silvopasture among farmers and natural resource professionals in the US Midwest examines how outreach and education about the principles and practices of silvopasture accompanied changes in perception about it. Our findings highlighted that interest in silvopasture has grown through local communities of practice that exchange information about management strategies appropriate to the complex, long-term, and context-dependent nature of silvopasture.

Multi-party agroforestry: emergent approaches to trees and tenure on farms in the Midwest USA, documents innovations to address land access as a major social barrier to wider application of silvopasture and sustainable agriculture generally. We describe cases of landowners, operators, and investors cooperatively adapting various land access and tenure arrangements through shared objectives, intensive planning, and ongoing coordination.

Dedication

To Rob Horwich, who helped me see that if people are the problem, they are also the solution.

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Thanks to the land and all its inhabitants and caretakers past and present. It is a privilege, though not a simple one, to work in the traditional lands of Ho Chunk and other native people, and to work on problems directly linked to land use changes tied to their removal from the land.

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Introduction

Ecological intensification of agriculture hinges on adapting ecosystem functions in lieu of external inputs. Simultaneously, ecological intensification aims to broaden the scope of human needs provided by agricultural landscapes. Beyond provisioning food, fiber and fuel, ecological intensification entails designing and managing agroecosystems to limit erosion, regulate water flow, sequester carbon, cycle nutrients, harbor wildlife, offer cultural values, and provide society with other benefits. To what degree these benefits are provided, viability of farm enterprises, the resilience of the underlying functions to perturbation, and comparisons to alternative land-uses are key questions in evaluating approaches to ecological intensification.

Management-intensive rotational grazing (MIRG) systems exemplify ecological intensification: rather than using myriad external inputs to raise and harvest feed for confined livestock, MIRG systems aim to provide feed and welfare needs of livestock through management of herd and pasture ecosystem. A growing body of literature has also evaluated favorably the ecosystem services provided by MIRG systems relative to other land uses.

Still, lacunae remain in understanding the contexts within which MIRG can meet objectives of individual farmers and other stakeholders. One such area of inquiry involves livestock impacts on native and undesirable vegetation. Historically, livestock overgrazing has had widespread negative impacts on prairie, savanna, and forest flora in the Midwest. However, recent investigations have demonstrated that prescribed grazing can play a role in the restoration and maintenance of floristic diversity in grasslands and savannas, as well as enhancing other ecosystem services. To what degree livestock can be used successfully for these purposes in other plant communities, specifically those with different levels of mature tree cover, remains largely untested.

With some important exceptions, however, restoring native species assemblages are typically not core objectives of MIRG systems. Rather, in most applications, introduced species (and select native species adapted for agricultural purposes) fill complementary niches in mimetic approximations of the structure and function of reference ecosystems. While tallgrass prairie is generally the reference ecosystem for MIRG, graziers and other stakeholders also have interest in oak savanna for ecomimetic adaptation, for several reasons:

> *Shade and shelter*: pasture tree canopies can provide dispersed shade to livestock to reduce heat stress in summer, as well as shelter from wind chill for out-wintered animals.
>
> *Supplemental production*: timber, various non-timber forest products, and additional foliage and mast forage add potential benefit.
>
> *Financial advantage*: Adding existing woodland to pasture acreage can be less expensive than leasing or buying new land, and in some cases changing land use to agriculture can confer reductions in property taxes.
>
> *Landscape appropriateness*: Historically savannas were common throughout the Midwest, indicating fit for climatic and edaphic conditions.
>
> *Use appropriateness*: Savanna plant species and their domestic analogs are adapted to intermediate levels of disturbance, including impacts of human uses such as fire and herbivores attracted to regrowth following fire.
>
> *Personal aesthetics and land ethics*: Other interests in savanna ecomimicry in MIRG systems stem from intentions to improve wildlife habitat, hunting and recreational uses, oak regeneration, invasive shrub control, landscape beauty, and traditional ecological knowledge.

Given the general need for ecological intensification of agriculture and the specific interests in adapting oak savanna structure and function to add overstory tree components to MIRG systems in the Upper Mississippi region of the USA, this dissertation describes a research program on *silvopasture*, a framework for the integration of trees with forage and livestock components of agroecosystems. While more common in other parts of the world, applications of silvopasture in this region's contexts have received limited scientific attention. As such, this set of studies aims to advance understanding of relevant ecological processes, appropriate management practices, and dynamics of diffusion and adoption of silvopasture.

The dissertation is organized in four parts, outlined briefly below. A prior version of chapter three was included as a chapter in the dissertation of Diane Mayerfeld at University of Wisconsin-Madison in 2020, and chapter four was published in *Sustainability* in 2019.

Chapter One: *Silvopasture establishment shifts plant community and soil properties in oak woodlands in the Driftless Area of the Midwest USA*, examines the biophysical and ecological appropriateness of silvopasture in degraded woodlands of the Driftless Area. We tested the influence of tree canopy thinning, forage establishment, and rotational grazing on environmental outcomes in on-farm experiments in Crawford County, Wisconsin.

Chapter Two: *Protecting seedling trees and managing competing vegetation in silvopasture establishment: on-farm experiments in the US Midwest*, presents participatory research conducted with farmers in four states adapting silvopasture practices on their land. We evaluated methods for providing protection from livestock and wildlife to trees planted in pastures.

Chapter Three: *Evolving conceptions of silvopasture among farmers and natural resource professionals in the US Midwest* assesses the impacts of outreach and education efforts about silvopasture in the upper Midwest from 2015-2019. We examine how increased outreach and education about the principles and practices of silvopasture accompanied changes in perception and assess future prospects for management-intensive integration of pastured livestock and trees in the region.

Chapter Four: *Multi-party agroforestry: emergent approaches to trees and tenure on farms in the Midwest USA*, documents how farmers and landowners have addressed a major social barrier to wider application of silvopasture and sustainable agriculture generally: land access. Given insufficient research on tenure models appropriate for agroforestry in the USA, the primary objective of this study was to identify examples of farmers practicing agroforestry on land they do not own; we describe eleven cases of cooperation in what we term *multi-party agroforestry*.

Taken together, these studies describe opportunities and challenges of wider application of silvopasture in the US Midwest. Chapter One focuses on intensification of management of woodland grazing, which is a widespread practice currently. Chapter Two looks at tree planting in pastures, which is not widespread but has been identified as a globally important climate change solution. Chapter Three examines the perceptions of silvopasture among those participating in education and knowledge exchange about it. Chapter Four considers a wider social context and its limitations on innovations, particularly issues arising from land access and tenure security.

Each of these investigations is more concerned with the *how* of silvopasture than the *why*. The latter question – *why silvopasture?* – is worth continued consideration, but understanding how silvopasture works on working farms is a necessary part of that consideration. Farmers are by necessity practical people. For all the promise of silvopasture, including the potential benefits enumerated earlier, it must be made to *work*, if it is to live up to those promises. Thus, this dissertation focuses on improving our understanding of the dynamics of agroecosystem transitions (Chapter One) and how innovations can aid in adaptively managing those transitions (Chapter Two), as well as the dynamics of social transitions (Chapter Three), and how innovations can aid in adaptively managing our place in those social systems (Chapter Four), all in the context of silvopasture. My hope is that deeper understanding of these fundamentals of agroecological transitions will play some small part in equipping agriculture to better meet the full range of society's needs, as well as informing society what we might do to make ecological intensification a more practical option for more farmers.

Chapter One: Silvopasture establishment shifts plant community and soil properties in oak woodlands in the Driftless Area of the Midwest USA

Keefe O. Keeley & Stephen J. Ventura

Abstract

Overgrazing by domestic livestock has historically degraded woodlands, but herbivory more generally represents a source of disturbance important to ecosystem structure and function. Oak ecosystems in the Driftless Area, and the eastern US more broadly, lack appropriate disturbance and are undergoing successional mesophication. Silvopasture potentially offers a land management strategy to mitigate the degrading effects of overgrazing and to restore successional heterogeneity to the landscape. In this study, we evaluated impacts of prescribed grazing and vegetation management on plants and soils in oak-dominant mixed species woodlands. Specifically, we assessed the influence of cattle, thinning canopies, and planting forages on shrub cover, floristic diversity, forage nutritive quality, soil cover, soil fertility, and soil microbial community structure. This was done on farms with already established rotational grazing management systems. Grazing reduced shrub cover where initial thinning occurred and more so with native than introduced shrub species. Planting agricultural forages reduced floristic diversity but did not increase forage quality. Bare soil exposure and soil compaction was greater in grazed areas, but canopy thinning appeared to moderate the former. No effects were detected on soil moisture or macronutrients. Impacts on soil microbial community composition were mixed. In grazed areas, soil actinomycetes were more abundant, soil fungi were less abundant, and fungi to bacteria ratio was marginally greater in areas without any grazing or vegetation management. Arbuscular mycorrhizal fungi were less abundant in grazed areas when canopy and shrubs were thinned. Our findings suggest that management of existing woodland grazing can be improved by prescribed canopy thinning and targeted management of the shrub layer.

Highlights

- Grazing reduced shrub cover only where initial thinning occurred and more so with native than introduced shrub species.
- Planting agricultural forages reduced floristic diversity but did not increase forage quality.
- Grazing increased soil exposure and compaction in the upper 10 cm of the soil profile; the former effect was moderated by canopy thinning.
- Impacts of grazing and vegetation management on soil microbial community composition were mixed.

Keywords

Silvopasture; shrub encroachment; agroecology; oak savanna; invasive species; restoration ecology; soil health; ecological intensification; soil microbial community

1. Introduction

While positive environmental outcomes have been linked to well-managed grazing in the upper Midwest USA (Franzluebbers et al., 2012; Lyons et al., 2000; Paine and Ribic, 2002; Sabatier et al., 2015; Spratt et al., 2021), the link between cattle and forest degradation has a much longer history. Over-grazing in woodlands severely diminishes their ecological and economic value (Adams, 1975). Herbaceous understory plants such as spring ephemerals are extirpated, giving way to introduced species and other vegetation with less value for wildlife (Cawley, 1960). Sparse ground cover, cattle trails, and compaction decrease soil water-holding and infiltration capacity and increase erodibility (Gifford and Hawkins, 1978; Steinbrenner, 1951; Stoeckeler, 1959). Timber regeneration is eliminated or skewed heavily toward browse-tolerant tree species (Dambach, 1944). Most studies, however, have compared heavily-stocked continuous grazing to the complete exclusion of grazing in woodlands. An emerging literature suggests more intensively managing grazing, in interaction with other land management activities, can lead to more desirable environmental outcomes in wooded landscapes (Harrington and Kathol, 2009; Henkin et al., 2006; Kuiters and Kirby, 1999; McIntyre and Martin, 2002; Orefice et al., 2016; Rotherham, 2013; Royo et al., 2010; Shiflet, 1963; Wisdom et al., 2006).

Vera (2013, 2000) theorized, with contemporary and historical ecological evidence, a succession-disturbance cycle for dynamic tree-grassland interfaces in Europe, and suggested it applies to eastern North America as well. The basis for the theory is that herbivores interrupt regeneration of open-grown trees except in thickets of thorny or otherwise unpalatable vegetation that confer associational resistance. As these trees grow to maturity above the browse line, they shade out the thickets, and herbivores prevent further tree regeneration that would close the canopy. When mature trees die, grass-dominant communities re-establish in their place, maintained by herbivore disturbance until thickets reestablish. These cycles may play out over hundreds of years, responding to stochasticity in climate, herbivore populations, and a range of anthropogenic disturbances. Vera’s theory has been challenged as overly broad (Mitchell, 2005), but remains influential and subject to continued refinement (Bond, 2019).

Similar successional dynamics may have been at play in the development and maintenance of plant diversity in the Driftless Area of the Midwest USA. A wide range of plant communities is adapted to this region, from treeless tallgrass prairie to closed canopy maple-dominant hardwoods (Curtis, 1959). Disturbance-adapted oak savannas covered 69% of the region at the time of European settlement (Shea et al., 2014). In contrast to much of Europe, fire, rather than herbivores, may have been a more important driver to plant community dynamics in the Driftless Area for the last ~12,000 years of human habitation (Kline and Cottam, 1979; Owen-Smith, 1987). Prior to that, fires would have been less common and less severe; lightning strike occurs most commonly in conjunction with precipitation events, and during the growing season when vegetation is less flammable generally. Yet a wide array of vegetation is adapted to high light conditions, suggesting an herbivore-mediated disturbance regime over evolutionary time scales. Furthermore, many light-demanding woody species have spinose structures associated with defense against mammalian herbivores (e.g., *Crataegus, Gleditsia, Prunus, Rosa, Rubus, Ribes, Zanthoxylum*). The co-evolution of spiny woody plants and ungulates adapted to browsing them – which predates changes in climate, fire-regime, and associated C-4 grasses – suggests that mammalian herbivory predates fire as the primary driver in the development of savannas (Charles-Dominique et al., 2016). Prior to the arrival of humans and increased fire incidence, Pleistocene mega-herbivores likely played a key role in reducing overstory competition from trees that reach a size refuge from extant herbivores (Bakker et al., 2016; Goheen et al., 2007; Owen-Smith, 1987).

To what degree this precisely describes the ecological history of the Driftless Area is perhaps not essential, since current and future ecosystem trajectories inevitably involve novel anthropogenic drivers (e.g. fragmentation, species introductions and extirpations, fire suppression, tillage and old-field reversion, climate change) (Knoot et al., 2015). What is germane is that vegetation communities exist in dynamic equilibrium where disturbance by both fire and mammalian herbivory are important drivers. Silvopasture – specifically grazing and canopy cover management – offers an opportunity to restore, or at least partially mimic, these processes and successional heterogeneity in the landscape (Garrett et al., 2004). With the important caveat of deer over-abundance, currently most of the landscape is either under-disturbed and undergoing mesophication, or over-disturbed via annual plowing or herbicide (Fei et al., 2011; Nowacki and Abrams, 2008). At the coarsest level of analysis, silvopasture represents a tool to re-establish a diversity of successional stages within a heterogeneous landscape (Harrington and Kathol, 2009).

In addition to the history of land degradation and the theoretical application of silvopasture for recovery of successional dynamics, the social context presents an imperative to better understand and improve woodland grazing rather than simply condemn it. In Wisconsin, where most of the Driftless Area is located, property tax assessment policy has created an incentive for landowners to graze livestock in farm woodlands. Agricultural use-value assessment provides tax relief for farmers by charging them according to the expected financial return from agricultural land use, rather than by market value, resulting in property taxes 10 to 30 times lower on woodlands that are pastured (Wisconsin Department of Revenue, 2021). Without proposing that new or vulnerable woodlands be grazed, it is pragmatic to presume Wisconsin farmers will continue to use their woodlands for grazing in order to qualify for this tax incentive.

Furthermore, beyond tax benefits, farmers cite shade, winter shelter, emergency forage in drought, livestock diet diversity, and shrub management as motivations for use of their woodlands for grazing (Keeley, 2014; Mayerfeld et al., 2016). However, intensive integrated management of trees, cattle and forage is currently uncommon in the region (Galleguillos et al., 2018; Mayerfeld et al., 2016). Currently, farmers in Wisconsin have little professional guidance about best practices for managing grazing in this region, as there has been scant research to inform it, other than forestry-related documentation of the negative impacts of over-grazing (Mayerfeld et al., 2016). It is therefore of interest to better understand of how silvopasture as an approach to ecosystem management might impact farm and ecological objectives in these contexts.

In this study, we evaluated how silvopasture establishment affected vegetation and soils in oak-dominant mixed species woodlands. Specifically, we assessed the influence of cattle grazing, thinning canopies, and planting forages on shrub cover, floristic diversity, forage nutritive quality, and soil cover, soil fertility, and soil microbial community structure. We hypothesized that rotational grazing would (1) reduce shrub cover, (2) influence floristic diversity via selective herbivory, (3) improve forage quality by maintaining vegetative growth phase of plants, and (4) increase soil compaction, bare soil exposure, soil fertility, and decrease the fungi to bacteria ratio in the soil microbial community. We also tested hypotheses that vegetation management – removing approximately half of the tree canopy and most of the shrub layer, as well as planting agricultural seeds and native seeds – would (5) reduce shrub cover when combined with grazing, (6) influence floristic diversity via simplification (agricultural seeds) or increased complexity (native seeds), (7) improve forage quality, and (8) decrease soil exposure by stimulating more plant growth on the forest floor.

2. Methods

2.1. Experimental site

The experiment was conducted in eight blocks distributed among three farm sites in the Kickapoo River watershed in Crawford County, Wisconsin. Block locations were selected for relative uniformity within and among blocks in terms of slope, aspect, canopy coverage, and soil type. Predominate soils are loamy-skeletal and fine-silty, mixed, active, mesic Typic Hapludalfs. Each farm raised beef cattle in a multi-paddock pasture system with herd rotation to a subsequent paddock each 2-10 days, with a paddock return interval of 30-50 days, based on forage growth and utilization. The eight 0.4 ha experimental blocks were established in mixed oak woodland that had not been grazed for at least the previous 20 years. Each block was two 0.2 ha whole plots: a grazed paddock which cattle had access to from adjacent open pasture on a managed rotational basis (GRA), and an ungrazed paddock from which cattle were always excluded (UNG) (Figure 1). Within each whole plot there were three subplots randomly assigned a vegetation management treatment, along with a pair of the same treatment randomly assigned to a subplot in the other whole plot of that block. There were four vegetation management treatments, which were established as subplots in an unbalanced incomplete block design (Table 1). The vegetation management treatments were established in 2015-2016 and included 1) an agricultural forage seed mix (AGR), and 2) a native seed mix (NAT), and (3) no seeds added (NOS), each of these with the overstory canopy thinned via tree felling to approximately 50% cover and the shrub canopy reduced to <10% cover via a skid steer forestry mulcher and handheld implements, and 4) a control treatment with no seeds and no thinning of the overstory tree canopy or shrubs (CTL) (Appendix 1). AGR was established by broadcasting seed between

August 20th and September 10th preceded by canopy clearing and followed immediately by an initial cattle rotation so hoof action could stimulate seed to soil contact. NAT was established by broadcasting seed in January in order to allow for cold stratification as well as conveyance of seed to soil via snow melt.

Unless a different sampling procedure is noted below, for each of the response variables we performed measurements via six subsamples per subplot located at permanent points randomly assigned on a stratified gradient of distance from the side of the plot open to cattle access (Figure 1). Block locations were arranged where the tree line was perpendicular to slope, and thus stratification of sampling points also represented the slope gradient.

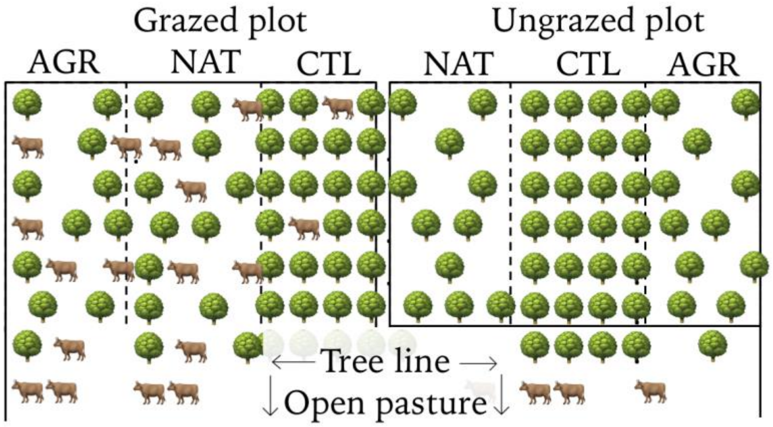


Fig. 1. *A schematic of an example 0.4 hectare experimental block area for a woodland silvopasture establishment experiment in Wisconsin USA. Main plot treatments are rotationally grazed and ungrazed areas. Subplots in each block were assigned in random pairs to three of the four vegetation management treatments: AGR, Agricultural forage seed mix planted; NAT, Native seed mix planted; NOS, No seeds planted (not shown); CTL, Control with no seeds, no canopy thinning.*

Table 1. Farms, blocks, and treatments in silvopasture establishment study in Midwest USA.

Farm	Block	AGR	NAT	NOS	CTL
A	1	X		X	X
A	2	X	X	X	
A	3	X	X		X
B	4	X	X	X	
B	5	X		X	X
B	6	X	X		X
C	7	X		X	X
C	8	X	X	X	

2.2. Vegetation measurements

We estimated shrub cover using a coverboard at a distance of five meters in both directions perpendicular to the stratification of the sampling points, June 7-9, 2018. The cover board is 2.5 m tall by 0.25 m wide and divided into five 0.5 m bands of alternating black and white. It is a modification of another visual obstruction method, the Robel pole, which is used to estimate vegetation biomass (National Applied Resource Sciences Center, 1999). The cover board was held upright by one person with the bottom of the coverboard centered at subsample quadrat point marker. Another person stood five meters away and estimated the percentage of each of the five bands that were visually obstructed by vegetation using six cover classes (0-5%; 5-25%; 25-50%; 50-75%; 75-95%; and 95-100%) following the Daubenmire method (Daubenmire 1959).

Leaf area index (LAI) of the shrub layer was measured and calculated on June 30, 2018 using an AccuPAR LP-80 ceptometer (Decagon Devices, Pullman, WA, USA). Directly above each of the permanent sampling points, we measured photosynthetically active radiation (PAR) at both 0.5 m height and at 2 m height. The instrument calculates LAI based on gap fraction analysis of PAR intercepted by the canopy to estimate LAI using calculations derived from the Beer-Lambert law to provide a robust approximation to destructive sampling (Norman and

Campbell, 1989; Welles and Cohen, 1996). Because we did not thin the overstory tree canopy in the Control areas, the readings above the shrub layer in that treatment were taken in a more shaded environment than the other treatments, so Control LAI index values are not comparable with other treatments.

At each sampling point, within a 1 m^2 quadrat, we counted living stems of each woody species. An individual stem was counted if there was no visible attachment to another stem, and it was growing from the root crown or base stem less than 5cm from the soil surface within the quadrat. We also counted the number of browsed points on each woody species within each quadrat. We measured the height of the tallest stem of each woody species within the quadrat from its tallest point vertically to the ground.

We assessed floristic diversity between May 21 and June 22, 2018, by recording the presence of all species in each quadrat and estimated their respective coverage using the classes noted previously. When a specimen could not be identified as a species, we recorded it by genera or documented it and assigned it an ID. Exclusively ID-assigned species were excluded from analysis. Shannon's and Simpson's diversity indices, respectively, were calculated so greater values represent greater diversity (Magurran, 2013).

Clipped forage samples were collected 2 m from each of the permanent sampling points in consistent orientation with respect to each block. Collection was limited to living herbaceous plants and leaves above 10 cm height and below 2 m height within 0.25 m^2 squares. Height of herbaceous forage was recorded at each clipping site. Subsamples from each subplot were pooled on site and packaged for transport July 14-15, 2018. Wet chemistry analysis of crude protein, acid detergent fiber, lignin, neutral detergent fiber, and *in vitro* neutral detergent fiber digestibility was conducted by the University of Wisconsin Soil and Forage Analysis Laboratory.

Relative forage value is an index that incorporates ADF and NDF as measures of digestible dry matter and dry matter intake, respectively (Rohweder et al., 1978).

2.3. Soil measurements

To evaluate soil compaction, we used a penetrometer (Field Scout SC900) to record soil strength at 2.5 cm depths successively to 45 cm (ASAE, 1999; Hemmat and Adamchuk, 2008). We took readings 5 m from each sampling point in consistent orientation with respect to each block when there was ample soil moisture to use the instrument.

To evaluate soil macronutrients, moisture, and microbial community composition, we collected one 30 cm probe of soil per sampling point; six subsamples were mixed to compose each observation. Samples for nutrient and moisture analysis were stored in sealed plastic bags and kept in a cooler out of the sun. Subsamples of 3 g for microbial analysis were scooped from the field mix bucket, visually scanned to ensure the absence of coarse biological material, and put immediately into sealed bags in a separate cooler chilled by solid carbon dioxide. We conducted all soil sampling July 2-5, 2018. Soil organic matter was measured by loss on ignition, extractable nutrients were measured by the Bray 1 method.

Bare soil exposure was assessed via visual estimate of percent bare soil in each quadrat at the same time and following the same protocols as plant species cover assessments described in 2.2. We measured litter depth from the duff layer surface to top of litter at three random points in each quadrat.

To assess microbial community composition, we assessed soil lipids, which are well suited biomarkers for differentiating fungi and bacteria (Frostegård et al., 2011; Frostegård and Bååth, 1996). Lipids were extracted using the technique as described in Oates et al. (2017). Briefly, 3 g of freeze dried soil was extracted using a modified Bligh and Dyer (1959) solvent system (chloroform:methanol:phosphate buffer, 1:2:0.8). After phase separation the aqueous phase was suctioned off and the lipids in the organic layer were dried down under partial vacuum. The lipids were then converted to fatty acid methyl esters (FAMEs) by saponification followed by acid-catalyzed transmethylation. The FAMEs were then extracted into hexane and methyl tert-butyl ether (1:1), dried and then resuspended in 300 ul hexane + MTBE with 19:0 ethyl ester added as a quantification internal standard. The finished extracts were analyzed using a Hewlett-Packard Agilent 6890A gas chromatograph (GC) (Agilent Technologies Inc. Co., USA) equipped with an Agilent Ultra-2 5% phenyl, 95% methyl polysiloxane capillary column and flame ionization detector. The FAMEs were identified based on retention indices using the Sherlock software system (MIDI, Inc., Newark, DE). We classified FAMEs according to existing data on their presence in various groups of microorganisms: for Gram-negative (GM-) bacteria the 16:1ω7c, cy17:0, 18:1ω7c, cy19:0 lipid biomarkers were used, for Gram-positive bacteria (GM+) i15:0, a15:0, i16:0, i17:0 PLFAs were used, for actinomycetes 10Me16:0 10-methyl, 17:0 10-methyl, and 10Me18:0 10-methyl were used, for fungi 18:2ω6 and 18:1ω9c were used and 16:1ω5c was used for arbuscular mycorrhiza fungi (AMF) (Joergensen and Wichern, 2008; Leckie, 2005; Lewandowski et al., 2015).

2.4. Statistical analysis

We performed statistical analyses in R (R Core Team, 2021). To test for treatment effects, we fit linear mixed effects models for each response variable with grazing and vegetation management and the interaction of these factors as fixed effects, and with blocking and its interaction with whole plot as random effects. Degrees of freedom in these models represent Satterthwaite approximations. We used the restricted maximum likelihood approach in the *lme4* package (Bates et al., 2015) as recommended for unbalanced designs in split plot experiments, despite pooling whole and split plot error degrees of freedom (Dean et al., 2017). For post-hoc analysis, we used the *emmeans* package (Lenth, 2021) to conduct pairwise comparisons among treatments using least-squares means, and for Management treatments we applied a P value adjustment via the Tukey HSD (honest significant difference) to control the family-wise error rate at 5%. For some response variables, data were natural log transformed to improve model fit.

3. Results

3.1. Shrub cover, shrub browsing, floral diversity, and forage quality

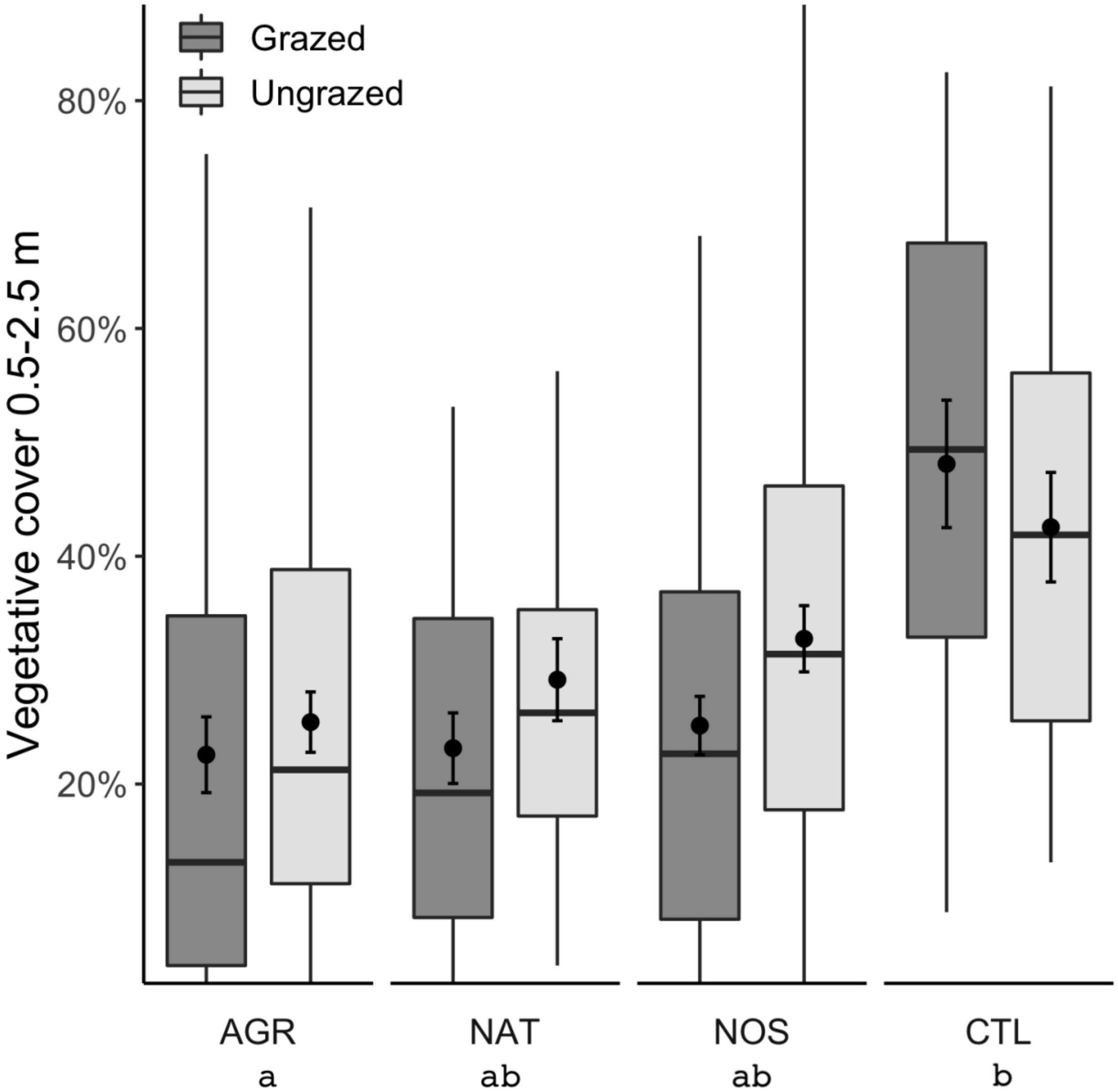
3.1.1. Shrub leaf area index and vertical cover

Grazing influenced leaf area index from 0.5-2 m (Table 2), with lower index values in grazed areas than the ungrazed areas (Figure 2). Grazing had no effect on vegetative cover in the 0.5-2.5 m range as estimated with vertical coverboard, but there was a Management effect (Table 2) driven by greater vegetative cover in the Control treatment compared to the Agriculture treatment (Figure 2).

Table 2. Linear mixed effects models test the main and interactive effects of grazing (rotational grazing or cattle exclusion) and vegetation management (no canopy thinning or seed, or canopy thinning with no seed, native seed, or agricultural seed) in an analysis of variance on a set of response variables in an on-farm experiment in Wisconsin, USA. Degrees of freedom as estimated by Satterthwaite method (numerator, denominator) are shown for the F statistic. Bold and italicized values indicate significant effects at P < 0.05 and P < 0.10, respectively.

Variable	Grazing			Vegetation management			Grazing x Veg. Mgt.		
	F	*df*	*P*	*F*	*df*	*P*	*F*	*df*	*P*
Vegetative cover 0.5-2.5m	0.55	1,6.35	0.485	4.51	3,25.99	**0.011**	0.34	3,26.82	0.795
Leaf area index 0.5-2m	7.10	1,7.41	**0.031**	2.05	3,27.84	0.130	0.96	3,28.16	0.425
Browsed points:woody stems	4.71	1,16.22	**0.045**	0.50	3,29.72	0.685	0.73	3,29.72	0.545
Native shrub height	7.67	1,7.04	**0.028**	4.67	3,27.22	**0.009**	0.47	3,28.01	0.703
Introduced shrub height	0.01	1,31.72	0.939	2.49	3,34.13	*0.077*	0.79	3,31.74	0.511
Species richness	1.68	1,32.77	0.204	5.15	3,34.09	**0.005**	2.52	3,32.77	*0.075*
Shannon's diversity index	0.04	1,32.92	0.845	5.14	3,34.06	**0.005**	0.67	3,32.92	0.577
Simpson's diversity index	1.22	1,8.38	0.300	2.64	3,27.37	*0.070*	0.21	3,28.79	0.889
Relative feed value	2.17	1,15.02	0.161	1.75	3,28.18	0.179	0.13	3,28.18	0.941
% Crude protein	5.30	1,5.55	*0.064*	0.66	3,23.91	0.584	0.76	3,25.37	0.529
Forage height	4.88	1,14.18	**0.044**	0.63	3,26.68	0.602	0.70	3,26.68	0.561
Soil strength, Spring 0-10cm	6.15	1,7.47	**0.040**	1.73	3,25.93	0.186	0.41	3,26.67	0.744
"" 12.5-27.5cm	0.24	1,8.53	0.635	0.91	3,26.61	0.451	0.66	3,28.23	0.586
"" 30-45cm	2.64	1,24.01	0.117	0.57	3,24.57	0.640	0.30	3,23.97	0.822
Soil strength, Fall 0-10cm	12.23	1,7.71	**0.009**	1.59	3,27.64	0.214	2.79	3,28.19	*0.059*
"" 12.5-27.5cm	0.56	1,8.09	0.477	0.55	3,27.42	0.650	1.61	3,28.65	0.208
"" 30-45cm	1.23	1,27.92	0.277	0.54	3,30.12	0.661	1.56	3,27.98	0.221
Bare soil	14.62	1,33.16	**0.001**	1.03	3,35.7	0.389	0.13	3,33.16	0.941
Litter depth	1.23	1,27.92	0.277	0.54	3,30.12	0.661	1.56	3,27.98	0.221
Soil organic matter	0.05	1,7.81	0.833	1.48	3,26.53	0.241	0.49	3,28.54	0.694
Soil phosphorus	3.15	1,8.03	0.114	2.08	3,26.87	0.126	1.09	3,28.86	0.368
Soil potassium	3.08	1,7.43	0.120	1.10	3,26.66	0.365	0.64	3,27.45	0.595
Soil moisture	0.65	1,32.0	0.425	0.34	3,34.73	0.794	1.44	3,32.15	0.250
Soil microbial biomass	0.40	1,8.34	0.546	0.18	3,27.17	0.912	0.70	3,29.13	0.557
Soil fungi:bacteria	3.43	1,32.18	*0.073*	1.41	3,35.39	0.256	1.86	3,32.38	0.157
Soil fungi	5.24	1,32.96	**0.029**	0.53	3,34.13	0.662	0.83	3,33.02	0.484
Soil AMF	1.77	1,7.67	0.222	1.12	3,26.94	0.357	3.11	3,28.08	**0.042**
Soil bacteria	1.05	1,29.91	0.313	2.48	3,30.06	*0.080*	1.68	3,29.79	0.193
Soil actinomycetes	6.06	1,32.94	**0.019**	2.19	3,33.2	0.107	2.43	3,32.95	*0.083*
Soil GM+:GM-	0.06	1,8.11	0.820	0.30	3,27.83	0.824	0.16	3,28.54	0.921

(A)


Grazed
Ungrazed
Vegetative cover 0.5-2.5 m
80%
60%
40%
20%
AGR
a
NAT
ab
NOS
ab
CTL
b

(B)

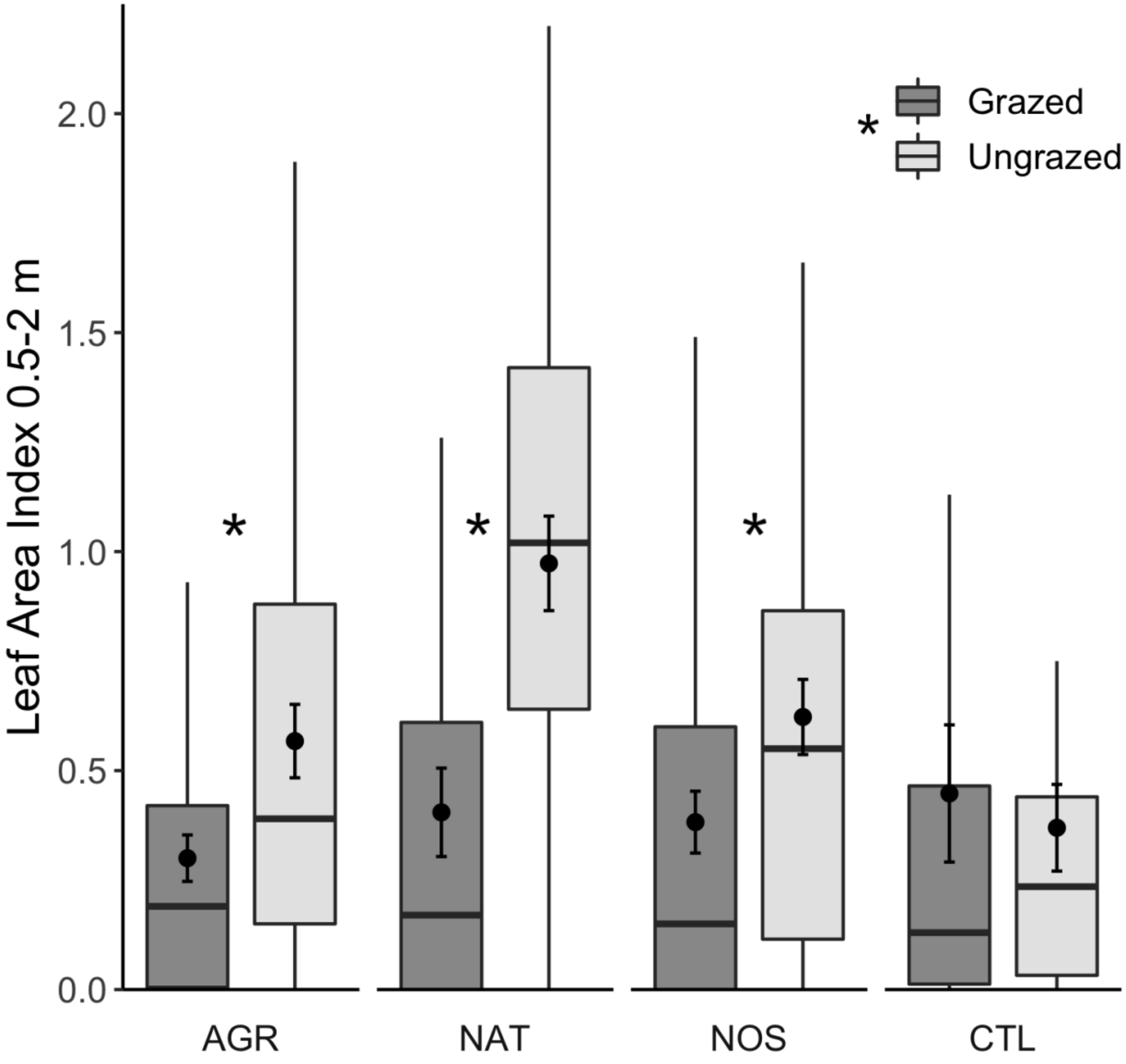


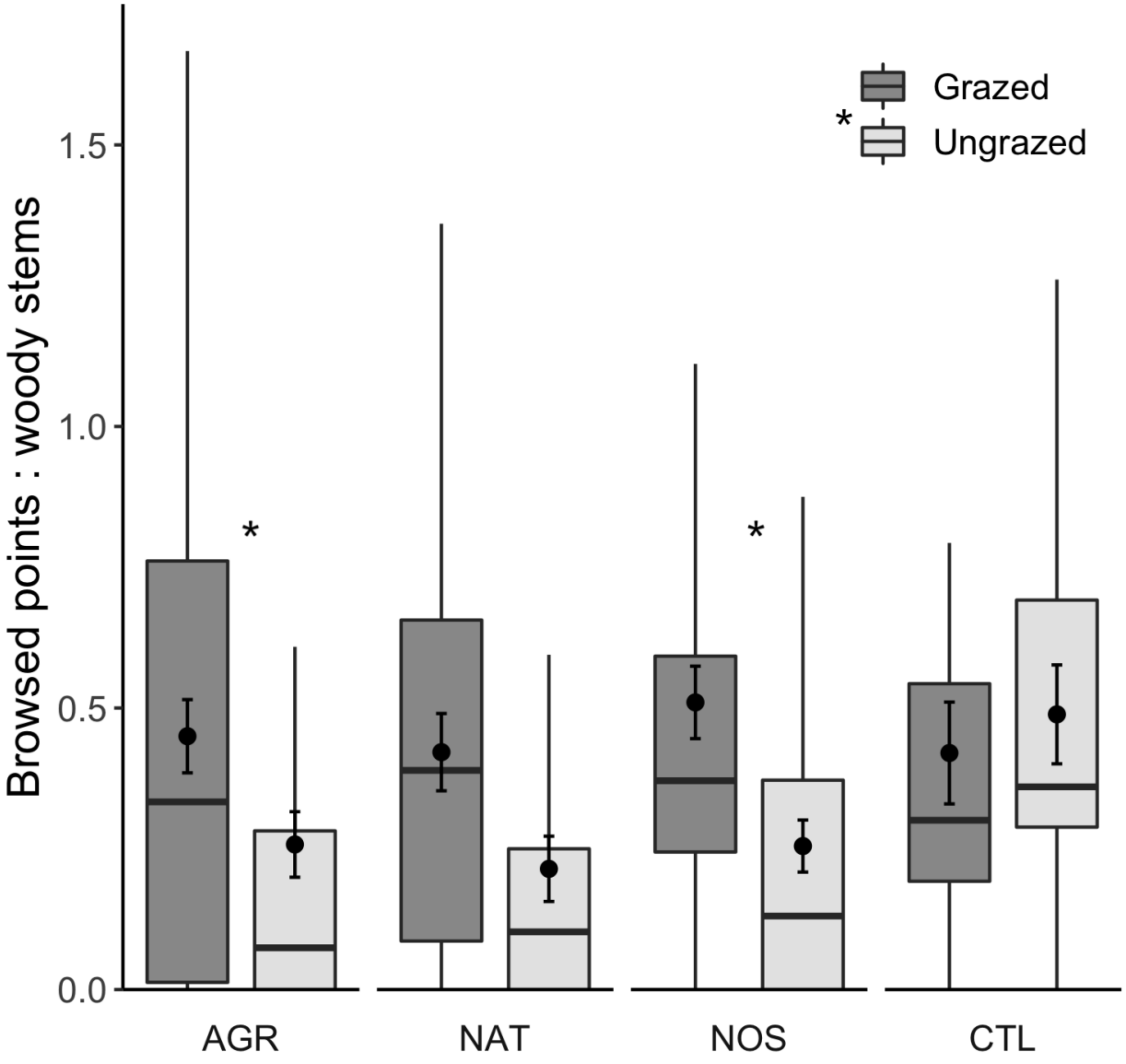
Fig. 2. *Vegetative cover of shrub canopy as assessed by (A) visual cover estimate with a vertical board from 0.5-2.5 m and (B) Leaf area index 0.5-2.0 m and (B) in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species woodland in Wisconsin USA. Within each box, horizontal lines denote median values; boxes*

extend from the 25th to the 75th percentile; vertical lines extend a 1.5 interquartile range. Dot and error bars represent mean ± 1 SE. If there was a main effect of management, treatments that share a letter were not significantly different (Tukey HSD, $p < 0.05$). Asterisks mark significant differences between grazed and ungrazed treatments, including pairwise contrasts within management treatments, and marked at the legend if there was a main effect of grazing ($p < 0.05$).

