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Agroforestry at the Landscape Level

Much of the work on agroforestry in North America has focused on six distinct practices—windbreaks, silvopasture, alley cropping, riparian and upland buffers, forest farming, and urban food forests—considering their functions, applications, and designs. These practices are typically planned and implemented for sites on individual farms and ranches to meet producer objectives, and therefore a site-scale perspective is the dominant lens through which these interventions are viewed. Incorporating a landscape perspective, however, can add significant value when designing agroforestry practices for enhancing multifunctionality. Understanding how individual sites function in the larger landscape can help identify where and how to design agroforestry practices to more effectively produce ecosystem services. A landscape framework involves looking beyond field boundaries and property lines to determine how a site is influenced by off-site conditions and how the site affects the surrounding landscape. At this broader scale, connections with other land uses become relevant, and more comprehensive land-based solutions can be developed.

This chapter focuses on the application of a landscape-level perspective to enhance delivery of ecosystem goods and services from agroforestry in order to create more resilient agricultural landscapes. The first section provides an overview of landscape ecology, the patch–corridor–matrix model, recent approaches for improving matrix quality, and the multifunctional landscape framework. The second section explores opportunities for agroforestry to contribute to a culture-based food supply that could improve human health and build on local knowledge. In the next section, an introduction to methods for assessing landscapes offers guidance for strategically placing agroforestry practices based on landscape and site conditions. Merging theory and application, a case study of the Upper Sangamon River Watershed demonstrates the value of research methods applied at the landscape scale. The final section describes how expanding landscape-scale agroforestry research could help to bring greater benefits and broader implementation.

Background

Landscape Ecology Framework

The discipline of landscape ecology—the study of biological, physical, and human interactions of a geographical area—offers a basis for integrating agroforestry into the landscape (Forman & Godron, 1986). Landscape ecology considers the spatial patterns of the fixed landscape elements that create landscape structure, which influences the movement of

things such as animals, water, and nutrients. Landscape functions (the flow of things between landscape elements) and changes with time are characterized using various landscape ecology approaches.

While broader concepts guiding the discipline are more than a century old, the term *landscape ecology* was first used in 1939 by Carl Troll, a German geographer (Turner, 1989, 2005). In the 1980s, landscape ecology found a foothold in North America, and the patch–corridor–matrix model emerged to provide a framework, general principles, and a language for describing landscape structure (Forman, 1995a). The model describes the landscape as a “mosaic” consisting of three different types of spatial elements (patches, corridors, or matrix), each of which can be either natural or human in origin (Forman, 1995a, 1995b). The variation in plant communities across the landscape creates the patchwork heterogeneity that can be viewed in aerial images.

The *matrix* consists of the dominant landscape type or the background in the mosaic. The *patches* are areas of vegetation distinct from the surrounding landscape. Patches often consist of seminatural habitats that may be large enough to protect interior species and water networks, but

they can also be smaller “stepping stones” that may support dispersal of species between large patches (Forman, 1995b). The *corridors* are linear features, often narrow strips of vegetation, that can be isolated elements but are more commonly found connecting patches of similar vegetation.

The patch–corridor–matrix concept has been widely used for sustainable landscape planning, in both urban and rural contexts (Lovell & Johnston, 2009b). For applications in temperate agroforestry, the matrix would typically consist of cropland. Treed habitats such as those involving forest farming could serve as patches, while riparian buffers and windbreaks might serve as corridors. Small patches of trees can serve as “stepping stones” that also increase connectivity (Forman, 1995b). Agroforestry elements typically perform six different landscape functions (Fig. 14–1).

This model, however, is less effective in describing agroforestry practices that are highly integrated into the landscape, such as alley cropping and silvopasture. In those cases, the resolution at which the treed features become distinct from the crops is so fine that an alternative approach is needed to fully capture the landscape heterogeneity and related ecological functions.

