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Designing multifunctional woody polycultures according to landowner preferences in Central Illinois

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Abstract Multifunctional woody polycultures (MWPs) are an alternative agricultural practice gaining interest in the U.S. Corn Belt as an option for combining agricultural production and conservation goals. MWPs integrate fruit, nut, timber, and/or bioenergy crops adjacent to annual crops. Previous studies revealed that landowners lack adequate information to make informed decisions regarding the adoption of MWPs. Following up on that work, this study engaged with 15 rural landowners in the Upper Sangamon River Watershed of Central Illinois to identify their design preferences, their information needs, and the adoption potential for MWPs. Landowner-specific designs were constructed based on three predefined alternative scenarios distinguished by their focus on: (1) production, (2) conservation, or (3) cultural functions. Two semi-structured interviews were conducted with landowners before and after the design process. Results from quantitative analysis and qualitative interpretation showed landowners preferred designs that integrated high levels of edible nuts and berries in an efficient, machine-harvestable arrangement. Nut-producing species, notably northern-adapted varieties of pecan (*Carya illinoinensis*), were the most preferred. The most influential motivators for the design and adoption of MWPs were utilizing high-value edible crops, improving pollinator and wildlife habitat, and increasing productivity of marginal land. While important, landowners felt these motivators still did not overcome limitations in the practical application of MWPs due to a lack of harvest machinery, of post-harvest processing facilities, and of accessible markets. The study findings demonstrate that a lack of reliable economic, marketing, and management information severely constrains the adoption potential of MWPs despite landowner interest in using MWPs on marginal lands.

Keywords Multifunctional woody polycultures · Landowner · Preferences · Design · Scenarios · Visualizations · Participatory

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Introduction

The U.S. Corn Belt

The simplification of agricultural landscapes and intensification of annual row-cropping systems has led to a reduction in diverse perennial habitats that provide an extensive range of ecosystem services (Foley et al. 2005; Wright and Wimberly 2013; Landis 2017). Decreasing sustainability of rural landscapes has given rise to a need for alternative land use strategies (Matson et al. 1997; Montgomery 2007; MacDonald et al. 2013; Robertson 2015). Researchers and policymakers have suggested using marginal lands unsuitable for row crops as strategic areas to mitigate the negative impacts of conventional agriculture (Wells et al. 2003; Kang et al. 2013; Gelfand et al. 2013). Marginal lands encompass a broad range of areas unsustainable for agricultural production due to one or more of the following factors (Kang et al. 2013; Richards et al. 2014): (1) little to no profitability, (2) biophysical constraints (flood frequency, poor soil quality, erodible land, etc.), and (3) constraints limiting the efficient cultivation of the land, such as difficulty of access or curving field edges.

In the U.S. Corn Belt, research has shown that converting only a small proportion (5–15%) of marginal land to perennial species may have disproportionately large impacts for social and environmental sustainability by improving water quality, biodiversity, and aesthetics for rural areas (Schulte et al. 2006; Gobster et al. 2007; Atwell et al. 2009b, 2010; Brandes et al. 2016; Mattia et al. 2018a). Previous work on conversion of marginal land has focused mainly on using perennial grasses and short-rotation woody crops for biofuels or feedstock (Tilman et al. 2009; White 2010; James et al. 2010; Cope et al. 2011; Gelfand et al. 2013; Verdade et al. 2015) or on implementing conservation habitats such as the Conservation Reserve Program (CRP) for ecosystem services (Wells et al. 2003; Werling et al. 2014). While both options offer viable benefits, they may overlook opportunities for landscape multifunctionality, because they focus on either production or conservation, not on both goals simultaneously.

Multifunctional woody polycultures

To connect production and conservation, researchers have suggested the use of agroforestry that integrates profitable fruit, nut, and/or timber crops on marginal lands (Jose et al. 2012; Trozzo et al. 2014a; Mattia et al. 2018b; Lovell et al. 2018; Wolz et al. 2017). In the U.S. Corn Belt, such systems have taken on a variety of names/descriptions such as multifunctional perennial cropping systems (MPCs) (Mattia et al. 2018b), multifunctional woody polycultures (MWPs) (Lovell et al. 2018), or agroforestry that produces high-value fruit, nut, or timber crops (Jose et al. 2012; Trozzo et al. 2014a; Wolz et al. 2017). This paper uses the term "MWPs" for the proposed systems and defines them as the purposeful mixing of multiple high-value woody crops species using one or more of the five agroforestry practices (Jose et al. 2012) to promote production, ecosystem, and cultural services. Perennial herbaceous species for biofuels or feedstock may also be incorporated as they can play an essential role in producing conservation benefits (Gelfand et al. 2013; Masters et al. 2016; Mattia et al. 2018a), but they are not the primary focus of MWPs.

Previous studies have focused on landowner perceptions, motivators, barriers, and adoption potential in an attempt to understand and improve the spread of MWPs and similar practices (Strong and Jacobson 2005; McGinty et al. 2008; Valdivia et al. 2012; Trozzo et al. 2014b; Mattia et al. 2018b). Landowners have been shown to be motivated by the potential of improving ecosystem services and by government policy that favors perennial practices. They also acknowledged the breadth of conservation functions possible when using agroforestry (Strong and Jacobson 2005; Trozzo et al. 2014b; Mattia et al. 2018b). However, acknowledging benefits does not lead directly to agroforestry adoption (Atwell et al. 2009a), as evidenced by its minimal integration into the U.S. Corn Belt region (Atwell et al. 2009b; Valdivia et al. 2012). Landowners in the Corn Belt have stated that a lack of information, lack of support tools, and minimal experience with agroforestry were significant barriers to adoption (Valdivia et al. 2012; Mattia et al. 2018b).

Landowner-informed design

By working with landowners during the agroforestry design process, researchers can begin to satisfy the various information needs and preferences of landowners as they come about. Most research on the design and adoption of innovative agricultural practices has occurred before or after the decision process, almost never during it (Le Gal et al. 2011). Involving stakeholders in the design process can help improve the efficiency of the process and utility of the product by providing insight into the preferences and decisions as they are occurring (Le Gal et al. 2011).

Several researchers have called for increased engagement with landowners during the design and adoption process to reduce gaps in information and understanding, especially given the complexity and variability of multifunctional systems such as agroforestry (Cardoso et al. 2001; Lovell and Johnston 2009; Atwell et al. 2010; Trozzo et al. 2014b; Mattia et al. 2018b). Landowners have invaluable knowledge of their own systems and can provide researchers with technical information and site-specific context that focuses the research process on designs and tools valuable and applicable for the end-user. Despite recognizing the value of landowner expertise informing the development of design and support tools (Oliver et al. 2012), very few studies have worked collaboratively with landowners to design MWPs or similar systems specific to their land (Haggar et al. 2001; Cardoso et al. 2001), especially in the U.S Corn Belt (Atwell et al. 2009a; Mattia et al. 2018b). Direct engagement with landowners can be costly and time-consuming in a long-term study, but these should be considered necessary hurdles in the process of building successful agroforestry designs for end-users (Cardoso et al. 2001).

Aims of the study

In this study, we aimed to identify landowners' design preferences for MWPs and satisfy their information needs by working directly with fifteen individuals to design MWPs for their land. The study builds on research by Mattia et al. (2018b) which outlined potential adopters of MWPs and general attitudes toward them but did not identify landowners' specific design preferences. The participatory design study described here examines the design and configuration of MWPs that landowners prefer to use on their land, motivators and barriers to using them, and the rationale for their decisions. The study incorporated two related research methodologies to integrate stakeholder and scientific knowledge: (1) the framework method for sustainable ecological planning (Ahern 2006) and (2) the design in landscape ecology model from Nassauer and Opdam (2008). We hypothesized that by working collaboratively with landowners we could identify their design preferences for MWP species and practices, explain their reasons for preferring them, and address previously identified barriers to system adoption. These insights could then be linked with previous work (Mattia et al. 2018b) to inform research on MWPs regarding the needs of potential adopters as well as to improve the strategies used for promoting multifunctional systems.