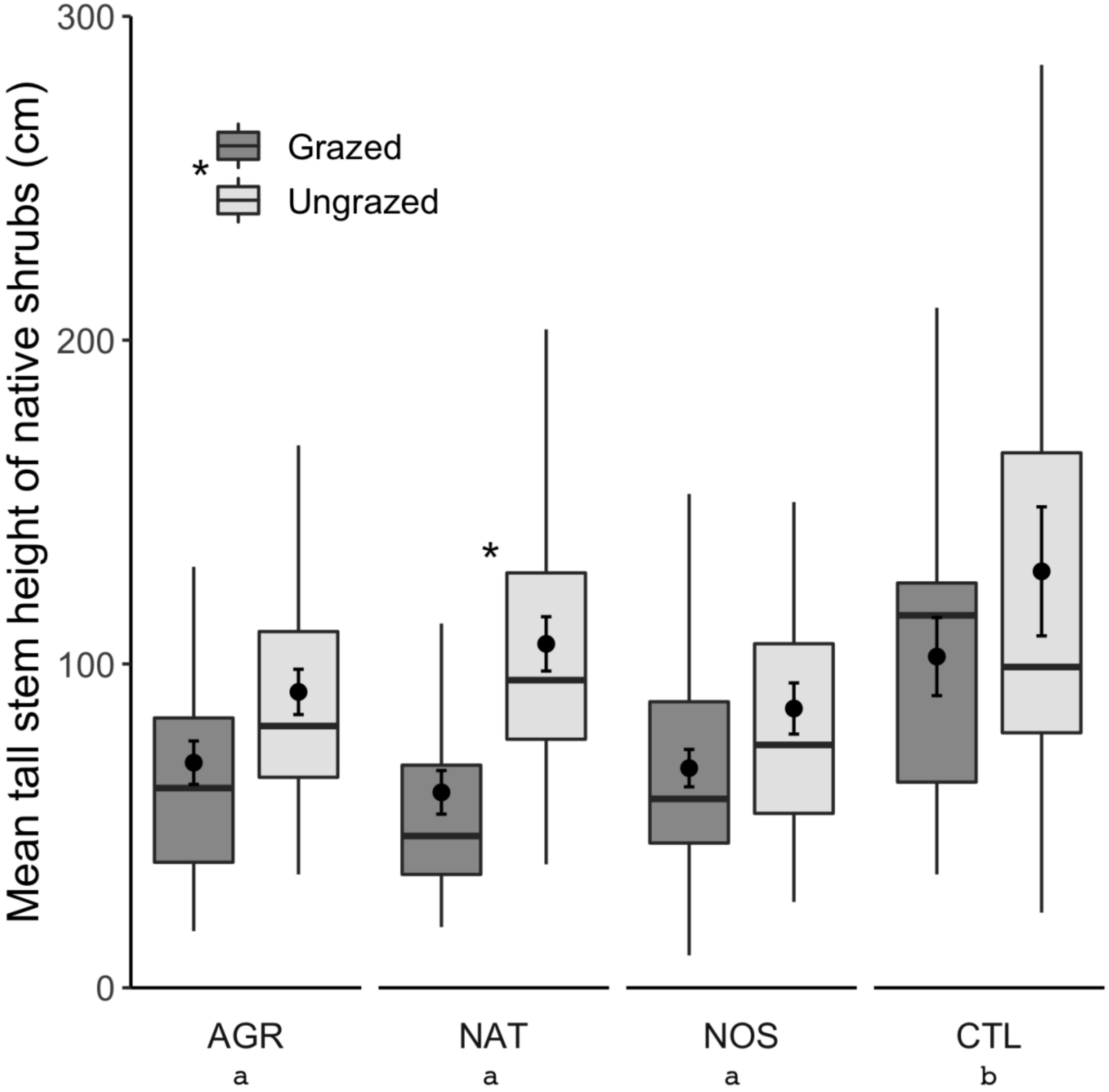
3.1.2. Browsed:stem ratio and mean tall stem among native and introduced shrubs

The ratio of browsed points on woody stems to total woody stems was significantly greater in grazed areas; however, the ungrazed control areas had the greatest ratio value of any treatment combination (Figure 3). We also measured the tallest stem of each shrub species in sampling points (Figure 3). Among native shrubs there was an effect of grazing reducing stem height, and these native shrubs were tallest in treatments where the overstory and shrub layer was not thinned initially (Table 2) (Figure 3) (Appendix 2). In contrast, introduced shrub species were tallest where the overstory and shrub layer was thinned, and there was no effect of grazing on introduced shrubs (Table 2) (Figure 3).

(A)


Browsed points : woody stems
0.0
0.5
1.0
1.5
Grazed
Ungrazed
*
*
*
AGR
NAT
NOS
CTL

(B)


Mean tall stem height of native shrubs (cm)
300
200
100
0
Grazed
Ungrazed
*
*
AGR
a
NAT
a
NOS
a
CTL
b

(C)

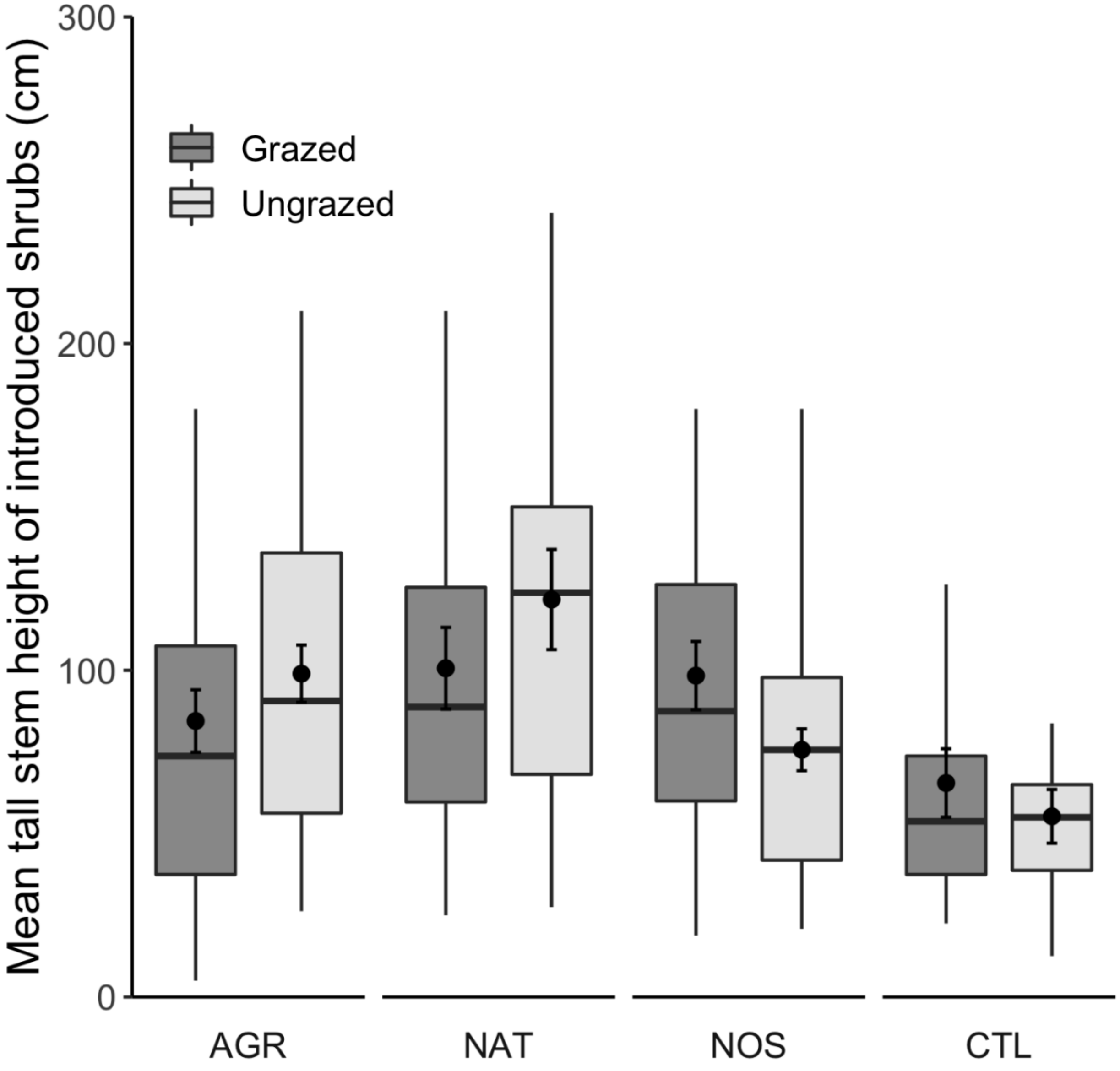


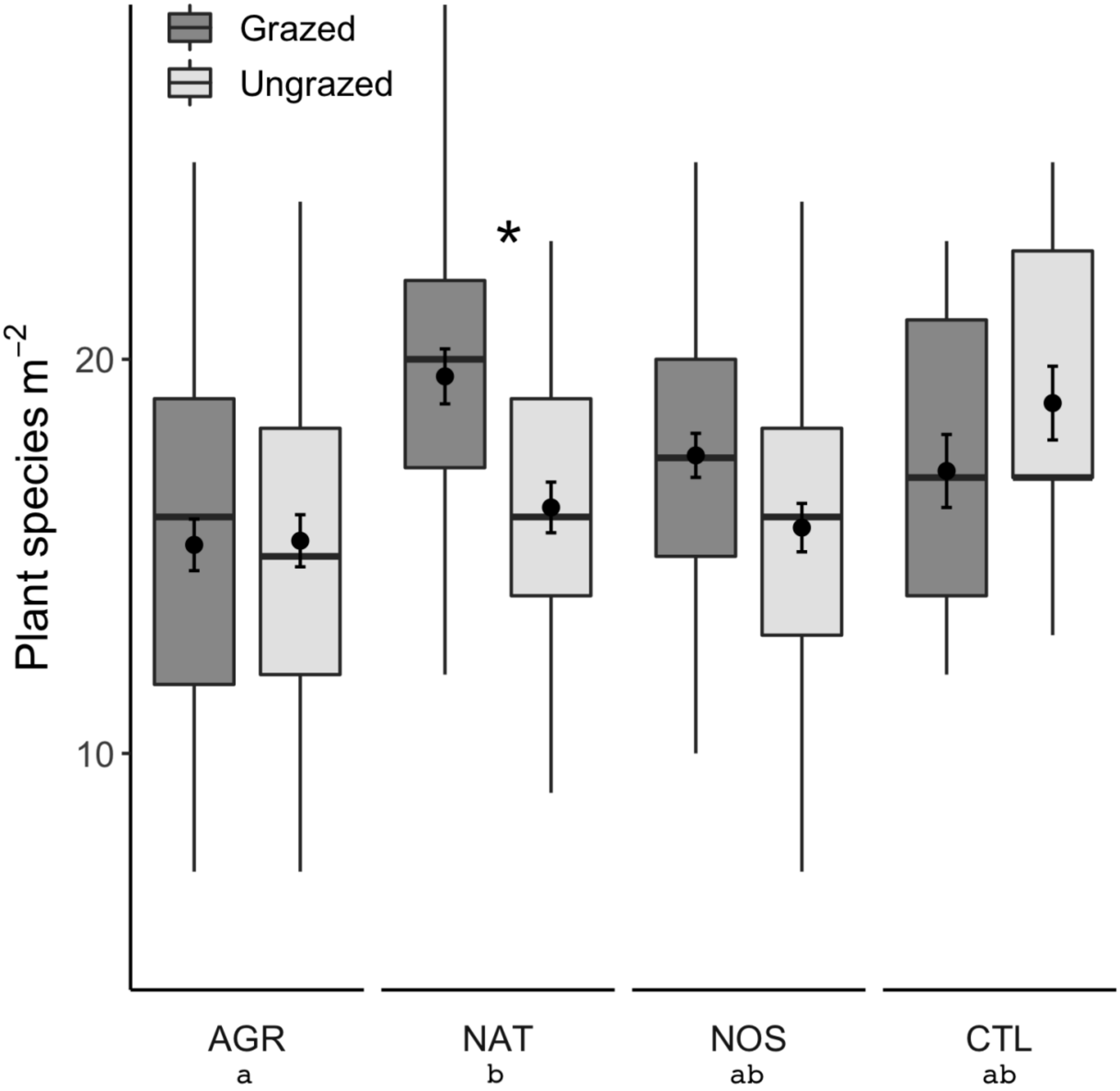
Fig. 3. *Shrub herbivory as measured by (A) ratio of herbivore-browsed points on woody stems to the total count of woody stems, mean tall stem height of (B) native and (C) introduced shrub species in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species woodland in Wisconsin USA. Within each box, horizontal*

lines denote median values; boxes extend from the 25th to the 75th percentile; lines extend a 1.5 interquartile range. Dot and error bars represent mean ± 1 SE. If there was a main effect of management, treatments that share a letter were not significantly different (Tukey HSD, $p < 0.05$). Asterisks mark significant differences between grazed and ungrazed treatments, including pairwise contrasts within management treatments, and marked at the legend if there was a main effect of grazing ($p < 0.05$).

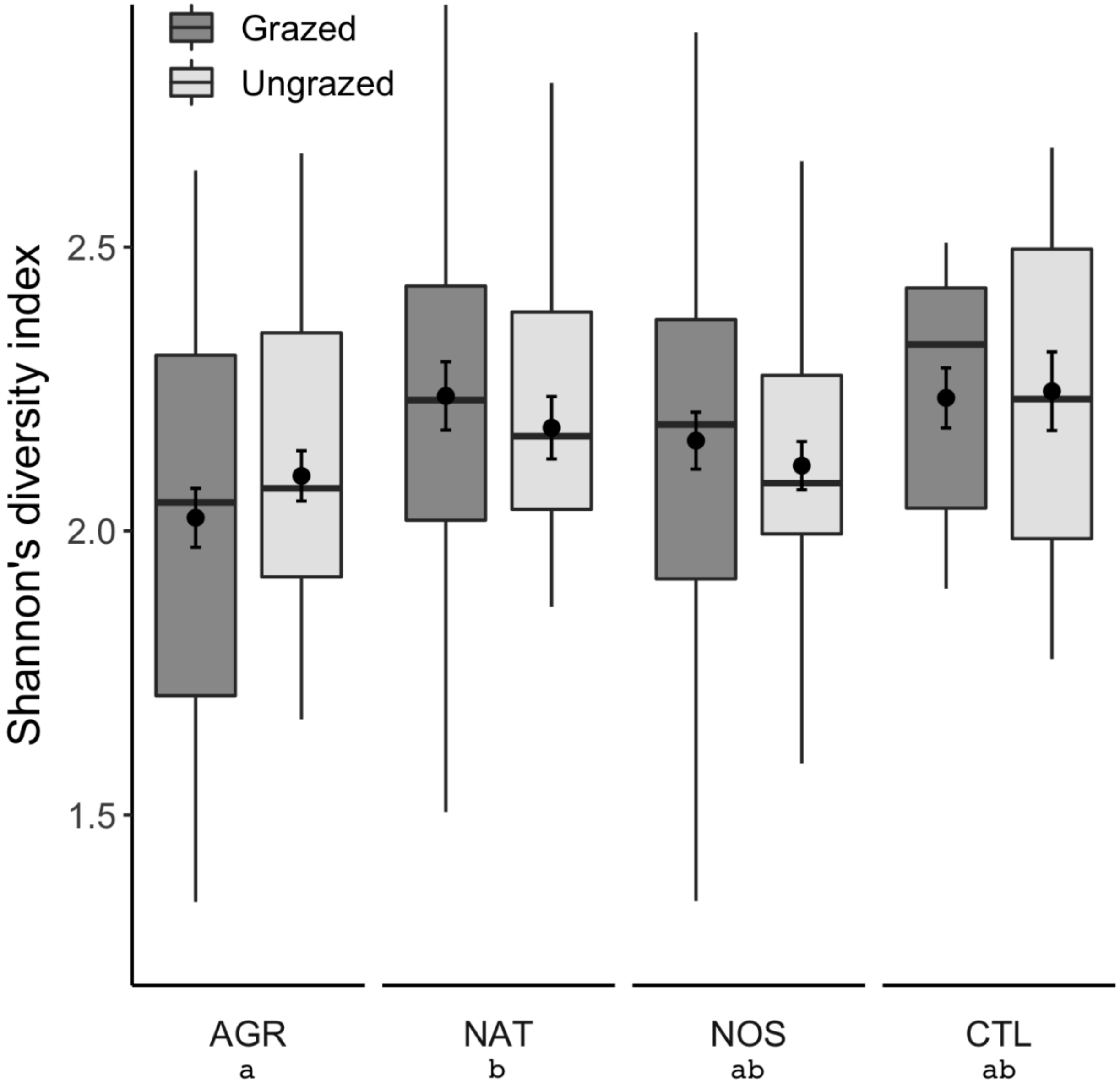
3.1.3. Floristic diversity

We recorded all plant species in six 1 m^2 quadrat subsamples per subplot and assessed their respective abundance via visual estimates of cover. There was an effect of Management on species richness (Table 2) driven by greater richness in the Native than the Agriculture treatment (Figure 4). Plant diversity as quantified by Shannon's diversity index also showed a Management effect, and was likewise greater in areas where we planted native seeds, compared to the agricultural treatment. According to Simpson's diversity index, however, which relative to Shannon's index emphasizes evenness rather than rare species, there was only weakly significant Management effect, and plant diversity was greater in control areas than the agricultural treatment (Table 2).

(A)


Grazed
Ungrazed
Plant species m^{-2}
20
10
*
AGR
a
NAT
b
NOS
ab
CTL
ab

(B)


Grazed
Ungrazed
Shannon's diversity index
2.5
2.0
1.5
AGR
a
NAT
b
NOS
ab
CTL
ab

(C)

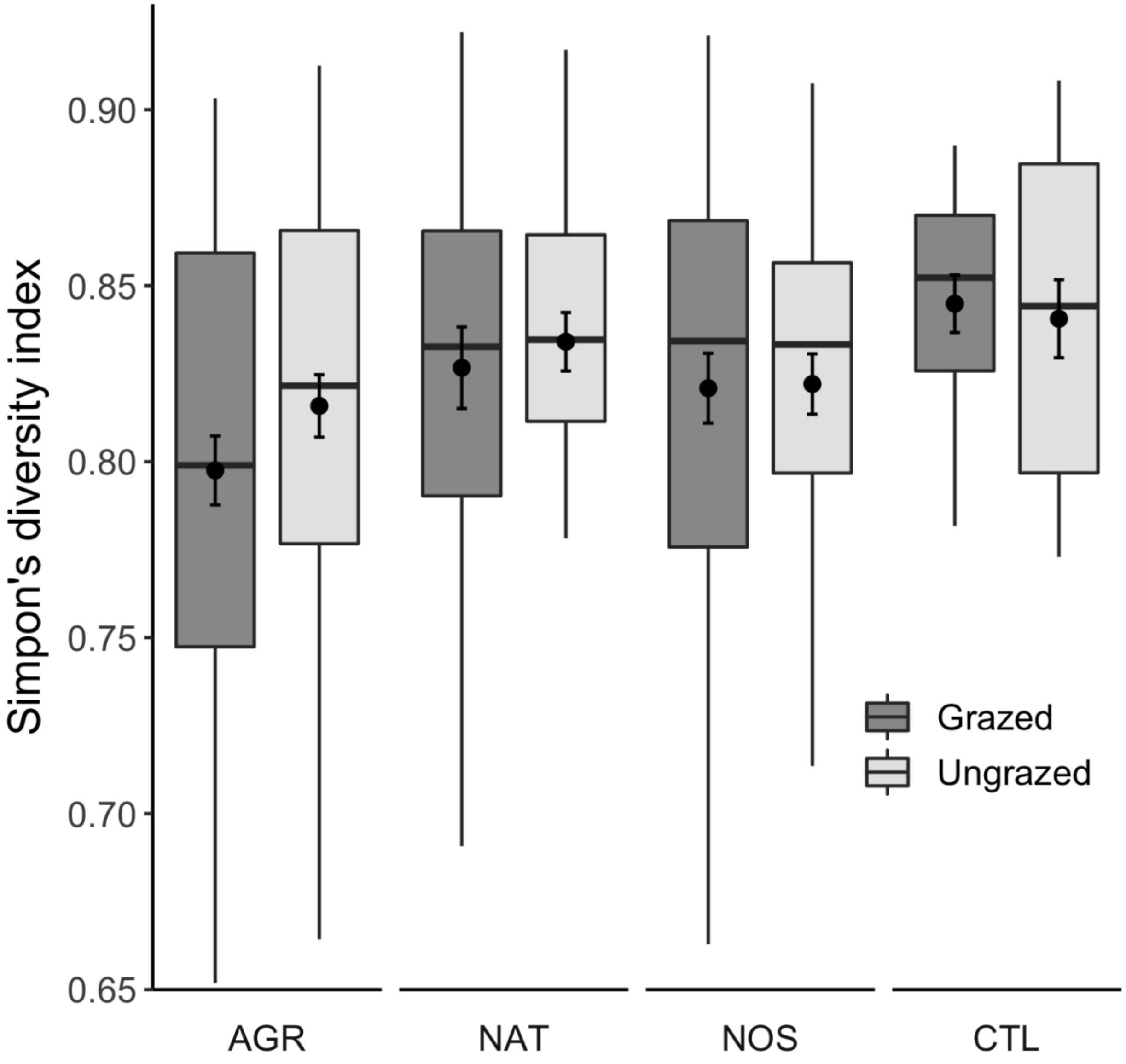


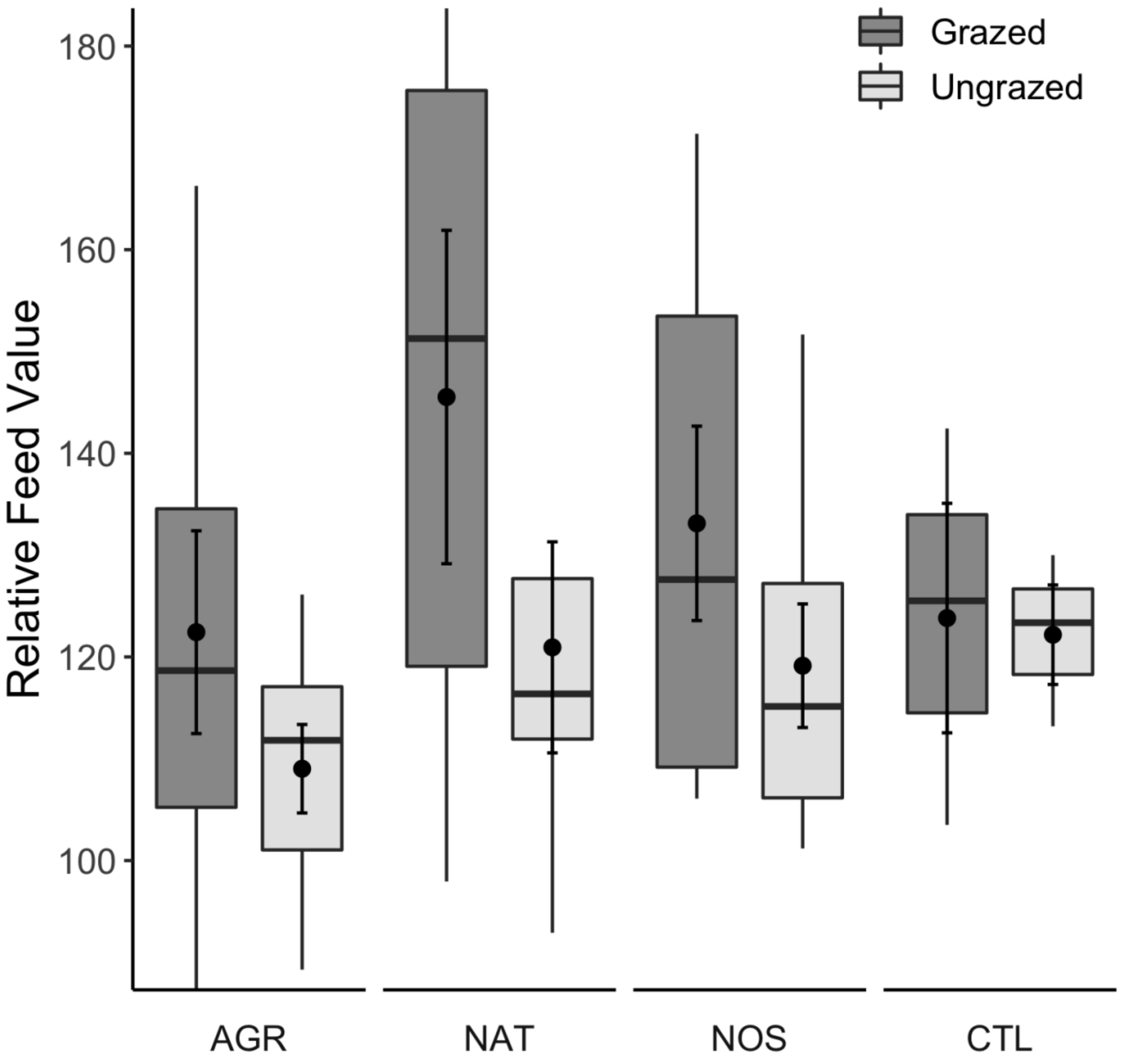
Fig. 4. *Floristic diversity as assessed by (A) Plant species richness, (B) Shannon's diversity index, and (C) Simpson's diversity index in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species woodland in Wisconsin USA. Within each box, horizontal lines denote median values; boxes extend from the 25th to the*

75th percentile; lines extend a 1.5 interquartile range. Dot and error bars represent mean ± 1 SE. If there was a main effect of management, treatments that share a letter were not significantly different (Tukey HSD, $p < 0.05$). Asterisks mark significant differences between grazed and ungrazed treatments, including pairwise contrasts within management treatments, and marked at the legend if there was a main effect of grazing ($p < 0.05$).

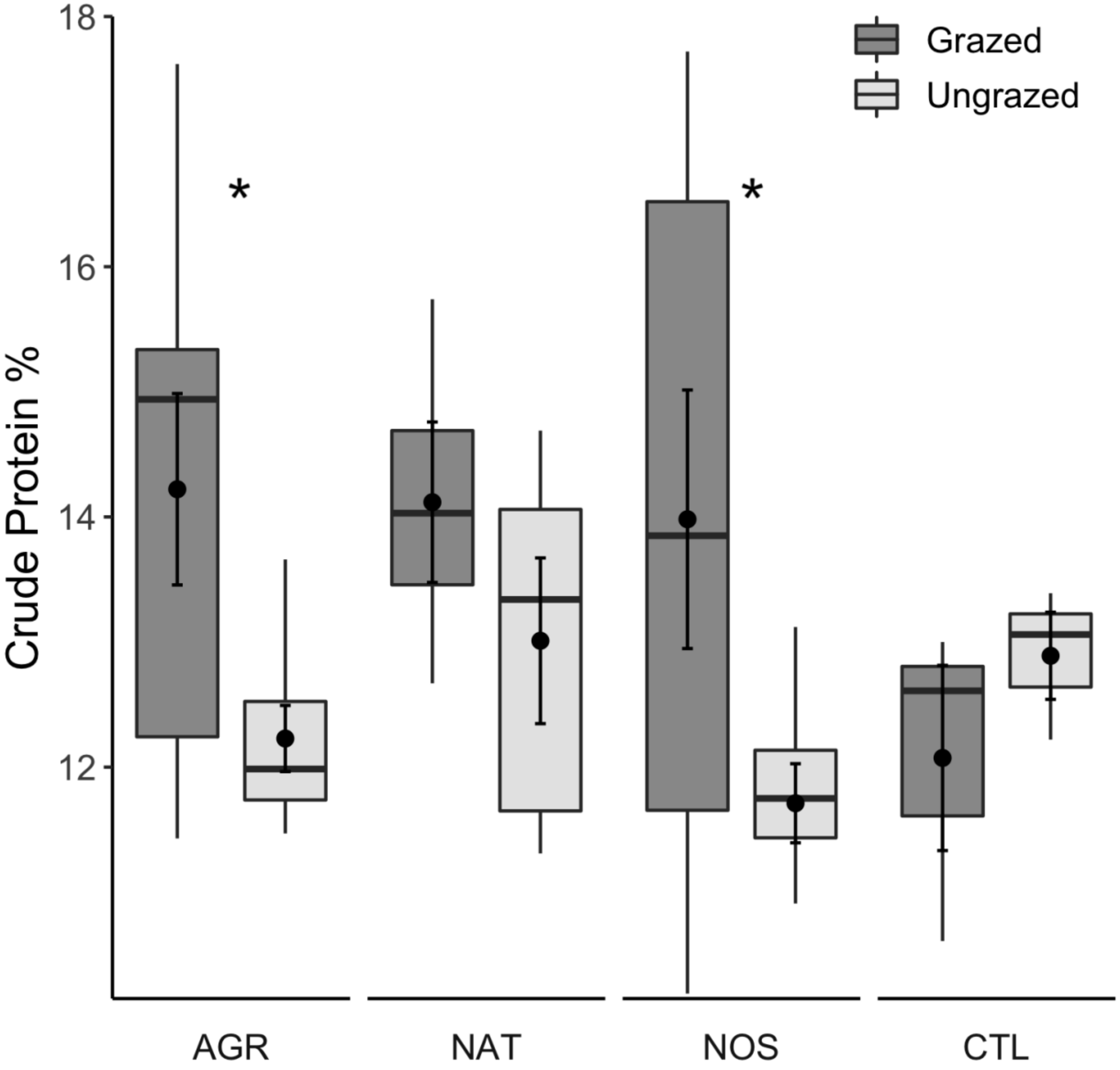
3.1.4. Forage quality

We evaluated forage quality via wet chemistry analysis of clipped samples. There was no effect of treatments on Relative Feed Value (RFV) (Table 2) but there was substantial variation in the data (Figure 5). Crude protein content was greater in grazed areas of some management treatments (Figure 5) and a grazing effect was weakly significant overall (Table 2). The height of standing forage at the clipping site was lower in grazed areas (Figure 5).

(A)


Relative Feed Value
180
160
140
120
100
Grazed
Ungrazed
AGR
NAT
NOS
CTL

(B)



(C)

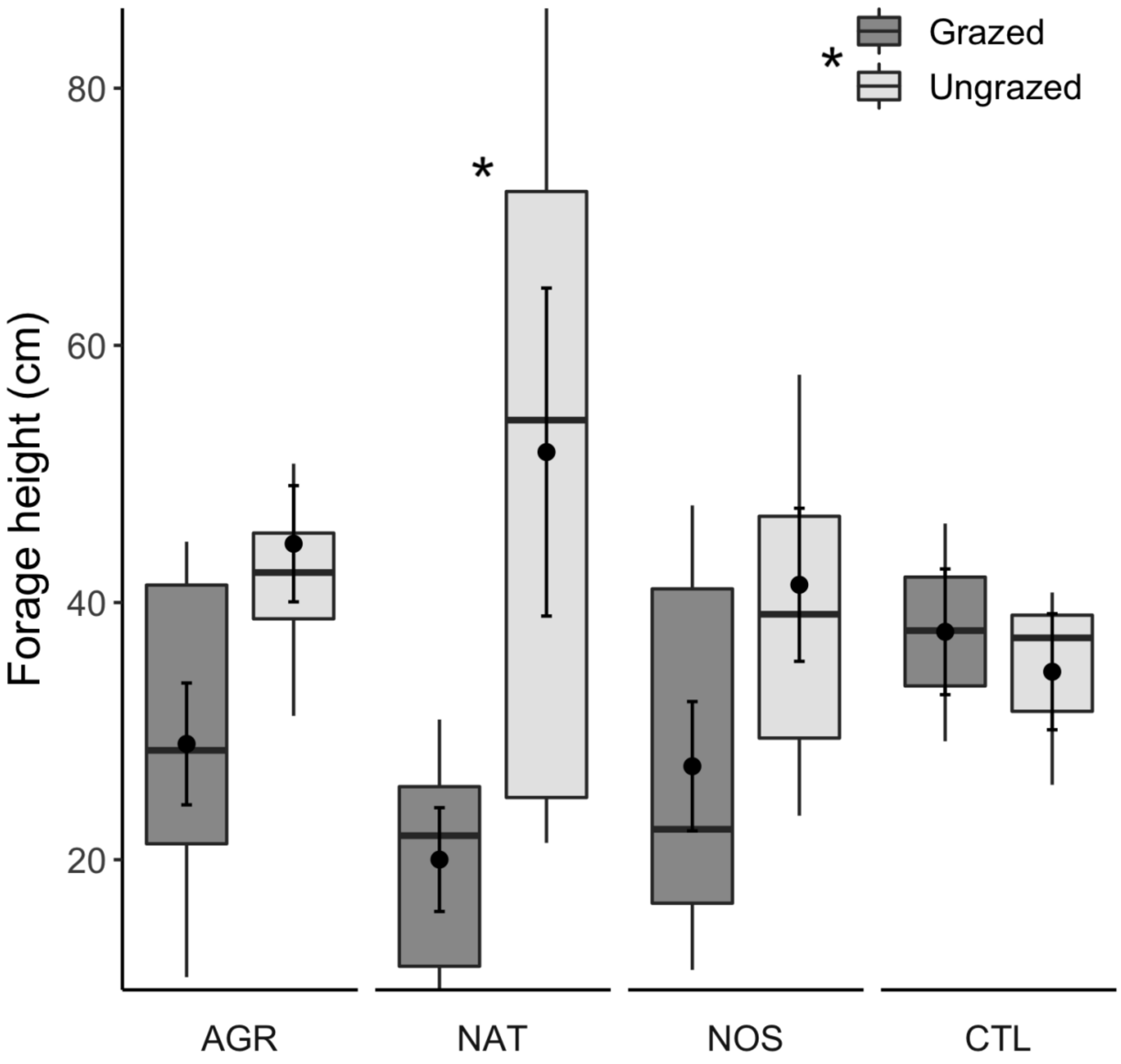


Fig. 5. *Forage quality as assessed by (A) Relative Feed Value, (B) percent crude protein, and (C) forage height in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species woodland in Wisconsin USA. Within each box, horizontal lines denote median values; boxes extend from the 25th to the 75th percentile;*

lines extend a 1.5 interquartile range. Dot and error bars represent mean ± 1 SE. If there was a main effect of management, treatments that share a letter were not significantly different (Tukey HSD, $p < 0.05$). Asterisks mark significant differences between grazed and ungrazed treatments, including pairwise contrasts within management treatments, and marked at the legend if there was a main effect of grazing ($p < 0.05$).