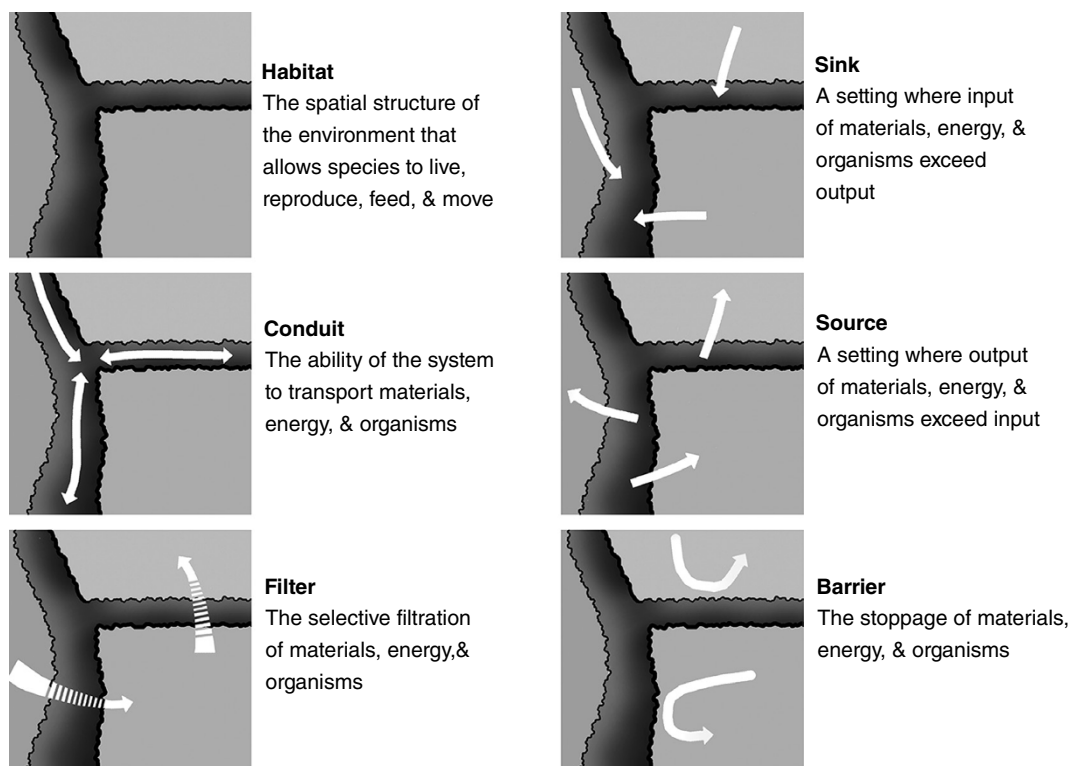


Fig. 14–1. Six landscape-level functions of agroforestry provided within the patch–corridor–matrix model.

Matrix Quality

Consistent with the patch–corridor–matrix model, conservation efforts have historically emphasized the protection of large, high-quality patches and the development of corridors to connect them. An alternative approach is to improve the quality of the entire matrix by incorporating smaller features at a finer scale or transitioning to an alternative land use altogether (Perfecto & Vandermeer, 2002; Vandermeer & Perfecto, 2007). Increasing the complexity of landscape structure through the addition of perennial habitats has been proposed as the best alternative for reversing the negative impacts of landscape simplification and the resulting loss of ecosystem services. These perennial habitats would support and conserve the biodiversity that serves as the foundation of ecosystem services (Landis, 2017). Additionally, improving the complexity of the landscape can enhance cultural functions including visual quality and recreation (Angileri & Toccolini, 1993; de la Fuente de Val, Atauri, & de Lucio, 2006; Dramstad et al., 2001).

The integration of seminatural habitats such as agroforestry features will result in greater fine-scale heterogeneity, which will increase the connectivity of the entire landscape (Bailey, 2007; Lovell & Johnston, 2009a). Large forest patches are key to supporting the conservation of interior species that are often at risk (Robles, Flather, Stein, Nelson, & Cutko, 2008). By creating the necessary tree structure to function like a forested buffer, agroforestry can enlarge the area of effective interior forest habitat and turn smaller, less viable patches into more effective interior habitat (Dosskey, Bentrup, & Schoeneberger, 2012). Small isolated patches and scattered trees can also play an important role by serving as seed sources for

the surrounding landscape (Benayas, Bullock, & Newton, 2008). Agroforestry habitats cover only a small proportion of most landscapes, yet the contributions to ecosystem functioning can be disproportionately large (Boutin, Jobin, & Belanger, 2003; León & Harvey, 2006). By focusing on the quality of the matrix, we move beyond the simple valuation of habitats as either “suitable” or “uninhabitable” (Baudry et al., 2003) to capture those agroforestry practices that truly combine trees with crops or livestock, such as alley cropping and silvopastoral systems.