More broadly, this study presents a region-specific example of agroforestry design wherein multiple unique alternatives are developed with each participant, a methodology that has yet to be used extensively. We propose the study can be a vital step forward in understanding how agroforestry systems can be designed and adapted on a local and regional basis to overcome the site-specific barriers landowners face in a certain area. The methods and scope are widely applicable and can be replicated in multiple areas across the United States to encourage locally and regionally adapted MWPs that, when joined, can begin working toward accessing established specialty crop markets.

Materials and methods

Study area

The study was conducted in the Upper Sangamon River Watershed (USRW), located in Central Illinois in an intensively cropped region of the United States referred to as the Corn Belt (Green et al. 2018). The watershed has soil erosion and water quality concerns similar to those seen throughout the Corn Belt (Keefer and Bauer 2011). Draining approximately 3000 square kilometers of land, the watershed consists largely of portions of eight counties: Champaign, Christian, DeWitt, Ford, Macon, McLean, Piatt, and Sangamon. The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) reported that 79% of land in the USRW was being used to grow corn and soybeans in 2017. The other major land uses include developed land, about 10%, and grassland, wetlands, and forested areas, totaling about 9% (USDA NASS 2017). The 2012 agricultural census reported that harvestable perennials made up less than 1% of reported income from agricultural products in the USRW (USDA NASS 2012). Mattia et al. (2018a) reported that 7% of agricultural land in the USRW was suitable for conversion to MWPs due to low crop productivity and high soil erosion potential.

Participants

Participants were rural agricultural landowners in the USRW previously identified by Mattia et al. (2018b) as having medium to high-potential to adopt MWPs. Landowners who stated they would convert land to MWPs on their property were classified as high-potential adopters. The landowners with the greatest potential for adoption included young, educated farmers, with available marginal land they would consider for MWPs. Such landowners are deemed logical participants to consider when assessing the validity, design, and management of a relatively new agricultural innovation (Rogers 2003). Forty-five letters asking about interest in participating in a study of MWP land use were mailed to previous survey participants. The letters provided information on MWPs, requested landowner participation in this study, and offered a stipend for participation. Fifteen participants of various backgrounds, ages, and fields of work agreed to be involved. Not all landowners were farmers, but all owned land in agricultural production. Participant demographics are outlined in Table 1.

Phases of the study

The study was carried out in two phases, adapted from Tress and Tress (2003). In phase I, a researcher interviewed participants on their land to build a working relationship, discuss their property, and identify their interests related to MWPs. The first interview, along with input from landscape ecologists and crop scientists, helped guide the creation of three scenarios aimed toward one of the three primary goals of MWPs: production, conservation, and cultural. In phase II, a researcher used the three scenarios to guide the development of three unique MWP designs for each participant's land. The designs were visualized and presented to the participants along with a supplemental information booklet describing MWPs in detail. Participants were interviewed again on their property to discuss the designs and identify preferences, adoption potential, and future policy goals for improving the adoption and diffusion of MWPs.

Phase I: the first interview

Semi-structured interviews, 60–90 min in length, were conducted with landowners on their properties from September to October 2016. The interviews were recorded with landowner permission using both a phone and laptop voice recorder. The interviews were transcribed within 48 h of completion. The intent of the interview conducted before the design process was to gather data on what three plausible future scenarios would guide the MWP designs, to establish preferred locations for the MWPs with each landowner based on their identification of marginal land, and to identify familiarity, interest, and perceptions of existing MWPs and perennial crop species. The interviews were loosely structured because the conflicting nature of many transformative technology adoption studies has exposed the need to allow landowners to lead the discussion based on how their preferences and decisions are shaped (Adebiyi et al. 2016).

The first interview consisted of three sections. First, participants were shown three sets of four images displaying examples of MWPs. Each set of images focused on a specific design goal: food, timber, or conservation. The MWPs were presented using a predetermined description that explained the design, products, layout, harvesting, and management. Participants were asked to provide feedback on their likes, dislikes, and interest in each of the MWPs shown. Second, the participants ranked the previous MWPs by preference. They discussed their familiarity with the systems, proposed locations for plantings, and offered information on their preferred species, barriers and motivators, and general influences. Third and last, the participants used an aerial map of their land to identify areas they viewed as marginal.

Table 1 Demographics of the fifteen landowners participating in the study

Age range	Gender	Farming experience (year)	Acres owned	Primary income from farming?	Work their land themselves?	Farm description
20–40	F	0	300	Yes	No	Corn–soybean; fruits, nuts, and berries
	M	7	43	No	No	Corn–soybean
	M	10	900	No	Yes	Organic corn–soybean–wheat
	M	4	97	No	No	Hay production; conservation land
	M	26	125	No	Yes	Wheat; hay production
40–60	F	3	15	No	Yes	Livestock grazing
	F	20	400	Yes	Yes	Livestock grazing; mixed grains
	F	6	20	Yes	Yes	Fruits, berries, vegetables, and flowers
	M	10	40	No	Some	Corn–soybean; fruits, nuts, and berries
	M	0	50	No	No	Corn–soybean
	M	3	290	No	No	Corn–soybean
60–80	F	25	400	No	No	Corn–soybean
	M	0	160	No	No	Corn–soybean
	M	44	2500	Yes	Yes	Corn–soybean
	M	40	50	Yes	Yes	Livestock grazing; hay production

Phase I: scenario technique

This study used a scenario technique to survey participants on what MWPs may plausibly and reasonably be implemented on their land. Such techniques typically build scenarios to guide future policy goals and planning for a landscape or region (Tress and Tress 2003; Nassauer et al. 2011). Scenarios are the framework, descriptions, or imagined policy goals used to describe a set of alternative future landscapes. The product of a specific scenario is an alternative future landscape (Nassauer and Corry 2004; Steinitz et al. 2005), referred to hereafter as a design, which includes the integration of MWPs into a landowners property. The scenario methodology used in this study differs in technique by building unique designs specific to participants' land with the participants themselves. Three scenarios were developed through a combination of previous research (Mattia et al. 2018b), knowledge of MWPs and policy regarding them, and the results of initial interviews with study participants.

Phase II: the design process

A stepwise planning and design process that combined landowner and researcher knowledge was used to build plausible and reasonable MWP designs for landowners. The design process began with the first interview in which landowners identified their marginal lands and specific needs and preferences. These details were combined with information on soil type, pH, drainage, and flood frequency gathered from the USDA Natural Resources and Conservation Service (NRCS) Web Soil Survey to build "opportunity lands", or areas of potential MWP placement. Species placement and combinations were determined by the given scenario, landowner input on preferences, and the theory for the design and makeup of MWPs (Lovell et al. 2018). Design plans were prepared using AutoCAD to ensure geospatial accuracy and to organize quantitative data related to species count and area use. Figure 1 displays the general steps that researchers used to build a set of designs for each landowner.

Phase II: species selection

Species selection was based on consultation with experts in the fields of agroecology, forestry, and landscape design as well as on consideration of species used in existing MWPs. In total, 40 species with high environmental and economic potential within the U.S. Corn Belt were selected as "best bets".