3.2. Soil compaction, fertility, moisture, exposure, and microbiology

3.2.1. Soil compaction

We measured soil strength as an analog of compaction of the soil using a cone penetrometer in the spring of 2018 following one rotation of grazing, and again in the fall following 2-3 additional rotations. There was a significant effect of grazing in the spring and the fall at 0-10 cm (Table 2); there was greater soil strength in the grazed areas at these shallow depths but not deeper in the soil profile (Figure 6).

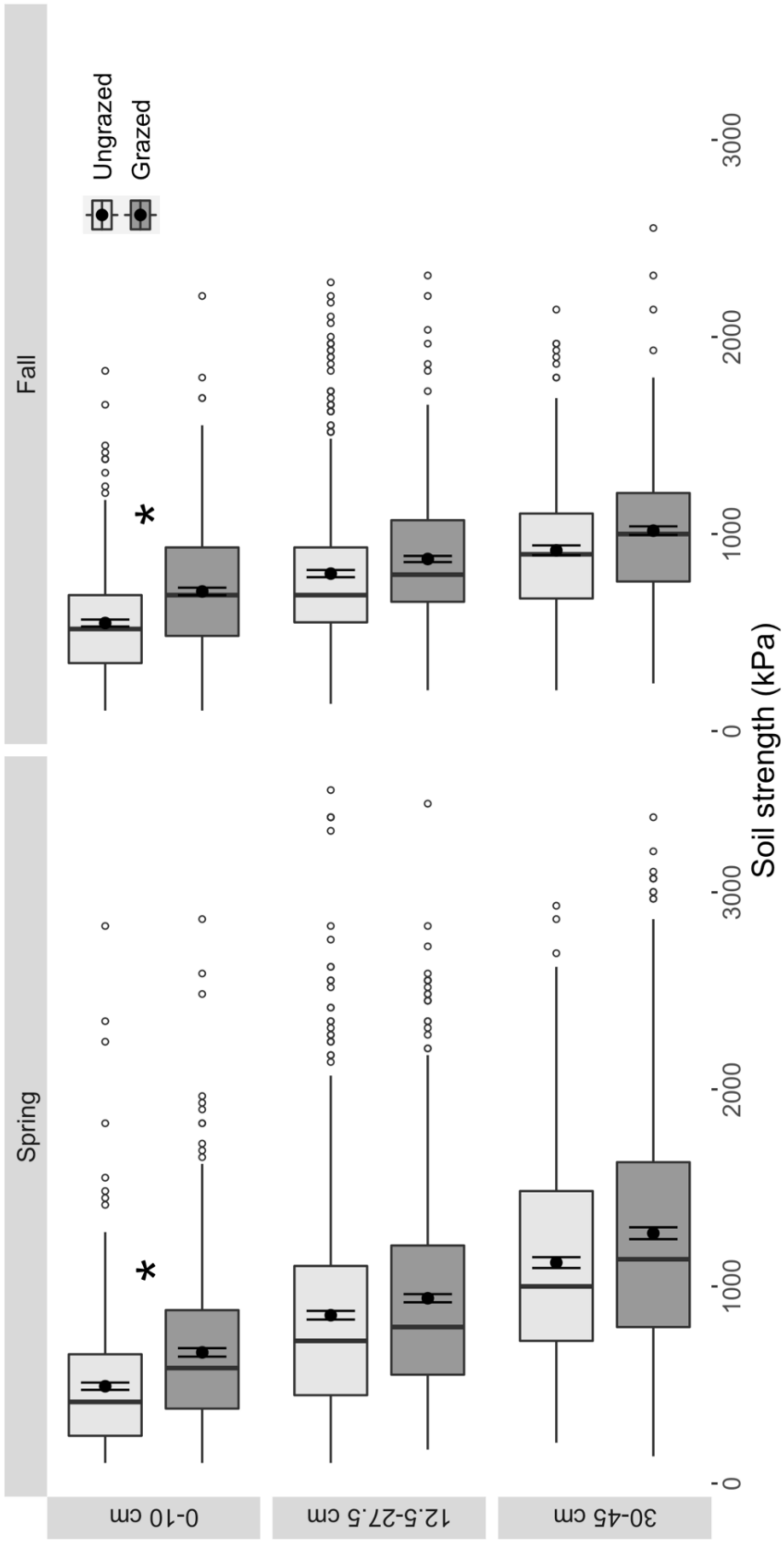

Spring
Fall
0-10 cm
12.5-27.5 cm
30-45 cm
*
*
Ungrazed
Grazed
0
1000
2000
3000
0
1000
2000
3000
Soil strength (kPa)

Fig. 6. *Soil strength measured by resistance to penetration in grazed (GRA) and ungrazed (UNG) plots in a mixed species woodland in Wisconsin USA June 4-5 and September 27-28, 2018. Within each box, horizontal lines denote median values; boxes extend from the 25th to the 75th percentile; lines extend a 1.5 interquartile range and open dots denote observations outside that range. Dot and error bars represent mean ± 1 SE. Asterisks mark significant differences between grazed and ungrazed treatments (*$p < 0.05$*).*

3.2.2. Soil fertility, exposure, and litter depth

Grazing had a significant effect on the bare soil assessed as percent cover (Figure 7). Soil organic matter, phosphorus, potassium, moisture, and litter depth did not differ among grazing treatments or management treatments (Table 2)(Figure 8).

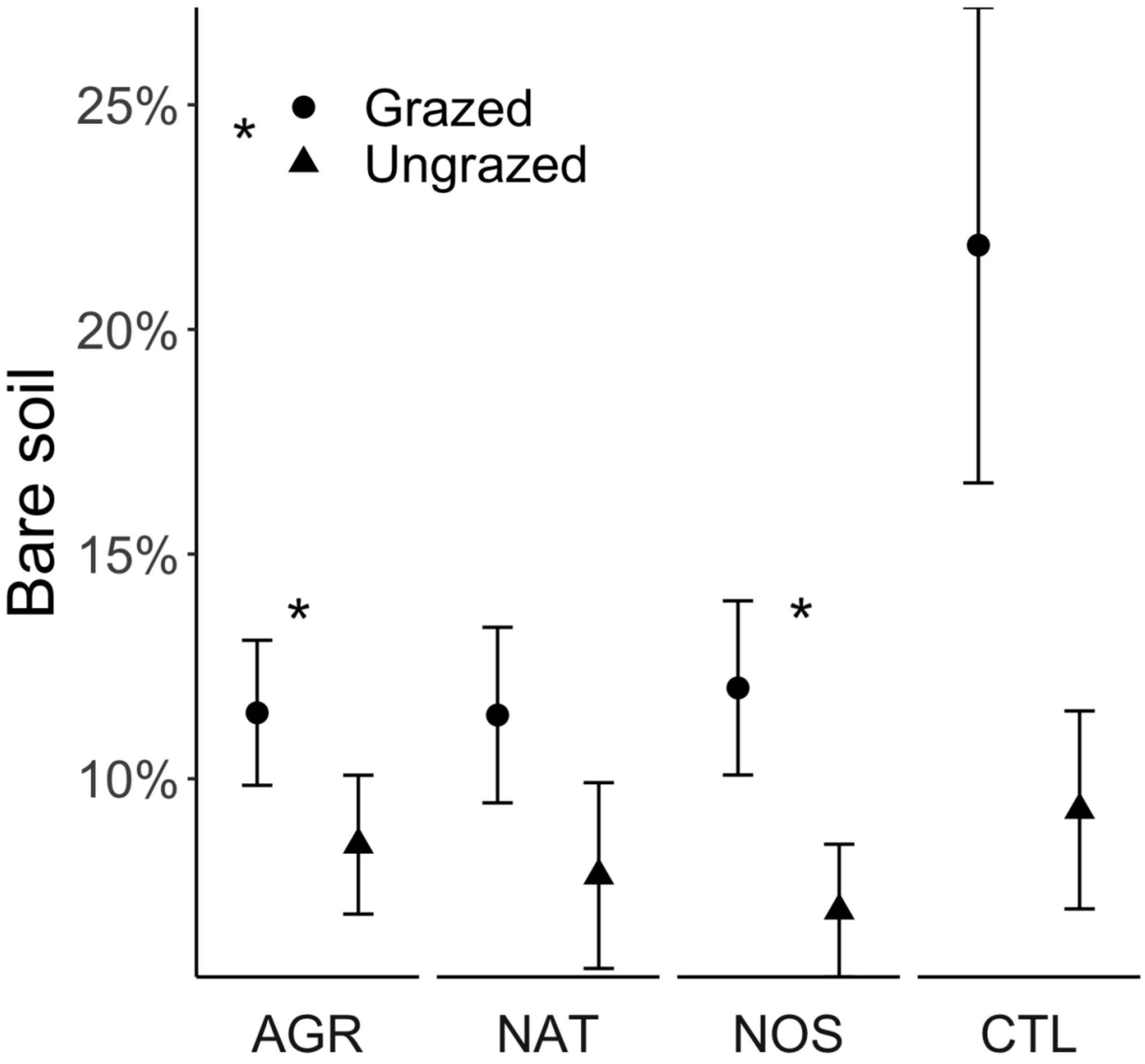


Fig. 7. *Percent cover assessed as bare soil in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species woodland in Wisconsin USA. Values are mean ± SE. Asterisks mark significant differences between grazed and ungrazed treatments, including pairwise contrasts within management treatments, and marked at the legend a main effect of grazing ($p < 0.05$).*

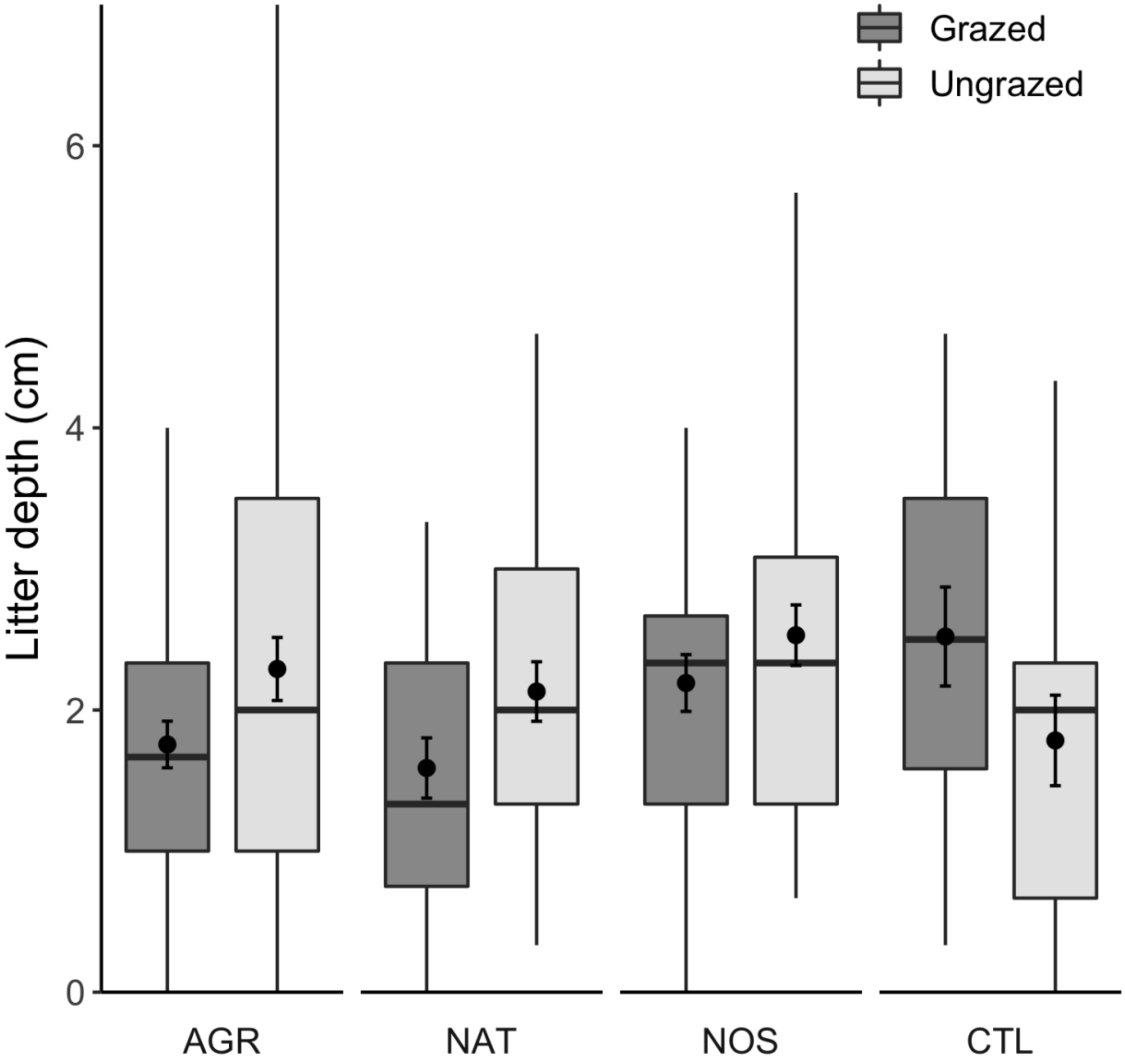


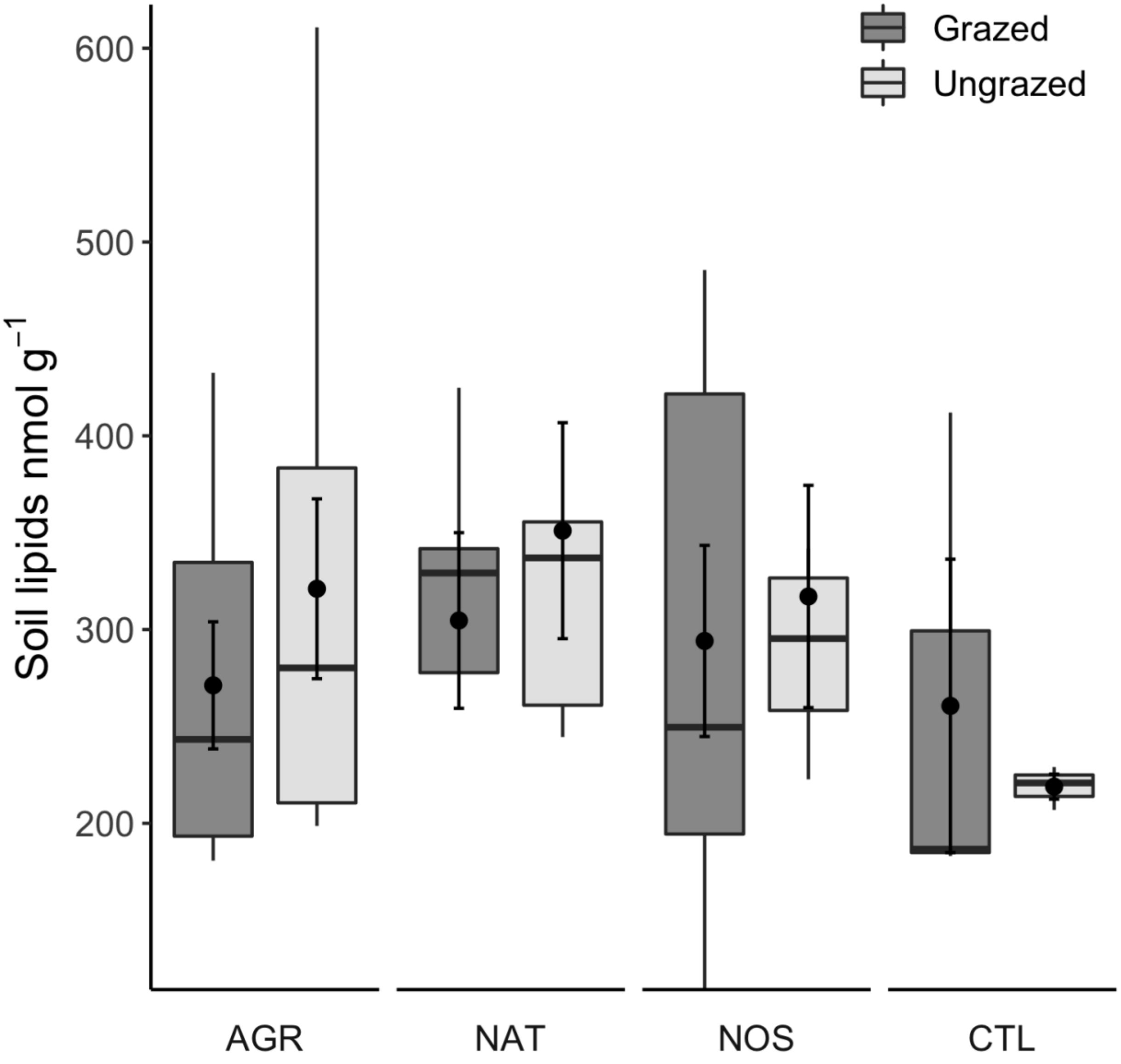
Fig. 8. *Litter depth in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species woodland in Wisconsin USA. Within each box, horizontal lines denote median values; boxes extend from the 25th to the*

75th percentile; lines extend a 1.5 interquartile range. Dot and error bars represent mean ± 1 SE.

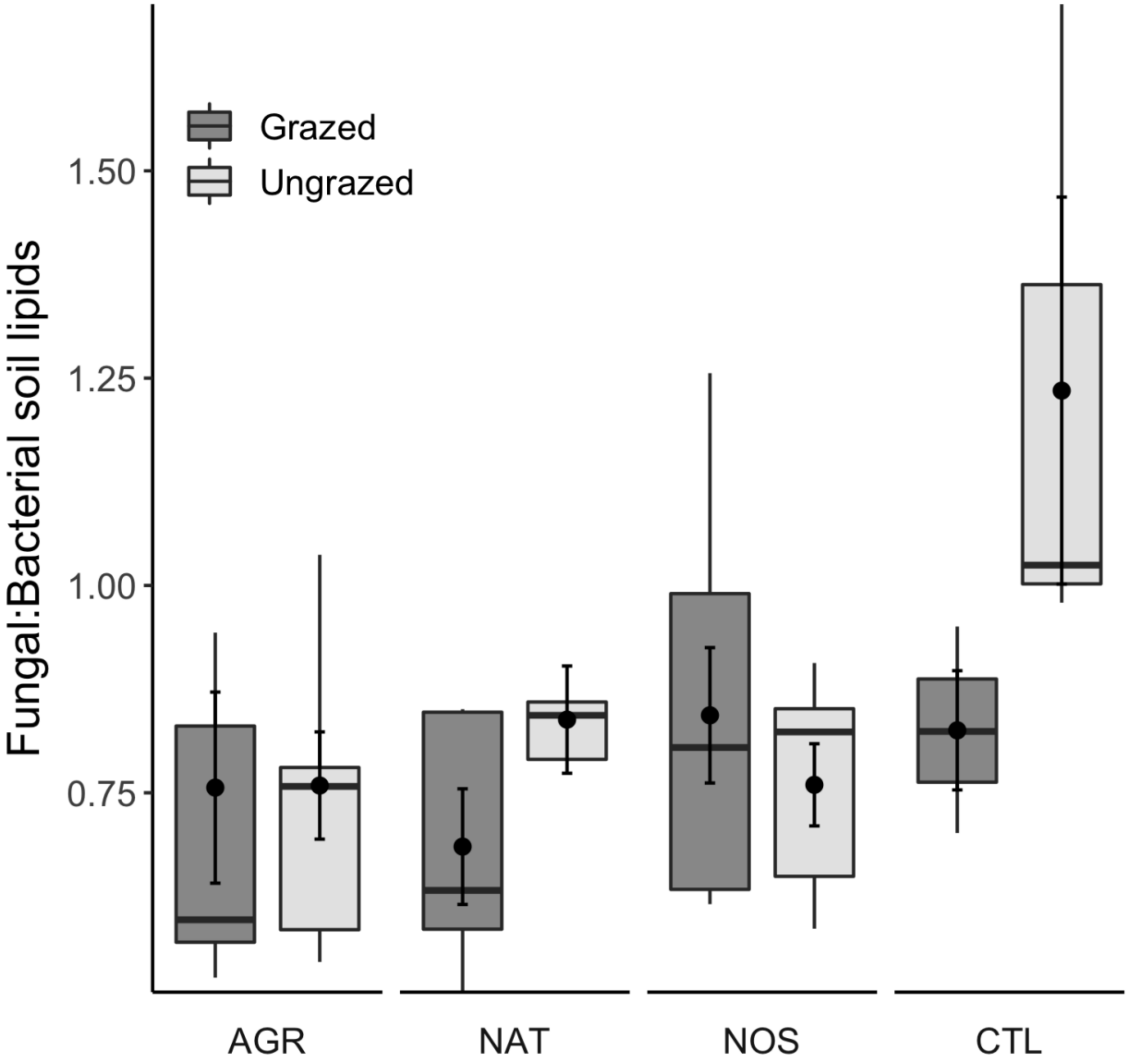
3.2.3. Soil microbial community

We evaluated the abundance of soil microbial taxa using extracted soil lipids as biomarkers. There were no treatment effects on total microbial biomass, bacteria overall, or relative abundance of gram (-) or gram (+) bacteria. There were more abundant fungi in ungrazed areas, including arbuscular mycorrhizal fungi specifically where the canopy was thinned, while there were more actinomycetes in grazed areas (Table 2). The influence of grazing on the ratio of fungi to bacteria abundance was weakly significant and greatest in the ungrazed and unthinned areas (Figure 9).

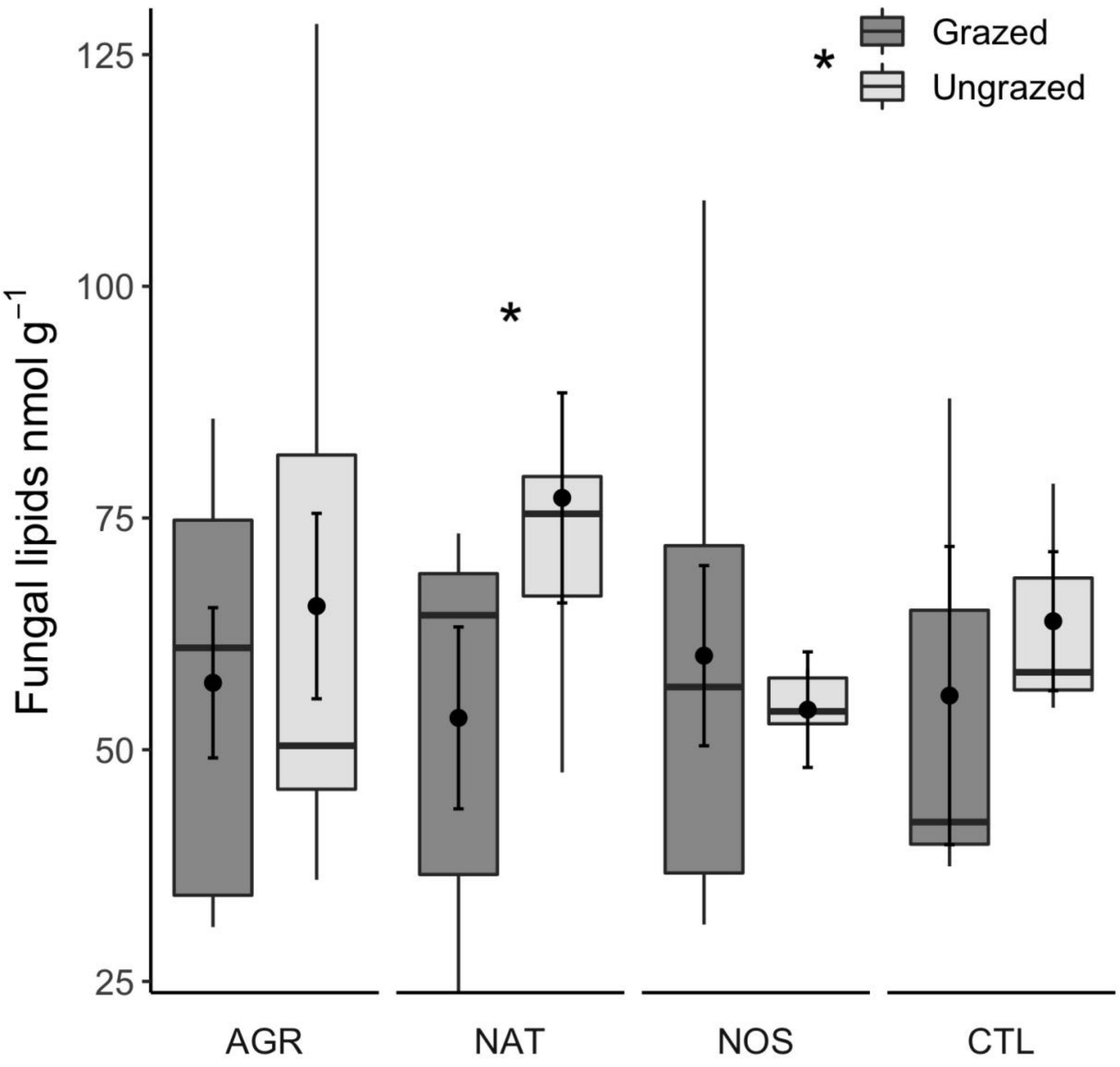
(A)


Grazed
Ungrazed
Soil lipids nmol g^{-1}
600
500
400
300
200
AGR
NAT
NOS
CTL

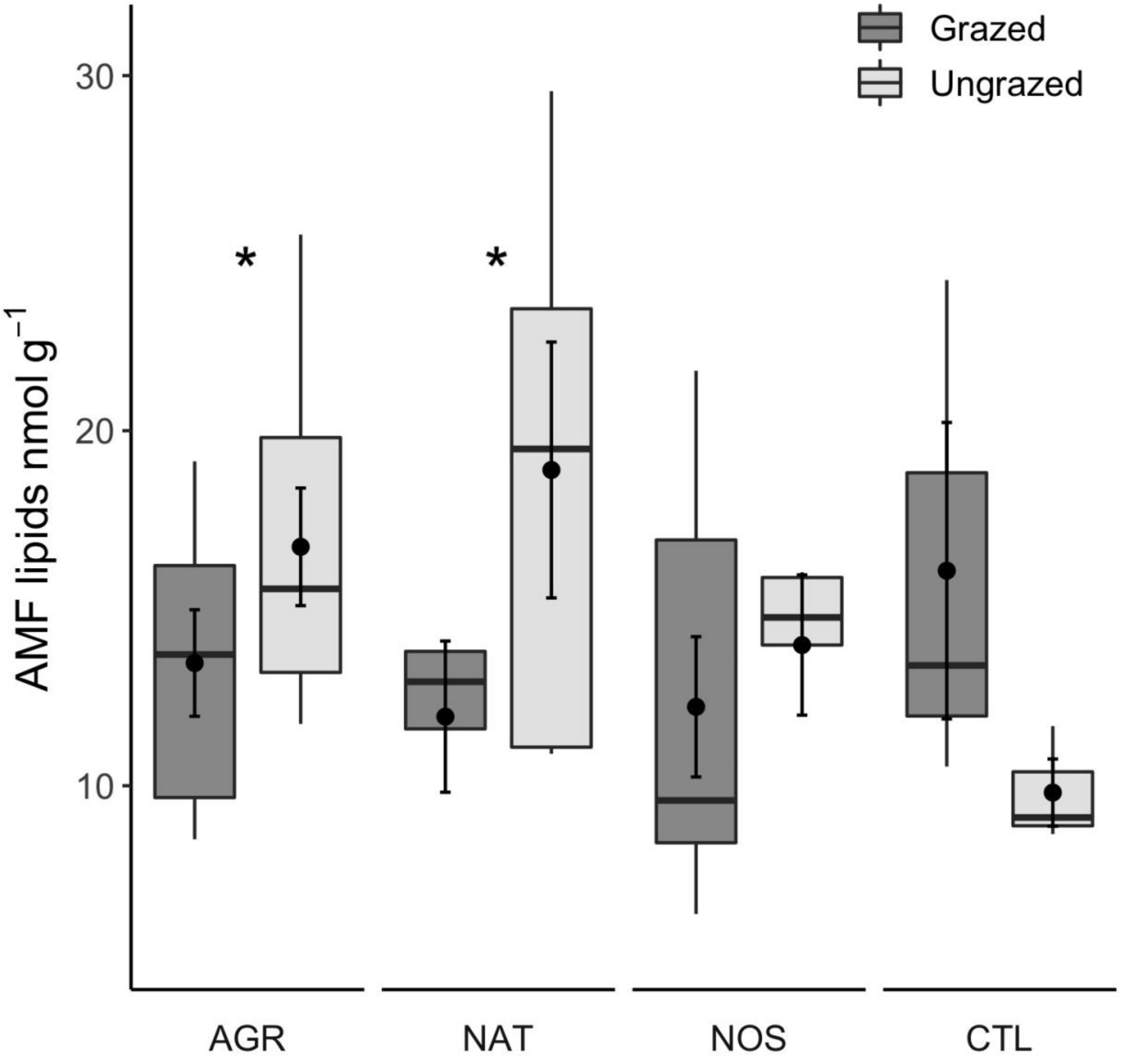
(B)


Grazed
Ungrazed
Fungal:Bacterial soil lipids
1.50
1.25
1.00
0.75
AGR
NAT
NOS
CTL

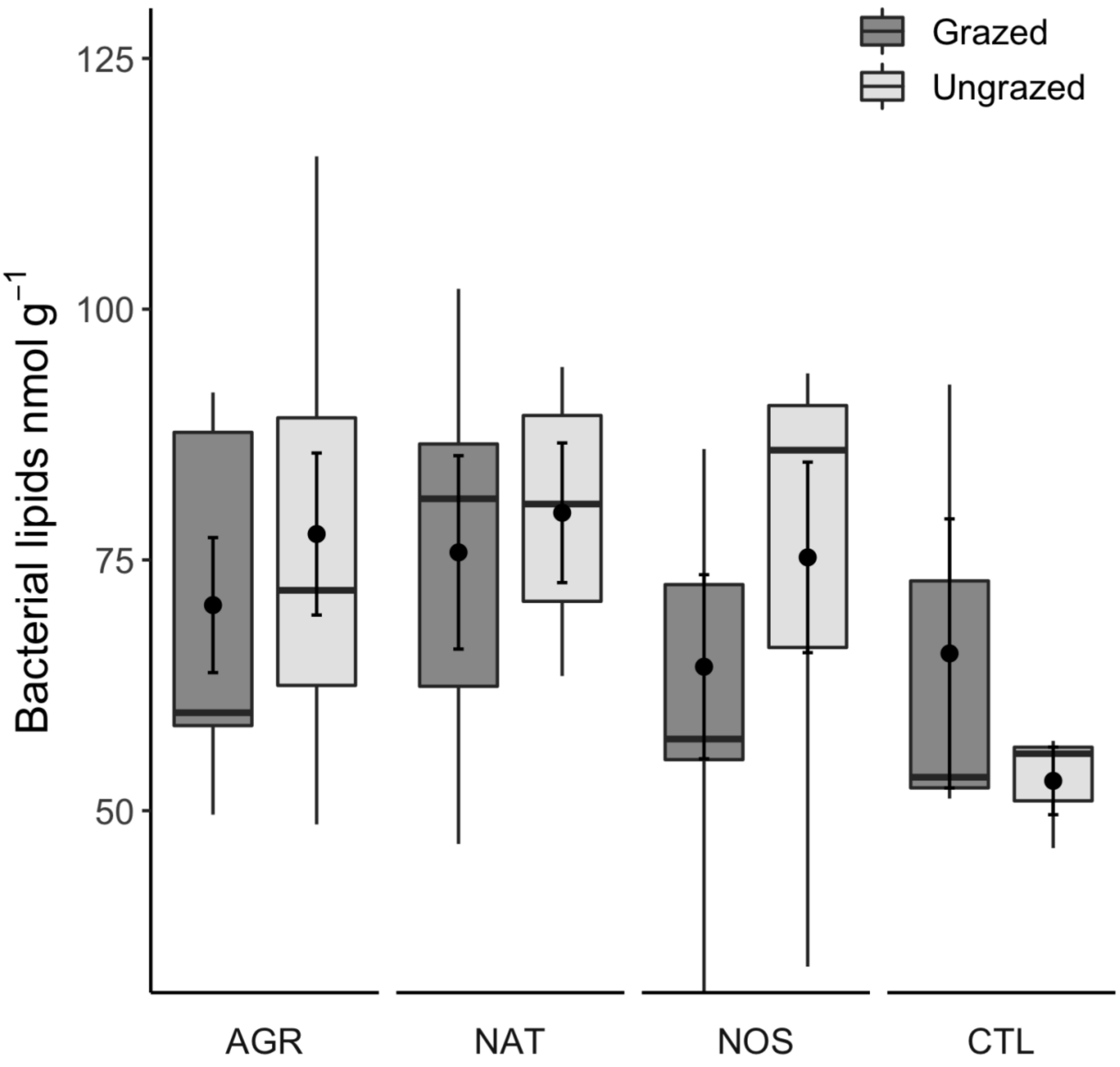
(C)


Fungal lipids nmol g^{-1}
125
100
75
50
25
Grazed
Ungrazed
*
*
AGR
NAT
NOS
CTL

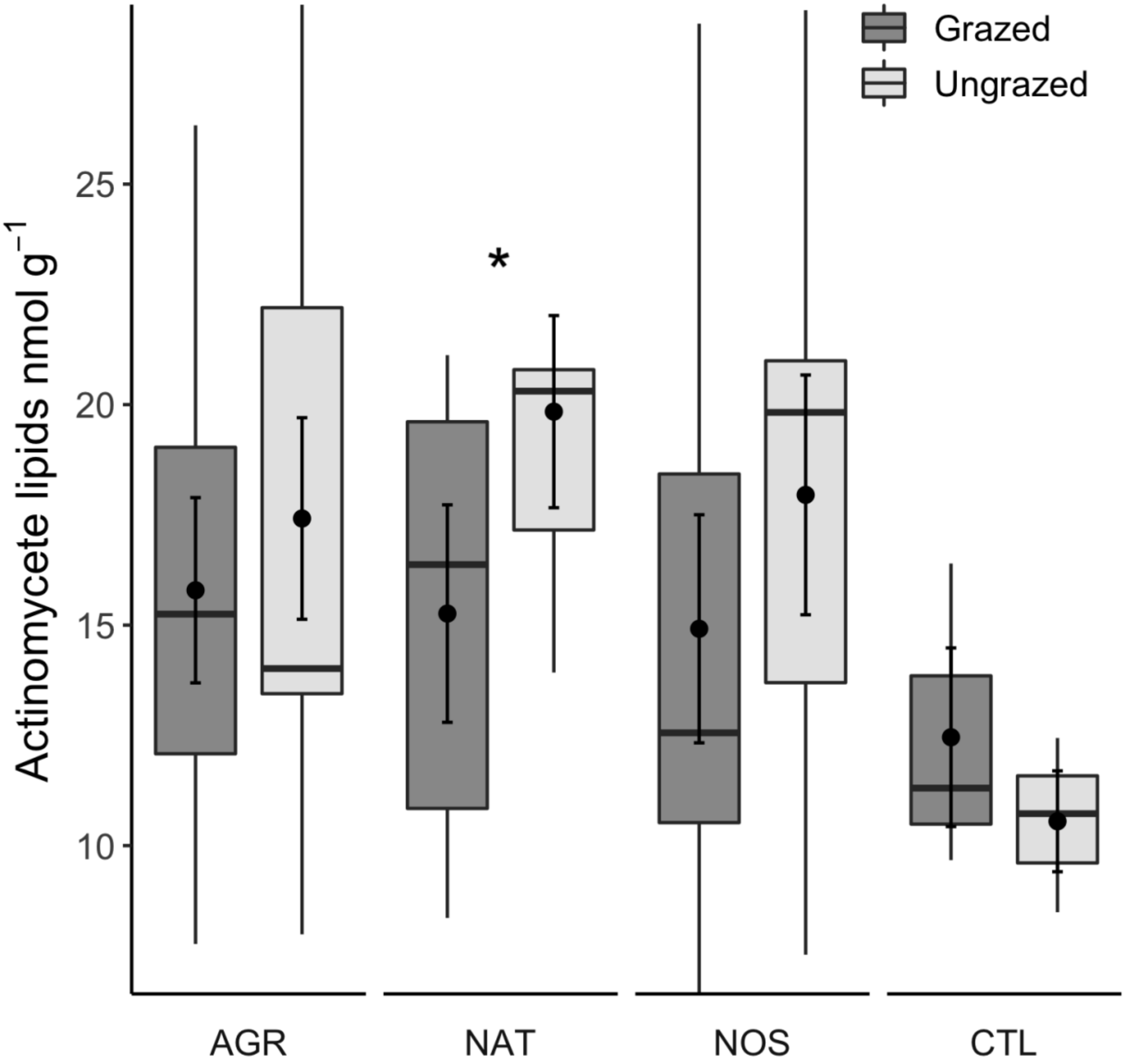
(D)



(E)


Grazed
Ungrazed
Bacterial lipids nmol g⁻¹
125
100
75
50
AGR
NAT
NOS
CTL

(F)


Grazed
Ungrazed
Actinomycete lipids nmol g^{-1}
25
20
15
10
*
AGR
NAT
NOS
CTL

(G)

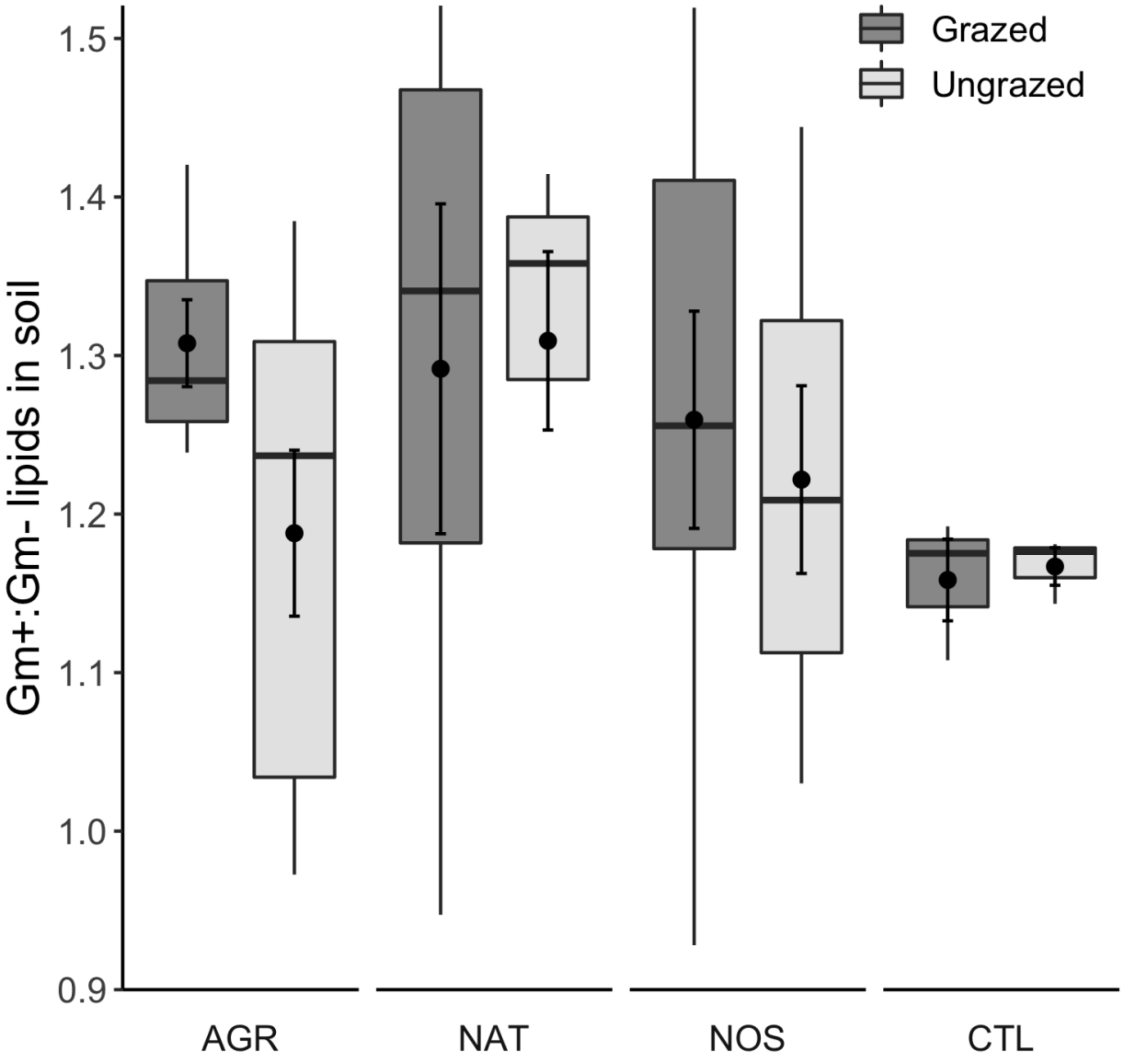


Fig. 9. *(A) Content of total soil lipids (nmol g^{-1} soil); (B) ratio of soil fungal to bacterial lipids; (C) fungal lipids; (D) arbuscular mycorrhizal fungi (AMF) lipids; (E) bacterial lipids; (F) actinomycete lipids; (G) ratio of Gram+ to Gram- bacteria lipids in grazed (GRA) and ungrazed (UNG) plots by nested vegetation management treatments of agricultural seeds (AGR), native seeds (NAT), and no seeds with (NOS) and without (CTL) a thinned canopy in a mixed species*

woodland in Wisconsin USA. Within each box, horizontal lines denote median values; boxes extend from the 25th to the 75th percentile; lines extend a 1.5 interquartile range. Dot and error bars represent mean ± 1 SE. If there was a main effect of management, treatments that share a letter were not significantly different (Tukey HSD, $p < 0.05$). Asterisks mark significant differences between grazed and ungrazed treatments, including pairwise contrasts within management treatments ($p < 0.05$).