Multifunctional Landscape Framework

With a focus on matrix quality as an appropriate goal for agroforestry implementation, a multifunctional landscape approach could offer a framework for developing more comprehensive land-based solutions. Multifunctional landscapes demonstrate that agriculture has the potential to provide not only production functions (goods) but also ecological functions such as biodiversity, nutrient cycling, and carbon sequestration and cultural functions including recreation, cultural heritage, and scenic beauty. The idea of landscape “functions” is consistent with the “ecosystem services” framework, where the provisioning, regulating, and cultural services are provided by different ecosystems or landscapes (Madureira, Rambonilaza, & Karpinski, 2007). The multifunctional landscape approach encourages a focus on the overall performance of agroecosystems, in which multiple functions can be combined or stacked, instead of considering only production (Dosskey, Wells, Bentrup, & Wallace, 2012; Jordan & Warner, 2010; Lovell et al., 2010; Lovell & Johnston, 2009a) (Fig. 14–2). Similarly, approaches that seek to bundle ecosystem

Increasing landscape performance by stacking functions

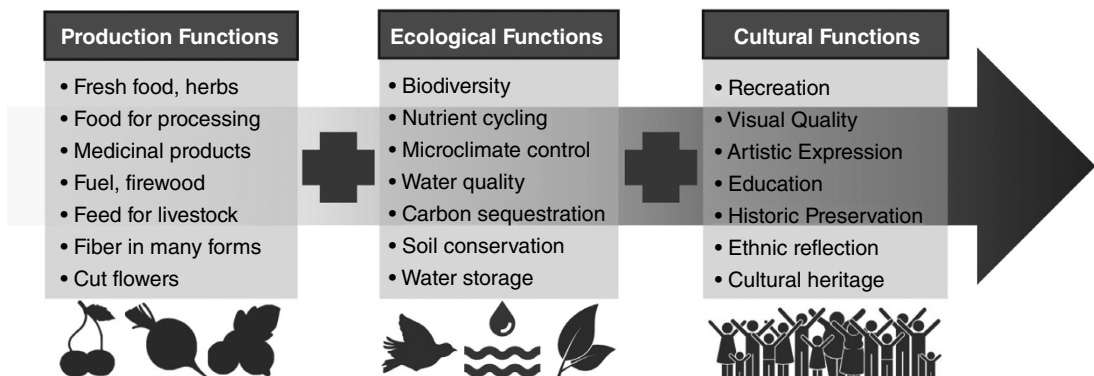


Fig. 14–2. Multifunctional landscape framework for increasing landscape performance.

services could result in comparable outcomes (Huang et al., 2015).

In many regions throughout the world, agricultural policy has promoted landscape multifunctionality (also referred to as “multifunctionality of agriculture”). In Europe, for example, agri-environmental schemes provide public funds that pay farmers for the benefits they provide to society including biodiversity conservation, water quality, carbon sequestration, and rural tourism (Sutherland, 2004). Examples of objectives from these programs that could cover agroforestry include “preservation of landscape and historical features such as hedgerows, ditches and woods” and “conservation of high-value habitats and their associated biodiversity” (European Commission, 2017). Similar policies exist in the United States, such as the Conservation Reserve Program administered by the USDA. These policies, however, are often written in a manner that intentionally separates production from conservation by discouraging food production or specifically restricting harvest (Raymond, Reed, Bieling, Robinson, & Plieninger, 2016). Furthermore, little consideration is given to cultural functions, and funding is often not provided to support these efforts (Raymond et al., 2016). Despite the challenges, agricultural policies are starting to offer a vision for redesigning the landscape to support the “transition to sustainable food systems” (Gliessman, 2010), while at the same time expanding the suite of goods and services provided (Jordan & Warner, 2010).