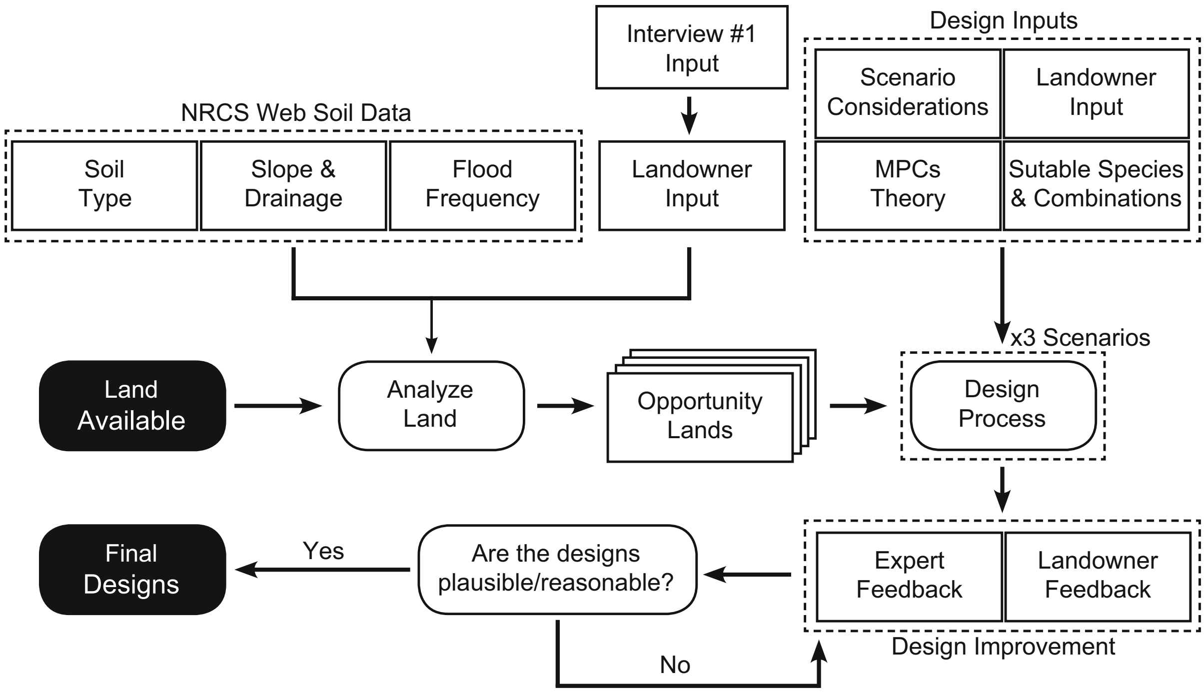

Fig. 1 Flowchart outlining the steps taken to design MWPs for landowners based on three scenarios

Phase II: species combination

MWPs integrate various agroforestry and NRCS conservation practices such as riparian forest buffers, hedgerow planting, and multi-story cropping. Specific practices are used to target environmental or landowner issues while producing a saleable product such as fruits, nuts, or berries. Figure 2 shows an example of a windbreak used in the plans created for landowners. Multiple productive species that are both profitable and provide conservation benefits are incorporated, such as northern-adapted varieties of pecan (*Carya illinoinensis*; hereafter referred to as northern pecan), American hazelnut (*Corylus americana*), and elderberry (*Sambucus canadensis*).

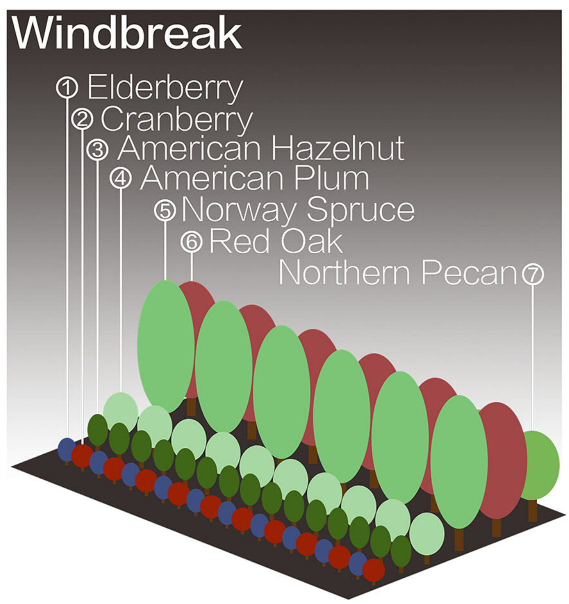

Fig. 2 Example of an MWP windbreak used in landowner designs that integrates productive species into a system to be used in conservation programs

Phase II: design feedback

Participants were asked to provide feedback on the three proposed designs to improve their plausibility and reasonability. Participants were given general descriptions of each design along with a draft of the layout to help explain the purpose of the designs and how they function. Each participant provided feedback electronically or through the mail on a standardized form. The feedback was used to remove unrealistic or impossible designs and integrate specific participant needs that were not met. Experts in the fields of ecology, crop science, and forestry were also consulted to review the designs. All feedback was considered and appropriately incorporated to create the final iterations of the designs.

Phase II: design visualization

In combination with a landscape designer, each final design was visualized in the form of a photorealistic landscape plan for presentation to landowners. The plan image showed the entirety of the participant's land with scenario-specific MWPs incorporated (Figs. 3, 4). Participants also received one visualization of a non-specific perspective view to show how MWPs would appear if the landowner was looking at the system at maturity (Fig. 5). Google Earth was used to provide aerial imagery and Adobe Photoshop 18.0 for the creation of the visualizations.

Phase II: final designs and supplemental information

In total, 45 unique designs, three for each landowner, were created. Final designs were mailed to landowners along with a list of species and their quantities in each design. Landowners also received an information booklet describing the species, plant costs, management, products, timeline, cultural and environmental benefits of MWPs. Examples of potential cash flow per acre of select single and multi-species systems with and without ownership costs were included in the booklet as well. Participants were asked to review the information and consider which designs they preferred and prepare any questions or concerns they had. A follow-up interview was scheduled between two and six weeks after the designs were received by the landowner.

Phase II: the second interview

The second set of interviews were conducted in June 2017 using the same procedures as the first interview. The second interviews consisted of both open-ended and rating questions using a Likert scale. Participants assessed the three designs in comparison with their current land. The various elements or patterns in each design were discussed, and feedback was documented. After examining the designs, participants commented on their general preferences, ideas for improvement, motivators, and barriers to using MWPs. Next, the participants were asked to design a system they saw as optimal for their land by incorporating the preferred components of their three designs into a final plan they would be most likely to use. Last, participants provided critical feedback on the design process, the validity of MWPs, and the necessity of MWPs in U.S. agriculture as a whole.

Data analysis

Data analysis occurred concurrently with the development of each step in the study. Audio recordings of interviews were transferred into Audacity, a digital audio editor, to prepare the audio files for transcribing. Each interview was transcribed using Microsoft Word. Completed transcriptions were transferred to Microsoft Excel 2016 and landowner responses were organized by interview questions.

Both quantitative and qualitative data from the second set of interviews were used in interpreting landowner preferences. Quantitative interview data were tabulated and compared across different categories in Microsoft Excel. The frequency of responses, mean ratings, and median ratings were calculated to understand preferences for design scenarios, species, practices, motivators, and barriers. Qualitative interview data were coded and analyzed using NVivo 11 Pro. Contextual information about the landowners was coded first and then the interview responses were coded into six categories: preferences, management and experience, finances and economics, biophysical factors, social and cultural, government and policy. These categories are adapted from the five categories of factors that influence agroforestry adoption described by Pattanayak et al. (2003). The coded data were explored for trends and patterns in landowner responses in connection with the quantitative data. Last, the optimal designs created by landowners during the second interviews were analyzed by counting the occurrence and frequency of species and practices used. The underlying themes in combination with the stated preferences for designs, species, practices, and development of an "optimal design" were used to understand landowners' preferences.