4. Discussion

Our study assessed the impacts of silvopasture establishment on plants and soils in mixed species woodlands. We found support for a number of our hypotheses in documenting how grazing and vegetation management influenced a range of responses among plants and soil parameters.

Our hypothesis that grazing would reduce shrub cover was supported where initial treatment two years prior included removing >90% of the shrub layer. In contrast, cattle did not reduce shrub cover in the absence of initial mechanical removal, which is consistent with other observations that as shrubs reach a size refuge, they become less vulnerable to herbivory (Beck and Peek, 2005; Briggs et al., 2005). The preference of cattle and wildlife for browsing young growth sprouts of cut shrubs, compared to mature stems, was reflected in fewer browsed points relative to total woody stems in Control areas (Figure 3). We also observed selective herbivory on native shrubs over introduced shrubs (Figure 3), which could be due to different forage values or palatability among those species (Hedtcke et al., 2009). Galleguillos et al. (2018) found that grazed woodlands in this region had greater shrub cover and more introduced shrub species. This suggests that although grazing may slow shrub encroachment, cattle that selectively browse new growth on native species are insufficient for shrub management in woodland pastures: in addition to initial cutting, further disturbance or alteration of herbivory patterns may be necessary. Furthermore, native shrubs represent a significant portion of the plant diversity on these sites; our results and others suggest that maintenance of this diversity requires adaptive application of multiple disturbance types (Dornbusch et al., 2020; Firn et al., 2013; Royo et al., 2010).

The reduction in diversity we observed where we planted agricultural forages highlights that extirpation of native species is a tradeoff to be expected where this management strategy is pursued (Hejda et al., 2009). The competitive growth habit of forages we planted, as well as greater grazing pressure, may have been drivers of the lower levels of plant diversity observed there. Although it was not a strong effect, our finding that plant species evenness was greatest in the ungrazed control plots was contrary to our hypothesis (Figure 4). This on one hand was not expected since our treatments removed dominant shrubs and added new species, and represented what we expected to be an intermediate level of disturbance would increase evenness (Roxburgh et al., 2004). On the other hand, removing shrubs in wooded pastures can reduce functional diversity (Oksuz et al., 2020), and intensification of land use can lead to the dominance of specific traits that reduce evenness (Hillebrand et al., 2008; Schaub et al., 2020). Our vegetation sampling was limited to the summer season, so we may not have observed some species with growth phenology outside that season such as spring ephemerals.

We found that forage quality was consistently high across management treatments that were rotationally grazed, which suggests that planting introduced forages is not always necessary to improve forage quality in woodland silvopasture in this region (Figure 5). Hedtcke et al. (2009) also reported high shrub forage quality in this region, as well as Highland beef cattle utilization of shrub leaves roughly equal to intake of grass and forbs. Although our study was not designed to evaluate forage yield, which is a primary objective for open pastures and harvested forages, farmers in our study region have cited other objectives of equal or greater importance in woodland pastures, including shade, winter shelter, emergency forage in drought, livestock diet diversity, property tax relief, carbon sequestration, biodiversity, and recreation (Keeley, 2014; Mayerfeld et al., 2016). Planting forages in woodland pastures may not advance these objectives. Furthermore, we found no support for our hypothesis that planting forages reduce the amount of bare soil, although thinning the canopy did reduce bare soil in grazed areas (Figure 7). Given the history of species introductions intended to improve pasturage only to become noxious *(cf. Rosa multiflora* and *Phalaris arundinacea*), our findings suggest that professional recommendation regarding woodland silvopasture should limit planting of introduced forages pending evidence in this region that benefits consistently outweigh costs and risks.

Soil compaction, and the problems it causes for water infiltration and root growth, has long been recognized as an issue with pasturage of woodlands in the Driftless area and globally (Stoeckeler, 1959; Trimble and Mendel, 1995). It is unclear to what degree the effect of grazing on soil strength that we detected in this study represents a consequential difference. Soil strength was in most cases less than 1,500 kPa, the value at which point root growth can begin to be reduced, and in almost all cases below 2,500 kPa, at which point root growth ceases for some plants (Kees, 2005). Sensitivity to soil compaction also varies considerably among plant species (Kozlowski, 1999). Our observations should not be taken as definitive. Soil strength as measured by penetrability in an indirect and moisture-sensitive measure of compaction. Furthermore, our observations were made during the third season of grazing, and while most compaction does happen initially, it can compound over longer time scales.

Beyond the impact of soil compaction on plants, water infiltration is an important ecosystem service in this region, given the catastrophic flooding that the Kickapoo River watershed experiences periodically and increasing extreme precipitation events. We did not measure infiltration directly, and while soil resistance to penetration gives some indication of infiltration, they do not always vary together due to the importance of macropore space to infiltration (Sharrow, 2007). Several recent studies measured infiltration in grazed forest, silvopasture, and open pasture, and found no conclusive differences, but did not include a comparison with ungrazed areas (Stewart et al., 2020; Vaughan, 2016). At the basin scale, baseflow of streams in the Kickapoo River watershed has increased substantially over the last century (Juckem et al., 2008). which has been attributed not only to increased precipitation, but reduced intensity of land use, including grazing, (particularly on hillslopes, which tend to be sandier relative to clayey soils of ridges and loams of valleys), although quantifying these changes based on intensity of grazing remains uncertain (Trimble, 2009). Coble et al., (2020) highlight that relative to open pastures, greater evapotranspiration from silvopastures, however, may help regulate flooding by accelerating water uptake during periods of soil water availability. In woodlands that will continue to be grazed, it is an open question to what degree overland flow in extreme precipitation could be mitigated by implementing rotational versus continuous grazing, and by opening the canopy and thus increasing light to herbaceous layer (Gifford and Hawkins, 1978; Sharrow, 2007; Trimble and Mendel, 1995).

We did not observe any meaningful differences in soil moisture, litter depth, or fertility in terms of macronutrients. In the soil microbial community, there was a weakly significant effect of grazing on fungi:bacteria ratio, which was largely the result of more abundant fungi in the ungrazed areas, as well as more actinomycetes in grazed areas. In grazed areas where canopy and shrubs were thinned, arbuscular mycorrhizal fungi were less abundant than in ungrazed areas. These findings warrant further study to help elucidate how different classes of microbes respond to disturbance, and how microbial community composition can affect carbon cycling and other ecosystem functions (Bardgett and van der Putten, 2014; Malik et al., 2016; Strickland and Rousk, 2010). More detailed studies of soil microbial communities and related changes in soil and ecosystem functions would help us understand both site-level effects and wider landscape impacts of silvopasture establishment, as well as succession-disturbance dynamics in the soil microbiology generally (Fichtner et al., 2014; Giai and Boerner, 2007; Wang et al., 2020).

Interpretation of our findings would be aided by more study of long-term responses to targeted integration of livestock in oak ecosystem management (Dey et al., 2010), as well as assessments across a range of initial conditions. For example, cattle might be integrated with other livestock (Harrington and Kathol, 2009; Rosa García et al., 2012), or be habituated to browsing undesirable shrubs (Petersen et al., 2014). Midwestern oak savanna restoration can benefit from vegetation management in addition to fire (Bassett et al., 2020; Haney and Apfelbaum, 1993), so an analog of patch-burn grazing as practiced in mesic grasslands could be explored for these systems (Scasta et al., 2016). For oak regeneration, the “shelterwood-burn” technique in particular might adapt prescribed grazing to offset costs and aid in shrub management, along with periodic cessation of grazing and fire based on seed mast and seedling recruitment (Arthur et al., 2012; Brose et al., 1999; Iverson et al., 2017; Knoot et al., 2010). Agroecosystem research and management at appropriate temporal scales for these systems could be facilitated by multi-stakeholder planning (Atwell et al., 2010; Chenyang et al., 2020; Keeley et al., 2019; Knoot et al., 2010b; Reynolds et al., 2021).

5. Conclusions

Overall, this study indicated that thinning the overstory canopy and the shrub layer, in concert with rotational grazing, had mixed impacts on plants and soils. Cattle preferentially browsed native over introduced shrub species, so managing introduced shrub encroachment may require adaptive application of multiple disturbances. Planting agricultural forages reduced floristic diversity but did not increase forage quality, which suggests that planting of introduced species should be limited pending evidence in this region that the benefits consistently outweigh the costs and risks of doing so. Bare soil and soil compaction increased in grazed areas, but canopy thinning appeared to moderate the former effect. We saw evidence of compaction in the top 10 cm of soil in the third season of grazing but did not directly assess impacts on plants or water infiltration. Grazing and thinning each influenced the soil microbial community; this warrants more study. Given the historical record of land degradation by overgrazing and contemporary uncertainty with regards to how intensively managed silvopasture can mitigate those impacts, as well as the need to add more successional diversity to oak ecosystems, our findings suggest that ecological outcomes in existing woodland pastures could be improved by prescribed canopy thinning and targeted management of the shrub layer, and that more research is warranted to compare outcomes of various grazing regimes.

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8. Appendices

8.1. Appendix 1: Species planted in treatments

Species planted by seed broadcasting in Agriculture treatment
Dactylis glomerata, Orchardgrass, var. Latar*
Phleum pratense, Timothy, var. Barpenta*

Lolium multiflorum, Annual Ryegrass, multiple vars. In Green Spirit Italian Blend*
Lolium perenne, Perennial Rye, var. BG24T*
Festuca pratensis, Meadow Fescue, HDR Blend*
Festuca pratensis x Lolium multiflorum, Festolium, var. Spring Green
Bromus sitchensis, Brome, var. Hakari
Medicago sativa, Alfalfa, var. Viking
Trifolium repens, Clover, var. Ladino White*
Trifolium pratense, Clover, var. Medium Red*
Lotus corniculatus, Birdsfoot Trefoil
Trifolium hybridum, Clover, Alsike*

Species planted by seed broadcasting in Native treatment
Dicots
*Anemone cylindrica**
Anemone virginiana
Astragalus canadensis
Baptisia alba
Ceanothus americanus
Dalea candida
Dalea purpurea
Desmanthus illinoensis
Desmodium canadense
Desmodium glutinosum
Desmodium illinoense
Dodecatheon meadia
Eryngium yuccifolium
Eupatorium altissimum
Eupatorium maculatum
Eupatorium perfoliatum
Eupatorium purpureum
Lespedeza capitata
Liatris aspera
Liatris pycnostachya
Lysimachia quadriflora
Lysimachia quadriflora
*Monarda fistulosa**
Solidago rigida
Solidago speciosa
Solidago ulmifolia
Thalictrum dasycarpum
Tradescantia ohiensis
*Veronicastrum virginicum**
*Zizia aurea**

Monocots
Andropogon gerardii

Bouteloua curtipendula
Bromus kalmii
Bromus latiglumis
*Elymus canadensis**
Elymus hystrix
Elymus villosus
Elymus virginicus
Festuca subverticillata
Panicum virgatum
Schyzachyrium scoparium
Sorghastrum nutans
Sphenopholis obtusata
Sporobolus heterolepis

**Observed in floristic surveys*

8.2. Appendix 2: Species observed in floristic surveys

Native shrub species observed
Cornus racemosa
Cornus alternifolia
Corylus americana
Rhus glabra
Ribes spp.
Rosa blanda
Rubus occidentalis
Rubus idaeus
Rubus allegheniensis
Prunus virginiana
Prunus americana
Sambucus spp.
Viburnum lentago
Viburnum dentatum
Zanthoxylum americanum

Introduced shrub species observed
Berberis thunbergii
Elaeagnus umbellata
Lonicera maackii
Lonicera morrowii
Rhamnus cathartica
Robinia pseudoacacia
Rosa multiflora

Other woody species observed

Acer negundo
Acer rubrum
Acer saccharum
Betula papyrifera
Carya ovata
Carya cordiformis
Celtis occidentalis
Crataegus spp.
Fraxinus pennsylvanica
Juglans nigra
Juniperus virginiana
Malus spp.
Morus spp.
Ostrya virginiana
Pinus resinosa
Populus grandidentata
Populus tremuloides
Prunus americana
Prunus virginiana
Quercus alba
Quercus macrocarpa
Quercus velutina
Salix spp.
Tilia americana
Ulmus parviflora

Other plant species observed
Acalypha rhomboidea
Actaea rubra
Adiantum pedatum
Ageratina altissima
Agrimonia spp.
Alliaria petiolata
Ambrosia artemisiifolia
Amphicarpaea bracteata
Anemone quinquefolia
Apocynum androsaemifolium
Aquilegia canadensis
Arctium minus
Asclepias syriaca
Aster shortii
Athyrium filix-femina
Barbarea vulgaris
Botrypus virginianus
Calstegia spithamaea
Campanulastrum americanum

Cardamine pensylvanica
Celastrus spp.
Centaurea maculosa
Cerastium fontanum
Chaiturus marrubiastrum
Circaea canadensis
Clematis virginiana
Cryptotaenia canadensis
Cystopteris fragilis
Daucus carota
Dioscorea villosa
Dryopteris carthusiana
Echinocystis lobata
Elymus spp.
Erigeron spp.
Eutrochium spp.
Fragaria vesca
Galium aparine
Galium circaezans
Galium concinnum
Geranium maculatum
Geum canadense
Hackelia virginiana
Helianthus spp.
Heracleum lanatum
Hiercium spp.
Hydrophyllum virginianum
Hylodesmum glutinosum
Hypericum spp.
Lactuca canadensis
Lactuca floridana
Leonurus cardiaca
Leucanthemum vulgare
Lobelia inflata
Lysimachia ciliata
Maianthemum racemosum
Matteuccia struthiopteris
Medicago lupulina
Monarda fistulosa
Onoclea sensibilis
Osmorhiza claytonii
Osmorhiza longistylis
Oxalis stricta
Parthenocissus quinquefolia
Persicaria spp.
Persicaria virginiana

Phalaris arundinacea
Phryma leptostachya
Physalis spp.
Pilea pumila
Plantago spp.
Poa pratensis
Podophyllum peltatum
Polygonatum biflorum
Polymnia canadensis
Potentilla recta
Potentilla simplex
Ranunculus abortivus
Ranunculus recurvatus
Rumex crispus
Sanicula gregaria
Scrophularia marilandica
Smilax spp.
Solanum carolinense
Solanum dulcamara
Solidago spp.
Stellaria media
Taraxacum officinale
Teucrium canadense
Toxicodendron radicans
Triosteum aurantiacum
Urtica dioica
Verbascum thapsus
Verbena urticifolia
Viola spp.
Vitis riparia
Zizea aurea

Chapter Two: Protecting seedling trees and managing competing vegetation in silvopasture establishment: on-farm experiments in the Midwest USA

Keefe O. Keeley, Kristine E. Gruley, Kevin J. Wolz, Stephen J. Ventura

Abstract

Silvopasture – the integration of livestock, forage, and trees – can generate multiple high-value products with minimal off-farm inputs while enhancing ecological functions. Establishing silvopasture via tree planting in pastures remains largely untested in the Midwest USA. We tested techniques for integrating various types of livestock with seedling trees in pastures on four farms in Wisconsin, Illinois, and Indiana. We compared efficacy of different techniques for mitigating livestock and wildlife damage to trees and for reducing competition from nearby herbaceous vegetation. We also conducted semi-structured exit interviews with participating farmers to document their qualitative assessment of strategies to establish and manage trees planted in pastures.

Effective methods for protecting seedling trees and managing competing vegetation in silvopasture varied based on livestock species. Little to no protection was needed for pastured poultry. Wire cages most effectively prevented damage from larger livestock, but this method also was the most expensive and presented challenges for managing competing vegetation. For large-scale silvopasture establishment, a combination of electric fencing with tree tubes worked well for protecting the trees from damage while allowing livestock grazing to help manage competing vegetation. Farmer interviews highlighted that farm context and goals, such as optimizing for time and expense rather than maximizing tree growth and survival, influence appropriate tree protection techniques.

1. Introduction

Most silvopasture establishment research in the USA has occurred within existing stands of mature trees on marginal land (Garrett et al. 2004). Planting seedling trees to establish silvopasture has received relatively little research, especially in actively grazed pastures. Common guidance involves excluding livestock entirely from silvopastures until trees reach sufficient maturity to withstand browsing and rubbing (Nowak et al. 2003). Although in some cases this plant-and-wait approach potentially reduces the expense of protecting trees and the risk of livestock damaging the trees, this guidance is unsuitable for some farms. Financial, logistical, or other factors make it impractical to cease grazing. For some farmers, livestock raised on pasture between tree rows represent a primary revenue stream, and it may not be feasible to harvest a paddock for hay or cultivate another crop. Furthermore, in many areas browsing by overabundant white-tailed deer (*Odocoileus virginianus*) reduces growth and survival of unprotected tree seedlings, so young trees need to be protected from large animal herbivory even if livestock are excluded from the pasture (Strange and Shea 1998).

Successful approaches to establishing trees in active pastures must adapt to context to mitigate both livestock damage and weed competition (Fike et al. 2004). Furthermore, different livestock and wildlife require different protection strategies (Jose et al. 2017). In Virginia, tree tubes and wire cage shelters improved growth and limited livestock damage to tree seedlings in silvopastures (Bendfeldt et al. 2001). Single-strand electric fence protected hardwood seedlings from beef cattle browse in Missouri, while a foliar bittering agent spray was ineffective (Lehmkuhler et al. 2003). Although there are tradeoffs of time and expense in tree protection, low density plantings used for high value tree crops and silvopasture benefit economically from protection (Stace 1993).

Competition from existing vegetation also represents a potential detriment to the growth and survival of seedling trees planted in active pastures (Van Sambeek and Garrett 2004; Balandier et al. 2006). Houx III et al. (2013) demonstrated that herbicide-maintained vegetation-free zones conferred increased growth to black walnut (*Juglans nigra*) in tall fescue (*Lolium arundinaceum*) pastures in Missouri. Organic alternatives such as weed mats may be effective, though Strange and Shea (1998) reported that they can increase deer browse. Livestock have been used to manage undesirable pasture vegetation in a number of contexts (e.g., Harrington and Kathol 2009; Frost et al. 2012; Teague et al. 2013). Further study is needed to determine site conditions and techniques for using livestock to reduce competitive effects of pasture vegetation on seedling trees (Jose et al. 2017).

This study focuses on evaluating techniques to improve establishment success of seedling trees in active pasture by reducing (1) livestock and wildlife damage and (2) vegetation competition. We conducted trials with various combinations of tree protection methods and livestock species in pastures on four farms in Wisconsin, Illinois, and Indiana USA to compare tree establishment outcomes and management costs. The experiments were designed and implemented with cooperators who hosted on-farm trials. We took this participatory research approach to account for the variable contexts of different pastured livestock operations, and we expected effectiveness of tree establishment techniques to vary accordingly by farm. We also conducted semi-structured exit interviews with participating farmers to document their qualitative assessment of strategies to establish and manage trees planted in pastures.

2. Methods

Participating Farms

In 2015, four farms each established silvopasture by planting a diverse selection of seedling trees for fruit and nut crops, timber, forage, shade, and shelter (Table 1, Figure 1). Two farms planted trees into existing pasture/hay, and two farms planted trees contemporaneously with converting row crop fields to permanent pasture. Each farm planted tree seedlings as two-three year old bare root stock.

Driftless Pastures

Michael Dolan owns Driftless Pastures in Iowa County, Wisconsin. He established trees in 70 acres of pasture in 2015 and raised 30 grass-fed steers and 300 pastured broiler chickens. The silvopasture was interplanted more densely in 2016. Driftless Pastures is part of a larger farm (Seven Seeds Farm), which has about 7,000 fruit and nut trees on 70 acres of pastures used by cattle, hogs, chickens, and ducks. One reason Dolan planted silvopasture on Driftless Pastures is because he believes that it mimics the natural ecosystem and will improve the atmosphere, environment, and health.

Nightfall Farm

Elizabeth and Nathan Brownlee own Nightfall Farms in Jennings County, Indiana, where they raise sheep, hogs, chicken, and turkey on pasture. All Nightfall Farm livestock are offered supplemental feed, except for sheep, which are 100% grass/pasture fed. Pasture rotations were as follows: sheep once daily, chickens twice daily, hogs every two to four days, and turkeys every six days. The Brownlees decided to incorporate silvopasture into their grazing plan to help mitigate heat and drought effects on the livestock. In 2015, they established five acres of silvopasture and raised 11 hogs, 1200 chickens, 7 lambs, and 110 turkeys on a combination of feed and pasture that included but was not limited to the silvopasture. They planted 10 acres more silvopasture in 2016 and raised 17 hogs, 1600 broiler chickens, 45 laying hens, 13 lambs, and 100 turkeys on feed and pasture that included but was not limited to the silvopasture.

Green Fire Farm

Jacob Marty co-owns Green Fire Farm in Green County, Wisconsin, where he raises cattle, hogs, turkeys, and chickens on pasture. He planted two acres in silvopasture in 2015 with about 300 fruit and nut trees including chestnuts, persimmons, pecans, redbud, apple, and pear. In 2016, he planted ten more acres with 1000 fruit shrubs, 900 trees, and pollinator habitat vegetation. The trees are intended to provide forage for livestock as well as aesthetic value. Marty planted trees with 45 foot (13.7 m) spacing between rows.

Seven Sisters Farm

Cathe Capel owns Seven Sisters Farm in Champaign County, Illinois and raises sheep and poultry. In 2015, Capel established 10 acres of perennial polyculture and alley cropping, including silvopasture where sheep graze in the alleys. Perennial crops grown on the farm include chestnuts, serviceberries, currants, gooseberries, and hazelnuts. Capel wanted to establish silvopasture to help restore some of her acreage to a sustainable system that provides ecological services to the local watershed and to provide fruit and nuts for her family and a small surplus to sell.

Table 1. *Farms participating in silvopasture establishment study in Midwest USA and features of the experiment conducted at each farm respectively.*

Farm and location	Silvopasture established	Livestock	Trees in trial	Tree protection methods in trial
Michael Dolan Seven Seeds Farm Iowa County, WI	70 acres in 2015 into new pasture; in 2016 interplanted more densely	Cattle	Apple, cherry	Poly single strand fencing 5’ Tree Pro Miracle tubes Arbor Shield wire cages
Elizabeth & Nate Brownlee Nightfall Farm Jennings County, IN	10 acres in 2015 into existing pasture	Sheep, hogs, chickens, turkeys	Ash, bald cypress, hickory, oak, persimmon, willow, pecan, hazelnut	Homemade wire cages Electric net fencing 5’ Tree Pro Miracle tubes
Jacob Marty Green Fire Farm Green County, WI	2 acres in 2015 into new pasture; 10 additional acres in 2016	Hogs, sheep	Apple, chestnut, pecan, plum, basswood	5’ Tree Pro Miracle tubes Blue-X tree tubes Arbor Shield wire cages
Cathe Capel Seven Sisters Farm Champaign County, IL	10 acres in 2015 into existing pasture	Sheep	Chestnut	5’ Tree Pro Miracle tubes 4’ Tree Pro Miracle tubes 18” Tree Pro Bark tubes Arbor Shield wire cages

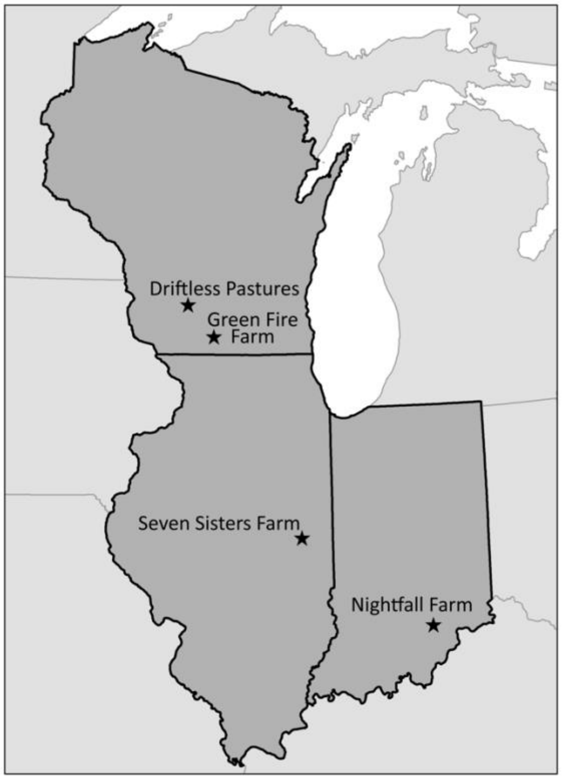

Figure 1. *Locations of four farms in Wisconsin, Illinois and Indiana USA participating in the study.*

Study Design

Each farm tested at least two of the following treatments against a no-protection control:

1) portable single-strand electric fencing
2) portable net electric fencing
3) polyethylene tubes
4) steel wire cages

Each treatment was replicated at least twice on each farm and measurements were taken on a standard number of trees in each replicate (Table 2). Treatment locations at each farm were assigned randomly except on Nightfall Farm due to practical constraints. Some farms tested multiple models of polyethylene tree tubes. Farms conducted tests with one or more livestock species, including cattle, sheep, hogs, chickens, and turkeys. This study design allowed comparison of treatments and livestock species within farms as well as contrasting findings among farms as distinct experiments.

On each farm, we made measurements on seedling trees and adjacent vegetation (referred to as weeds due to potential competition with trees, though in most cases these were also forage for livestock) before and after at least one grazing event in 2016 and 2017. Some treatments were discontinued in 2017.

Table 2: *Data collection at farm trials recorded level of browse damage and competing vegetation on seedling trees assigned different protection treatments following a protocol including the parameters as shown here.*

Before or After Livestock	**Protection Treatment**	**Lives tock**	**Tree Species**	**Browsed or damaged**	**Tree Height**	**Weed height at tree**	**Weed height @ 30cm**	**Weed height @ 1m**	**Weed cover 30cm**	**Weed cover 1m**
B-Before or A-After Rotation	Drop down menu	Drop down menu	Drop down menu	H-Heavy S-Some N-None	Record in cm	Record in cm	Record in cm	Record in cm	H-Heavy S-Some N-None	H-Heavy S-Some N-None

We conducted semi-structured exit interviews with each participating farmer to document their qualitative assessment of techniques tested to establish pasture trees on their respective farms. Interviews discussed objectives and approaches for planting trees, and lessons learned about combinations of livestock, trees, protection techniques, paddock layout, and management.

Materials

Materials used for the on-farm trials of pasture tree seedling establishment methods included:

- electric net fence (~$130/164’ [50 m]; ElectroNet 9/35/12 Electric Netting, Premier 1 Supplies, Washington, IA, USA)
- polyethylene single-strand electric fence (~$36/660’ [221 m]; 1/16” Poly Wire, Gallagher, Oswego, IL, USA)
- electric fence energizer ($200)

- pig-tail posts (~$4 each)
- t-posts for temporary corners (~$5 each)
- 2’ (0.6 m), 4’ (1.2 m) and 5’ (1.5 m) Tree Pro brand polyethylene tube tree protectors ($0.90 Bark Pro, $3.35 and $4.05 Miracle Tubes, Tree Pro Inc, West Lafayette, Indiana, USA)
- Blue-X TreeShelter polyethylene sleeves ($4.00 each, Blue-X Enterprises, Inc., Sacramento, CA, USA)
- Arbor Shield steel wire cages ($29.77 each, Cobacha LLC, New York, NY, USA)
- materials for homemade steel wire cages ($10.64 each, custom cut 8’x4’ welded steel wire in 4-inch panels, ½” diameter steel rebar)

Analysis

Each livestock species within each farm was analyzed independently as a separate experiment each year. Tests for differences among treatments were conducted with data collected after grazing events. Differences in response means among treatments were determined by one-way ANOVA, with pairwise differences tested via Tukey HSD or Tukey-Kramer post hoc analysis. In experiments with two treatment levels, t-tests were performed. Data were analyzed using SYSTAT 10 (San Jose, CA). Presence/absence data for Seven Sisters Farm tree damage data were analyzed using Pearson’s chi square test. Significant differences are reported at $p < 0.05$. In figures with box plots, boxes extend from the 25th to the 75th percentile with a horizontal line to denote median values; vertical lines extend a 1.5 interquartile range; outlier observations beyond that range represented by dots; the ‘X’ represents an inclusive mean.

3. Results

Driftless Pastures

The farm compared effects of cattle grazed rotationally in paddocks with unprotected seedling trees, as well as trees protected Arbor Shield wire cages, Tree Pro Miracle Tubes, and single-strand electric fencing set at a distance of 30-60 cm from trees. In 2016, tree height was greatest in the electric fencing treatment (Figure 2). Cages were most effective at protecting trees from damage ($F_{3,76} = 58.9$, $p < 0.0001$; Table 3). Single-strand electric fencing was also significantly better than tree tubes and no protection treatments at reducing browsing damage from cattle (Table 3). Notably, some of the damage sustained on unprotected trees and trees protected by tubes included reduction in tree height after cattle grazing (Figure 2).

Weed heights near trees protected by single-strand electric fencing were significantly higher than all other treatments (Figure 2). For all other treatments, weed height within a meter of the trees was relatively well controlled by grazing events with the exception of 0 cm distance from trees protected by wire cages (Figure 2). For trees protected by wire cages, weed heights 0 cm from the trees increased post grazing since cattle were not able to access vegetation within and immediately adjacent to the cages.

Table 3: *Browsing damage on seedling trees by visual estimate index after grazing by cattle for each protection treatment at Driftless Pastures in 2016 (each treatment n=20). Index classifications were 1: little to no browsing damage (0-33% foliage removed), 2: moderate browsing damage (34-66% foliage removed), 3: high browsing damage (67-100% foliage removed), and 4: dead. Means not sharing a letter are significantly different (Tukey-Kramer p < 0.05).*

Treatment	***Damage (±variance)***
No protection	2.50 (±0.26)a
Arbor Shield cages	1.05 (±0.05)c
5’ Tree Pro tree tubes	2.65 (±0.24)a
Single-strand electric	1.50 (±0.26)b

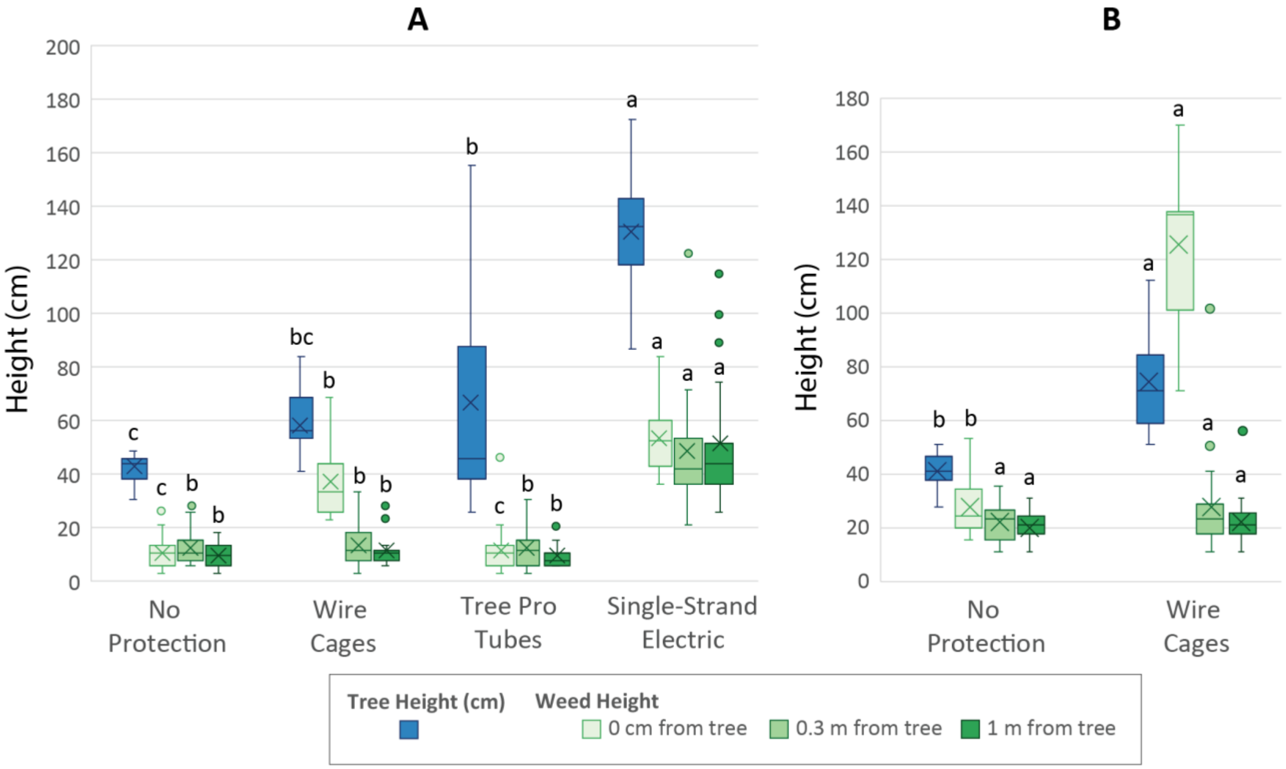

Figure 2: *Tree height and weed height after cattle grazing events in (A) 2016 and (B) 2017 at Driftless Pastures in Wisconsin USA. Tree protection treatments included a no protection control, Arbor Shield wire cages, 5' (1.5 m) Tree Pro tree tubes, and single-strand electric fencing (each treatment n = 20). Response means that share a letter were not significantly different within respective measurements among other treatments, i.e., within the same shade of color (Tukey-Kramer $p < 0.05$).*

Farmer observations

Although wire cages were the most effective at controlling browsing, cages were also the most time consuming and expensive to install. Single-strand electric fencing was found to be highly effective at protecting trees from damage, and aa worked well for adult cattle. Calves, however, could get under the fences and damage trees. Another potential downside of single-strand electric fencing is that weed pressure was the highest (Figure 2). Tubes were found least effective for protecting trees from damage, as cattle could easily knock over the tubes and browse or trample the trees.