Even with a goal of improving landscape performance, tradeoffs between functions will inevitably exist (Lovell et al., 2010), and these will be most intense on highly productive portions of a farm. For instance, soil fertility is a crucial determinant of the location and extent of treed habitats, with areas of high fertility more likely to be deforested for cultivated crops (Seabrook, McAlpine, & Fensham, 2007). One alternative is using agroforestry practices on sensitive or marginal areas instead of targeting fields with highly productive soils that consistently produce the best crop yields (Jordan & Warner, 2010). These marginal or sensitive areas are often located in floodplains or wet spots, where they are hotspots for the loss of nutrients such as nitrogen and phosphorus. With such a strategy, the establishment of perennial vegetation in agroforestry would have the greatest benefits in ecological functions while minimizing losses in productivity of conventional crops (Lovell et al., 2018).

Several multifunctional landscape approaches are available to help guide agroforestry planning

and navigate the inevitable trade-offs. These approaches often emphasize whole-farm planning and design (Huang et al., 2015), working at the scale at which management and land use decisions are rendered (Rigby, Woodhouse, Young, & Burton, 2001; Rotz et al., 2005). Strategies to integrate or conserve trees on farms are more successful when they take into account the preferences and values of farmers and rural residents (Seabrook, McAlpine, & Fensham, 2008). Farm design methods that allow landowners to compare different alternatives for the landscape can be quite valuable for assessing overall performance in the multifunctional landscape framework (Stanek & Lovell, 2020; Stanek, Lovell, & Reisner, 2019). The Multifunctional Landscape Assessment Tool proposed by Lovell et al. (2010) is an example of an approach that allows the comparison of alternative scenarios for the design of an agroecosystem. Overall, the multifunctional agriculture approach provides a mechanism for agroforestry to do more than only produce food. The framework can also support the broad range of ecosystem services that improve the environmental and social health of communities, even offering a delivery mechanism for training growers in new skills, educating the public about food systems, and retaining cultural identity for communities (Leakey, 2014).

Contributing to a Culture-Based Food Supply

Incorporating a landscape perspective in agroforestry offers an opportunity to build on the multifunctional agricultural framework and create a culture-based food supply that supports human health and cultural values in addition to enhancing food security (Fig. 14–3). For instance, nuts and berries grown in agroforestry practices can play an important role in providing key vitamins and nutrients for human health in addition to supporting cultural connections to food. To have meaningful impact on these functions and objectives, landscapes incorporating agroforestry need be informed by cultural knowledge and be designed and implemented at scale.

Improving Human Health

Regarding the relationship between our food system and human health, we have historically focused on undernutrition in developing countries, often neglecting the issues of overconsumption and poor nutritional quality of food found in North America and other temperate zones. As the quality of the human diet deteriorates, new health risks emerge in our

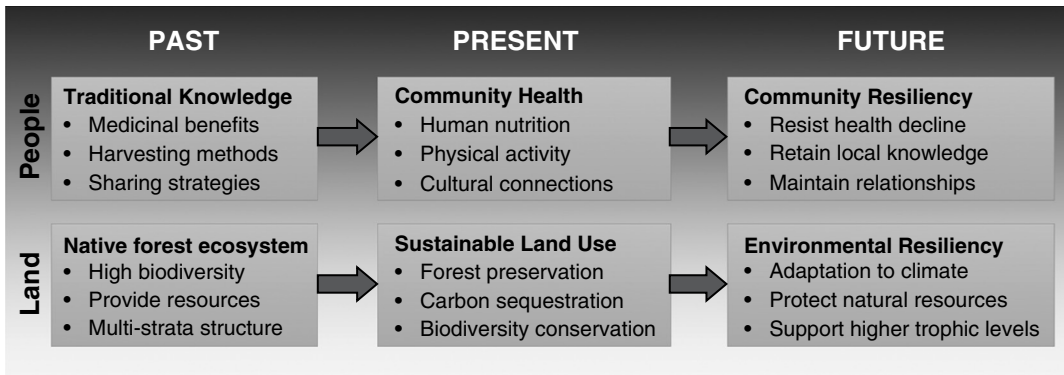


Fig. 14–3. For a culture-based food supply, contributions from land and people of the past can lead to a favorable present and future.