Fig. 3 Subsection of an existing landscape plan visualization prior to the design of MWPs

Results and discussion

Developing scenarios from initial interviews with landowners

The first interview allowed landowners to describe the MWPs they saw as plausible in the future and the goals they would aim to achieve by using such systems. Landowners were most interested in MWPs oriented toward edible food production, somewhat interested in those focusing on conservation benefits, and least interested in strictly timber-based systems (due to the length of time required for timber maturity). Landowners', lacking interest in timber, saw cultural goals as valuable assets to the potential use of MWPs. Results from the first interviews in combination with input from natural resource professionals revealed three possible scenarios under which MWPs may develop in the future—production, conservation, and cultural—that are described in the following sections.

Production design scenario

The production scenario assumes an interest in local, sustainable food grows rapidly across the U.S. Corn Belt and enables a stronger market for perennial fruit and nut crops. Multiple facilities are built to process and distribute nuts, fruits, and berries across the Corn Belt region, and harvesting equipment becomes cheaper and more accessible to small-scale farmers. Wholesale and retail markets become available for MWP crops, and relatively high timber prices encourage the planting of hardwood species. The general public and landowners acknowledge marginal lands to be ideal candidate locations for perennial crops, but government support for such crops increases only minimally, placing more emphasis on profitability

Fig. 4 Subsection of a landscape plan visualization incorporating MWP practices for the production scenario given to one landowner

than on conservation benefits. The complexity of the MWPs remains low to ensure they are profitable and easily harvestable. Species common in this scenario are Chinese chestnut (*Castanea mollissima*), northern pecan (*Carya illinoinensis*), black walnut (*Juglans nigra*), black currant (*Ribes nigrum*), aronia (*Aronia melanocarpa*), and elderberry (*Sambucus* spp.).

Conservation design scenario

The conservation scenario assumes increasing public interest in native perennial species for their various environmental, ecological, and cultural benefits, resulting in favorable government policies. The USDA NRCS and Farm Service Agency (FSA) increase funding for the establishment, management, and research of native perennials through various conservation programs such as the CRP and the EQIP (Environmental Quality Incentives Program). In these programs, landowners can now harvest materials selectively from conservation lands as long as their ecological functions are maintained. Marginal lands, even if not previously cropped, can be incorporated into conservation programs. Ecosystem services and wildlife habitat are quantified in terms of public service and are eligible for tax breaks. Species diversity is increasingly supported by public policy and becomes more appealing to landowners. Species common in this scenario are northern pecan, prairie crabapple (*Malus ioensis*), juneberry (*Amelanchier alnifolia*), American plum (*Prunus americana*), American hazelnut (*Corylus americana*), American persimmon (*Diospyros virginiana*), elderberry (*Sambucus canadensis*), and aronia.

Fig. 5 Visualization of a perspective view looking at an MWP windbreak alongside annual row crops. This image was provided to landowners in an information booklet alongside their respective designs to help them understand the makeup, use, and function of MWPs

Cultural design scenario

The cultural scenario assumes the population in rural areas continues to decrease and there are growing concerns over the loss of culture, public engagement, and interest in rural lands. Regional planners and government agencies become interested in alternative crops and marginal land uses as pathways toward improving the cultural benefits of agricultural lands. Landowners begin to explore new routes of maintaining their incomes while addressing the growing cultural concerns. Perennial plants, both edible and not, increase in use as a way of improving aesthetic quality, diversifying homesteads, and providing agrotourism and recreation opportunities. Public interaction with rural land, largely from people living in urban areas, becomes profitable. Research institutions and state agricultural extension agencies invest in on-farm field trials and educational sites to explore innovative cropping systems and ways to re-engage new generations of farmers. Species common in this scenario include Chinese chestnut, European hazelnut (*Corylus avellana*), black currant, northern pecan, aronia, eastern redbud (*Cercis canadensis*), and a diversity of native perennial grasses.

Landowners' design scenario preferences

The second interviews allowed researchers to identify the types and components of MWPs preferred by landowners. Table 2 displays landowners' rankings of and interest in the three designs. Designs for the production scenario were ranked as most preferred by eight of the fifteen participants, while cultural was least preferred, being ranked last by ten participants. Conservation designs—ranked second by ten participants—were the second most preferred. However, it should be noted that when landowners were later asked to rate their interest in using each of the three designs, there was little difference in the means of the scores. Landowners often explained that there were aspects of all designs they preferred, and they found it challenging to choose only one design. As each design offered unique species and species combinations, landowners were able to identify various aspects in each design they perceived to be best suited for specific areas of their land.

Table 2 Landowners' ranked preferences of the three design scenarios and their rated interest in using them

Scenario	Rank frequency			Rated interest	
	1st	2nd	3rd	Mean[a]	Median
Production	8	4	3	3.6	4
Conservation	3	10	2	3.3	3
Cultural	4	1	10	3.4	3

Likert scale used for landowners' rated interest: (1) not interested, would not adopt; (2) slightly interested, would adopt very little; (3) somewhat interested, would adopt some; (4) moderately interested, would adopt a majority; (5) extremely interested, would adopt most or all

[a]Mean scores are indicative only, as a Likert scale is not strictly a numerical rating

Landowners were asked to give their main reason for preferring or not preferring each design; their responses are summarized in Table 3. The justifications for selecting the "most preferred" design typically mirrored the goals of that scenario, whereas not preferring a design was often justified as its being difficult to manage or too complex, not suitable with goals, or simply less favorable than other designs. In general, production designs were preferred for their profit potential and variety of known productive edible species. Cultural designs were seen as unprofitable, less compatible with the existing farming system, and often quite laborious to manage. Conservation designs were favored for their diversity but often did not elicit notably strong reactions.

Landowner responses to the production scenario

Landowners commonly referenced the potential for profit, in both the short-term and long-term, as justification for favoring the production scenario. They found the design to be very "straightforward" and "no-nonsense", maximizing production while still maintaining a level of useful diversity. Relatively early-producing berry crops such as elderberry and aronia could be paired with slower maturing crops such as black walnut and northern pecan to maximize value through time. There was a notable difference in responses between age groups: all five landowners aged 60 or older preferred the production scenario most and the cultural least, while only one of five landowners aged 20 to 40 favored the production scenario most.

The majority of older landowners were corn–soybean farmers, while younger farmers utilized more "alternative" farming systems, which may explain a predisposition of older landowners to favor production benefits of MWPs. Age has been negatively associated with conservation behaviors because of a shorter planning horizon of older landowners (Baumgart-Getz et al. 2012). However, this association is contested by other research using age as a predictor of conservation adoption which has shown the association to be insignificant or positive (Knowler and Bradshaw 2007). Reimer et al. (2014) suggest conservation behavior is often context specific and numerous factors influence decision making.