For farms establishing a small number of trees in a pasture with cattle, wire cages are likely the best option for protecting trees from browsing damage if there is a method for controlling weed pressure immediately adjacent to the trees. Cages can also be used multiple times for additional tree establishment. Cattle tended to respect these protection mechanisms and did not graze right up to the cages. Because of the labor and expense of cages, however, observations outside replicated trials suggested that a combination of electric fencing with tree tubes work very well protecting the trees and would be better for larger scale establishments. One benefit to using the tree tubes in conjunction with a single-strand electric fence is that newly establishing trees can be located within the pastures when weeds are high (Figure 3). The tree tubes are especially beneficial for slower growing trees, such as chestnuts. Additionally, towards the end of the grazing seasons, deer can become a problem eating trees, so consideration must be made for protecting establishing trees from both livestock and deer.

In addition to controlling pasture/weed height by livestock, weeds were mowed once a year during mid-summer. Fences were moved to get both sides of the tree rows and were mowed as closed to the trees as possible without harming them. The felled pasture/weeds also provided mulch to help keep weed pressure down around the trees. Dolan found diminishing returns to mowing more often than once per year.

After two more grazing seasons, Dolan is excited about the progress of the silvopasture establishment, and it is a great diversity tool for the farm. It can provide more options down the road, especially if one farming enterprise is not performing. Additionally, Dolan is eager for livestock to begin to benefit from the shade and additional fodder as the trees start to produce fruit and nuts.

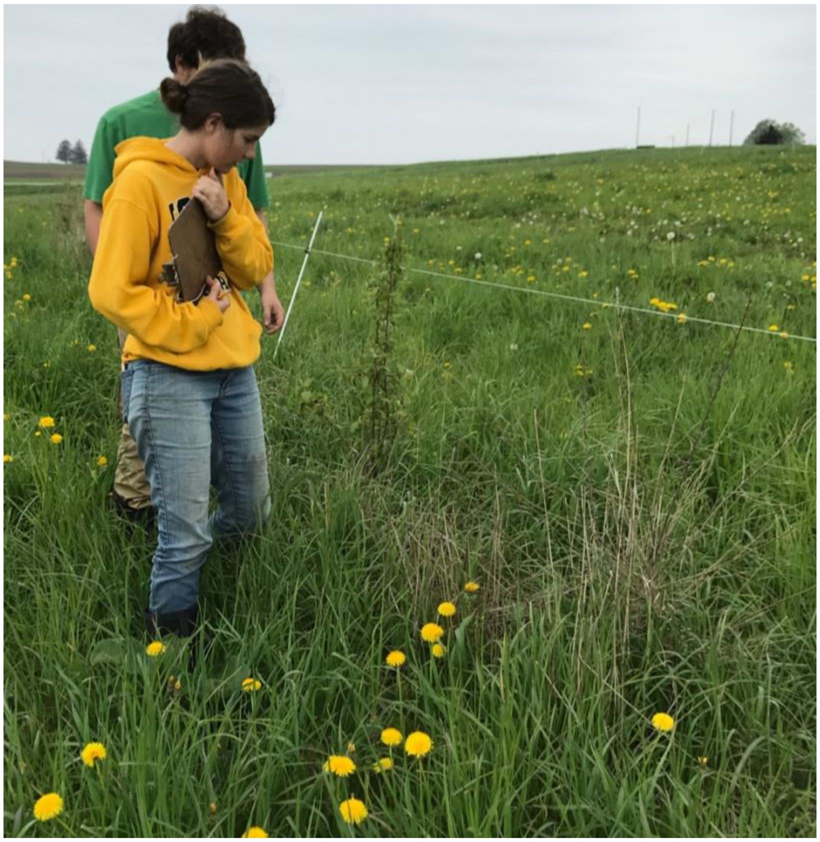

Figure 3: *Photo of Chloe Park and Michael Dolan at Driftless Pastures measuring tree and weed height in a paddock with trees protected by single-strand electric fencing. Notice the weed height makes it difficult to see trees. Photo by K. Gruley.*

Nightfall Farm

Tree heights were greatest when protected by wire cages in sheep and poultry silvopastures (Figures 4 and 5). Browsing damage by sheep was significantly higher on unprotected trees compared to all other treatments ($F_{2, 89} = 46.45$, $p < 0.0001$; Table 4). In fact, after the first grazing season, 90% of the unprotected trees were heavily damaged after sheep grazing. By the end of the second grazing season, only a quarter of the unprotected trees sustained little-to-no damage, and over 50% of the trees were heavily browsed. In contrast, very little damage was seen on unprotected trees by poultry. Of the unprotected trees in the control plots, oak, persimmon, willow, and bald cypress were damaged after a grazing event (Table 5).

Electric net fence and wire cage treatments were mulched, so comparisons of livestock impacts on competing vegetation were limited to between tubes and no protection controls (Figures 4 and 5).

Table 4: *Browsing damage by visual estimate index after grazing by sheep and poultry for each protection treatment at Nightfall Farm in 2017. Index classifications were 1: little to no browsing damage (0-33% foliage removed), 2: moderate browsing damage (34-66% foliage removed), 3: heavy browsing damage (67-100% foliage removed), and 4: dead. Means within livestock not sharing a letter are significantly different (Tukey-Kramer p < 0.05).*

Livestock	***Treatment***	***n***	***Damage (±variance)***
Sheep	No protection	20	2.8 (±0.4)a
	Electric net fencing	30	1.1 (±0.3)b
	5’ Tree Pro tree tubes	22	1.2 (±0.3)b
	Homemade wire cages	21	1.2 (±0.2)b
Poultry	No protection	25	1.1 (±0.4)a
	Electric net fencing	20	1.2 (±0.5)a
	5’ Tree Pro tree tubes	22	1.2 (±0.3)a
	Homemade wire cages	21	1.4 (±0.5)a

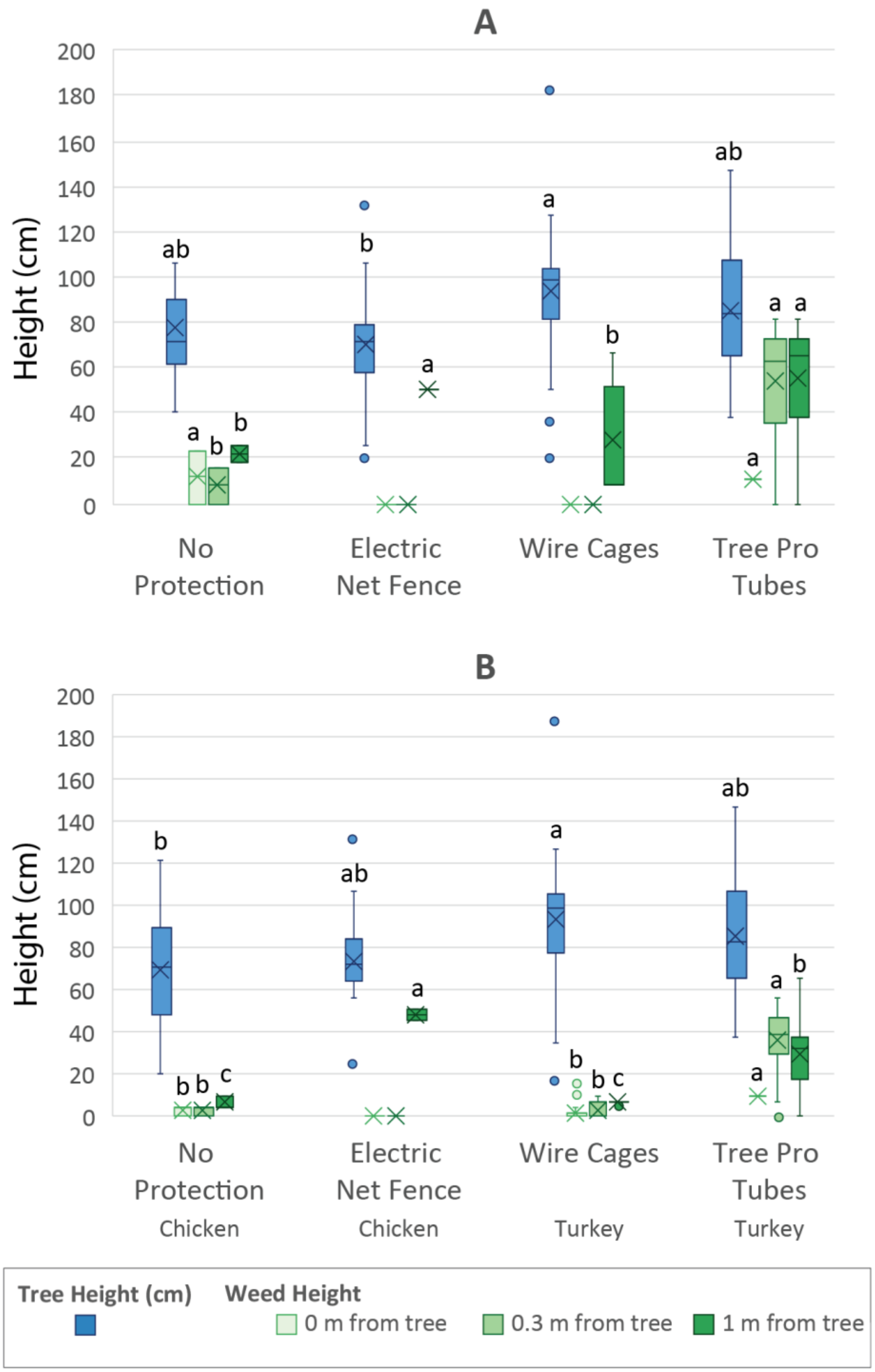

Figure 4: *Tree height and weed height after grazing events in (A) sheep and (B) poultry silvopastures at Nightfall Farm in 2016. Tree protection treatments included a no protection control (A: n = 20; B: n = 25), electric net fencing (n = 22), homemade wire cages (n = 21), 5' (1.5 m) Tree Pro Miracle Tubes (A: n = 30; B: n = 20). Response means that share a letter were not significantly different within respective measurements among other treatments for each livestock class, i.e., within the same shade of color (Tukey-Kramer $p < 0.05$).*

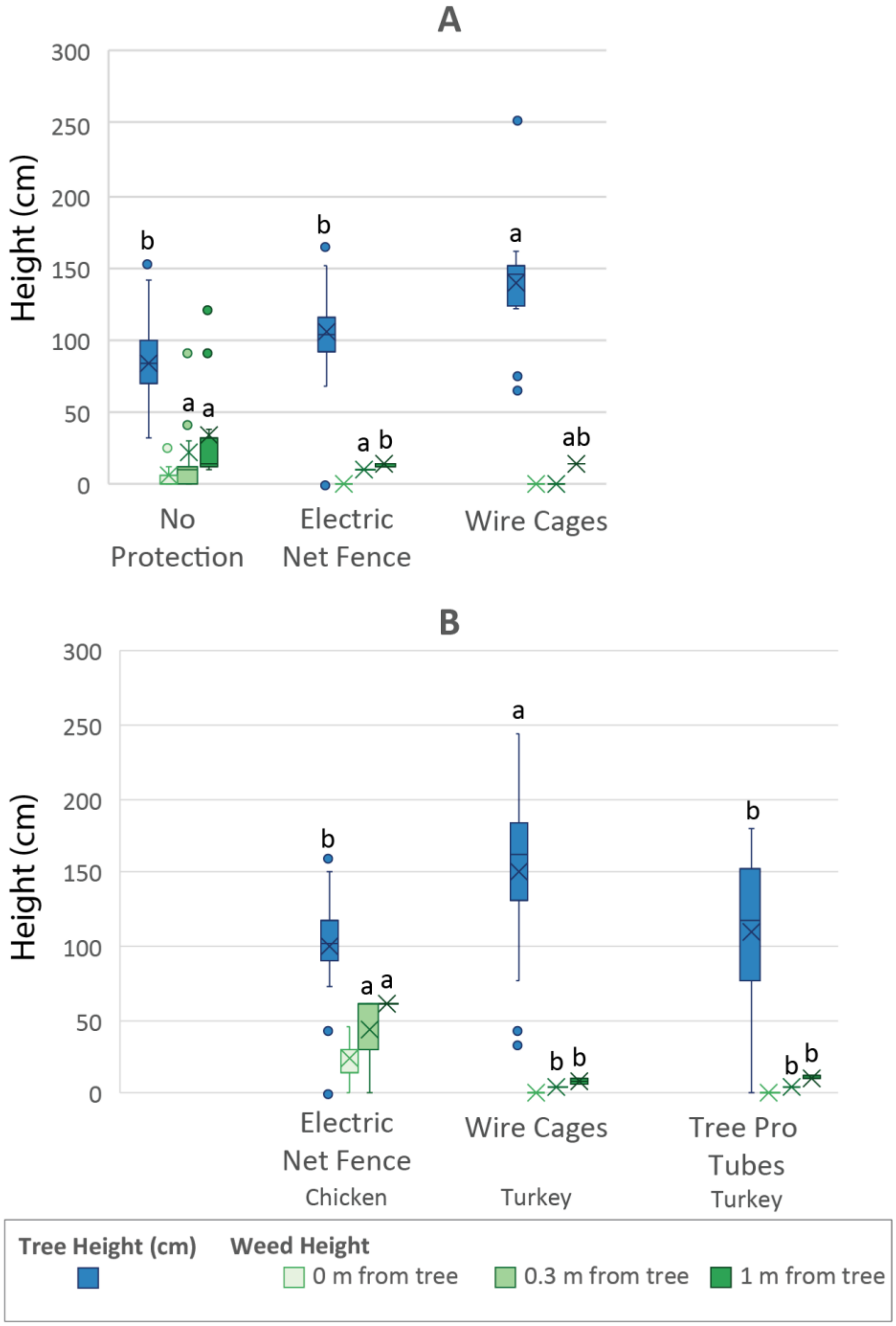

Figure 5: *Tree height and weed height in (A) sheep and (B) poultry silvopastures in 2017 at Nightfall Farm. Tree protection treatments included a no protection control (n = 40), electric net fencing (n = 21), homemade wire cages (A: n = 10; B: n = 20), and 5' (1.5 m) Tree Pro Miracle Tubes (n = 19). Response means that share a letter were not significantly different within respective measurements among other treatments for each livestock class, i.e., within the same shade of color (Tukey-Kramer p < 0.05).*

Table 5: *Assessment of damage to trees before and after sheep grazing events by tree during 2016 at Nightfall Farm.*

	Before				**After**			
	None	**Some**	**Heavy**	**Dead**	**None**	**Some**	**Heavy**	**Dead**
Oak (*Quercus spp.)*	9	0	0	0	5	0	**4**	0
Persimmon (*Diospyros spp.)*	19	0	0	4	9	0	**10**	4
Ash (*Fraxinus spp.)*	2	0	0	0	2	0	0	0
Hickory (*Carya spp.)*	3	0	0	0	3	0	0	0
Willow (*Salix spp.)*	5	0	0	0	1	0	**3**	**1**
Bald Cypress (*Taxodium distichum*)	3	0	0	0	2	0	**1**	0

Farmer observations

Wire cages worked the best for protecting the trees from livestock; the trees were taller than trees in other treatments. After sheep grazed the establishing silvopastures, trees were often stripped of leaves, at least partially; however, they almost always bounced back. Sheep loved rubbing on the tree tubes and would often bend some of the tubes in half, or completely knock the tubes as well as the trees down. They typically tended to focus their rubbing on a few tubes, leaving the rest standing.

Weed height patterns after poultry grazing were different than for sheep. Given that chickens caused little to no browsing damage to trees, and the weed heights surrounding these trees decreased, tree protection treatments may not be necessary when establishing silvopasture with poultry. Weed pressure was reduced by both sheep and poultry where weeds were not kept artificially low by mulching.

Although not in the study, hogs were also grazed in establishing silvopasture at Nightfall Farm. In general, hog grazing was problematic for unprotected trees—especially species like persimmon. Sycamores (*Platanus occidentalis*) and cottonwoods (*Populus deltoides*) held up better to hog rooting.

The amount of forage available in pastures exceeded the capacity of livestock to graze it; thus, some alternative weed management practices were employed. Once a year, usually in the spring, old paper feed bags were laid down near trees with overlying bark mulch to keep the weeds down. Pastures were grazed twice a year, resulting in tall pastures with many plant species.

Overall, the trees are doing well and the Brownlees are happy with their silvopasture progress—the trees are starting to be noticeable from the road. They are happy that that the silvopasture is fulfilling their goals and it is not much effort to maintain after the initial planting was done.

Green Fire Farm

Tree protection techniques tested were 5’ (1.5 m) Tree Pro Miracle Tubes (hogs and sheep), 5’ (1.5 m) Blue-X tree tubes (hogs and sheep), and Arbor Shield wire cages (hogs), and a no protection control (hogs). Electric net fence was used to partition paddocks by treatment. Wire cages were the best at protecting trees from damage by hogs ($F_{3,16} = 15.3$, $p < 0.0001$; Figure 6), as this was the only method that prevented damage and tree height reduction, and the only treatment in which all trees survived. Almost all other trees in the other three protection treatments died after hog grazing the first year. In sheep silvopastures, trees protected by Tree Pro Miracle Tubes were taller than trees protected by Blue-X tree tubes by the second year (Figure 6).

Arbor Shield wire cages showed the greatest weed heights close to the tree, decreasing in height reduction with distance from the tree (Figure 6). Conversely, weed height was lowest closest to the trees in the unprotected and tree tube protection treatments after hog grazing and were higher with increasing distance from the tree/tube. These patterns demonstrate that the hogs were attracted to the unprotected trees and tree tubes and effectively repelled by the wire cages. Sheep grazed down weed height close to the tree tubes (Figure 6).

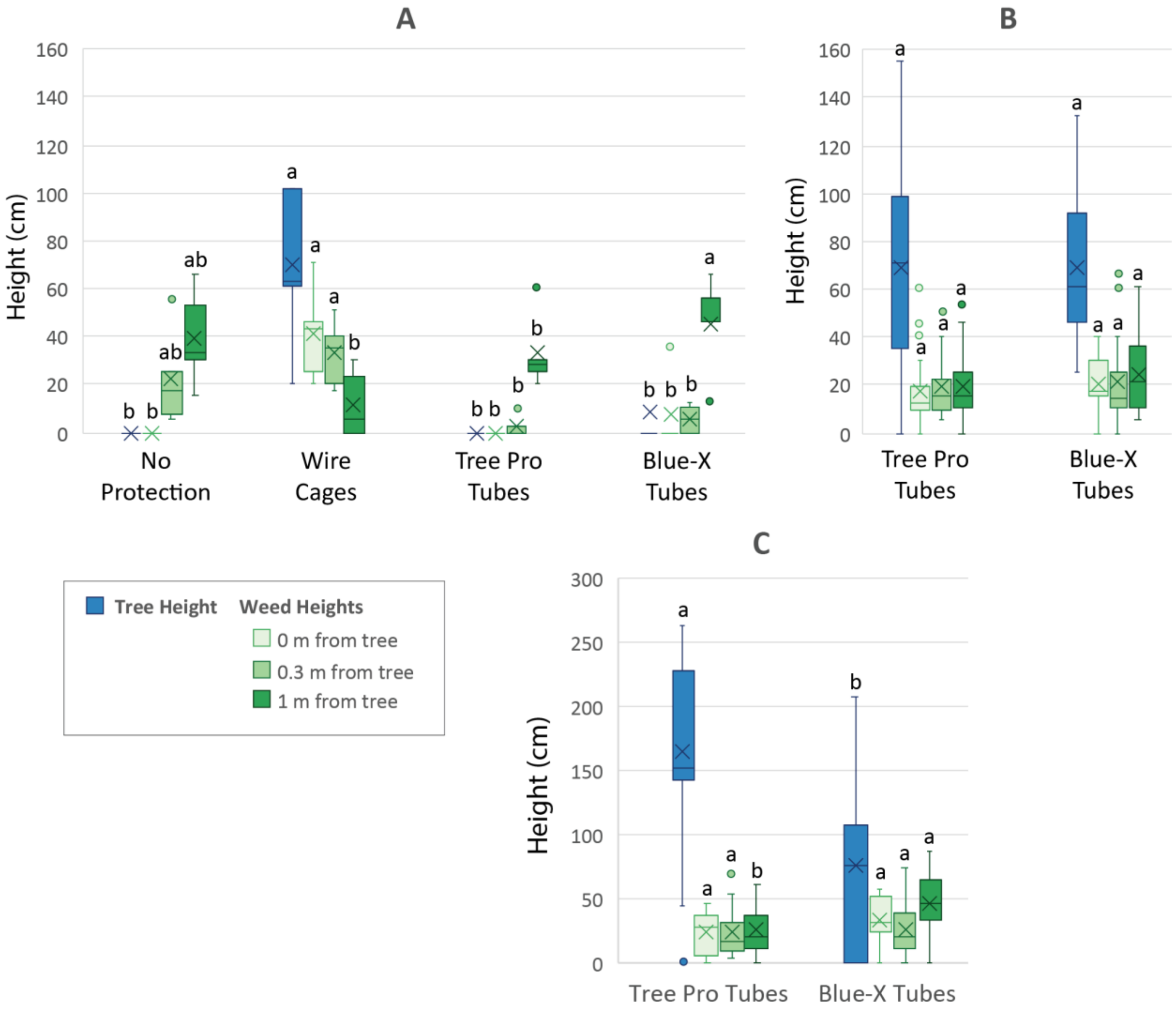

Figure 6: *Tree height and weed height with 2016 (A) hog, (B) sheep, and (C) 2017 sheep grazing at Green Fire Farm in 2017 (note change in scale on axis). Tree protection treatments included a no protection control (n = 5), Arbor Shield wire cages (n = 5), 5' (1.5 m) Tree Pro Miracle Tubes (A: n = 5; B: n = 20; C: n = 24), and Blue-X tree tubes (A: n = 5; B: n = 18; C: n = 27). Response means that share a letter were not significantly different within respective measurements among other treatments for each livestock class, i.e., within the same shade of color (Tukey-Kramer p < 0.05).*

Farmer observations

Although tree height and weed height data showed no significant differences between Tree Pro tree tube and Blue-X tree tube protection treatments after sheep grazing in 2016, in 2017 measurements and information provided in exit interview with the farmer provided some additional insight into these two treatments. Sheep were often able to knock over the tree tube protection and browse trees resulting in lower tree height after grazing events in 2017 (Figure 6). Sheep were often more inquisitive of the tree tubes initially and would browse the leaves and strip the bark rather than eating the pasture surrounding the trees. In general, Tree Pro tubes held up better to the livestock rubbing compared to Blue-X tubes, which sometimes folded like accordions, leading to more bark stripping. Hogs, on the other hand, would graze the silvopasture first before they became interested in the tubes to scratch or play. Hogs rubbed and scratched on the trees until the trees were knocked over, and then they would pull the trees out of the ground and perhaps browse the trees. Browsing the trees was secondary to rubbing and playing with the trees. After the second season of grazing, over 70% of trees protected by Blue-X tubes died, whereas less than 25% of trees protected by Tree-Pro tubes died (data not shown). Blue-X tubes also had sharper tops, so the wind tended to girdle trees once they were tall enough to grow out of the tubes (Table 6). Although not a tree protection method evaluated in the trial, Marty found that 2-3 strands of electric fencing effectively kept both sheep and hogs away from the trees, especially if livestock were trained to this type of fencing.

In general, tree tubes were in constant need of being stood back up. Stakes are an important factor in success using tree tubes. The wooden stakes used at Green Fire Farm were difficult to pound more than a foot (30 cm) into the ground, so they were top-heavy. Thinner stakes were easier to get deeper into the ground but were flimsier and easier for livestock to knock over. Once trees were knocked down, it seemed they were weaker such that wind would later knock the tubes and trees down. The farmer will likely use steel rebar or fiberglass stakes in the future that are driven into the ground at least 18 inches (45 cm).

The Tree Pro tree tubes not only held up to sheep better than Blue-X tubes but also did a good job of keeping away deer and voles. They seemed to create a good living environment for trees to thrive when they remain standing. Average tree heights at the end of the second growing season for trees protected by Tree Pro tree tubes were 173.9 cm whereas the averages for Blue-X tubes were 91.3 cm (Figure 6).

Marty found the 45-foot (14 m) spacing adequate for sheep and hogs; however, more space would probably work better. If Marty could do it over, he would use 90- or 160-foot (28 m or 50 m) spacing for sheep and hogs and use square paddocks rather than narrow paddocks that followed contours. Not only are the square paddocks more efficient for setting up portable fencing for rotational grazing, but it gives the animals more space between trees. With the 45-foot spacing, livestock were never more than 20 feet (6 m) away from the trees, which may have led to more tree-livestock interaction. Additionally, planning for larger paddocks can accommodate more livestock if the goal is to grow that enterprise. Cattle, however, likely need even more space—at least 200-foot (60 m) spacing. He encourages farmers to consider the purpose of silvopasture (e.g., commercial production from tree crops vs. shade for livestock) in paddocks and silvopasture design.

Marty installed the protection several weeks after the trees were planted, which in retrospect was a mistake—trees were hard to find when the weeds were high. In general, livestock varied with their responses to grazing in the silvopasture. Young livestock were more likely to trample the silvopasture than graze it. Hogs worked well with grazing as long as they could not access the trees, until it rained while they were in the silvopasture and were not able to be moved for a few days. Hogs tend to root and make the silvopasture very bumpy, so in the future, Marty plans on using hogs in long-term rotation, where hog grazing would be followed up with a cover crop for a year before planting another perennial pasture for sheep and cattle grazing. After two additional grazing seasons have passed, approximately 30-40% of the trees remain. He is appreciative of his involvement in this project as a learning experience and plans to use what he learned to expand the silvopasture enterprise in the coming years.

Table 6: *Costs and benefits of tree protection methods used in hog and sheep silvopastures at Green Fire Farm in Wisconsin USA.*

	Tree Pro tree tube (5’, 1.5 m)	**Blue-X tree tube (5’, 1.5 m)**	**Arbor Shield wire cage**	**Electric multi-strand polywire fence***
Cost	$4.05 per tree	$4 per tree	$29.77 per tree	~$1 per foot (30 cm)
Sturdiness	Mostly	Little	Very	Very
Install time	Quick	Slow	Very slow	Quick
Reusable	Maybe?	No	Yes	Yes
Comments	Rolled over edge at top prevents girding	Flimsy, sharp top	Potential injury to livestock, potential injury to people installing	Challenges: weed height management; energizer source, finding young trees in grass/weeds

**Electric multi-strand polywire fence was not tested as a tree protection treatment, but was used to separate paddocks.*

Seven Sisters Farm

Methods to protect newly established chestnut trees from sheep in 2017 included Arbor Shield wire cages, 4’ (1.2 m) and 5’ (1.5 m) Tree Pro Miracle tubes, and 2’ Tree Pro Bark Pro tubes (0.6 m). Tree stem growth data was not significantly different among the four treatments (Figure 7). Trees protected by the Miracle tubes and the cages were taller than trees protected by the 2’ Tree Pro Bark Pro tubes ($F_{3,89} = 7.0$, $p < 0.001$; Figure 7).

Trees protected by the shorter Bark Pro tubes were also the most heavily browsed—more than 90% of the trees in this treatment had browsing damage, compared to just over 10% of trees protected by the 5’ tubes had browsing damage, as did 40% of trees protected by wire cages, and 60% protected by 4’ tubes ($\chi^2_{(3,\ N = 93)} = 35.07$, $p > 0.001$; Table 7). Seven Sisters Farm hosts a large wild deer population. Since the sheep are shorter and cannot browse as high as deer, it is likely that any browse damage to trees in the 4’ and 5’ tubes was caused by deer rather than the sheep. Wire cages were found to work well as long as the tree is growing straight and does not lean against the cage. However, if they do lean against the cage, they are likely to undergo significant damage to the stems (Table 7). Approximately 75% of trees protected by the cages were damaged in this way.

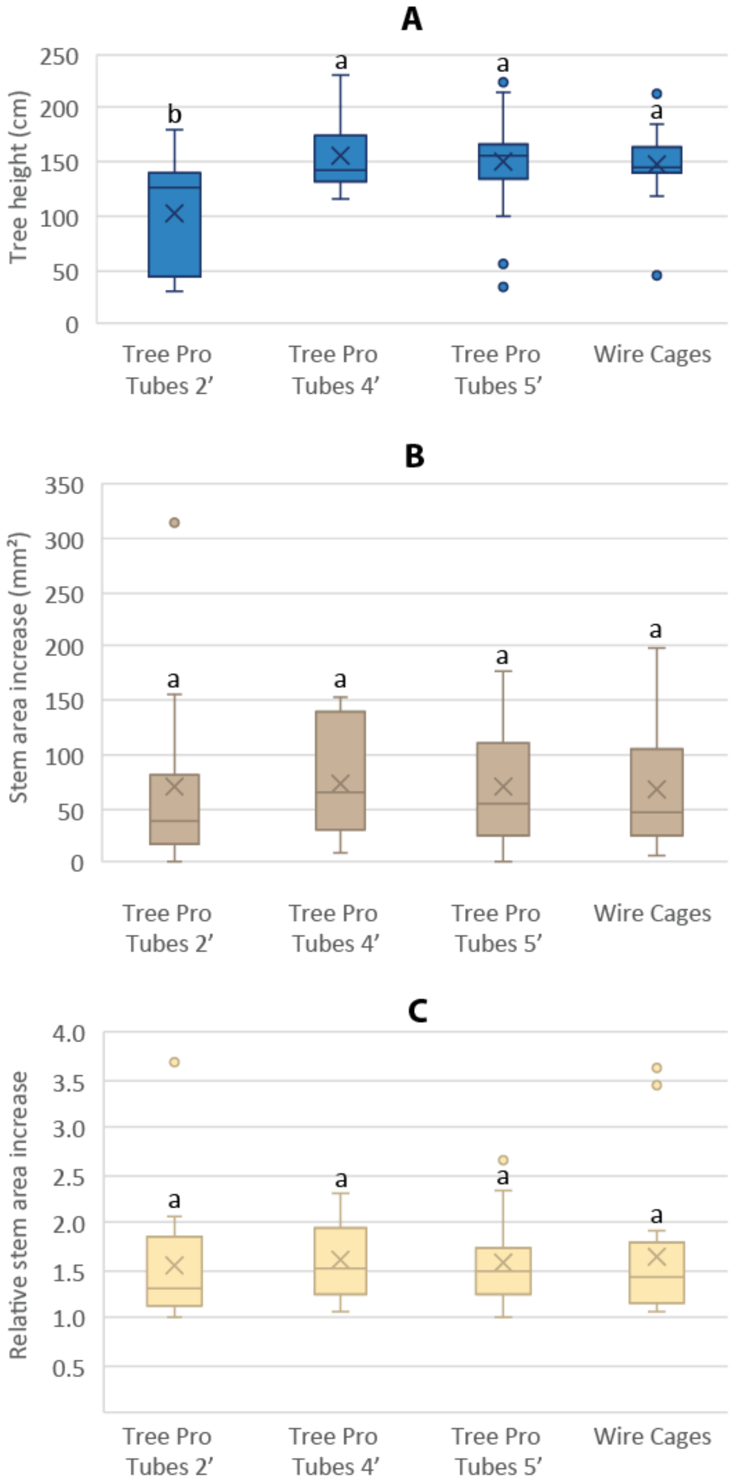

Figure 7: *(A) Tree height, (B) stem area increase, and (C) relative stem area increase with sheep grazing at Seven Sisters Farm in Illinois USA from 2015-2016 for each of four tree protection treatments, 2' (0.6 m) Tree Pro Bark Pro, 4' (1.2 m) Tree Pro Miracle Tubes, 5' (1.5 m) Tree Pro Miracle Tubes, and Arbor Shield wire cages (see Table 7 for respective sample sizes). Response means that share a letter were not significantly different (Tukey-Kramer at* $p < 0.05$*).*

Farmer observations

Some of the benefits found with the taller tree tubes is that they made mowing and weed management easier because the tubes made the trees easy to locate. Additionally, because the tubes did not have ventilation holes at their base, herbicide could be sprayed along the row without damaging the tree crops. However, insects can become an issue in the tubes. For example, if Japanese beetles (*Popillia japonica*) get into a tree tube with a hazelnut inside, they are likely to totally defoliate the plant. Wasps also found the tree tubes habitable and can build nests in the tubes that are hard to detect. Additionally, chestnuts emerging out of the tubes commonly have trunks too weak to stand straight, so they often need to be staked to prevent rubbing of the trunk on the tube edge.

Along with protecting the trees from browsing damage, some argue that metal cages can force trees to develop trunk strength early on and become stronger. This result was not observed during the length of this study. Although data was not specifically collected on weed heights at this farm, weeds were more difficult to manage with the Arbor Shield protection treatment due to difficult access to the cage interior.

Currants that were not protected were completely defoliated by the sheep, and hazelnuts without protection were also heavily browsed. Interestingly, of the hazelnuts that were protected by tree tubes, shoots growing outside of the tubes were less likely to be browsed than shoots from unprotected trees. This could be due to noise or movement of the tree tube deterring deer and sheep away.

Table 7: *Select damage prevalence data for Tree Pro tubes and Arbor Shield wire cages as well as associated cost per protection unit and install time per tree for Seven Sisters Farm in Illinois USA.*

Treatment	**n**	**Damage Prevalence (%)**							**Economics**	
		Browse	*Bark*	*Root*	*Metal Rub*	*Burrow*	*Plant Heave*	*Mouse Nest*	*Unit cost*	*Install time*
Bark Pro Tube 2' (.6 m)	16	93.8	18.8	0.0	0.0	0.0	18.8	0.0	$0.90	0:55
Miracle Tube 4' (1.2 m)	20	60.0	20.0	5.0	0.0	10.0	15.0	15.0	$3.35	1:15
Miracle Tube 5' (1.5 m)	37	10.8	8.1	0.0	0.0	10.8	8.1	16.2	$4.05	1:15
Arbor Shield 5' (1.5 m)	20	40.0	35.0	5.0	75.0	25.0	0.0	0.0	$15.00	6:30

4. Discussion

Our findings illustrate silvopasture establishment via customized approaches that reflect the contexts, goals, and constraints of several farms. In our study, participating farmers cited goals for trees planted in their pastures including fruit and nut crops, timber, forage, shade, shelter, water quality, soil improvement, habitat restoration, and carbon sequestration. Although these goals were generally longer-term than the scope of this study, we assessed techniques for tree planting in open pastures in the interest of meeting these goals. Observations by farmers collected at the conclusion of the study indicated broadly positive reflections on the potential of their silvopastures to meet their goals. Contrary to implications in other literature that exclusion of livestock is necessary during tree seedling establishment, appropriate protection from livestock allowed for cost-effective tree establishment in actively used pastures (Arbuckle 2009). Moreover, protection from browsing by wild ungulates, namely white-tailed deer is a primary factor in the success of hardwood tree planting in the US Midwest, so tree seedlings generally need to be protected whether or not livestock are present (Redick et al. 2020).

Our study exemplified the challenge of developing technical guidance for context-adaptive agricultural practices, as well as the application participatory research to address this challenge by incorporating diverse practices and outcomes (Lyon et al. 2011; Goma et al. 2001; Haggar et al. 2001). Our study followed the recommendation of (Oliver et al. 2012) and others to engage farmer participation during all phases of the study. Farmers identified the research need, participated in shaping study design, partnered in implementation and data collection, added qualitative findings based on their observations, validated results, and contributed to outreach efforts to share findings through on-farm events and conference presentations.

Rather than designing a study that attempted to identify a narrowly defined best technique, we conducted on-farm research with multiple farms. This approach allowed us to compare the value of similar techniques for similar aims applied in different contexts, thus offering a means to incorporate farmer knowledge and experience into practical recommendations generated out of this research. One illustration of the value of this participatory approach is our finding that on different farms, different tree protection strategies were necessary depending on stock type and grazing habits, and on weed pressure. Even among the same type of livestock, there were differences among farms; for example, sheep farmers found success with different treatments. At Nightfall Farm, sheep knocking down tubes was a common problem. At Green Fire Farm, Tree Pro tubes worked well but the type of stake determined how well they held up to the sheep, and Blue X tubes worked poorly. At Seven Sisters Farm, sheep did not disturb the tubes.

Qualitative farmer observations further highlight the importance of the farm's context in determining appropriate tree protection, as well as the importance of the details of technique for desired outcomes. Farmers reflected on lessons learned in terms of the details such as the spacing of fencing, how deep stakes are driven, and the timing of various activities. As part of this study farmers interacted with each other and participated in outreach and education with other farmers. In these conversations, farmers often emphasized *how* they made the tree protection method work rather than *which* method work. Qualitative observations also allowed for assessment and learning beyond the specific treatments in trials. For instance, at Driftless Pastures the farmer observed that electrified single-strand polywire in addition to tree tube protection was most effective. Although the study design included both polywire and tree tube treatments, it did not assess them in combination.

To varying degrees, several of the farmers made it clear that maximizing growth and survival of their trees was not their goal. Rather, they were interested in optimizing their limits on time and expense with an acceptable level of tree growth and survival. This was evident both with regards to managing livestock browse on trees, as well as managing weed pressure. Although metal cages consistently provided the greatest protection from livestock, they were the most expensive, and most time-intensive to install and to manage weeds.

Our results also point to the need for evaluating the initial size of tree seedlings. In a study establishing tree-based intercropping in Quebec Canada, planting 6-yr *Quercus rubra* and *Acer saccharum* at greater initial cost compared to 3-yr seedlings, the larger stock was more cost-effective due to increased survival and growth after five years (Rivest and Cogliastro 2019). Although other studies have found instead that younger stock proved more cost-effective (Struve et al. 2000; Watson 2005; Dostálek et al. 2009), to our knowledge similar studies have not been performed in the context of silvopasture establishment; planting trees with an effective size refuge from livestock could provide benefit that outweighs the costs of protecting smaller trees. Size of tree seedlings has also been linked to improved survival in areas with high levels of deer browsing (Zaczek and Steiner 2011).