communities, including food allergies and intolerances, resistance to antibiotics, and conditions such as metabolic syndrome (Gordon, Negri, & Snyder, 2017). To reduce these risks, landscapes incorporating agroforestry can be purposefully designed to provide nutritional value for improving human health (Gordon et al., 2017). Agroforestry has the potential to reduce the prevalence of metabolic syndrome and improve community health by supplying natural foods such as berries (Park et al., 2015) and by encouraging physical activity in the care of tree crops (Baceviciene et al., 2013). Healthy diets, particularly those high in plant-based foods and lower in animal-based products, not only improve the longevity of individuals in a community but new evidence shows benefits for the biosphere. These consumption patterns result in lower greenhouse gas emissions, lower water use, and less energy consumption (Aleksandrowicz, Green, Joy, Smith, & Haines, 2016).

Building on Traditional Ecological Knowledge

Although indigenous communities may call agroforestry by a different name (e.g., traditional management, forestry, food security), their traditional ecological knowledge offers important lessons for how to create and manage agroforestry systems to support culture-based food systems (Rossier & Lake, 2014). In addition, agroforestry landscapes can offer a valuable connection to local traditional knowledge and cultural values. In the past, the study of indigenous agroforestry might have been considered less “scientific” than experimental research (Olofson, 1983), but we now recognize that these agroforestry systems and their associated landscape management practices can serve as a model for modern, locally adapted food systems

(Schoeneberger, Bentrup, & Patel-Weynand, 2017). Traditional ecological knowledge facilitates the implementation of practices such as controlled burning, pruning, sowing, tillage, water management, and sustainable plant and animal harvesting (Box 14–1).

These agroforestry systems produced a range of traditional subsistence foods such as wild berries, nuts, and herbs that provided important health benefits with their high nutrient levels and medicinal values (Lila et al., 2014; Rossier & Lake, 2014). Plants also provided materials for basketry, dyes, and other culturally significant products. The cultivation and gathering of such items is recognized as an important physical and social activity for native communities (Baceviciene et al., 2013; Flint et al., 2011). The rules for sharing traditional ecological knowledge and resources and the arrangements for common property use are important components of sustaining productive landscapes, even today. The indigenous peoples of the Gwich’in region in the Northwest Territories of Canada offer insight into the deep level of knowledge and importance of retaining it. Elders in the community contribute to an important knowledge base on the abundance and distribution of native “dark” berries that offer nutritional and medicinal value. The landscape supports a wide range of species including cranberry (*Vaccinium vitis-idaea* L.), blueberry/bilberry (*Vaccinium uliginosum* L.), cloudberry (*Rubus chamaemorus* L.), red currant (*Ribes triste* Pall.), and black currant (*Ribes hudsonianum* Richardson). For the system to remain successful and sustainable, harvesters must be knowledgeable of the spatial distribution and maturity timing, at the same time respecting the property rights and unwritten rules of sharing (Teetl’it Gwich’in Renewable Resources Council, Parlee, & Berkes, 2006).

Box 14–1. The Karuk tribe, traditional ecological knowledge, and agroforestry

In Northern California, the Karuk tribe traditionally managed entire watersheds and ecosystems on their ancestral lands to meet their dietary, cultural, and spiritual needs. Their diverse, multistory agroforestry systems produced forest-grown foods, such as tanoak acorn, pine nut, huckleberry, hazelnut, camas bulb, gooseberry, raspberry, deer, elk, and mushroom, as well as salmon and eel from the Klamath River and its tributaries. In addition, these systems produced medicinal herbs like wormwood, plus willow, bear grass, and hazel for basket making. The tribe used prescribed burns at different intensities and frequencies, as well as a variety of pruning, gathering, and hunting techniques to manage their tanoak and Douglas-fir dominated forests. Fire cleared oak groves of encroaching conifers and killed the weevils that ruin acorns. The controlled burning removed dense underbrush, making it easier to harvest these resources while renewing the meadow grasses for grazing deer and elk. Fire also allowed willow and hazel trees to produce the straight shoots needed for baskets. For salmon dependent on clean, cold water, the burns helped maintain water quality and the amount of water returned to streams where salmon spawn. While these resources are still present, they are scarce compared with historic levels, and efforts are underway to use traditional ecological knowledge to help manage these forests. The Six Rivers National Forest is partnering with the Karuk tribe to combine their holistic vision and traditional ecological knowledge with lidar and GIS to help restore these resources and improve forest health (U.S. Forest Service, 2018).