We suggest one possible explanation for the discrepancy between age groups may be the

Table 3 Landowner rationales for selecting their most or least preferred design scenario

Why ranked as…	Production	Conservation	Cultural
Most preferred?	Profit (3)	Diversity (2)	Meets long-term goals
	Food production (3)	Native species	Structure and variety
	Abundance of trees		Diversity and efficiency
	Simplicity		Well designed
Least preferred?	Management concern	Preferred other designs	Not profitable (2)
	Lack of diversity	Does not want trees	Preferred other designs (2)
	Does not meet goals		Does not meet goals
			Management concerns
			Less productive
			Difficult for farmer
			Not suitable with business
			Labor concerns

Each entry represents one response except where multiple responses are indicated in parentheses importance of profitability and the lack of complexity associated with the production scenario. Ecosystem services and long-term profit were stronger motivators for younger landowners but were not considered independent of profitability. MWPs must be profitable since "a farm by definition is an economic proposition" (landowner). This theme is consistent with previous findings suggesting the importance of profitability in tree crop systems (Lynch and Brown 2000), especially for nonoperator landowners with close ties to farming (Arbuckle et al. 2009). However, there is evidence suggesting that economic performance is not the primary driver in adopting systems similar to MWPs (Valdivia and Poulos 2008) and diverse systems should not be solely valued based on economics (Barbieri and Mahoney 2009).

Landowner responses to the conservation scenario

Windbreaks designed in the conservation scenario were popular among numerous landowners for their ability to meet production and conservation goals. Under CRP contract, landowners are eligible to receive payments for implementing conservation practices on marginal lands. In Central Illinois, windbreaks are one of the most accepted and needed practices due to the lack of tree cover, to flat topography, and to persistent winds. Windbreaks are typically used solely for conservation purposes, but those designed for MWPs incorporate timber-, nut-, fruit-, and berry-producing species. One landowner stressed the importance of using a windbreak not only conservation but also for "something we can potentially harvest".

For some landowners, including native species that provide edible products and increase diversity was also appealing, yet many landowners, especially those of greater age, felt they would not be able to manage a design with such vast diversity of species. Landowners suggested limiting the species diversity of MWPs to a level that allows the systems to be entirely harvestable by machine. Very few landowners were willing to support practices that were strictly for conservation and would require hand harvesting of crops, which points to a significant barrier to adopting conservation focused MWPs. The vast skillset needed to efficiently build diversity into a working landscape is a challenge for landowners and researchers alike as discussed by studies examining multifunctional landscape design (Dosskey et al. 2012). Additional tools and frameworks to manage the diversity of MWPs in a practical and profitable manner, similar to the ecological planning methods used in this study (Ahern 2006; Nassauer and Opdam 2008), will be needed to meet the increasing demand for multifunctionality in the agricultural landscape (Dosskey et al. 2012).

Landowner responses to the cultural scenario

In the cultural design, aspects of cultural identity, aesthetics, and research were incorporated in ways unique to each landowner based on his or her described values and goals. Several landowners found the unique design elements, such as non-linear plantings, flowering borders, and agrotourism, to be of great value. Aesthetics were found to be of significant importance to landowners regarding the cultural scenario. Flowering species such as eastern redbud and aronia allowed landowners to have "aesthetics that are low maintenance". Eastern redbud trees in combination with other productive crops were found to be an attractive design element because landowners viewed the redbud as "one of the most beautiful trees out there". Previous studies have shown that sociocultural benefits can be significant factors in agroforestry interest and adoption (Ryan et al. 2003), especially among landowners not associated with the conventional farming mindset (Arbuckle et al. 2009; Barbieri and Valdivia 2010).

In spite of landowner interest, the cultural scenario was the least preferred, which landowners described as being due to a lack of "real world" practicality. Adding a complexity of perennial plants into the landscape requires additional labor, and without an explicit monetary return, landowners were hesitant to favor such designs. Cultural elements integrated into MWPs are worth considering, but they are likely rarely the focus of landowners, as profitability and conservation benefits were shown by this study to be more influential.

Landowner preferences for MWP species

Participants were asked which three species they most preferred to use in MWPs. Their responses were sorted into four functional categories: timber, nut, fruit, berry, and other. Of the 45 total responses, nut-producing crops were the most preferred (14), followed by berry-producing shrubs (12), timber trees (e.g., black walnut and hickory; 9), fruit trees (6), and other (4). Nut-producing species were seen as novel ideas for the landscape; they are both uncommon and underutilized in the USRW. Landowners saw the use of nut-producing species as a way of producing long-term, high-value crops on many portions of their marginal land.

The most preferred species was northern pecan (as identified by seven landowners naming it among their three most preferred; Table 4). Northern pecan was described by many as appealing because of its high-value, edible nuts and potential for use as timber. Seven landowners chose species from three separate categories of crops, while only one landowner chose all three species from a single category (timber). Nineteen species were identified in this exercise, indicating the vast diversity of species that can be used and are of interest in MWPs. It appeared that landowners were open to using a variety of species to maximize their production as well as using them in mixes of two or three species.

Landowner preferences for MWP practices

Preferences for MWP practices in Central Illinois were identified by analyzing the occurrence and frequency of practices used in the optimal designs created by landowners (Table 5). A multi-species orchard containing two or three perennial crops was landowners' most commonly used practice when building an optimal design with researchers. The multi-species orchards were typically placed on small marginal lands no more than three to four acres in size. They consisted of alternating rows of a single edible crop species, one row containing a tree crop (fruit or nut) and another containing a berry crop, with adequate in-row and between-row spacing to be machine-harvestable. The landowners' goal of using a multi-species orchard was usually some method of diverse edible production to complement current farming practices. The second most common MWP practice was the use of borders, such as riparian buffers or windbreaks, for timber or food production. Alley cropping was not found to be favorable due to concerns regarding interactions with the row crop and management difficulties.

The overall greater interest in using food producing crops relative to those purely for conservation, mainly timber, runs counter to results from other studies showing fruit and nut production may not be landowners' preferred form of agroforestry (Barbieri and Valdivia 2010; Arbuckle 2013; Trozzo et al. 2014a). The difference may be the result of landowners in this study being predetermined high-adopters of such systems as well as their learning about MWPs throughout the study, which may have lowered the perceived risk of using MWPs. The differences may also be attributed to the complexity of agroforestry designs, which are often site-specific, influencing the occurrence and preference of practices. The deviation in functional preferences seen here supports the need for further research into regionally adapted MWPs.

Landowner motivators and barriers to adopting MWPs

The top three motivators for landowners considering adopting MWPs were (1) growing high-value edible

Table 4 Ten most frequent responses from landowners asked which three species they would most prefer to use in MWPs on their land

Genus	Species	Common name	# of responses
Carya	*ilinoinensis*	Pecan	7
Juglans	*nigra*	Black walnut	5
Aronia	*melanocarpa*	Aronia	4
Corylus	*americana; avellana;* hybrid	Hazelnut	4
Ribes	*nigrum; rubrum*	Currant	4
Castanea	*mollissima*	Chestnut	3
Malus	*domestica*	Apple	3
Quercus	*rubra; alba; bicolor*	Oak	3
Rubus	(Multiple)	Raspberry	2
Sambucus	*nigra*; *canadensis*	Elderberry	2

Species are grouped by genus where landowners did not indicate a specific genus and species preference

Table 5 Total number of times the following MWP practices were used by landowners in their final optimal designs

Practice	Number of times used in the optimal designs
Multi-species orchard	21
Riparian buffer	11
Orchard	10
Hedgerow	7
Timber border	7
Windbreak	7
Grass strip	6
Silvopasture	4
Multi-species, mixed native orchard	4

crops, (2) improving pollinator and wildlife habitat, and (3) productive use of marginal land (Table 6). Nearly two-thirds of landowners said the importance of these top three motivators increased after they learned more about MWPs throughout the study. This change may be attributed to landowners' improved understanding of the functioning of MWPs and their use on marginal lands throughout the design process, which increased their interest and thus motivations for adoption. This is similar to findings by Valdivia and Poulos (2008) who found knowledge of a practice to be the strongest positive factor in increasing the probability of being interested in two agroforestry practices (riparian buffers and forest farming). When landowners learn of a new farming practice, such as MWPs, they understand the potential benefits better and are further motivated by them to adopt the practice.