Managing competing vegetation was a challenge in silvopasture tree planting that intersected variously with tree protection methods on given farms, as well as different livestock, objectives for trees, and constraints among farms. It was clear on all farms that livestock activity, including sheep, poultry, cattle, and hogs, provided various level of reduction in the height of vegetation around trees (Figures 2, 3, 5, and 6). Different tree protection techniques allowed livestock to impact competing vegetation but not the tree; which technique did so varied by livestock. Wire cages, for example, made it difficult for livestock as well as farmers to access and manage vegetation next to the trees. On Green Fire Farm, two-strand electrified polywire, which was not one of the methods assessed in this study, became the farm's preferred system for protecting trees from hogs while facilitating weed management. It is generally known that growth and survival of planted tree seedlings increases with management of competing vegetation, but targeted research could aid farmers in optimizing tree growth and survival within the context of pasture management constraints (Burner and Brauer 2003; Mekonnen et al. 2019).

The findings we present here on tree and weed height are based on measurements taken after grazing events. There were some differences among treatments before measurement, which means we measured effectiveness of treatments in protecting seedling trees not only from livestock, but also from deer and other environmental factors. We consider these the most important results from a "farm-ready" point of view, even though the influence of environmental factors limits interpretation of livestock alone as the cause of differences we observed among treatments.

Silvopasture establishment techniques need more research, both in institutional settings as well as on-farm studies (Jose et al. 2017). Insufficient research has been done to assess pasture tree planting establishment techniques in the US Midwest (Schoeneberger 2009; National Academies of Sciences, Engineering, and Medicine 2019; Domke et al. 2020). Pasture-based management of livestock in general is well supported in the literature as offering farmers an alternative to confinement systems that can improve farm- and societal-level outcomes

(Franzluebbers et al. 2012; Spratt et al. 2021). However, even among pasture-based livestock systems, pasture trees can be considered simply a management nuisance and counter-productive to forage growth (Smith 1942; Mayerfeld et al. 2016; Louah et al. 2017). Furthermore, pasture on marginal land in humid environments such as the US Midwest often has existing trees growing, so some shade is available without the additional tree planting (Keeley 2014; Galleguillos et al. 2018). However, as was the case for two of the farms in this study, transition of annual cropland to intensively-managed pasture requires tree planting for shade as well as other objectives (Keeley et al. 2019). More research to develop effective tree establishment techniques will not only assist in achieving on-farm objectives, but also help realize the potential of silvopasture to meet other societal goals (Wolz et al. 2018; Reynolds et al. 2021; Cook-Patton et al. 2020).

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Chapter Three: Evolving Conceptions of Silvopasture among Farmers and Natural Resource Professionals in the US Midwest

Diane Mayerfeld[1,2], Keefe O. Keeley[1,3], Mark Rickenbach[1], Adena Rissman[1], Stephen J. Ventura[1]

Highlights

- The taboo around integrating livestock and trees appears to be weakening, and some agricultural advisors have begun to provide silvopasture advice.
- Perceptions of silvopasture are influenced by temporal, geographic and social contexts, including recent weather history, landscape attributes, markets for forest and agricultural products, existing land uses, and supportive communities of practice.
- The complex, long-term, adaptive nature of silvopasture creates challenges for research and adoption, but some farmers and resource professionals are committed to the practice despite its complexity and uncertainty of outcomes.

Abstract

Silvopasture has recently gained attention as an agroecological practice that may simultaneously meet farmer goals and provide environmental benefits, including climate change mitigation. At the same time there are significant concerns about the potential for livestock to damage trees and forest soils. Like other agroecological systems, silvopasture combines management complexity with limited research knowledge. We asked: 1) How are attitudes toward and knowledge of

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[1] University of Wisconsin-Madison, Nelson Institute for Environmental Studies

[2] University of Wisconsin-Madison, Division of Extension and UW-Madison Center for Integrated Agricultural Systems

[3] Savanna Institute

silvopasture evolving among farmers who practice grazing, agricultural advisors, and foresters? and 2) How did coverage of silvopasture change between 2009 and 2019 in a popular grazing publication? We conducted mixed-methods research on silvopasture attitudes and knowledge among farmers, agricultural advisors, and foresters in Wisconsin between 2014 and 2019. Perceptions of silvopasture were influenced by recent weather history, markets for forest and agricultural products, existing land uses, and other contextual factors. Some farmers and agricultural advisors were committed to silvopasture despite obstacles to implementing the practice, and agricultural advisors increased their willingness to provide silvopasture advice to farmers and professional colleagues. Finally, a multi-county supportive community of practice was associated with greater enthusiasm for the practice. This interest in silvopasture suggests a need for greater collaboration among forestry and agricultural professionals.

Keywords

Silvopasture, adoption, agroforestry, Midwest, human dimensions, agroecology

1. Introduction

Silvopasture is an agroforestry practice that intentionally integrates livestock, forage production, and trees. Within the USA, silvopasture systems integrating beef cattle with fast-growing southern pine plantations have been most widely adopted and most studied (Clason 1998; Kallenbach, Kerley, and Bishop-Hurley 2006; Ares, Louis, and Brauer 2003; Grado and Husak 2004; Nair et al. 2007; Shrestha, Alavalapati, and Kalmbacher 2004; Cubbage et al. 2012). More recently, silvopasture has been proposed as a practice that can improve environmental outcomes and profits compared to the widespread practice of unmanaged grazing of woodlands in the upper Midwest (Garrett et al. 2004; Ford et al. 2019). Silvopasture is also seen as an approach to increase carbon storage and reduce the net climate change impacts of agriculture, as well as increase resilience to weather extremes (Baah-Acheamfour et al. 2014; 2016; Hawken 2017; Howlett et al. 2011; Montagnini and Nair 2004; Patel-Weynand, Bentrup, and Schoeneberger 2017).

At the same time, there is a long history of natural resource professionals opposing the integration of livestock with trees, especially in western Europe and the USA (Abbott 1954; Dambach 1944; Ahlgren et al. 1946; Guise 1950). This opposition stems in part from situations where livestock damage forests, but it also coincided with the professionalization of forest management and the associated assumption that the best use of a forest is to produce timber (Dana and Fairfax 1980; Rubino 1996). Forestry professionals continue to be more skeptical of and less knowledgeable about silvopasture than agricultural advisors and farmers. The latter two groups are more likely to support silvopasture, while acknowledging that livestock can compact soil and create erosion (Arbuckle 2009; Mayerfeld, Rickenbach, and Rissman 2016; Stutzman et al. 2019).

Most of the social science research on silvopasture in temperate regions has focused on economic analysis, silvopasture knowledge of resource professionals, and stakeholder perceptions of benefits and costs (Blanco et al. 2019; Shrestha, Alavalapati, and Kalmbacher 2004; Frey et al. 2012; Mayerfeld, Rickenbach, and Rissman 2016; Orefice et al. 2017). Stakeholders perceive shade and shelter for livestock as key benefits of including trees in the grazing system. Increased income is another widely cited benefit, although in some cases the income benefits are expressed indirectly, for example as “increased utilization of farm woodland” (Orefice et al. 2017). Reports of silvopasture challenges or disadvantages are less consistent, but problems with maintaining fences and lack of knowledge about silvopasture management are key concerns. Frey et al. (2012) addressed changes in perceptions over time; they reported that farmers in Argentina perceived more benefits and had fewer concerns about silvopasture after they had several years of experience than when they were first considering the practice.

Following the suggestion of Garrett et al. (2004) that silvopasture may improve environmental and economic outcomes in woodlands degraded by poor management, researchers in the Midwest and Northeastern US began to study silvopasture establishment in existing woodlands (Demchik, Thompson, and Schossow 2005; Orefice, Smith, et al. 2017; Orefice et al. 2019; Ford et al. 2019). Many of the forests in these regions are or were grazed, and much of the existing pasture is in woodlands.

The agroforestry community distinguishes between silvopasture, where there is active management of the trees, forage, and livestock to balance economic and environmental outcomes; and woodland grazing, where there is little or no deliberate management of the forage layer, the trees, or the timing and intensity of livestock use (Brantly 2014). The limited information available indicates that management of woodland pastures varies, but that in most cases they are not managed as silvopasture. In Wisconsin and surrounding states, the number of farms with pastured woodland exceeds the number of farms practicing rotational grazing, and greatly exceeds the number of farms using agroforestry practices including silvopasture as well as forest farming, windbreaks, alley cropping, and riparian buffers (Figure 1). Across the USA, 326,279 farms had pastured woodland, 265,162 farms practiced rotational grazing, and only 30,853 farms practiced agroforestry in 2017 (USDA-NASS 2019a; 2019b).

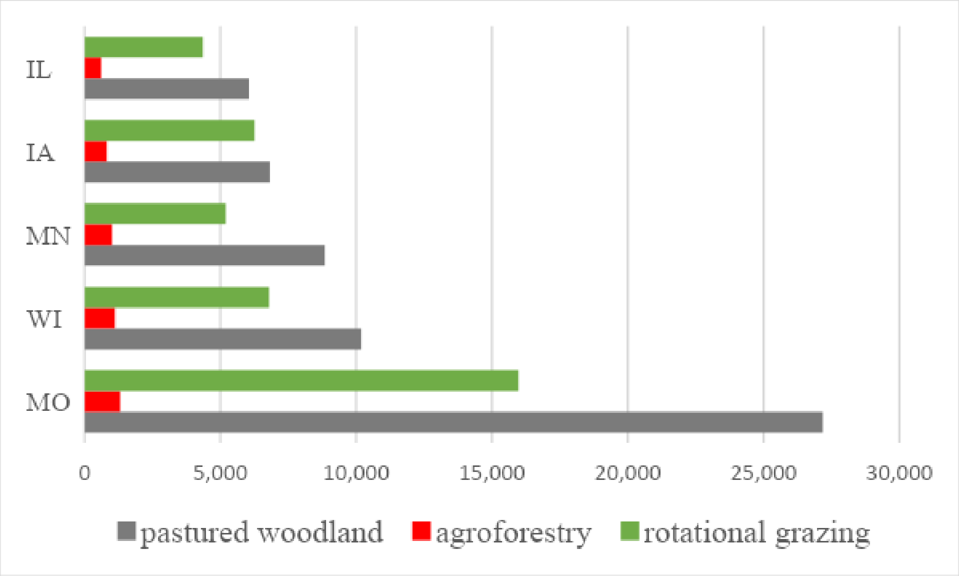

Figure 1. Number of farms in Wisconsin and nearby states engaged in the following three practices in 2017: rotational grazing, agroforestry (including but not limited to silvopasture), and pastured woodland. To an unknown degree, silvopasture is presumably practiced on a subset of the farms reporting each of these respective practices.

Although some farmers practice silvopasture without knowing the technical term, farmers and natural resource professionals in Wisconsin report that most cases of woodland grazing do not include active management of the forage or trees, and only 23% of farms with pasture practice rotational grazing, a necessary component of silvopasture management in this region (Keeley 2014; Mayerfeld, Rickenbach, and Rissman 2016; USDA-NASS 2019b; Galleguillos, Keeley, and Ventura 2018).

In this context of complexity, controversy, emerging research, and extensive woodland grazing where silvopasture could potentially be practiced, we sought to assess if and how attitudes toward and knowledge about silvopasture changed during the six years following the initiation of silvopasture research and outreach in and around Wisconsin. Specifically, we asked two research questions:

1. How did attitudes toward and knowledge of silvopasture evolve among farmers who practice grazing, agricultural advisors, and foresters during the study period?
2. How did the amount and type of coverage of silvopasture change between 2009 and 2019 in a popular grazing publication?

2. Methods

This is a descriptive, exploratory mixed-methods study (Byrne and Ragin 2009; Yin 2009). To assemble our case, we used (1) focus group and individual interviews clustered in two regions as the basis for a comparative case study, (2) end of program evaluations, and (3) content analysis of a popular grazing publication. This approach allowed us to examine silvopasture attitudes and knowledge in context, examine interactions among factors, and assess changes over time. Research with human subjects was approved by the UW-Madison Institutional Review Board (# 2015-1521).

The subjects of our study were three categories of silvopasture stakeholders in Wisconsin: *farmers*, *agricultural advisors*, and *foresters*, with the latter two categories referred to collectively as *resource professionals*. Agricultural advisors included university extension, public agency, and NGO staff, and grazing consultants. Foresters included university extension and state agency staff and private foresters. We focused our study on southwestern and northwestern Wisconsin, but also included stakeholders throughout the state.

In 2014 we began interviewing farmers, agriculture advisors, and foresters about their views on integrating livestock grazing with trees. In their capacities as educators, two of the authors (one with University of Wisconsin Extension and one with the Savanna Institute, an NGO focused on agroforestry research and education) also began conducting educational outreach about silvopasture in 2014. In 2015 we initiated two silvopasture research trials on a university research station and two commercial farms. Our work occurred in the context of other agroforestry outreach and research in the region and nationwide. For most farmers and resource professionals in Wisconsin, the workshops, conference presentations, and pasture walks we helped organize were a major source of silvopasture exposure.

2.1 Interviews

We conducted twelve focus group interviews with farmers, agricultural advisors, and foresters between 2014 and 2019 (Table 1). We also conducted individual interviews with two agricultural advisors, a forester, and five farmers who could not participate in the focus groups but were interested in contributing to the project. The focus group interviews form the foundation for our case study. The individual interviews supplemented the focus group interviews and provided a check that there were not issues and questions that participants hesitated to bring up in a group setting.

The results of the six focus group interviews in 2014, 2016, and September 2017 serve as a baseline of silvopasture knowledge and attitudes early in the study period. In these initial interviews we asked the participants for their thoughts about integrating grazing livestock with trees and about silvopasture. Although the September 2017 interview took place more than three years after the start of the project, the participants were all foresters with whom we had no previous interactions, and for whom our questions about silvopasture were novel.

The four focus group interviews conducted in 2018 and 2019 included twelve individuals who had participated in earlier interviews, as well as at least six participants who had participated in one or more silvopasture events, such as a pasture walk or presentation. In these later interviews we added prompts asking participants where they had first heard about silvopasture and asking them to reflect on changes in silvopasture knowledge, attitudes, and practices in the past five years.

The focus group interviews conducted in January and March 2017 were intermediate in nature. We had not interviewed the participants before, but they were aware of our work, and some had attended a silvopasture event before the interview. Like the individual interviews, they supported the findings of the early focus groups.

Table 1. Focus groups dates and participants

Year	Month	# people*	Male	Female	Farmer	Ag. advisor	Forester	Other
2014	Feb	8	4	4	2	2	5	1
2014	March	2	1	1		2		
2014	May	7	7	0	7			
2016	March	12	8	4	12	1		
2016	Oct	5	3	2		5		
2017	Jan	3	2	1	3			
2017	March	2	2	0	1		1	1
2017	Sept	9	9	0	1		9	
2018	Sept	8	8	0	8**			
2018	Nov	12	9	3	12			2
2019	Jan	7	5	2	2	4	2	1
2019	Feb	6	6	0	5	2		

*The sum of farmers, foresters, and agricultural advisors exceeds the total number of interviewees because several of the natural resource professionals also farm.

**This focus group took place outdoors after a pasture walk, and participants did not fill out a demographic form, but all described themselves as farmers in introductions.

Our interviews were clustered in two regions, which formed the basis of our comparative case analysis: northwestern Wisconsin and the Driftless Area of southwestern Wisconsin (we refer to these regions as “northwestern” and “southwestern,” respectively). The northwestern region is a relatively level landscape shaped by glaciation, with agricultural systems limited by a short growing season and low natural soil fertility. In contrast, southwestern Wisconsin was not glaciated, and it has steep topography, making it marginal for large-scale row crop production.

Both areas contain substantial woodland. In southwestern and northwestern Wisconsin counties woodland accounts for 15 to 36% of total farmland (USDA-NASS 2019a). Roughly 30% of farms have beef cattle, and 6 to 21% of farms have dairy cows.

2.1.1 Interviewees

Participants in five focus groups conducted in 2014 and 2019 were invited based on their experience as grazing farmers or as resource professionals. The other seven focus groups took place in the context of conferences or pasture walks and were open to any event attendees who chose to participate.

Participant ages ranged from under 30 to over 70, and length of time in their current position (including farming) ranged from less than 2 years to more than 50 years. The amount of land farmers had in woodland was highly variable, from no woods on the farm to the majority of land in woods, with many respondents having between 10 and 50% of their land in woods. Thirty-three participants managed beef or dairy cattle; five managed sheep, goats, poultry, bison, or pigs. We recruited farmer participants through grazing networks, so most of the farmers we spoke with practiced rotational grazing (also known as managed grazing or adaptive multi-paddock grazing). Education levels ranged from high school (10th grade) to graduate degrees in the farmer focus groups. All resource professional respondents had a 4-year college degree or higher.

The farmers participating in the focus groups represented a range of experience with and attitudes towards silvopasture. Each farmer focus group had at least one farmer who had no trees in their pastures, as well as at least one farmer who was managing pasture with trees.

2.1.2 Interview structure and analysis

For the interviews we used guiding questions but also allowed the conversation to flow naturally and encouraged respondents to interact with each other as well as the interviewer(s). Our semi-structured approach aimed to cover the same set of topics in each interview without restricting discussion more than necessary for time constraints. All focus group interviewees consented to having the session recorded, but the recorder malfunctioned at one focus group.

Transcripts from the 2014 to 2017 focus groups were coded manually using a grounded theory approach (Morgan, Fellows, and Guevara 2008). Focus groups in 2018 and 2019 were coded manually according to the categories that emerged from the initial coding, as well as their responses to a new prompt about changes in knowledge and attitude.

2.2 Evaluation

During the study period we conducted numerous educational programs on silvopasture, including conference presentations, pasture walks, and workshops. We used end of program evaluation forms to collect information from participants about their perceptions of silvopasture, as well as their silvopasture information sources and needs. These evaluation results supplement the interview findings.

2.3 Content analysis

Graze magazine focuses on grazing advice, and both farmers and agricultural professionals use it as an information source. The magazine is headquartered in Wisconsin and has been reaching an audience of farmers using managed grazing since 2000. It has approximately 2,000 paid subscribers across the U.S., Canada, and overseas, with high concentrations of readers in the Upper Midwest and Northeast states. We conducted a summative content analysis of *Graze* from January 2009 to May 2019 for several terms that we thought would appear in any discussion of silvopasture or integration of livestock with trees (Hsieh and Shannon 2005). The search terms we used were “shade”, “silv”[4] “tree”, “wood”, “heat”, “brush”, “forest”, and “shrub”. We only counted instances of the term that related to the integration of livestock with trees. In addition to noting when and how often the topic of trees in grazing systems came up, we assessed how trees were discussed. This analysis provided an additional window on attitudes toward silvopasture, as well as the availability of silvopasture information in the farming community.

2.4 Note on author engagement

During the study period authors DM and KK also conducted silvopasture field trials in southwestern Wisconsin, and we organized and presented at a variety of silvopasture outreach events. Thus, we were actively engaged in discussions around silvopasture in the state at the same time that we were conducting this study. Our roles as researchers and educators likely influenced who was willing to be interviewed and may have affected what interviewees said. Our active participation in silvopasture research and outreach allowed us to observe conversation around silvopasture beyond the formal methods of interviews and written evaluation responses.

3. Results

Table 2. Overview of silvopasture knowledge and attitudes in Wisconsin USA and surrounding states from 2014-2019 interviews with farmers, agricultural advisors, and foresters; evaluations following educational events; and content analysis of a popular grazing publication.

Finding	**Changes and Trends**
Attitude: A relatively small but dedicated set of farmers	● Farmers’ confidence with silvopasture management depended on their goals and own farm experience.

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[4] We used “silv” to capture alternative spellings, e.g., silvapasture or silvo-pasture or silvopasturing or silvipasture.

is interested in exploring silvopasture. (3.11, 3.12)	● Farmers’ and resource professionals’ attitudes toward silvopasture were influenced by local context, such as timber markets and recent weather, and by participation in communities of practice.
Attitude: The taboo around silvopasture is weakening, and some agricultural advisors began to provide silvopasture advice. (3.12, 3.2)	● Early in the study period resource professionals did not address silvopasture in their work. Late in the study period some agricultural advisors gave silvopasture advice, and some foresters were open to considering silvopasture applications. ● Coverage of the benefits of trees in pasture systems increased during the study period in a popular grazing publication.
Knowledge: Silvopasture management is more complex, and site- and goal-specific than the dominant grain and livestock systems in the region. (3.11, 3.13)	● Throughout the study period silvopasture variability and uncertainty continued to challenge resource professionals. ● Farmers and agricultural advisors are experimenting with silvopasture to meet goals such as shade and shelter for livestock, brush management, and increased forage. ● There is demand for locally-relevant information about silvopasture management, economics, and environmental impacts.

3.1 How did attitudes toward and knowledge of silvopasture evolve among farmers and resource professionals during the study period?

3.1.1 Farmer attitudes and knowledge

Throughout the study period farmers expressed a range of attitudes toward silvopasture, from uncertainty about its environmental and economic sustainability on their farms to strong enthusiasm for the practice. We did not observe an overall shift to more positive or more negative attitudes among farmers, but we did see differences in how farmers discussed the topic at different times, depending on individual farm experience and wider contextual factors.

In all the focus groups, farmers who had been managing silvopasture on their land demonstrated their knowledge by talking about specific management practices and observations based on their experience. In the group interview setting, farmers who did not have personal silvopasture experience did not portray themselves as having silvopasture knowledge, even though some of them mentioned having read or heard about the practice. Often farmers in the focus groups avoided using technical language, including the term silvopasture, even when they were familiar with the terminology.

Several themes appeared in all the interviews: the potential impact of silvopasture on animal welfare, farm profitability, soil and water quality, biodiversity, and the presence of shrubs. However, at the later focus groups there were some shifts in emphasis that reflected changes in the weather patterns and agricultural economy, as well as and increased knowledge about silvopasture on the part of both farmers and resource professionals. Key research findings from interviews, as well as from written evaluations following educational events and content analysis of a popular grazing publication, are summarized in Table 2.

Most of the discussion in our farmer interviews centered on conversion of existing farm woodlands to silvopasture, although at least three of the farmers interviewed had planted trees in their pastures. None of the focus group participants expressed direct opposition to silvopasture.

Key benefits interviewees associated with silvopasture were shade and shelter for livestock; the potential for increased income because of additional pasture, harvest of forest products, and/or lower property taxes associated with converting woodland to silvopasture; and reduction of brush (i.e., understory shrubs that obstruct herbaceous forage growth, passage and visibility). Concerns included the potential for damage to trees and soils, as well as increased labor to maintain fences and manage the forage layer when trees are present.

These benefits and concerns reflect the interactions between shared norms and individual constraints and experience. Take these comments from a farmer in a focus group in 2016. Early in the focus group we asked all the farmers to comment on whether they were currently integrating their grazing with trees or considering it. One farmer explained

> I have pigs and am interested in feeding the pigs acorns. I've been bringing the pigs acorns because I know that the pigs can really tear up an environment. I

> have a lot of closed woods with really nice trees and wouldn't dare let the pigs go there. But this little segment that was logged. It has some nice scattered oaks, … but what's filling in between them is popple, little tiny popple [*Populus sp.*]. Four inches apart – you can't even walk through it. … I suppose if you're a woodcock it's wonderful. If I were going to move a hog under an oak tree it would be on that piece right there. And then with the hopes that … I could turn this stand into silvopasture with these sparse oaks if I can get rid of the popple, which I'm sure a hog can do. … It seems like a good idea, but I'm not sure. …. Most people would say you're not ruining a great field or anything. But there could be something wonderful in there – I don't know.

After an hour of discussion among the 11 farmers in the group, ranging from the animal welfare and tax benefits of silvopasture to its potential impacts on forest soils and trees, this same farmer was still struggling to reconcile the norms of providing animal welfare, running a profitable farm, and caring for the environment:

> You're rich in direct proportion to the things you can afford to leave alone. And I'm very cautious. When I talk about doing this with hogs – soil science guy says watch out for damage – well leaf cover looks like soil cover to me – things look pretty healthy [as they are now] … should I even mess with it? That [good woods] is off limits to me; I only toy with the idea of the popple growth. But then woodcock would love that popple.

Hogs embody the conflicting norms around silvopasture particularly strongly because they are highly sensitive to heat stress and thus can benefit from shade, but are also very likely to cause severe soil disturbance because of their rooting behavior. Farmers in all the focus groups spoke about the differences between livestock types, as well as other factors that could affect silvopasture success on a specific farm:

> "Question for those using trees at the edge [of fields]: are those trees dying? Ours haven't. Oak, maple, little bit of silver popple."
>
> "Where my trees are, they're tamarack, and [the livestock] rubbed the bark all off, and they're dying."
>
> "If you don't have enough trees and you leave them [the livestock] in long enough, yes, they will [kill trees]. The trick is don't leave them in there very long…. I notice my oak trees grow really fast now that there are animals in there. … Less competition, more sunlight. Clover, meadow fescue, orchardgrass, some red clover in the open areas. It's my best pasture in the summertime, during the drought."

The practice of silvopasture is of potential interest to livestock farmers who practice grazing. In all the focus groups, farmers emphasized careful management of grazing timing, intensity, and duration as important to mitigating negative impacts on the soil and plants, as well as maintaining the performance of their livestock. Because the timing and duration of grazing is a critical component of silvopasture management, farmers who practice rotational or adaptive multi-paddock grazing are well positioned to implement silvopasture. Within this group of potential adopters, a subgroup is actively interested in learning about and implementing silvopasture. Although the practice remains poorly understood and adds significant management, that subgroup of interested farmers remained engaged with silvopasture throughout the study period, as evidenced by participation in silvopasture events and by comments in our interviews. Some farmers showed increasing confidence in silvopasture over the study period while others expressed more concern about the labor and management needed.

In northwestern Wisconsin in 2015 a farmer who had recently converted some woods to silvopasture spoke primarily about the challenges of converting and expressed concerns about how the trees would hold up to livestock impact. In the focus group conducted 32 months later, that farmer was confident about his ability to manage silvopasture (which he often referred to as savanna) and enthusiastic about its benefits for his livestock:

> …my [open] pastures always go into dormancy July and August, pretty much. And the savanna pastures do not because of the trees. And while it's not great tonnage, it's of great value because they still have grass when they normally wouldn't…. And now that I've done that, what I value even more is it creates a tremendous amount of diversity in the animal's diet. And I'm absolutely convinced my animals do better than others, not because of genetics, but because of that diversity in their diet. And I really value my savannas because of that. The trees grow faster. We have a lot more game than you normally would, if you're into hunting and that kind of thing.... And if I had to sell land, I'd sell my pastures before I'd sell my savannas.

The grazing network in northwestern Wisconsin included two agricultural advisors who actively supported silvopasture, one of whom had worked with this farmer throughout the process of establishing his silvopasture. In 2014 this network included two presentations and a panel discussion about silvopasture in its spring conference. Farmers learned they could talk about silvopasture with their grazing consultant, and during our study period several of the pasture walks hosted by the network featured silvopasture. In November 2018 the network's conference again featured a silvopasture presentation.

In contrast, in southwestern Wisconsin agricultural advisors who helped coordinate the grazing networks did not promote silvopasture. Farmers in the initial southwestern focus group identified brush management as a major benefit of silvopasture. While they continued to express interest in managing brush, the 2019 farmer focus group in southwestern Wisconsin placed greater emphasis on the limits of using livestock as a site management tool and on the limits of current silvopasture knowledge.

For example, one farmer in the 2019 focus group had cleared an area of woodland for silvopasture. He spoke about how nice it was to regain access to the old oak savanna that had become impassable due to dense understory growth during the years when livestock were excluded. But later in the conversation he added:

> We have problems with black locust, and seeing all those runners pop up, it's just a carpet. … I think [the cattle] get some of those initial sprouts, but it's more of a supplement. With the kind of management system [we use], they're not going wild on it. I do notice they'll get those young, tender sprouts. But if it gets beyond that maybe they'll take a nip of a couple leaves. That's typically what I observe with cattle.

This statement reflected a broader discussion about the challenge of getting sufficient livestock browsing and physical impact to control weedy shrubs and trees without damaging soils or desirable trees. In this same focus group, the farmers discussed the superior ability of goats to browse shrubs but also noted that, like all livestock, goats do not spare the species that a land manager might want to keep. The group also discussed the additional labor required to manage and market multiple livestock species. Similarly, where farmers in the 2014 focus group spoke of silvopasture as a tool to restore savanna habitat, farmers in the later focus group in southwestern Wisconsin discussed the difficulties and limitations of using livestock for ecological site management such as savanna restoration.

Still, although there was much discussion of the challenges of using grazing to manage the shrub understory, most of the focus group participants felt that livestock could help in some situations. The site with black locust referenced above was part of a silvopasture establishment trial, and in areas planted with improved forages, it was noted that black locust resprouting was much less of a problem compared to areas that weren't planted and areas that were planted but did not have grazing. Another farmer, who was overall one of the most skeptical of silvopasture, commented

> We had a watershed meeting here last month and one of the members ... fenced off his woods…. Now it's five years [later] and it's grown up with all this stuff he doesn't want. So he's kind of, 'what do you do, how do you win, or do you have to just be patient and you have to wait fifty, a hundred years for nature to kindly kill this stuff off on its own' or what.

Another respondent said of silvopasture as a strategy to manage brush, "It's not a silver bullet by any means, but it's certainly I think moving in the right direction."

One new concern that came up in the later focus group in the northwest was the worry that the growing acceptance of silvopasture in the area could be set back by one bad example:

> And then also I'm beginning to wonder about we can make all this progress and ... we're bound to find somebody who's going to do this all wrong. And it's going to be on a major highway and everybody's going to see it where there are 5,000 animals on 10 acres and the hillside comes down and all the trees die. So we need

> some research to say, "Well, based upon the research, you should never have been doing that or been allowed to do it. And that's why this all happened." It's not the concept. It's the execution of it that was wrong.

This quote illustrates the sense that this loose group of farmers and resource professionals is making progress by working together, as well as their awareness that the approach of integrating grazing with trees still needs to develop clearer guidance, and that research will play an important role in developing that guidance.

Attitudes about the economics of converting woodland to silvopasture showed both similarities and differences between the southwestern and northwestern focus groups. In Wisconsin the property tax assessment categories result in lower tax levies on wooded pasture than on ungrazed forest land (not enrolled in state forestry tax incentive programs), and in both areas property taxes were cited as an economic incentive to let livestock graze woodlands. Farmers in both regions saw silvopasture as a way to access those tax benefits without causing the environmental damage associated with unmanaged livestock access to woodlands.

In northwestern Wisconsin, where paper mills provide a market for trees that are not timber quality, several farmers mentioned income from commercial thinnings of their woodlands to establish silvopasture. In southwestern Wisconsin the market for wood is limited to high quality sawtimber, and none of the farmers in that area spoke about income from thinning their woods to establish silvopasture.

3.1.2 Resource professionals’ attitudes and knowledge

Among resource professionals (i.e., agricultural advisors and foresters) support for silvopasture increased or did not change over the course of the study period. In earlier interviews the agricultural advisors were all open to the idea that silvopasture could play a positive role in Wisconsin grazing farms, and several mentioned examples of farmers who were already experimenting with silvopasture. However, except for one professional in northwestern Wisconsin, they did not talk about providing silvopasture advice in the course of their work. In contrast, in the later interviews several agricultural advisors spoke about incorporating management of paddocks with trees in grazing plans or other advice to farmers:

> I usually look at the trees and the cover, see if it's a heavy cover, that might be something we maybe stay out of or just go into during the hot periods for just shade. And if it's a mixed cover with quite a bit of open area, then that might be a separate area for late summer grazing when it's hot.

In 2014 that advisor had said “We were asked to do a presentation on grazing in the woods …. And we denied it. We didn’t want to get into that” (Mayerfeld, Rickenbach, and Rissman 2016). In 2019, when asked if incorporating areas with trees was standard practice for grazing specialists, the advisor said, “Right now we're working on that because they usually just see woods, and they just line them out [of the grazing plan].” While this statement shows that many agricultural advisors still were not comfortable providing silvopasture advice, it also indicates that it had become acceptable to promote silvopasture as an agricultural practice to professional colleagues, which was not the case five years earlier.

Foresters did not report giving silvopasture management advice but indicated that the opposition to any integration of livestock with trees was softening over time. In a 2019 interview a forester commented that forestry guidance to farmers with woodlands used to be "Don't burn, don't graze and just let it go.” He went on to say

> And now what do we do? We tell people, ‘Burning's not so bad. And actually it's fantastic,’ and, ‘Oh, you might want to think about grazing.’ So it's like, okay. We've come a long ways on that.

We also found that foresters in our focus groups varied widely in their attitudes toward silvopasture. At the beginning of this project, we were warned that most foresters were likely to strongly oppose any integration of livestock and trees. In our direct interactions we found that foresters were indeed strongly critical of poorly managed woodland grazing, but most were open to considering how silvopasture management might improve environmental outcomes, at least in some settings. As one forester commented,

> Certain agricultural producers out there are going to graze the woodlands, and that's just economics. It's going to happen. So, we should look for those opportunities that we can decrease the environmental impact based on that.

This tentative acceptance of silvopasture was evident both in mixed focus groups that included agricultural advisors as well as foresters, and in a focus group with all foresters. Several expressed particular interest in the potential for goats to manage invasive species. Like the interviews, evaluation results suggest that foresters' attitudes toward silvopasture are variable (Figure 2). Nearly half of respondents did not know what foresters' attitudes were, but the other respondents reported that forester attitudes toward silvopasture were roughly evenly split between supportive and unsupportive, with many perceived as neutral.

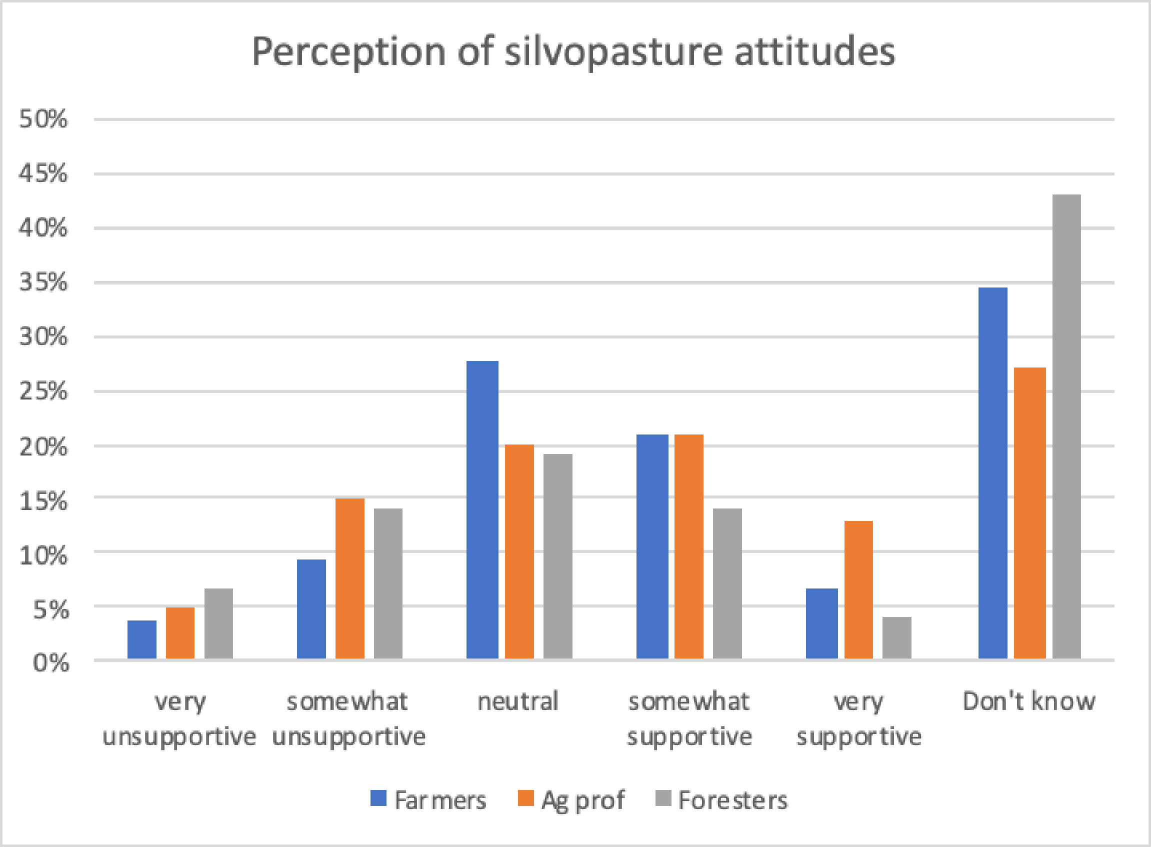

Figure 2. Aggregated end of program workshop evaluation responses, 2014-2019, in Wisconsin and Minnesota, USA, to the question "Thinking about the past year, how supportive or unsupportive are professionals and farmers in your county toward silvopasture?" N = 107

Resource professionals' comments about silvopasture were influenced by changes in broader contexts impacting farms and surrounding communities. Two years before our initial focus group the region had experienced severe drought and extreme heat, while the summers of 2017 and 2018 were relatively cool and wet, and 2018 included extreme precipitation events and flooding. The later focus groups placed less emphasis on the value of trees for shade and woodlands for emergency source of forage, and more emphasis on how silvopasture might handle extreme precipitation. Similarly, shifts in the farm economy were reflected in the discussion. In 2014, when commodity crop prices were high, resource professionals thought silvopasture management might improve environmental outcomes when conversion of pasture to row crop cultivation led to more woodland being converted to pasture. In 2019 resource professionals discussed the increased interest in alternative crops and land management systems such as silvopasture, given depressed crop prices.

> The agriculture economy right now, it's especially bad for dairy farmers, but nobody is making very much money right now. This is the first time I've ever heard discussion among dairy farmers about diversifying. … They're thinking they need to reduce their risk by adding other crops and other sources of income, and trees might be [one of those alternatives].

Although the specific issues changed over time, the discussion among farmers, as well as resource professionals, often highlighted how attitudes toward silvopasture interacted with regional resource and socio-economic issues.

3.1.3 Complexity, diversity, and uncertainty

Even though the taboo around discussing the integration of livestock and trees has weakened in our study area, the nature of silvopasture raises challenges for resource professionals who want to offer clear, research-based, financially-sound advice. Silvopasture entails a complex set of principles and practices drawn from both forestry and agricultural science, with context-dependent applications, making universal management prescriptions difficult to develop and deliver. As one forester commented when a focus group was discussing the potential for silvopasture to help with oak regeneration,

> I think there are so many variances that could go about this. The type of cattle. If it's beef, dairy cattle, sheep, goats, whatever. There's so many variances in that. The tree species you're wanting to regenerate. The time of year. It seems like a whirlwind of a headache that you're trying to put together.