Sources: (adapted from Lake, 2013; Lake, Tripp, & Reed, 2010)



Ron Reed of the Karuk Food Crew collecting gooseberries in a landscape managed by traditional ecological knowledge (photo credit: Colleen Rossier)

For indigenous communities, agroforestry can offer unique opportunities but also challenges related to climate change. Some evidence indicates that climate change will negatively impact the productivity of important wild berries in areas such as Alaska, where berry abundance is declining or becoming more variable (Hupp, Brubaker, Wilkinson, & Williamson, 2015). On the positive side, traditional practices offer insight for adaptation and mitigation in the face of variable climate conditions (Schoeneberger

et al., 2017). The diversity of nutrient-rich species can serve as an adaptation strategy to improve the health of communities (Lila et al., 2014) and to spread the risk of inconsistent harvests (Altieri & Nicholls, 2017). The mitigation potential of traditional agroforestry can be found in the increase in carbon storage from above- and belowground biomass, as well as lower greenhouse gas emissions resulting from fewer inputs from pesticides, fertilizers, and energy (Altieri & Nicholls, 2017).

Assessing Landscapes for Agroforestry

While agroforestry practices offer an important application of landscape multifunctionality including a culture-based food supply, the potential to integrate trees into productive landscapes can be complicated in North America, particularly in those areas where annual crops are well established and highly productive. At the landscape scale, a goal might be to strategically place these treed systems where they could most effectively optimize the targeted benefits. This strategy also makes sense in terms of using public funds to incentivize agroforestry practices because the ecological and cultural functions can serve the broader community while any reduction in production functions (yield) primarily impacts the landowner. Using landscape analysis techniques, trained planners can play important roles in purposefully designating space for different uses, including the placement of permanent vegetation and habitat types such as agroforestry.

One tool to aid in strategically planning and designing agroforestry practices is landscape assessments. Landscape assessments spatially describe resource conditions within a larger planning area and identify opportunities to produce environmental and production benefits with targeted management activities, including agroforestry practices (McHarg, 1995). Landscape assessments provide a way to understand the relationships between landscape structure and functions, environmental problems, and agroforestry opportunities (Box 14–2). Assessments can be used to identify key conditions and processes in a landscape:

- problems and where they occur
- opportunities and where they occur
- sources and causes of the problems
- where and how resources flow across the landscape
- structure of the landscape and how it controls sources and movement

Assessing landscapes is greatly enhanced with the use of GIS—databases for managing, processing, and analyzing spatial information in a visual manner that aids decision-making. With the increasing availability of spatial data and enhanced computing power, the use of GIS has become commonplace in land use planning and natural resource management. For example,

remotely sensed LiDAR (light detection and ranging) data can yield a variety of high-resolution data products such as 1-m digital elevation models that could be used for evaluating flow paths in riparian forest buffers (Wallace et al., 2018) or vegetation canopy maps that can guide tree thinning operations in silvopasture systems (Hung et al., 2005). The Soil Survey Geographic (SSURGO) database provides soils information mapped at scales ranging from 1:12,000 to 1:63,360, suitable for planning at the farm to watershed scales (USDA–NRCS, 2016). Most states and federal agencies have GIS data clearinghouses that provide free or low-cost access to a broad selection of spatial data that can be useful for planning agroforestry practices.

Despite the availability of publicly available data sets and the benefits of using GIS, the use of these analysis and planning tools in temperate agroforestry applications has been limited (Bentrup & Leininger, 2002; Carver, Danskin, Zaczek, Mangun, & Williard, 2004; Ellis, Bentrup, & Schoeneberger, 2004; Fagerholm et al., 2016; Mattia, Lovell, & Fraterrigo, 2018). One way to use GIS in agroforestry is to rank and combine data layers based on suitability for a particular function (Fig. 14–4). A primary advantage of using GIS is the ability to merge the assessments to identify where multiple functions or objectives can be simultaneously achieved with agroforestry practices (Fig. 14–5).