The top three barriers for landowners considering adopting MWPs were: (1) lack of infrastructure for post-harvest processing and packaging; (2) potential labor requirements; and (3) a lack of markets, harvesting equipment, and experience with horticultural and timber crops (Table 7). These barriers are

Table 6 Responses when landowners (n = 15) were asked to rate motivators for adopting MWPs on their land

Motivator	Percentage of landowners responding with the given rating							Mean[a]
	0	1	2	3	4	5	6	
Growing edible, high-value crops	0	0	0	0	47	33	20	4.73
Improving pollinator and wildlife habitat	0	7	0	0	47	27	20	4.47
Productive use of marginal land	0	0	0	13	40	40	7	4.40
Long-term investment and profit	0	7	7	13	20	33	20	4.27
Improving aesthetic quality	0	0	0	13	67	7	13	4.20
Improving soil quality	7	0	7	13	27	27	20	4.13
Preventing soil erosion	0	0	7	27	27	33	7	4.07
Increasing biodiversity	0	0	7	27	40	13	13	4.00
Improved recreation and human use	0	0	0	27	60	7	7	3.93
Improving water quality	0	7	20	13	27	13	20	3.80
Using native plants	0	0	7	40	27	20	7	3.80
Decreasing future labor requirements	13	13	0	33	13	13	13	3.13
Differs from corn and soybeans	13	0	13	33	27	7	7	3.07
Conservation payments	27	20	7	13	20	0	13	2.33

A Likert-type scale from 0 (not at all a motivator) to 6 (convinces adoption of MWP) was used

[a]Mean scores are indicative only as a Likert-type scale is not strictly a numerical rating

acknowledged by other studies which state that markets and infrastructure for specialty crops in MWPs are often lacking (Gold et al. 2004; Strong and Jacobson 2005; Cernusca et al. 2012) and that they are being addressed by researchers (Mori et al. 2017). More than half of landowners indicated that the "need for more information", previously the most significant barrier to adoption (Mattia et al. 2018b), was satisfied after participating in this study because the provided information allowed them to better conceptualize and understand the use of MWPs. Moving forward though, landowners expressed they would need more explicit information on the establishment and management, associated costs, and markets for products to feel confident in adopting MWPs.

Limitations

This study contains limitations that should be considered when examining and building on its findings. The sample size is small (n = 15) and non-random. The sample of participants consists of early innovators, those with a high potential for adopting MWPs. The study did not attempt to examine conventional farmers with little to no interest in adopting perennial crop systems. This research was explicitly centered on one portion of a watershed, which limits the ability to make direct comparisons to other regions because of cultural, economic, and social differences. Still, the methods are transferable and findings useful when comparing study results. For species selection, a "best-bet" approach that allowed for standardization of design elements was used rather than an optimization model. The designs were hypothesized to achieve predefined societal, environmental, and economic values aligned with their respective scenarios but may react differently when implemented. However, using scenario techniques with a small subset of landowners provides invaluable information that is difficult to gather with studies that are more extensive. Finally, a lack of familiarity with MWP species was a limitation for landowners when attempting to provide critical feedback on designs and describe their preferences. This was anticipated by researchers and was one reason for providing an information booklet with the designs.

Table 7 Responses when landowners (n = 15) were asked to rate barriers for adopting MWPs on their land

Barrier	Percentage of landowners responding with the given rating							Mean[a]
	0	1	2	3	4	5	6	
Lack of infrastructure for post-harvest processing and packaging	0	0	0	33	33	20	13	4.13
Time and labor requirements	0	7	13	13	33	27	7	3.80
Lack of harvesting equipment	0	0	20	20	40	20	0	3.60
Lack of markets to sell crops	7	0	13	20	27	33	0	3.60
Unfamiliarity with enterprises and products	7	7	0	40	13	20	13	3.60
Cost of establishment/management	7	0	13	27	33	20	0	3.40
Financial risk or profitability concerns	13	7	13	13	33	13	7	3.13
Difficult to manage or farm around	7	7	20	27	27	7	7	3.07
Lack of financial support and incentives	7	7	13	33	27	13	0	3.07
Slow growth of perennial crops (i.e. years to maturity)	7	7	20	40	20	7	0	2.80
Lack of community and extension resources	7	13	7	53	13	7	0	2.73
Lack of necessary information and research	13	20	20	13	13	13	7	2.60
Takes land out of production	33	13	7	33	0	7	7	2.00
Unsuitable with lifestyle or goals	27	13	20	20	13	7	0	2.00

A Likert-type scale from 0 (not at all a barrier) to 6 (prevents adoption of MWP) was used

[a]Mean scores are indicative only as a Likert-type scale is not strictly a numerical rating

Future work

Future work concerning MWPs and similar systems in Central Illinois and beyond should consider several noteworthy findings of this study. First, planners and researchers must consider profitability as a key indicator of successful MWPs. Ecosystem services and cultural benefits are valuable in shaping interest but as expressed by landowners in this study, they will likely be overlooked in the face of an unprofitable farming enterprise.

Second, placement of MWPs should focus on marginal lands as indicated by landowner willingness to do so and their strong disapproval for converting profitable farmland. Practices such as alley cropping, which use profitable land, are unlikely to take hold in Central Illinois until these attitudes change.

Additionally, the development of cooperatives or shared infrastructure for the harvest and processing of MWP products may be a necessity for expanded regional implementation. MWPs target marginal lands for use, which are often not in abundance for any one landowner. This limits a single landowner's scalability and increases the cost per acre, both of which can be mediated by working within a larger cooperative structure to access downstream markets.

The next step for MWP research is working with landowner adopters to monitor long-term management and impacts. Of those who indicated an intention to adopt some portion of their design (thirteen of the fifteen landowner participants), only a few are expected to do so in the near future, which would provide a small but useful selection of farms to study.

Conclusions

In this study, we aimed to identify landowners' preferences for the design and adoption of MWPs in the USRW of Central Illinois. We found that the diversity of potential species and practices possible when using MWPs offered the flexibility to meet the needs of nearly all participating landowners and their unique landscapes, but we also found that MWPs can be difficult to implement given the substantial experience necessary to successfully establish, manage, and market high-value perennial crops. Landowners expressed the most interest in production-based systems, although they acknowledged the importance of conservation and cultural goals as well.

The ideal MWP design for landowners was most often a combination of the three design scenarios presented, with an underlying requirement for profitability. Landowners who did not prioritize profit were typically more concerned with providing ecosystem services or preserving the landscape for later generations. Marginal lands were seen as the ideal location for MWPs. The most preferred species were nut-producing with potential for timber, primarily northern pecan and black walnut, while several berry crops, mainly aronia, currant, and elderberry, were regarded highly as well. Nonnative crops or those difficult to sell or manage were less likely to be incorporated into a landowner's ideal design. Furthermore, despite the fact that nearly all landowners indicated an intention to use MWPs, widespread adoption will likely be limited until a larger cooperative structure is established to overcome the barriers mentioned in this study. The challenges are not unique to MWPs though, as they are common among diversified farming practices.