Furthermore, there are substantial limitations in the fundamental knowledge base, including a lack of regional research. Both natural resource professionals and farmers questioned the applicability of silvopasture research on southern pine plantations to the mixed hardwoods of the upper Midwest:

> I'd like to see some controlled experiments in the northern forest rather than just from the southern United States where we could show an impact on the accumulation of forest product.

This comment was followed by a discussion of the differences between southern pine plantations and diverse northern hardwoods, including slower growth of northern trees, and concluded with the observation that "it might take two generations of scientists to get an answer."

3.1.4 Confusion around silvopasture policy and financial support

In the early focus groups, there was only one mention of the possibility of financial support from public agencies for silvopasture. Most of the later interviews, however, included discussion of the possibility of Natural Resources Conservation Service (NRCS) support for silvopasture. This type of financial assistance (provided through NRCS from the US Department of Agriculture) can be an important aspect of silvopasture economics since establishment costs can be substantial, but the interviews reflected considerable uncertainty. NRCS provides financial assistance for rotational grazing but traditionally has strongly discouraged grazing of woodland. There have been some efforts to have NRCS in Wisconsin and some surrounding states provide financial assistance for silvopasture establishment by planting trees, but the current reimbursement rates are low, farmers often do not realize they can ask for this assistance, and most agricultural advisors are uncertain about the current policies for silvopasture assistance, as this exchange among resource professionals illustrates:

> "And, if we start thinking about silvopasture agroforestry, is that a cost share practice at all? For NRCS?"
>
> "Not right now."

> “So now it would be 100% on the landowner to, again, how long before they start generating revenue or income from that?”
>
> “Well, wait a minute -- for planting we don't call it silvopasture, we call it tree planting. So if you want to plant trees in the pasture, we do cost share that…. There's also biological brush management… So there's other practices. We don't call them silvopasture.”

Another agricultural advisor (and farmer) in a different 2019 interview commented:

> And then, with the new EQIP which I work with for cost-sharing with fence or for fencing and watering [for managed grazing], it's like they are more into promoting converting tillable ground or work ground that can be pasture. When I first started, if you could prove or show there was history of grazing at one time then they would cost share to put the fencing in. But now, if it's got trees on it, they won't cost share at all. So that's actually going to probably blow up your silvopasture part of it to some extent, too.

In 2014 resource professionals spoke in general terms about the need for more information on the economics of silvopasture. In the 2019 interview, resource professionals in the southwestern part of the state devoted considerable discussion to the need for better markets for a variety of tree products, from lower quality wood to nuts, in order to increase the economic viability of silvopasture. This focus on markets and financial assistance in later interviews reflects a shift to thinking about silvopasture implementation and advice in concrete rather than abstract terms.

Finally, throughout the study period, farmers and resource professionals stressed that Wisconsin property tax policy is an important economic consideration for silvopasture. Resource professionals were frustrated by the fact that the current law provides a tax break for any pastured woodland, regardless of management and environmental outcomes, and farmers spoke about considerable variation in how local tax assessors interpret the rules. In the November 2018 focus group, one farmer described discussing silvopasture with the assessor:

> “We pay much more real-estate taxes on woodland than on cropland, and so last spring, I invited our assessor to come out to the farm. And he was knowledgeable of silvopasture but hadn't seen any of it, and he didn't want to go out with me. We sat down and looked at our maps, and he wanted me to show him where I had hardwire.… He lowered our valuation - I don't remember how much - quite a bit on those acres.”
>
> “So he accepted your explanation?”
>
> “Yup.”
>
> “And seemed to be knowledgeable enough to adjust for that?”
>
> “Yup. He's heard about it, but he just…"
>
> “You were the first person he'd talked to specifically about it.”
>
> “Yeah, well, we're probably the only rotational grazers in our area.”

3.2 How did silvopasture coverage change from 2009-2019 in a grazing periodical?

Content analysis of a long-established grazing periodical revealed that during the past decade there was an increase in attention to silvopasture, as well as a growing appreciation generally of trees as assets to pasture-based livestock systems. Figure 3 summarizes the number of times our search terms appeared in *Graze* in a grazing management context in articles and announcements.

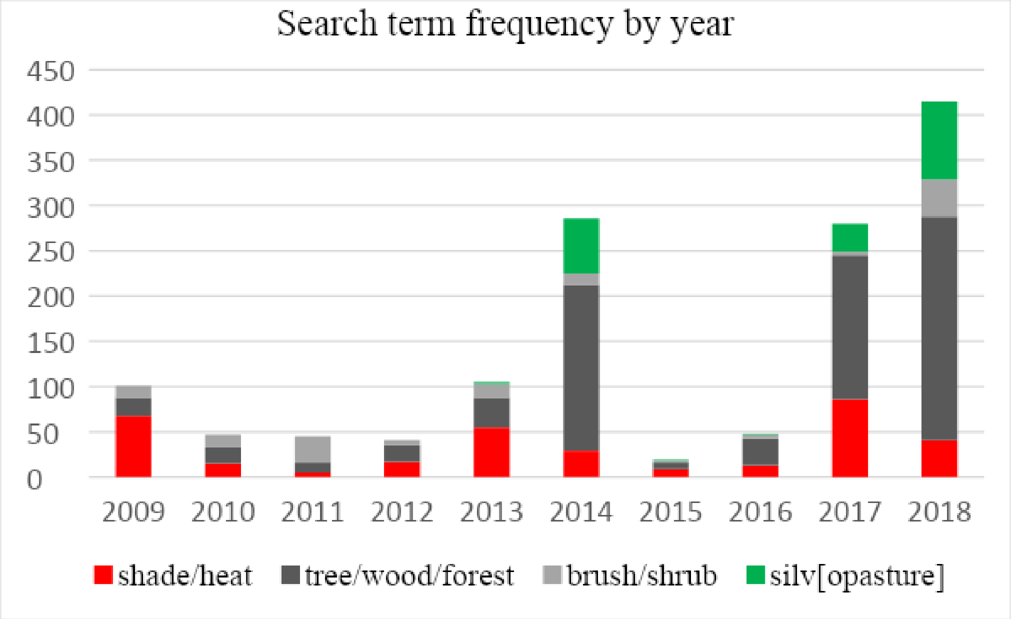

Figure 3. Occurrence of search terms in *Graze* related to integrating management of trees, pasture, and livestock. 2009, 2013, and 2017 had special features on managing heat stress.

From 2009 until late in 2013 the term "silv[opasture]" was never used in the publication. In November 2013 the term appeared for the first time in an announcement of a combined silvopasture and grazing conference. Then in 2014 *Graze* featured three articles about silvopasture by Tracy Frisch, and the word appeared more than 60 times. In 2015 and 2016 there were no silvopasture articles, and the word only appeared once each year, but in 2017 the word appeared 31 times. In 2018 the word silvopasture appeared 86 times, with articles about silvopasture by Bret Chedzoy and Joe Orefice in five different issues. In the first six months of 2019 the word appeared eight times -- four times in articles that were not explicitly about silvopasture and the other four times in an article about living barns by Brett Chedzoy, a silvopasture researcher and advocate from New York state. However, although the word "silvopasture" does not appear until 2013, many articles both before and after that date refer to the use of trees in pasture systems.

In 2009, 2013, and 2017 Graze included a feature where five experienced graziers from different states responded to the question "How do you manage heat stress?" In each of those years use of shade from trees was one of the most common strategies cited in the answers, but there is a progression over that time from barely mentioning shade to discussing shade management in some detail.

In 2009 only one response listed use of shade as a main strategy, and all mentions of shade were quite brief, like this quote from a Minnesota farmer:

> If the heat gets real bad, we use our few shaded paddocks, putting the cows there for a few hours in the middle of the day. We try to use these paddocks sparingly to avoid creating mud pits (Mroczenski et al. 2009).

In 2013, following the unusually hot and dry summer of 2012, three of the five responses discussed shade management as a primary strategy for dealing with heat stress, and two of those responses devoted several paragraphs to describing how they manage the use of their shaded paddocks. Here is the final paragraph from one of those responses:

> We re-fenced a few of the milk cow areas last year to get more trees in some paddocks. We use those paddocks in the day and then go to the shadeless paddocks at night. There are times when if we see a hot spell being forecast, we'll alter the rotation if we can to make sure the cows have the shade paddocks in the day. If the timing for that doesn't work and it's too hot for the cows, we'll bring them in the barn in the afternoon until they can go back out. We have been thinking of planting some trees in all the paddocks so that in the future everyone can just stay in their paddocks (O'Neill et al. 2013).

In 2017 all five respondents discussed using shaded paddocks to manage heat stress, and four of those responses listed access to tree shade as a primary strategy. Those four farmer-advisors each devoted several paragraphs to describing how they manage the use of their shade paddocks, including reserving shaded paddocks for hot weather, timing access to shade for daytime and access to unshaded pastures at night, and need for frequent rotation (Sheffer et al. 2017).

After using trees for shade, the most common positive mention of trees in grazing systems was to provide shelter in winter. Often, trees and/or shrubs were also mentioned as causing problems (e.g., excess manure accumulation, shelter for predators, or damage to fences) or as something to remove in order to create new pasture. Figure 4 groups search term appearances from 2009 through 2013 and from 2014 to mid-2019, not including the articles about managing heat stress or the articles about silvopasture. Even excluding the articles on silvopasture, trees are more often characterized as an asset to the grazing system after 2013 than before. The reporting on silvopasture and the role of trees in grazing systems reflects increased interest in the practice at the same time that it transmits knowledge.

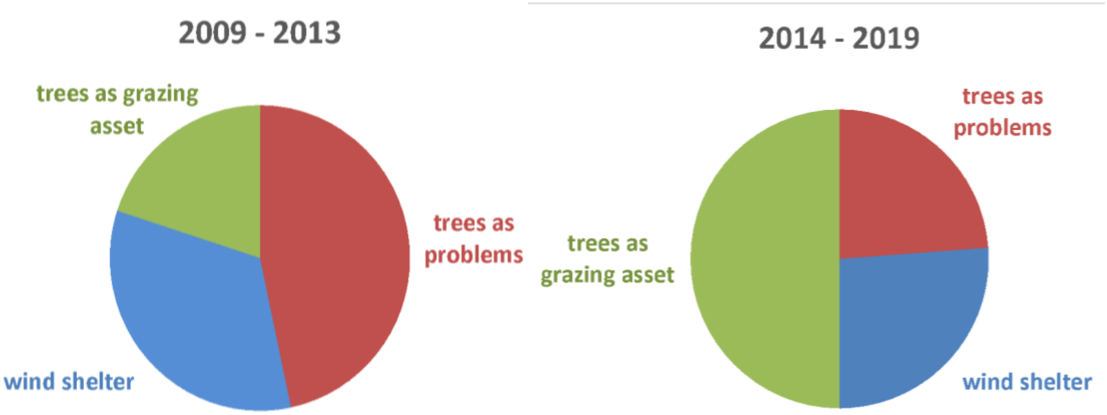

Figure 4. Context of search terms (tree, wood, forest) in articles before and after January 2014, excluding articles about silvopasture or *Graze* advisors addressing heat stress.   2009-2013 n = 45 appearances of search terms in 50 issues; 2014-2019 n = 42 appearances of search terms in 56 issues.

4. Discussion

From an environmental perspective it would be preferable to have all pastured woodlands in the US Midwest either not grazed at all or managed as silvopasture, with grazing conducted on a rotational basis guided by forage and soil conditions. However, farmers are unlikely to begin rotational grazing in just their woodlands, so one barrier to adoption of silvopasture is that it is limited effectively to farms that practice rotational grazing. As Figure 1 shows, in 2017 there were 6,786 farms practicing rotational grazing in Wisconsin, and only 1,120 farms practiced any kind of agroforestry (including but not limited to silvopasture). Nationally 265,162 farms reported practicing rotational grazing, and only 30,853 practiced any kind of agroforestry. Both in Wisconsin and regionally farms that already practice rotational grazing constitute the likely pool of potential silvopasture adopters. Our findings describe how silvopasture is perceived by these potential adopters and identify some of the contexts fostering and limiting the application of silvopasture in this region.

In the absence of a robust history of silvopasture research in this region, those farmers who want to implement silvopasture must act simultaneously as managers and informal researchers, observing conditions on the farm and results of previous management and adjusting their actions accordingly. To support farmers engaged in this type of work, agricultural researchers and advisors can facilitate farmer-to-farmer knowledge exchange and help identify underlying agroecological principles that guide but do not dictate management (Lyon et al. 2011; Poncet, Kuper, and Chiche 2010; Röling and Jiggins 1998). In northwestern Wisconsin, where several agricultural advisors embraced that role and explicitly invited knowledge exchange about silvopasture, we observed good communication among farmers about their experience and a clear increase in support for the practice in the grazing community. In southwestern Wisconsin, which also had an active grazing network but lacked an embedded facilitator of silvopasture knowledge exchange, farmers remained interested in silvopasture but cautious about its challenges and feasibility.

Our interviews reflect the inherent complexity of practicing silvopasture, as well as a dearth of regional research. Many researchers have observed that complex agroecological innovations require a shift from a technology-transfer paradigm of advisors delivering prescriptive direction to a systems-based paradigm of advisors facilitating farmer-led innovation and knowledge exchange (Provenza et al. 2013; Röling 2009; Blesh and Wolf 2014; Lyon et al. 2011; Ingram 2015). When farmers and resource professionals in our study emphasized the need for local research and demonstration, they were implicitly recognizing limits to scalability and the reality that a practice that is sustainable in one location may have different impacts when transferred to other biophysical and socioeconomic settings (Wigboldus et al. 2016).

As other research has demonstrated, individual knowledge and social support (e.g., an active community of practice) are important, but contextual factors (e.g., a local market for pulp-grade wood) also factor crucially into the viability of the innovation (Loorbach, Frantzeskaki, and Avelino 2017). This dynamic, wherein grassroots-level actors' knowledge, agency, and coordination are constrained or supported by contextual factors, is often analyzed in sustainability literature with what is called a multilevel perspective (Klerkx, Aarts, and Leeuwis 2010; Wigboldus et al. 2016; Geels 2002; 2011; Elzen et al. 2011; Ingram 2015). In our case, a multilevel perspective offers a heuristic for how contextual factors (including markets, research and extension practices, tax policy and agency support, cost and availability of labor, and other land uses), interact with individual knowledge and social support to influence the viability of silvopasture. For instance, in northwestern Wisconsin, the grazing network and its embedded facilitators of silvopasture knowledge-exchange, as well as the pulp market, were more important factors in how the viability of silvopasture was perceived compared to southwestern Wisconsin.

Silvopasture, like all agroforestry practices, brings an added temporal challenge. Farmers managing forages and livestock on a one to three-year basis for short term revenue must simultaneously manage for trees with a growth period from multiple decades to over a century. The uncertainty of long-term outcomes in silvopasture poses challenges for farmers and researchers (Arbuckle 2009). We suspect that this uncertainty helps explain why most agricultural advisors involved in this study did not report promoting silvopasture, even though the taboo around integrating livestock with trees weakened over the course of the study. Methodologies to manage under conditions of uncertainty in long-lived complex systems, such as adaptive resource management, have not been as well developed for sustainable agriculture as in the conservation and forestry literature, though the adaptive grazing movement is addressing the concept (Teague et al. 2013). Despite its critiques (Doremus 2011), adaptive management may offer a useful framework for resource professionals and farmers to develop working silvopasture systems in novel environments such as the mixed hardwoods of Wisconsin. Grazing networks, with their history of peer-to-peer knowledge exchange and their promotion of adaptive rather than prescriptive management, offer an appropriate starting point for co-creation of silvopasture knowledge in this context of complexity and limited local research.

Confusion around financial assistance and property tax policy added another barrier to silvopasture adoption in our study. As of this writing, the Natural Resource Conservation Service in both Wisconsin and Minnesota is working on clarifying state standards for financial assistance for silvopasture establishment and management (Hart 2019). These policy efforts represent a significant step forward in making silvopasture accessible for farmers, and also reflect the change in attitudes toward silvopasture that has occurred in the region.

5. Conclusion

Silvopasture in the US Midwest remains an uncertain proposition for most farmers and natural resource professionals, due in part to the history of woodland degradation by livestock overuse, and in part to the inherent complexity of the practice. Whereas prior to 2014 there was little research and education about silvopasture in the Midwest, more marked interest in silvopasture emerged and persisted in and around Wisconsin from 2014-2019. Of the two regions we studied, the enthusiasm, knowledge, and practice of silvopasture grew in northwest Wisconsin, which coincided with the development of a community of practice that included farmers and agricultural advisors cooperating in a favorable set of landscape and market circumstances. In contrast, farmers remained more skeptical toward the practicality of silvopasture in southwest Wisconsin where markets were less favorable and farmer adopters and professional advocates did not coalesce into a silvopasture community of practice.

We also observed changes in attitudes among agricultural advisors and foresters: early in the study period most of these resource professionals did not discuss silvopasture in public, but later in the study period some agricultural advisors gave silvopasture advice, and some foresters' attitudes reflected increasing openness to silvopasture in certain situations. Overall, the findings from this study suggest that 1) contextual factors such as climate, landscape attributes, markets, and existing land uses influence stakeholders' attitudes about silvopasture, and 2) positive attitudes and knowledge about silvopasture can be cultivated in local communities of practice that exchange information about management strategies appropriate to the complex, long-term, and context-dependent nature of the practice.

The diversity of potential silvopasture composition and design options in this region coupled with the time required to study trees means that standard agricultural research and extension approaches are insufficient to support farmers practicing silvopasture. Rather, farmers, resource professionals, and researchers need to collaborate over the long term. This process of collaboration can begin using general principles derived from silvopasture, forestry, and grazing research and experience, but it must adaptively adjust those principles based both on formal measurements and on farmer observations.

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Chapter Four: Multi-Party Agroforestry: Emergent Approaches to Trees and Tenure on Farms in the Midwest USA

Keefe O. Keeley [1,2,], Kevin J. Wolz [1], Kaitie I. Adams [1], Jeannine H. Richards [1,2], Erin Hannum[3], Severine von Tscharner Fleming [4,5] and Stephen J. Ventura [2,6,7]

[1] Savanna Institute, Madison, WI, USA

[2] Nelson Institute for Environmental Studies, University of Wisconsin-Madison, Madison, WI, USA

[3] Farm Commons, Duluth, MN, USA

[4] Greenhorns, Pembroke, ME, USA

[5] Agrarian Trust, Weare, NH, USA

[6] Department of Soil Science, University of Wisconsin-Madison, Madison, WI, USA

[7] Land Tenure Center, University of Wisconsin-Madison, Madison, WI, USA

Abstract: Agroforestry represents a solution to land degradation by agriculture, but social barriers to wider application of agroforestry persist. More than half of all cropland in the USA is leased rather than owner-operated, and the short terms of most leases preclude agroforestry. Given insufficient research on tenure models appropriate for agroforestry in the USA, the primary objective of this study was to identify examples of farmers practicing agroforestry on land they do not own. We conducted interviews with these farmers, and, in several cases, with landowners, in order to document their tenure arrangements. In some cases, additional parties also played a role, such as farmland investors, a farmer operating an integrated enterprise, and non-profit organizations or public agencies. Our findings include eleven case studies involving diverse entities and forms of cooperation in multi-party agroforestry (MA). MA generally emerged from shared objectives and intensive planning. MA appears to be adaptable to private, investor, institutional, and public landowners, as well as beginning farmers and others seeking land access without ownership. We identify limitations and strategies for further research and development of MA.

Keywords: land tenure; land-use change; beginning farmers; private land conservation; case study; alley cropping; silvoarable; silvopasture; windbreak; human dimensions

1. Introduction

Agriculture plays a major role in local land degradation as well as global pressures on natural system boundaries [1–4]. Most efforts to make agriculture more sustainable focus on mitigating negative environmental impacts through marginal improvements such as increasing resource use efficiency of existing systems or curtailing destructive practices [5–8]. Relative to most incremental approaches, agroforestry—the intentional combination of trees with crops or livestock—represents a potentially more transformative approach to enhancing crop production and other ecosystem functions in agricultural landscapes, including overyielding relative to component monocultures, carbon sequestration; promoting biodiversity; improving soil and water quality; and increasing resiliency to social and environmental perturbations [9–15].

Substantial constraints to the wider application of agroforestry persist [14,16,17]. For established farmers, limited time and knowledge constrain agroforestry adoption, as do prevalent perceptions that trees do not belong in farming systems [18–20]. Farms often also have substantial sunk costs in existing enterprises, which, along with the advanced average age of farmers, disincentivize investment in new enterprises featuring crops with long-term returns on investment [21]. Beginning farmers, on the other hand, are, in some ways, better positioned to practice agroforestry, but face a different set of constraints. Beginning farmers are more inclined toward agroforestry and less likely to specialize in row crops and grains [22,23]. Access to land, however, represents a major barrier for beginning farmers [24]. Because beginning farmers often lack capital for land purchase, leasing can be a more accessible option.

Thirty-nine percent of all farmland in the USA is leased rather than owner-operated, including 54% of all cropland and even greater proportions in regions where intensive grain production is concentrated [25]. However, most agriculture lease terms are one-year cash rent, which lacks the security of tenure necessary to invest in long-term value added to that land [19]. Investments in trees, soil health, infrastructure such as fencing, and other elements of agroforestry systems are not reasonable financial investments when there is risk of lease non-renewal prior to sufficient return on investment [26]. Given these factors, tenure models outside of land ownership and short-term leases are needed to facilitate agroforestry (Table 1).

Table 1. Potential benefits of agroforestry for landowners and farmers *.

For the Landowner	For the Farmer
Receive consistent income	Gain affordable long-term tenure of land
Have a caretaker of the property	Build skills and experience
Gain improvements to the property	Establish a profitable business
Realize increased property value	Share in innovation of agroforestry practices
Receive conservation funding	Develop a model to be replicated elsewhere
Option to share profits	Create a rewarding and enjoyable livelihood
Attain a legacy of revitalizing the land	Attain a legacy of revitalizing the land

* Adapted from [27].

The implications of various forms of tenure for integrating trees and agricultural landscapes have been studied in tropical countries, but rarely in temperate zones, where agroforestry is less common [18,28–31]. Given the lack of research on the topic, the primary objective of this study was to describe examples of farmers practicing agroforestry on land they do not own in the Midwest USA. We conducted interviews with these farmers and, in several cases, with landowners to learn about how these parties developed suitable tenure arrangements for agroforestry. In some cases, three or more parties played a role, including investors, another farmer operating an integrated enterprise, and/or a community stakeholder group. Given the diversity of entities and forms of cooperation, we broadly term these arrangements *multi-party agroforestry* (MA).

2. Methods

The primary aim of this study was an exploratory documentation of MA on farms in the Midwest USA. Because our initial observations indicated MA is uncommon, we sought to document all instances feasible. Through the social networks of the authors and farms connected with the agroforestry-focused non-profit organization Savanna Institute (savannainstitute.org; Madison, WI, USA), we identified 15 farms that potentially fit our criteria for MA: growing trees intentionally integrated with other crops or livestock on land not owned by the farmer. One case, Brix Cider, did not fully meet our criteria since it involved orchards in which apples were the only crop; we included this case in order to demonstrate a harvest access arrangement that could be applicable to MA.

We contacted one or more of the parties (e.g., landowner, farmer) from the 15 potential cases of MA and requested a one-hour interview. Four cases were unavailable or declined to be interviewed and are not included in this research. With two exceptions, we interviewed the farmer to collect data for each of the remaining 11 cases. One exception was Greg Judy, who reviewed and approved the case study of Green Pastures Farm based on information we collected from his written materials and recorded talks [32–35]. The other exception was Silverwood Park;

this case study was written by an author who represented one of the parties developing the project.

We conducted phone interviews in January through March of 2019. To ensure consistency, the same researcher conducted all interviews. We employed a semi-structured interview format to ensure each conversation covered the same topics. Topics and probing included questions about the farm operation, agroforestry practices, land access, and relations with other parties (Table S1 appended).

Each interview was recorded and used, along with publically available documents, to prepare written case studies that were subsequently reviewed and approved by interviewees. With different types of arrangements (e.g., written lease or not; number of parties involved) the amount of information among cases varied.

3. Results

Our findings include 11 case studies of MA in the Midwest USA involving a variety of entities and forms of cooperation (Tables 2 and 3).

Table 2. Select cases of multi-party agroforestry and farm characteristics in the Midwest USA.

Farm	Location	Primary Products	Acres	Farming Entity
Feral Farm	Jefferson, WI	Chestnut, small fruits, hay	10	Sole proprietorship
Vulcan Farm	Sidney, IL	Perennial polycultures, nursery	10	LLC
Saturn Farm	Ogden, IL	Chestnut, hazelnut, currant	21	LLC
Humble Hands Harvest	Decorah, IA	Livestock, vegetables, nuts	22	Worker-owned cooperative
Green Pastures Farm	Rucker, MO	Livestock, timber, mushrooms	1600	LLC
Aspen Farm	Soldiers Grove, WI	Livestock	110	LLC
Silverwood County Park	Edgerton, WI	Chestnuts, timber, small grains, fruit	18	Non-profit organization

Main Street Project Research Farm	Northfield, MN	Poultry, hazelnuts, elderberry	100	Non-profit organization
Farley Center Farm Incubator	Verona, WI	Vegetables, perennial polyculture	43	Beginning farmers
Community Groundworks	Madison, WI	Vegetables, small fruits, nuts	15	Community gardeners
Brix Cider	Mt. Horeb, WI	Apple cider	~50	LLC

Table 3. Key attributes of multi-party agroforestry for select cases in the Midwest USA.

Farm	Parties	Lease (Years)	Payment	Tree Ownership	Landowner Rights	Right of First Refusal	Distinctive Attributes
Feral Farm	Landowner & farmer	15	Cash rent	Farmer	Use of alleys for hay or livestock	Yes	Communication clause; future alley use for pasture
Vulcan Farm	Landowner & farmer	99	Cash rent	Landowner: trees as trees; Farmer: trees as crops	Alley grazing, trees as trees, personal harvest	Yes	Landowner enrolled in CRP; market adjusted lease rate
Saturn Farm	Landowner, investor & farmer	30	Cash rent	Farmer	None	Yes	Farmer enrolled in CRP; absentee landowner
Humble Hands Harvest	Cooperative, LLC landowner, and donors	1	Custom cash rent	Cooperative	None	Yes	Coop manages commons; neighborhood farmland investors
Green Pastures Farm	Landowners & farmer	>7	Custom cash rent	Landowner	Access; hunting	Preferred	Infrastructure in leases
Aspen Farm	Farm owner, landowner, herd owner, herd manager	1	Cash rent	Landowner	Access; hunting	No	Lessee converted forest silvopasture
Silverwood County Park	Municipality, 2 non-profits, 2 farmers	Varies	Varies	Landowner	Designated public access	N/A	Municipal landowner
Main Street Project Research Farm	Non-profit, landowners, farmers, LLC, investor	Varies	Varies	Non-profit	House site	Yes	Multiple landowners
Farley Center Farm Incubator	Non-profit, farmers	1	Cash	Landowner	USDA organic standards	N/A	Informal security of long-term tenure
Community Groundworks	Land trusts, non-profit, public	50	None	Non-profit; public access	None	N/A	Public harvests at will
Brix Cider	18 landowners & value-added business	None	Varies	Landowner	All except agreed harvest	None	No formal or legal contracts

3.1. Feral Farm

Feral Farm is a 10-acre chestnut alley cropping operation located on land leased from a 290-acre grass-based grazing farm in Wisconsin. Casey Dahl ("the farmer") planted the farm in 2014 as a perennial polyculture operation that included small fruits and other plantings. The operation and business model shifted since to focus on chestnuts to accommodate changes in the farmer's lifestyle, including moving over 200 miles away. Despite the challenges of distance, the farmer and landowner have worked closely to keep their arrangement mutually beneficial. The landowner has continued to operate the grazing farm and communicates with the farmer when the chestnut operation requires attention.

Before founding Feral Farm, the farmer previously grew annual vegetables and managed established orchards on leased land without written agreements. These handshake agreements worked well, but the farmer wanted to establish his own tree crops. Lacking the capital to buy land, he sought out the possibility of a longer-term land lease. He found an opportunity through a casual conversation with a landowner who was familiar with agroforestry through speakers at conferences and wanted trees on her farm. However, she did not want to make the investment and lacked the time or expertise. Recognizing a good match of skill and opportunity, she offered to let the farmer plant trees on her land. The farmer and the landowner signed a lease within a year.

The Feral Farm lease has held strong over the first five years, despite some changes in circumstances and objectives, because of the inclusion of these elements:

Cash rent, long-term lease: Feral Farm has a 15-year lease, which is the maximum permitted length of an agricultural lease in the state of Wisconsin (Table 4). The lease does not include any provisions for renewal, due to state law. The farmer expects 15 years will provide sufficient time to establish his business value as collateral for a loan for further expansion. The farmer pays annual rent at a rate that fluctuates based on the average county farmland lease price.

Reserved landowner rights: Although the farmer's lease includes use of 10 acres, he pays a reduced rental price attributable to rent on the equivalent of the two acres occupied by his widely spaced rows of chestnut and fruit plantings. The landowner reserves the right to manage and harvest hay in the alleys between the tree rows, and the farmer must keep the alleys clear for landowner use.

First right of refusal: If the landowner chooses to sell, the farmer has the right of first refusal to purchase his 10 acres of land. If the land is sold to another party, the lease is designed so his 10 acres goes with the land, not the landowner, and the buyer would have to honor the lease.

Tree, infrastructure, and equipment cost: The farmer pays all costs associated with the orchard's establishment and maintenance. The landowner waived rent for the first two years, which allowed the farmer to invest more money into establishing the farm. If the farmer needs help from the landowner, he must hire her to do custom work. They share a strong commitment to keep everything above board and professional, but also help each other with small tasks.

Liability: The Feral Farm lease includes clear language about who is legally responsible if something goes wrong. This includes loss or damages to equipment and infrastructure as well as injuries to people. For example, there is a clause regarding parties and visitor groups.

Communication schedule: Several provisions in the lease detail requirements for communications between the farmer and the landowner. One requirement is an annual meeting between the farmer and the landowner. This has ensured dedicated space to talk about any issues that have arisen, such as when the farmer started making plans to relocate his residence to over

200 miles away. Another communication provision relates to the expectation of future grazing in the leased area. If the landowner decides she would like to incorporate her cattle into the leased area, she must submit a grazing plan and have it approved by the farmer.

Table 4. Term limits in states with laws specifying maximum length of agricultural leases *.

State	Years
Alabama	99
California	51
Colorado	99
Connecticut	99
Iowa	20
Massachusetts	99
Michigan	34
Minnesota	21
Mississippi	99
Montana	10
Nevada	25
New Hampshire	99
New Jersey	99
North Dakota	10
South Dakota	20
Vermont	52
Wisconsin	15
Wyoming	10

* Adapted from [27].

3.2. Vulcan Farm

Midwest Agroforestry Solutions, founded by Kevin Wolz ("the farmer") in 2013, establishes agroforestry-focused farms in the Midwest USA. The company currently has two farms, Vulcan Farm and Saturn Farm, both under long-term leases. Both farms are located in Central Illinois but have distinct lease structures, operations, and goals.

Vulcan Farm, a 10-acre farm in Illinois, was established in 2015. The landowner currently lives on the property and runs a small livestock business with sheep for fiber, as well as broiler chickens, laying hens, and turkeys. She was looking for a way to incorporate trees into her grazing practices for shade, fodder, and biodiversity, but knew she did not have the skills to take on such a project. The farmer was looking to lease land and was attracted to the benefits of incorporating livestock into his agroforestry operation. The farmer and the landowner met through a network of local farmers but did not begin long-term lease discussions right away. They began a relationship by helping each other with small projects, building trust over time, and generally getting to know how each other lived, farmed, and communicated. The initial lease discussion came up organically, and they moved forward to find an arrangement that could be mutually beneficial.

Vulcan Farm is designed and managed as an agroforestry farm and nursery, incorporating intensive perennial polyculture, windbreaks, alley cropping, and silvopasture. Trees and shrubs are planted in rows 25 feet apart.

The Vulcan Farm lease includes several important characteristics that facilitate a long-term, stable relationship between the farmer and landowner:

Cash rent, long-term lease: Vulcan Farm is leased by Midwest Agroforestry Solutions via a 99-year, cash rent lease, which is the maximum permitted length of an agricultural lease in the state of Illinois.

Reserved landowner rights: Since the landowner is the livestock farmer in the partnership, she reserves the right to hay or graze the alleys between tree rows. At the beginning of the lease, the landowner cut hay between the rows but has since installed a fence around the area and grazes sheep in the alleys.

Market-adjusted lease rate: The annual lease payment is below-market; the price reflects the value of the landowner’s reserved rights. To ensure that neither party is caught in an unfavorable economic situation, the lease price adjusts every 5 years in accordance to standard market metrics.

First right of refusal: The farmer has first refusal rights similar to Feral Farm's. In addition, the lease is attached to the deed of the property and is recorded with the county so that any potential buyers are aware of the existence of the lease. There is also detailed language that determines how the property is appraised if the farmer were to purchase it.

Splitting tree value: Recognizing the potential for mutual benefit, the farmer and the landowner have also partnered in the investment of trees on the property (Figure 1). The landowner paid for the cost of wild-type trees for the habitat and shade value they provide, since she and her sheep reap the benefit from the ecosystem services provided by the trees regardless of their productivity. The farmer paid for the cost difference of using improved genetics for fruit and nut production, i.e., trees as crops. He benefits from the crop yield that comes from particular cultivars over and above their value as wild-type trees. This unique investment structure is also tied to appreciation of the property; when/if the farm sells, it will be appraised considering only the value of trees as trees, so that the farmer does not pay twice for value of productive trees.

USDA Conservation Reserve Program (CRP): The landowner enrolled in CRP, paid and was reimbursed for establishment of a CRP windbreak and pollinator strip, and she receives all related incentive payments. She contracted the leasing farmer to establish both practices.

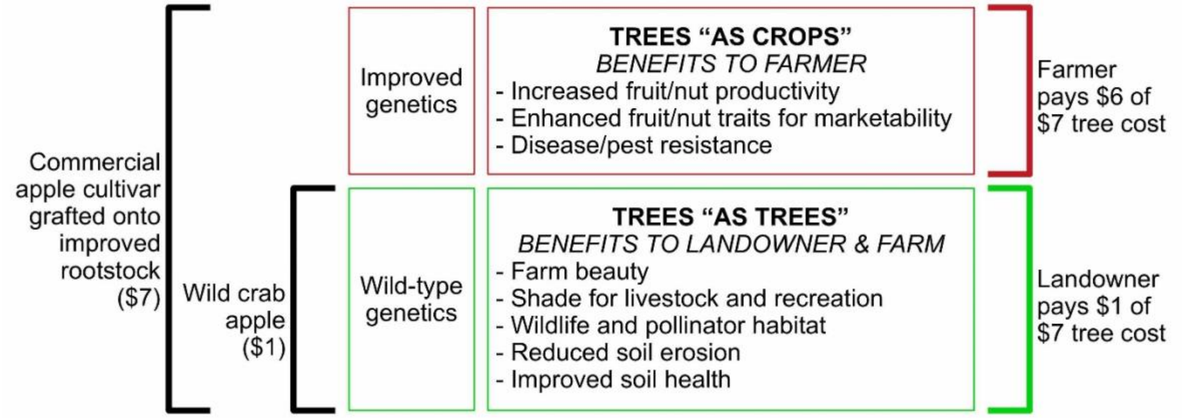
Commercial apple cultivar grafted onto improved rootstock ($7)
Wild crab apple ($1)
Improved genetics
TREES "AS CROPS"
BENEFITS TO FARMER
- Increased fruit/nut productivity
- Enhanced fruit/nut traits for marketability
- Disease/pest resistance
Farmer pays $6 of $7 tree cost
Wild-type genetics
TREES "AS TREES"
BENEFITS TO LANDOWNER & FARM
- Farm beauty
- Shade for livestock and recreation
- Wildlife and pollinator habitat
- Reduced soil erosion
- Improved soil health
Landowner pays $1 of $7 tree cost

Figure 1. Tree cost at establishment of an agroforestry planting can be split between farmer and landowner based on the value of trees as wild-type trees versus trees as crops, as was done at Vulcan Farm. An illustrative example for apple is included.

The farmer and the landowner worked with the non-profit organization Farm Commons (farmcommons.org; Duluth, MN, USA) to draft this unique agreement, which addresses many of the key hurdles that prevent new agroforestry farmers from getting started. Additional mutual benefits in their relationship include the farmer renting equipment, like a tractor, from the landowner, and the farmer benefits from the landowner living on the property and keeping an eye on the farm.

This year will be the fourth year of the lease, and there have been no major issues to date. The farmer feels that he has the support of the landowner, both legally and personally.

3.3. Saturn Farm

Saturn Farm, established in 2016–2017 in Illinois, shares some similarities with Vulcan Farm (long-term, cash-rent lease for an agroforestry operation with alley cropping and windbreaks), but there are also important differences. This property is 21 acres and is designed as a commercial chestnut, hazelnut, and currant operation, rather than a germplasm repository and nursery. Just like at Vulcan Farm, the farmer and the landowner at Saturn Farm knew each other for several years prior to signing the lease. When the landowner decided to move out of state, they worked together to negotiate a long-term lease that would support her desire for agroforestry on the farm.

The landowner was uncomfortable with a 99-year agreement, so they settled on a 30-year term with the option to renew at the end of the term. Both parties thought the duration was long enough to see a return on investment. The farmer worked with outside investors to provide capital for tree establishment and maintenance. There are some restrictions delineated by the lease (e.g., no use of genetically modified crops and no aerial spray applications), but there are no use or access rights reserved by the landowner. Unlike at Vulcan Farm, the farmer enrolled in CRP and receives the incentive payments for establishing windbreaks and pollinator habitat. The farmer and outside investors paid for, own, and will reap the profits from the trees, the well, and the irrigation system established on the farm.

The farmer says that working with an absentee landowner has worked well. The landowner gets a rent payment every year and knows the land use aligns with her values and future goals. The farmer gets autonomy on the land and is able to make his own business decisions, as long as they align with the lease terms.

Cash rent, long-term lease: Saturn Farm is leased by the farmer via a 30-year, cash rent lease, which both parties thought was long enough to see a return on investment.

No reserved landowner rights: While there are some restrictions delineated by the lease (e.g., no use of genetically modified crops and no aerial spray applications), but there are no rights reserved by the landowner (such as alley grazing rights).

Market-adjusted lease rate: The lease price adjusts every 5 years in accordance to standard market metrics.