Numerous systematic barriers opposing diversification in agroecosystems exist (Lin 2011; Roesch-Mcnally et al. 2018), most notably the economic policy incentives for intensive monoculture production (Lin 2011). In the Midwestern U.S., corn and soybean production has become the status quo (Green et al. 2018). Changing the current system will require a "joined-up" solution between numerous groups to link upstream farming systems developed by researchers and farmers with downstream markets and consumers utilizing the products (Meynard et al. 2017). Accomplishing this goal will require various actors at multiple scales, but it is a necessary hurdle for further landscape diversification. The framework used in this study to develop locally and regionally adapted multifunctional farming systems is one step among many for addressing the numerous challenges confronting the sustainability of agricultural landscapes.

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References

Adebiyi J, Schmitt Olabisi L, Snapp S (2016) Understanding perennial wheat adoption as a transformative technology: evidence from the literature and farmers. Renew Agric Food Syst 31:101–110. https://doi.org/10.1017/S1742170515000150

Ahern J (2006) Theories, methods and strategies for sustainable landscape planning. In: Tress B, Tress G, Fry G, Opdam P (eds) From landscape research to landscape planning. Aspects of integration, education and application. Springer, Dordrecht, pp 119–131

Arbuckle JG (2013) Farmer attitudes toward proactive targeting of agricultural conservation programs. Soc Nat Resour 26:625–641. https://doi.org/10.1080/08941920.2012.671450

Arbuckle JG, Valdivia C, Raedeke A et al (2009) Non-operator landowner interest in agroforestry practices in two Missouri watersheds. Agrofor Syst 75:73–82. https://doi.org/10.1007/s10457-008-9131-8

Atwell R, Schulte L, Westphal L (2009a) Linking resilience theory and diffusion of innovations theory to understand the potential for perennials in the U.S. Corn Belt. Ecol Soc. https://doi.org/10.5751/es-02787-140130

Atwell RC, Schulte LA, Westphal LM (2009b) Landscape, community, countryside: linking biophysical and social scales in US Corn Belt agricultural landscapes. Landsc Ecol 24:791–806. https://doi.org/10.1007/s10980-009-9358-4

Atwell RC, Schulte LA, Westphal LM (2010) How to build multifunctional agricultural landscapes in the U.S. Corn Belt: add perennials and partnerships. Land Use Policy 27:1082–1090. https://doi.org/10.1016/j.landusepol.2010.02.004

Barbieri C, Mahoney E (2009) Why is diversification an attractive farm adjustment strategy? Insights from Texas farmers and ranchers. J Rural Stud 25:58–66. https://doi.org/10.1016/j.jrurstud.2008.06.001

Barbieri C, Valdivia C (2010) Recreational multifunctionality and its implications for agroforestry diffusion. Agrofor Syst 79:5–18. https://doi.org/10.1007/s10457-009-9269-z

Baumgart-Getz A, Prokopy LS, Floress K (2012) Why farmers adopt best management practice in the United States: a meta-analysis of the adoption literature. J Environ Manage 96:17–25. https://doi.org/10.1016/j.jenvman.2011.10.006

Brandes E, McNunn GS, Schulte LA et al (2016) Subfield profitability analysis reveals an economic case for cropland diversification. Environ Res Lett 11:014009. https://doi.org/10.1088/1748-9326/11/1/014009

Cardoso IM, Guijt I, Franco FS et al (2001) Continual learning for agroforestry system design: university, NGO and farmer partnership in Minas Gerais, Brazil. Agric Syst 69:235–257. https://doi.org/10.1016/S0308-521X(01)00028-2

Cernusca MM, Gold MA, Godsey LD (2012) Using the porter model to analyze the US elderberry industry. Agrofor Syst 86:365–377. https://doi.org/10.1007/s10457-012-9546-0

Cope MA, McLafferty S, Rhoads BL (2011) Farmer attitudes toward production of perennial energy grasses in East Central Illinois: implications for community-based decision making. Ann Assoc Am Geogr 101:852–862. https://doi.org/10.1080/00045608.2011.575320

Dosskey M, Wells G, Bentrup G, Wallace D (2012) Enhancing ecosystem services: designing for multifunctionality. J Soil Water Conserv 67:37A–41A. https://doi.org/10.2489/jswc.67.2.37A

Foley JA, DeFries R, Asner GP et al (2005) Global consequences of land use. Science 309:570–574. https://doi.org/10.1126/science.1111772

Gelfand I, Sahajpal R, Zhang X et al (2013) Sustainable bioenergy production from marginal lands in the US Midwest. Nature 493:514–517. https://doi.org/10.1038/nature11811

Gobster PH, Nassauer JI, Daniel TC, Fry G (2007) The shared landscape: what does aesthetics have to do with ecology? Landsc Ecol 22:959–972. https://doi.org/10.1007/s10980-007-9110-x

Gold MA, Godsey LD, Josiah SJ (2004) Markets and marketing strategies for agroforestry specialty products in North America. Agrofor Syst 61–62:371–384. https://doi.org/10.1023/B:AGFO.0000029011.42829.83

Green TR, Kipka H, David O, McMaster GS (2018) Where is the USA Corn Belt, and how is it changing? Sci Total Environ 618:1613–1618. https://doi.org/10.1016/j.scitotenv.2017.09.325

Haggar J, Ayala A, Díaz B, Reyes CU (2001) Participatory design of agroforestry systems: developing farmer participatory research methods in Mexico. Dev Practice 11:417–424. https://doi.org/10.1080/09614520120066701

James LK, Swinton SM, Thelen KD (2010) Profitability analysis of cellulosic energy crops compared with corn. Agron J 102:675–687. https://doi.org/10.2134/agronj2009.0289

Jose S, Gold MA, Garrett HE (2012) The future of temperate agroforestry in the United States. In: Nair PKR, Garrity D (eds) Agroforestry—the future of global land use. Springer, Dordrecht, pp 217–245

Kang S, Post W, Wang D et al (2013) Hierarchical marginal land assessment for land use planning. Land Use Policy 30:106–113. https://doi.org/10.1016/j.landusepol.2012.03.002

Keefer L, Bauer E (2011) Upper Sangamon River watershed monitoring data for the USEPA targeted watershed study: 2005–2008. ISWS Contract Report 2011-03

Knowler D, Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32:25–48. https://doi.org/10.1016/j.foodpol.2006.01.003

Landis DA (2017) Designing agricultural landscapes for biodiversity-based ecosystem services. Basic Appl Ecol 18:1–12. https://doi.org/10.1016/j.baae.2016.07.005

Le Gal P-Y, Dugué P, Faure G, Novak S (2011) How does research address the design of innovative agricultural production systems at the farm level? A review. Agric Syst 104:714–728. https://doi.org/10.1016/j.agsy.2011.07.007

Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. Bioscience 61:183–193. https://doi.org/10.1525/bio.2011.61.3.4

Lovell ST, Johnston DM (2009) Creating multifunctional landscapes: how can the field of ecology inform the design of the landscape? Front Ecol Environ 7:212–220. https://doi.org/10.1890/070178

Lovell ST, Dupraz C, Gold M et al (2018) Temperate agroforestry research: considering multifunctional woody polycultures and the design of long-term field trials. Agrofor Syst 92:1397–1415. https://doi.org/10.1007/s10457-017-0087-4

Lynch L, Brown C (2000) Landowner decision making about riparian buffers. J Agric Appl Econ 32:585–596. https://doi.org/10.1017/S1074070800020678

MacDonald JM, Korb P, Hoppe RA (2013) Farm size and the organization of U.S. crop farming. USDA ERS ERR-152

Masters MD, Black CK, Kantola IB et al (2016) Soil nutrient removal by four potential bioenergy crops: *Zea mays*, *Panicum virgatum*, *Miscanthus* × *giganteus*, and prairie. Agr Ecosyst Environ 216:51–60. https://doi.org/10.1016/j.agee.2015.09.016

Matson PA, Parton WJ, Power AG, Swift MJ (1997) Agricultural intensification and ecosystem properties. Science 277:504–509. https://doi.org/10.1126/science.277.5325.504

Mattia CM, Lovell ST, Fraterrigo J (2018a) Identifying marginal land for multifunctional perennial cropping systems in the Upper Sangamon River watershed, Illinois. J Soil Water Conserv 73:669–681

Mattia CM, Lovell ST, Davis A (2018b) Identifying barriers and motivators for adoption of multifunctional perennial cropping systems by landowners in the Upper Sangamon River Watershed, Illinois. Agrofor Syst 92:1115–1169. https://doi.org/10.1007/s10457-016-0053-6

McGinty MM, Swisher ME, Alavalapati J (2008) Agroforestry adoption and maintenance: self-efficacy, attitudes and socio-economic factors. Agrofor Syst 73:99–108. https://doi.org/10.1007/s10457-008-9114-9

Meynard J-M, Jeuffroy M-H, Le Bail M et al (2017) Designing coupled innovations for the sustainability transition of agrifood systems. Agric Syst 157:330–339. https://doi.org/10.1016/j.agsy.2016.08.002

Montgomery DR (2007) Soil erosion and agricultural sustainability. Proc Natl Acad Sci 104:13268–13272. https://doi.org/10.1073/pnas.0611508104

Mori GO, Gold M, Jose S (2017) Specialty crops in temperate agroforestry systems: sustainable management, marketing and promotion for the Midwest region of the U.S.A. In: Montagnini F (ed) Integrating landscapes: agroforestry for biodiversity conservation and food sovereignty. Springer, Cham, pp 331–366

Nassauer JI, Corry RC (2004) Using normative scenarios in landscape ecology. Landsc Ecol 19:343–356. https://doi.org/10.1023/B:LAND.0000030666.55372.ae

Nassauer JI, Opdam P (2008) Design in science: extending the landscape ecology paradigm. Landsc Ecol 23:633–644. https://doi.org/10.1007/s10980-008-9226-7

Nassauer JI, Dowdell JA, Wang Z et al (2011) Iowa farmers' responses to transformative scenarios for Corn Belt agriculture. J Soil Water Conserv 66:18A–24A. https://doi.org/10.2489/jswc.66.1.18A

Oliver DM, Fish RD, Winter M et al (2012) Valuing local knowledge as a source of expert data: farmer engagement and the design of decision support systems. Environ Model Softw 36:76–85. https://doi.org/10.1016/j.envsoft.2011.09.013

Pattanayak SK, Mercer DE, Sills E, Yang J-C (2003) Taking stock of agroforestry adoption studies. Agrofor Syst 57:173–186. https://doi.org/10.1023/A:1024809108210

Reimer A, Thompson A, Prokopy LS, Arbuckle JG et al (2014) People, place, behavior, and context: A research agenda for expanding our understanding of what motivates farmers' conservation behaviors. J Soil Water Conserv 69:57A–61A. https://doi.org/10.2489/jswc.69.2.57A

Richards B, Stoof C, Cary I, Woodbury P (2014) Reporting on marginal lands for bioenergy feedstock production: a modest proposal. BioEnergy Res 7:1060–1062. https://doi.org/10.1007/s12155-014-9408-x

Robertson GP (2015) A sustainable agriculture? Daedalus J Am Acad Arts Sci 144:76–89. https://doi.org/10.1162/DAED_a_00355

Roesch-McNally GE, Arbuckle JG, Tyndall JC (2018) Barriers to implementing climate resilient agricultural strategies: the case of crop diversification in the U.S. corn belt. Global Environ Chang 48:206–215. https://doi.org/10.1016/j.gloenvcha.2017.12.002

Rogers E (2003) Diffusion of innovations, 5th edn. Free Press, New York

Ryan RL, Erickson DL, Young RD (2003) Farmers' motivations for adopting conservation practices along riparian zones in a mid-western agricultural watershed. J Environ Plan Manage 46:19–37. https://doi.org/10.1080/713676702

Schulte LA, Asbjornsen H, Liebman M, Crow TR (2006) Agroecosystem restoration through strategic integration of perennials. J Soil Water Conserv 61:164A–169A

Steinitz C, Anderson R, Arias H et al (2005) Alternative futures for landscapes in the Upper San Pedro River Basin of Arizona and Sonora. In: Proceedings of the 3rd international partners in flight conference, 20–24 March 2002, Asilomar, California, vol 1. United States Department of Agriculture Forest Service, Pacific Southwest Research Station

Strong NA, Jacobson MG (2005) Assessing agroforestry adoption potential utilising market segmentation: a case study in Pennsylvania. Small Scale For 4:215–228. https://doi.org/10.1007/s11842-005-0014-9

Tilman D, Socolow R, Foley JA et al (2009) Beneficial biofuels—the food, energy, and environment trilemma. Science 325:270–271. https://doi.org/10.1126/science.1177970

Tress B, Tress G (2003) Scenario visualisation for participatory landscape planning—a study from Denmark. Landsc Urban Plan 64:161–178. https://doi.org/10.1016/S0169-2046(02)00219-0

Trozzo KE, Munsell JF, Chamberlain JL (2014a) Landowner interest in multifunctional agroforestry Riparian buffers. Agrofor Syst 88:619–629. https://doi.org/10.1007/s10457-014-9678-5

Trozzo KE, Munsell JF, Chamberlain JL, Aust WM (2014b) Potential adoption of agroforestry riparian buffers based on landowner and streamside characteristics. J Soil Water Conserv 69:140–150. https://doi.org/10.2489/jswc.69.2.140

USDA NASS (2012) Census of agriculture: quick stats. https://quickstats.nass.usda.gov. Accessed 2 Apr 2018

USDA NASS (2017) Cropscape cropland data layer. https://nassgeodata.gmu.edu/CropScape/. Accessed 5 Feb 2017

Valdivia C, Poulos C (2008) Factors affecting farm operators' interest in incorporating riparian buffers and forest farming practices in northeast and southeast Missouri. Agrofor Syst 75:61–71. https://doi.org/10.1007/s10457-008-9129-2

Valdivia C, Barbieri C, Gold MA (2012) Between forestry and farming: policy and environmental implications of the barriers to agroforestry adoption. Can J Agric Econ 60:155–175. https://doi.org/10.1111/j.1744-7976.2012.01248.x

Verdade LM, Piña CI, Rosalino LM (2015) Biofuels and biodiversity: challenges and opportunities. Environ Dev 15:64–78. https://doi.org/10.1016/j.envdev.2015.05.003

Wells GR, Fribourg HA, Schlarbaum SE et al (2003) Alternate land uses for marginal soils. J Soil Water Conserv 58:73–81

Werling BP, Dickson TL, Isaacs R et al (2014) Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proc Natl Acad Sci 111:1652–1657. https://doi.org/10.1073/pnas.1309492111

White EM (2010) Woody biomass for bioenergy and biofuels in the United States: a briefing paper. United States Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland

Wolz KJ, Lovell ST, Branham BE et al (2017) Frontiers in alley cropping: transformative solutions for temperate agriculture. Glob Change Biol. https://doi.org/10.1111/gcb.13986

Wright CK, Wimberly MC (2013) Recent land use change in the Western Corn Belt threatens grasslands and wetlands. PNAS 110:4134–4139. https://doi.org/10.1073/pnas.1215404110