First right of refusal: If the landowner chooses to sell, the farmer has the right of first refusal to purchase the land. The terms are the same as the Vulcan Farm lease.

Tree, infrastructure, and equipment costs: The farmer has invested in extensive infrastructure on the land, including installation of a well and an irrigation system. At Saturn Farm, the farmer and outside investors paid for, own, and will reap the profits from the trees.

USDA Conservation Reserve Program (CRP): The farmer enrolled in CRP (windbreaks and pollinator habitat) and receives the incentive payments.

Establishment Financing: The farmer worked with outside investors to finance the establishment costs of the operation.

3.4. Humble Hands Harvest

Humble Hands Harvest is a 22-acre farm in Iowa raising livestock in alley pastures (mostly pigs and sometimes sheep) between rows of young nut trees, as well as annual vegetables on other parts of the farm. The farm business structure is a worker-owned cooperative with a mix of owned and leased land under operation.

The founders of the cooperative selected this model in part to facilitate the social and environmental justice mission of the farm. This model provides room for members to build equity, has an exit strategy, and intends to provide a pathway to land access for beginning farmers.

Multiple landowner leases: The cooperative leases some land at a below-market rate from an LLC formed by community members to hold the land until the cooperative can purchase it. The cooperative also leases some land owned by individual members of the cooperative.

Business structure: The worker-owned cooperative is governed by a written agreement.

Cooperative land ownership: Two farmers are currently owner-members of the cooperative. The business structure is designed so additional farmers can join the business and build equity in the cooperative. In addition to the leased land, some of the farm is land is owned by the cooperative.

Commons as member of cooperative: Some of the land, and the trees planted there, were donated. These parts of the farm are accounted for as a community-owned commons. The cooperative's charter includes the commons as a member, in the sense that the wider community also has equity in the business. If the farm were dissolved or a member of the cooperative exited, the equity associated with the commons would either remain with the farm or be distributed elsewhere in the community rather than being recovered by individual members of the cooperative.

Infrastructure ownership: The buildings and infrastructure (e.g., a well) on the farm are owned by the cooperative, in some cases with financing from the cooperative's members. The land with trees and infrastructure are owned by the cooperative or its members.

Path to ownership: The LLC that currently leases land to the cooperative was formed to provide secure tenure while the cooperative develops capacity to purchase the leased land. This structure is designed to build equity.

Tree, infrastructure, and equipment cost: Ownership and investment in tree, infrastructure, and equipment costs varies based on who owns the land (external landowners, member landowners, or the cooperative itself).

3.5. Green Pastures Farm

Greg and Jan Judy ("the farmers") own Green Pastures Farm, a grazing operation in Missouri that includes sixteen 16 separate properties; twelve of these properties are leased. Green

Pastures Farm’s primary products are grass fed and finished beef, hair sheep, timber, and log-grown mushrooms. They also work with two other farmers on their land who raise and manage hogs and pastured laying hens. Their animal management strategy focuses on keeping inputs low by working in balance with the natural landscapes of their properties. Green Pastures Farm currently manages 1600 acres, with 700 acres in grass and 900 acres in woodland.

Since the mid-1990s, on their land and land leased from nearby landowners, the farmers have worked to increase the beauty and value of the land through infrastructure improvements, forest management, and targeted multi-species grazing to manage understory and open pasture vegetation. They have established silvopasture areas on several of the farms, both owned and leased. The goals for the silvopastures are to improve the forage availability, livestock access to shade, timber quality, and aesthetic aspects of the property. Culled logs are used as much as possible for timber and mushroom production.

Each of the farmers’ lease agreements is unique to the property and the landowner. The farmers emphasize that leasing land rather than purchasing it frees up equity to invest directly into the animals and other aspects of growing the business. Key characteristics of his leases include:

Written, long-term lease: All Green Pastures Farm leases are legally binding, written leases lasting at least seven years. For the farmers, this duration ensures a return on investment.

Custom rent: Leases range from $0 to $25 an acre. The price reflects the infrastructure and land improvements the land needs to support grazing (e.g., installing ponds for water access, building permanent fencing, restoring overworked or poor land, etc.). This custom rent price recognizes the regenerative and beautification work Green Pastures conducts on the land.

Infrastructure cost: In general, the farmers plan for two years of infrastructure and land improvements, followed by five years of good production through sustainable grazing. Costs for fencing and materials are also written clearly into each lease to designate responsibilities for purchase, maintenance, and whether accounted for separately or in the rent price.

Landowner communication: The key to successful leases is in the relationship Green Pastures builds with the landowners. They invite landowners to experience how the cattle move and improve their land and update them monthly with a picture-rich email. As a gesture of the farmers' goodwill, landowners also receive meat from cattle raised on their land. The farmer says it is the responsibility of the farmer to maintain clear lines of communication. These strong relationships lead to long-term lease agreements and lease renewals.

Connected lease properties: Most of the farmer's leased properties are adjacent to each other so they can share resources, such as electricity and fencing. For example, one of his leased farms has the capacity to charge fences on five others.

3.6. Aspen Farm

Aspen Farm is an 80-acre home farm plus an adjacent 30 leased acres in Wisconsin. Dairy heifers, beef steer seasonal stockers, and sheep raised on pasture are the primary farm enterprises. The parties involved include:

Farmer: Owns the home farm and manages the farm business.

Herd manager: Paid for his labor involved in cattle management, pasture improvement, fence construction, and silvopasture establishment. He also seasonally grazes his own flock of feeder lambs on the home farm.

Livestock owners: Hire the farm to raise cattle on pasture during the 6–7 months of the grazing season.

Landowner: Leases land to Aspen Farm that is adjacent to the home farm on a one-year renewable lease.

The leased acreage includes open pasture as well as woodlands that have been degraded by overgrazing and logging. Parts of the leased land and the home farm were converted to silvopasture by the herd manager thinning the overstory and shrub canopy and establishing improved forages. The sheep have also been used to assist in vegetation management on the home farm.

The farmer and herd manager are pleased with the silvopasture because it increases the amount of forage available on the leased acreage. Both the farmer and landowner report enjoying the aesthetic and recreational aspects of a more open woodland pasture. The herd manager values the benefits of having forage available for animals to continue to graze where they seek shade, as well as the benefits of nutritional diversity via woody browse in silvopastures.

Cash rent, short-term lease: Aspen Farm leases 30 acres on a one-year renewable lease.

Reserved landowner rights: The landowner of the leased acreage has access for recreation and hunting. The landowner also specified that no saleable timber should be removed in the silvopasture establishment without his approval.

Lease rate: Negotiated periodically based on typical local rates for pasture rental.

Forest management: Farmer and herd manager decide how to use the woodlands for silvopasture, with the approval of the landowner.

3.7. Silverwood County Park Agroforestry Demonstration

Silverwood Park was donated to Dane County, Wisconsin with stipulations that the land continue to be actively farmed and used for agricultural education. Silverwood Park currently leases land to five farmers who grow a variety of annual crops. With the purpose of demonstrating agroforestry at the park, the Savanna Institute partnered with Friends of Silverwood Park (FOSP), the citizen-advisory group that manages the park.

Through a series of meetings over several months beginning in 2018, a plan was developed to establish an 18-acre alley cropping and windbreak demonstration area. The area is currently leased to an organic row crop farmer, who has been involved in all planning discussions and is very supportive of the project. He will continue to farm row crops on his regular rotations in the alleys between tree rows. The landowner, Dane County Parks, contributed initial funds to the tree purchase, installation, protection, and maintenance, but is not involved with any other aspect of management, product ownership, or research and education. The Savanna Institute has sought external funding from governmental and private grant-makers.

The primary project objectives are education, research on agroforestry crops and best practices, and demonstration of the profitability of such a system. Maximizing crop diversity while also demonstrating the feasibility of large-scale alley cropping drove the design. Alley cropping systems in the project include (1) timber trees (black walnut alternated with hybrid poplar) to showcase the potential for growing valuable timber species with minimal inputs while still maintaining cropland, and (2) interplanted chestnut and elderberry to demonstrate the integration of fruit and nut crops into alley cropping. In both systems, 80-foot between-row spacing accommodates the row crop farmer’s widest equipment. Additionally, plantings of aronia and black currant were designed for mechanical harvest and to demonstrate the potential of fruiting shrubs in lieu of, or adjacent to, row crop agriculture. Finally, a windbreak on the edge of the field will protect the tree crops from wind and potential pesticide drift from the neighboring conventional row crop field.

The designation of roles and responsibilities was a key outcome of the extensive meetings to build relationships and plan the operation (Table 5). These respective roles reflect the relative interest in involvement by each party. A memorandum of understanding is in place between the Savanna Institute and FOSP. Written lease agreements have also been negotiated among all parties.

Table 5. Roles and responsibilities of parties cooperating in agroforestry demonstration at Silverwood Park, Wisconsin USA.

Roles & Responsibilities	Friends of Silverwood Park	Savanna Institute	Mark Doudlah/External Contractor	Dane County Parks
Land tenure	Long-term lessee	Long-term sub-lessee	Sub-lessee	Landowner
Fundraising	Some responsibility for fundraising	Main responsibility for fundraising	May contribute cash or labor to costs	Capital expenses
Planning/design/ stakeholder engagement	Equal role	Equal role	Equal role	None
Installation	Contribute labor	Lead responsibility	Secondary responsibility	None
Ongoing management	Contribute labor	Oversee	Contribute labor	None
Ownership of products	Shared based on initial agreement	Shared based on initial agreement	Shared based on initial agreement	None
Research	Assist as appropriate	Lead responsibility	Assist as appropriate	None
Public programs	Shared responsibility	Shared responsibility	Assist as appropriate	None

3.8. Main Street Project Research Farm

Main Street Project (MSP) is a 501(c)(3) non-profit organization focused on developing programs to increase skills, income, and job access for Latinx immigrants working in the low-wage agricultural and food industries. Since 2010, MSP has piloted an innovative poultry agroforestry production system. Their related programs cover business planning, hands-on training, mentorship, and best practices for land stewardship, expansion, and replication. After almost a decade of developing and testing this model, MSP was ready to scale up and expand beyond their existing half-acre units.

Established in 2018, the MSP Research Farm sits on 100 acres outside of Northfield, Minnesota. The purchase, lease, and management of the land is a unique and community-informed partnership among the original landowners, investors, and the non-profit. Key features of the partnership include:

Innovative land ownership: The 100 acres where the Research Farm is located was originally owned by conventional farmers that lived next door to MSP Chief Strategy Officer Reginaldo Haslett-Marroquín. After a long period of relationship building, the landowners agreed to sell their tillable land for the MSP Research Farm. MSP owns 40 of the 100 acres, which is the most a non-profit organization can own in the state of Minnesota. An investor-landowner committed to the mission of MSP purchased 60 additional acres. The original landowners retain ownership of their farmstead site and some existing wetlands.

Land purchase financing: The 40 acres purchased by MSP was financed through a partnership with Iroquois Valley Farmland REIT, a certified B-Corporation that operates a Real Estate Investment Trust focused on organic farmland. Two key mechanisms facilitated by Iroquois Valley allowed Main Street Project to own the land:

Iroquois Valley’s soil restoration notes waive land payments during the first two years allowing farmers to invest in soil and business building.

Iroquois Valley’s commitment to financing small acreage purchases is uncommon for farmland investors.

Lease structure: The farm is managed by an LLC. The LLC holds a 21-year lease with each of the landowners. The partners, led by Main Street Project Chief Operations Officer Julie

Ristau, tried many different models and worked with multiple legal advisors. A challenge was finding people who could work outside of existing legal frameworks to create a new, legally protected way of viewing community land ownership and access.

Landowner responsibility: The two other landowners (the investor-landowner and the original landowners) are full partners in the development of the Research Farm. They all have a seat at the table and help make decisions in the plan for the land. The original landowners still live on the land and are working towards regenerative land management, something they were not interested in before being approached by Main Street Project. The investor-landowner is currently building a 2-acre homestead on their land.

3.9. Farley Center Farm Incubator

The Farley Center is a non-profit organization that owns 43 acres of farm and woodlands in Wisconsin with the intertwined missions of social, progressive change, community building, sustainability, and ecological justice. The center hosts a farm incubator program focused on providing education and access to beginning farmers, with the outlook that the farmers help the center care for the land. While each incubator farmer initially has access to a one-year lease, the Farley Center and the farmers work to build a community of trust and mutual support that has allowed farmers to invest in the land and their farm businesses long-term. The farm incubator is USDA certified organic, so every farmer is key to the center's commitment to soil building and ecological farming.

Ian Aley (the farmer) began leasing land and farming at the Farley Center seven years ago. At the time he ran a small vegetable-focused market garden with a small CSA and wholesale sales through a local marketing cooperative. After a few years of vegetable farming, the farmer decided to stop growing vegetables at scale and shifted his focus to perennial production. Because of the support of the Farley Center, he felt comfortable investing in fruit production (including apple, pear, peach, serviceberry, elderberry, cherry, paw paw, and others). He hopes to be able to offer fruit to the CSA programs of other farmers on the land. Even though the lease the farmer holds is not long-term, his plans for his land are.

Lease structure: While the individual parcels of land can only be leased in one-year increments, the non-profit welcomes farmers for the long term. There is an understanding that farmers are welcome to stay as long as they need. The farmer stresses the lease is more about relationship than contractual agreement. Because the land is owned by the Farley Center and governed by a board, there is stability. The farmers and non-profit view the land not as private property, but a common resource. He values the trust he has in the personal relationships at the center; if this was different, he would want a more stable lease.

Shared resources: Incubator farmers enjoy access to shared infrastructure (including water and cooler space), access to staff expertise and assistance, participation in bulk buying of supplies like potting mix and soil amendments, tractor rental, high tunnel space rental, and shared tools. Farmers also can participate in a marketing cooperative that sells farm goods wholesale to local restaurants and food outlets.

Peer support: Many Farley Center farmers are new Americans who both benefit and greatly contribute to the culture of mutual support. More established farmers often work closely with beginning farmers on the land.

Funding structure: Initial funding for the incubator farm program was mostly sourced through USDA grants, which provided for technical assistance, infrastructure and equipment, and operating support. But there was a need for more reliable funding. To address this, the Farley Center operates a green cemetery in woodlands that are not farmed on the property to generate income for staff and support of the farm program. While this revenue does not cover all costs, it provides stability for the farm and the farmers.

3.10. Community Groundworks

In Madison, Wisconsin, on 15 acres owned by a community land trust, the 501(c)(3) non-profit organization Community Groundworks runs a 5-acre, certified organic community farm focused on annual vegetable production. Community Groundworks also manages the Troy Community Garden (comprised of over 300 individual 400-square-foot garden plots). In addition to managing the farm, gardens, tree crops, and natural areas, along with an edible forest that includes fruit, berries, and nut trees, Community Groundworks coordinates closely with a 30-unit mixed-income housing development on the property. The non-profit also runs education and outreach programs for adults and youth, with the aim to connect the greater Madison area to farming, gardening, and the importance of human, land, and social health.

The history of the land and how this tenure arrangement evolved is complex. In 1995, 15 acres owned by the State of Wisconsin was planned for commercial development until community members banded together with local non-profits to devise a way to maintain public use of the site. In 1998, the state granted a 50-year lease to the 15 acres plus an adjacent 16 acres to Community Groundworks. The lease included a provision, executed in 2001, allowing Madison Area Community Land Trust to fully acquire the land title.

Land ownership and management: The land is owned by Madison Area Community Land Trust with a conservation easement held by Center for Resilient Cities.

Long-term lease: 50-year lease of 15 acres to Community Groundworks.

Infrastructure ownership: All infrastructure managed by Community Groundworks is owned by the non-profit.

Tree cost and maintenance: Edible perennials on land leased by Community Groundworks were planned and planted with grant funding that is no longer available. These edible perennials are in need of greater management.

Access: The harvests from this area are communal on a first come, first served basis.

Communication: Clear communication and planning is key to this arrangement that includes multiple nonprofits and organizations with differing missions.

3.11. Brix Cider

Marie and Matt Raboin ("the cider makers") began making cider commercially in 2016, two years after planting apple trees on the land they own in Wisconsin. They initially planned to establish a large enough orchard to grow their own apples for the cider operation, but the startup cost was ultimately greater than they could afford. This meant they would either need to buy apples or juice from large, out-of-state orchards or devise a more local, creative solution.

Through Marie's work for NRCS with farmers across the region she came across many farms with small orchards, operations with abandoned apple trees, and numerous aging growers who could no longer manage their trees. Matt and Marie devised a plan to work with these orchards by harvesting and making cider from surplus and less-than-perfect apples that would normally never reach consumers. They received a grant to test this idea by helping them establish strong relationships with the 18 different orchards they work with today.

The cider makers do not have any legal contracts with the landowners they work with. These casual agreements are often set up by calling the landowner, proposing to harvesting their trees, and setting a price. Most are very happy to allow them to pick, especially older people who have orchards. Many of these orchards have long been for sale but have not sold; partnership with Brix Cider has allowed them to avoid the undesirable alternative of cutting their trees down to sell or rent the land for row crops. These unique partnerships allow Brix Cider to source a large variety of local apples (within 30 miles) for the same price as buying them from outside of the community, with the added benefit of building connections to the land and people.

Since their own orchard will never produce more than 10% of the apples needed for the cider business, the cider makers are looking to harvest more apples each year. They are exploring many options, including more directly managing the orchards they currently work with. This would mean yearly pruning and maintenance, leading to larger yields and better apples. It also brings up the possibility of needing more formal agreements that would protect the cider makers' investment of time, labor, and travel. However, they emphasize that the smaller orchards like that they do not have to sign anything, and it allows all parties to be a flexible.

4. Discussion

In this section, we discuss (1) key features of multi-party agroforestry (MA), (2) land access and tenure in MA, strategies for further development of MA through (3) policy and programs and through (4) direct interventions, and (5) future research directions.

4.1. Key Features of MA

In contrast to independent landowner-operators as the archetype of agroforestry practitioners, this study describes 11 diverse cases of farmers practicing agroforestry on land they do not own in the Midwest USA. As with many other forms of agriculture, partnerships of landowners, operators, and investors can be adapted to agroforestry. We use the term partnership in the general sense; landowners did not have formal business partnerships with farmers in the cases we documented. Most of the agreements in this study developed from initial contact either via social networks or solicitation by one of the parties. To our knowledge, none of these arrangements were initiated through intentional match-making efforts of a third party. Most of the interviewees emphasized the value of developing personal and professional relationships at the outset of the partnership. This connection was important to build a sense of shared values and broad-scale objectives as a basis for then developing more specific arrangements. The case at Silverwood Park, for example, involved a series of meetings over the course of several months involving the municipal landowner, the citizen advisory group, the non-profit organization, and the collaborating farmer. Efforts to link beginning farmers with landowners are becoming more common; if such programs extend to MA, a continued emphasis on building relationships will be essential to their success [24].

A written agreement governed most, but not all, of the partnerships. One exception was Brix Cider; in that case the extent of agreements were one-time harvest payments and did not require capital investment to establish perennial crops. In most cases, farmers who established and maintained perennial crops and agroforestry on land they do not own required security of tenure extending for a sufficient period of time to recoup their investments. The landowners also faced a heightened stake in the success of an agroforestry venture since trees will remain on their property longer than annual crops.

A long-term lease was the most common vehicle for formalizing agreements between farmers and landowners, though other mechanisms were also explored (Table 6). The process of creating a long-term lease involved all parties cooperatively developing specific terms to meet their respective goals and putting the lease agreement in writing. A comprehensive account of this process is beyond the scope of this study (but see [27]). A number of features of long-term lease agreements for agroforestry require attention during their development: the length term of the lease; process for renewing or exiting the lease; the rent payment amount and schedule; conditions of selling or transferring the land, including right of first refusal; conditions of subleasing; scope of allowed/required uses; accounting for improvements, including trees and infrastructure; basis for ongoing communication, negotiation, and dispute resolution; and allocation of appreciated assets at termination.

Table 6. Select non-ownership tenure arrangements for agroforestry under U.S. common law *.

Default Characteristics of Tenure Arrangement	Lease	Easement (Appurtenant)	Easement (In Gross)	License
Binding to the land: Grants the farmer a property interest or legal right that attaches to the land and passes to future landowners	X	X		
Possession rights: Grants the farmer the exclusive right to possess or occupy the property	X			
Usage rights: Grants the farmer a right to use the property for some purpose(s)	X	X	X	X
Revocability: Can generally be revoked by the landowner at any time				X
Revocability: Can be revoked by the landowner at the time of death or when the property is sold			X	
Transferability: Can be transferred by the farmer during his lifetime or at death			X	

* Adapted from [27].

Several case studies highlight the importance of these items within the lease agreement to build on a shared understanding of expectations and responsibilities, as well as mitigate risk in case of changed circumstances. For example, Green Pastures Farm, Vulcan Farm, and Saturn Farm emphasized including the value of improvements in the terms of the lease.

Although the complexities and nuances are significant in planning for long-term agroforestry partnerships, our study demonstrates that the success of these partnerships depends on (1) building shared values and objectives among partners, and (2) paying attention to details in the planning process. When there is commitment among the multiple parties involved to these elements, land access and tenure models adapted to long-lived and diversified systems can be developed for farmers, landowners, and society to enjoy benefits of agroforestry [24].

4.2. Land Access and Tenure in MA

Land access represents a fundamental challenge for many farmers, especially for beginning farmers [36]. These case studies highlight how farmers accessed land and secured appropriate tenure for agroforestry enterprises without purchasing it. Developing relationships, articulating shared objectives, and conducting intensive planning were consistent themes in land access. Although mechanisms varied, a written agreement was common for securing tenure with a time horizon appropriate for agroforestry.

The case of Green Pastures Farm highlights how leasing land can ease the capital requirements required to begin and expand farming operations. Instead of tying up equity in land purchases, he invested in other expenses such as the trees, fencing, and animals. They also used infrastructure improvements and vegetation management on leased land to establish silvopasture and forest farming enterprises, thereby generating revenue on land that is fallow, degraded, or unsuitable for cultivation.

Certain features of the lease agreements at Feral Farm and Vulcan Farm facilitated beginning farmer tree crop enterprises. In both cases, the landowner operator continued to farm in the alley spaces between the rows of trees, making hay in the former case and pasturing sheep in the latter. The Feral Farm arrangement further freed capital for establishing tree crops by (1) effectively limiting the lease to the area corresponding to tree rows, and (2) delaying rent payments for the first two years. While this represented a financial concession from the landowner, it was agreeable considering the value of assisting a beginning farmer and the added value to her farm of the chestnut silvopasture. Both arrangements also include rental of equipment and services such as mowing for use in their operations. This ensures appropriate landowner compensation and clear expectations around their commitment to the lessee's operation.

The lease at Vulcan Farm also included a provision to allocate the value of trees—both the cost at establishment and in case of lease termination—according to their value as trees and their value as crops (Figure 1). Although, to our knowledge, this represents a novel strategy to make agroforestry accessible to a beginning farmer in the USA, the partitioning of value and use rights of trees and forests is common in other parts of the world [37].

In the cases of Main Street Project and Farley Center Farm Incubator, these organizations exist for the express purpose of providing opportunities for aspiring farmers to gain experience and resources they need. The agroforestry systems established at these farms can be considered part of the educational infrastructure, just as are the shared tools, equipment, and buildings. Not only does the harvest and sale from mature perennial crops potentially offer more immediate income opportunities for a new farm business, but the knowledge and skill gained by managing the established crops gives beginning farmers a window into how agroforestry could be integrated when they establish their own farms. In a slightly different fashion, Brix Cider's practice of harvesting from other mature orchards while their own orchard is not yet in full production makes use of existing tree crop infrastructure to develop their business without having to wait for their own trees to mature.

Although it has not been systematically surveyed, the authors' experience suggests that there are many more landowners in the Midwest USA who would like agroforestry on their land than there are farmers who are prepared to develop agroforestry enterprises (but see [18]). Generally, the USA faces a dearth of beginning farmers [38]. This is a particular limitation to agroforestry, given that farmers early in their careers are (1) better positioned to reap the benefits of long-lived perennial crops, and (2) more interested in alternative production systems [39]. A number of financial factors besides land access often make it difficult for beginning farmers to become established: the cost of healthcare, student debt, and the uncertainty of farm income [40]. In part due to these factors, beginning farmers often lack the support necessary for long-term enterprises such as agroforestry; hence, there is a need for policies that address these factors as part of a holistic strategy to foster land access via MA [41].

Private ownership undergirds most tenure arrangements in the USA, and MA arrangements can adapt to this context. Examples include Vulcan Farm, Saturn Farm, Feral Farm, Green Pastures Farm, and Brix Cider. Land use rights held in common can also facilitate agroforestry, e.g., via easements (Main Street Project), community land trusts (Community Groundworks), and public land ownership (Silverwood Park). Ownership by land trusts and non-profit organizations (Farley Center Farm Incubator) represents a combination of public and private interests; such organizations are generally private but chartered for public benefit [42].

Investors in agroforestry partnerships can also fill a critical role in providing access to land, capital for accessing land, and financing for start-up costs and operating expenses. Because agroforestry enterprises are often unfamiliar to conventional lenders, investors familiar with agroforestry can be key partners in equity (Saturn Farm), debt financing (Main Street Project & Iroquois Valley), and blended forms of capital that include local community support (Humble Hands Harvest). Although their investment in the Main Street Project Research Farm was in the form of debt financing, in other investments Iroquois Valley purchases farmland and leases the land to farmers who fit their criteria of positive social and environmental impacts. To this end, most farmers Iroquois Valley leases or lends to raise organic row crops or livestock; Main Street Project is their first farm featuring agroforestry. Notably, Iroquois Valley has developed financing strategies that reflect the delayed cash flow and return on investment inherent in transitioning to organic and long-lived perennial crops. As the interest in impact investing grows, MA could help counter the trend of worse environmental outcomes on leased land compared to owner-operated land [43].

Land-owning institutions are potentially well-positioned for MA [44]. Many institutions have underlying missions that support sustainable land use such as agroforestry, and also may not need to maximize short-term income from the land. This was the case for Silverwood Park, Farley Center Incubator Farm, Community Groundworks, and Main Street Project. These institutions may also have less property tax liability, reducing the cost of carrying land. Furthermore, institutions may be able to offer more stable tenure and governance than a privately owned parcel. This can lower risk to the farmer posed by potential changes in ownership, landowner priorities, and development threats. Conversely, turnover in staff and organizational complexities can add to the time needed for coordinating with institutional partners involved (Silverwood Park). If funding wanes for non-commercial plantings, management can lapse (Community Groundworks). Nevertheless, the use of land owned by municipalities, land trusts, religious groups, and other such institutions holds much potential for land access via MA.

4.3. Policy and Programs for Further Development of MA

Broadly, intersections of public and private interests in land use represent fertile ground for the further development of MA. Private ownership of land predisposes use for individual benefit—and in many cases these uses can work against public interests—but the public can encourage more desirable land uses via incentives and regulation [45]. Agroforestry systems produce saleable agricultural products and a host of services of value to public interest [9,15]. These ecosystem services and amenity values include maintaining water quality, providing wildlife habitat, sequestering and storing carbon, providing spaces for recreation, and reducing the risk of fire in a landscape [10,46,47]. Thus, MA represents a potential nexus for shaping private land use to encourage these public interests, but agroforestry generally is limited by a lack of support for farmers for providing these services to society [45,48].

Notable exceptions in this region include USDA programs that pay for establishment and land rental for conservation practices such windbreaks, riparian buffers, and pollinator habitat. These practices are part of the agroforestry systems on Vulcan Farm and Saturn Farm. On Vulcan Farm, the landowner made the contract with USDA, paid for the cost of practice establishment, and receives the annual incentive payments. On Saturn Farm, the leasing farmer made the contract with USDA, paid for the cost of practice establishment, and receives the payments. Another potential mechanism for public support of MA would be to offer tax credits that favor agroforestry, especially in situations where agriculture is causing resource concerns [49,50]. For example, these credits could encourage MA on the 8.0 million ha of land with expiring CRP contracts in 2019–2030 [51]. In contrast to incentives, direct regulation also represents a strategy to protect public interest in private land use. To improve water quality, Minnesota has a new law that will require riparian buffers; MA offers a potential mechanism for maintaining agricultural production in buffers while protecting water quality [52].

Both regulation and incentives involve persuading a private landowner to act in the public interest. By contrast, when land or rights associated with land use are held in broader trust, the public potentially has more direct leverage to encourage uses compatible with its interests. For example, the State of Minnesota has an easement program in which they effectively prohibit planting maize and soybeans in areas vulnerable to erosion by purchasing the rights to cultivate these crops there. Part of Main Street Project Research Farm is under this easement.

These examples demonstrate that although the private ownership is the foundation of most tenure arrangements in the USA—and MA can adapt to this context (e.g., Vulcan, Saturn, and Feral Farms)—land use rights held in common can also facilitate agroforestry, e.g., via easements (e.g., Main Street Project), community land trusts (e.g., Community Groundworks), and public land ownership (e.g., Silverwood Park).

Beyond public support for societal benefits from agroforestry, there is growing interest in mobilizing private capital to support ecosystem services [53]. For example, in water quality trading markets such as those in the Chesapeake watershed, landowners (and farmers to whom they lease land) can be paid to plant perennial crops rather than annual crops in riparian zones to protect water quality [54]. These payments are financed through fees on development, such as roadway expansion, that have unavoidable negative water quality impacts. Likewise, if carbon storage on farmland becomes monetized, agroforestry will be well positioned to generate income through those markets or subsidies as well [10,55,56]. Investment funds seeking positive social and environmental impact are already active in forestry, and the case of Iroquois Valley's investment in Main Street Project here provides an example of how private capital could support MA [57].

4.4. Direct Interventions for Further Development of MA

Although the case studies presented here demonstrate that MA can adapt to various contexts, there remain a host of broader contexts that limit agroforestry. Enumerating the limits to broader application of agroforestry is beyond the scope of this paper (but see [31]), but a number of intersecting factors represent potential intervention points for further development of MA.

Absentee landowners own much of the farmland that is leased in the United States [25]. Although these landowners may have interest in agroforestry, by virtue of lack of proximity they may be poorly positioned for the intensive planning many interviewees in this study emphasized as key to the success of a long-term agroforestry lease [18,20]. Furthermore, absentee landowners frequently contract with a land management company to oversee the use of their land, and often this company identifies the lessee farmer and manages that relationship in lieu of the landowner. Familiarity and interest in agroforestry among land management companies is unknown, but likely low. There are a limited but not insignificant number of contractors, consultants, and agency personnel in the USA available to assist landowners in establishing agroforestry, but there are few companies that offer ongoing management of agroforestry enterprises or facilitation of leases to agroforestry operators. This lack of back-stopping land management companies represents a significant limitation to the wider application of MA among non-farming landowners. One of the major risks to landowners in MA is that, if a lessee exits the lease prematurely, they risk being left with trees, fencing, and other agroforestry infrastructure, without capacity to manage the enterprise themselves or to readily identify a new operator.

Another limitation to wider application of MA is the scarcity of technical service providers (TSPs) qualified to develop plans that qualify for certain government subsidies. Beyond accessing financial assistance for establishment of agroforestry practices, plans prepared with the assistance of a professional third party have inherent value for multiple parties seeking agreement on land uses. The USDA NRCS offers a certification for TSPs to become qualified to write agroforestry plans, but there are few to none available in the most states (e.g., among the states represented by MA cases here: 15 total agroforestry TSPs in MO, IL, and IA; none in MN and WI [58].)

Other third parties that could aid in the development of MA are matchmakers and brokers to facilitate the parties identifying each other and assisting them in developing their arrangement. This strategy has been pursued by non-profit organizations and academic collaborators to form multi-party livestock grazing arrangements on private and public lands [59]. This match-making strategy has also been pursued by organizations seeking to facilitate farmland access for beginning farmers and could be customized for agroforestry [38,60].

4.5. Further Research Needs

To our knowledge, MA in the USA has not been previously described in the literature. Further development of MA could be aided by further study of the phenomenon. The limitations of this study suggest several directions for future research. For instance, the cases profiled were selected opportunistically based on the authors' awareness of their existence and the willingness of those involved to be interviewed. Future research could add to this base of knowledge via broader selection criteria. Critically, studies that include MA that did not result in outcomes desired by partners, or that were attempted but did not manifest, could provide insight into limitations and potential pitfalls.

Similarly, the MA case studies were primarily developed from the perspective of a single point in time. Although there was some reflection on the process that led to the present state, many of the cases are relatively early-stage partnerships. Longitudinal studies that track success of MA over time are needed [61,62]. Systematic assessment of factors influencing how well MA enables partners to achieve their objectives could be performed with more attention to progress over time. Beyond direct assessment of MA, research on factors that determine interest and ability to adopt could inform further development of the approach [20,63].

The geographic and topical breadth of this study was also limited. Research to apply multi-party models from related fields such as grazing and forestry could aid similar efforts in agroforestry [57,59]. We aware of examples in other parts of the USA, particularly forested landscapes, with multi-party forest farming arrangements for ginseng and other medicinal herbs. Documentation of MA in other places could also provide insight, especially in the tropics where agroforestry is much more common than most temperate landscapes, and the relationships between trees and land tenure has been the subject of more research [28].

5. Conclusions

This study documented a diversity of forms of cooperation in MA. MA generally emerged from shared objectives, intensive planning, and ongoing coordination. MA appears to be adaptable to private, investor, institutional, and public landowners, as well as beginning farmers and others seeking land access without ownership. MA represents a social mechanism for conservation in agricultural landscapes with the potential to enhance crop production and broader public benefits, including carbon sequestration; biodiversity; soil and water quality; and resiliency.

Potential limitations to wider application of MA include a lack of appropriate land management companies, technical service providers, and third-party match-makers and facilitators. Further research is needed to document and assess MA in other regions. There is also a need to evaluate outcomes of MA over time.

Supplementary Table 1. Semi-structured interview topics and example probing questions.

Topics	Example probing questions
Farm operation	Where are you located? How many acres are part of the operation? What type of business models are involved?
Agroforestry practices	What is currently under production? What type of agroforestry is happening there? Why did you start this operation?
Land access and tenure	Why do you think the other party wanted to work with you? What type of lease do you have? How many parties are involved? How did these relationships form? What are the roles of each party in the operation? What are their responsibilities? What happens if one party wants to exit the arrangement? What type of funding do you have access to?
Relations with other parties	What has worked well with your arrangement? What have been learning moments? What advice would you give others considering partnering with others in agroforestry? Are you involved in any federal or state conservation programs? Are you conducting any on-farm research?

6. References

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Conclusion

After several years of studying it, silvopasture continues to intrigue me. The concept pushes the agroecological and social boundaries of agriculture's tendency toward simplification. It suggests that by integrating livestock with their sources of feed, and by integrating farm and forestry enterprises, we might benefit farm and forest, as well as the greater good.

The extent to which silvopasture might live up to these promises is, to some degree at least, dependent on skillful application of the techniques involved in the practice. To that end, chapters one and two of this dissertation were investigations of silvopasture establishment techniques, in woodlands and open pastures, respectively. Given the historical record of land degradation by overgrazing and contemporary uncertainty with regards to how intensively-managed silvopasture can mitigate those impacts, as well as the need to add more successional diversity to Driftless plant communities, chapter one describes on-farm experiments that assess whether ecological outcomes of woodland grazing could be improved by prescribed canopy thinning and targeted management of the shrub layer, as well as planting of agricultural and native forages. Thinning supported some management objectives, but cattle preferentially browsed native shrub species, so further research could explore adaptive application of multiple disturbances, such as fire, as wells as habituating cattle to browsing introduced shrub species. Planting agricultural forages reduced floristic diversity but did not increase forage quality, so we suggest further research before planting of introduced species is promoted. We observed various effects of grazing on the soil microbial community; this also warrants more research. Grazing increased bare soil exposure and compaction in the upper 10 cm of the soil; the former effect was moderated by canopy thinning. The degree to which soil compaction by livestock in woodland environments can be moderated by more intensive management also remains an open question.

Out of woodlands and into open pasture, chapter two examined tree planting for livestock shade as well as other objectives. Our findings on the efficacy tree establishment techniques could not only assist in achieving on-farm objectives, but also help realize the potential of silvopasture to meet other societal goals. Most notably, pastures have been recognized as among the greatest area land use on land that was formerly forested, and thus promising for reforestation and attendant sequestration of atmospheric carbon. Planting trees on pastureland without taking it out of production—either permanently or temporarily while trees grow to a size refuge from livestock— raises the ceiling on how much acreage could potentially be planted. Thus, we evaluated methods to protect tree seedlings in actively-grazed pastures, and found different methods appropriate for different livestock in different farm contexts. Our findings suggested the potential of low-cost combinations of protective tubes and electrified fencing to be more widely adapted for pasture tree establishment, and that the cost-benefit trade-offs of larger tree seedling stock need to be documented.

Silvopasture also pushes social boundaries. The concept of technology transfer describes a social process conceptualized as a top-down linear path: production of knowledge and innovation in institutional research, then conveyed in educational extension and commercial application out to individual farmers. Chapter three explored how perception of silvopasture has evolved among farmers and professionals in our region. Our findings highlighted that in addition to scientifically-generated knowledge transferred through more conventional social channels as described above, interest in silvopasture has grown through local communities of practice that exchange information about management strategies appropriate to the complex, long-term, and context-dependent nature of the practice. This study spanned five years; for more robust conclusions about the social dynamics of silvopasture adoption, further research needs to measure adoption and outcomes over longer time horizons. Further research should also integrate assessments at farm and community scales with broader factors influencing adoption and outcomes such as climate change, economic environment, and policy incentives.

Beyond research and knowledge exchange, people practicing silvopasture challenge other social conventions as well, such as the typical focus on the farmer as an individual and as the landowner. In contrast to this independent landowner-operator archetype, chapter four describes farmers practicing silvopasture and other forms of agroforestry on land they do not own through partnerships of landowners, operators, and investors adapting various land access and tenure arrangements. We called this multi-party agroforestry, and it generally emerged from shared objectives, intensive planning, and ongoing coordination. These approaches might be considered techniques for social intensification of agriculture, or at least alternatives to social simplification as represented by the individual farmer-landowner archetype. It is reasonable to believe that there are wider benefits to society to be realized by more landowners and non-landowners engaging in multi-party agroforestry, so more research could help elucidate the intersection of public and private interests at play here, and what policies or other interventions might best facilitate desirable outcomes.

As the potential and as well the challenges of silvopasture become more widely recognized, I hope that the investigations described here offer aid to researchers, practitioners, and others working to develop more purposeful integration of livestock, trees, and people.