Landscape Scale Applications

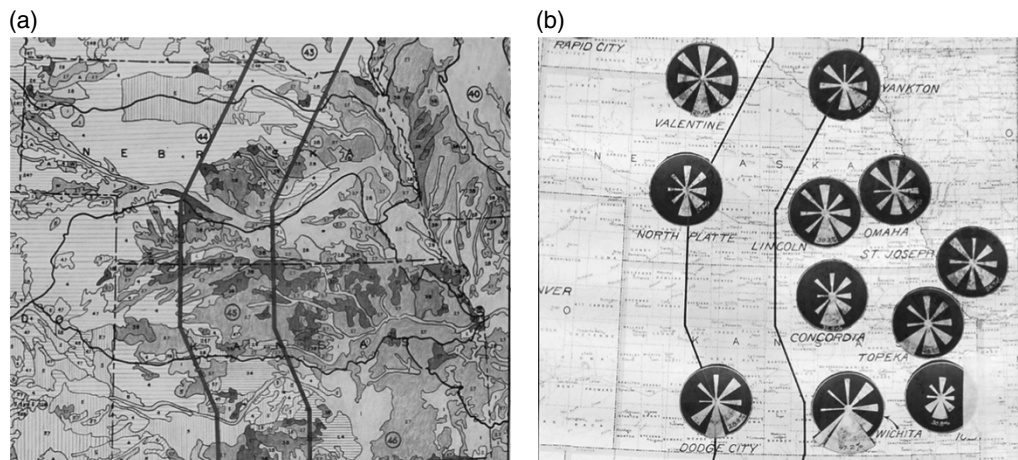
The following is a cross-section of examples where a landscape assessment approach can be used to augment the benefits derived from agroforestry. This list is not inclusive but rather illustrates the range of opportunities a landscape strategy can provide, and the real optimization comes from combining approaches to derive multifunctional systems.

Riparian Zones

Of the six agroforestry practices, riparian buffers typically receive the most attention in terms of placement within the landscape due to their prominent role in capturing and filtering runoff as well as their value for biodiversity functions. For water quality functions, the watershed or sub-watershed is a common boundary of analysis, and several different strategies have been used to determine the best placement and design of these practices. Fixed width buffers are the most straightforward, designating the protection of a given distance from the stream edge or other water body (e.g., a 50-m buffer zone on each side). Using GIS and remote sensing, buffer

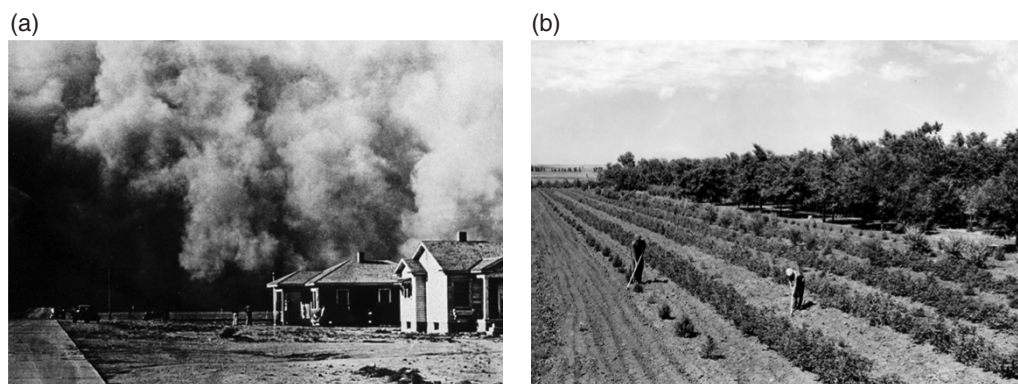
Box 14–2. Landscape Assessment for the Prairie States Forestry Project

Severe dust storms of the 1930s in the U.S. Great Plains region spurred the creation of the Prairie States Forestry Project (PSFP), a federal program designed to combat soil erosion by planting windbreaks. Through the PSFP, more than 29,900 km (18,600 miles) of windbreaks were planted on 30,000 farms from North Dakota into Texas (Williams, 2005).

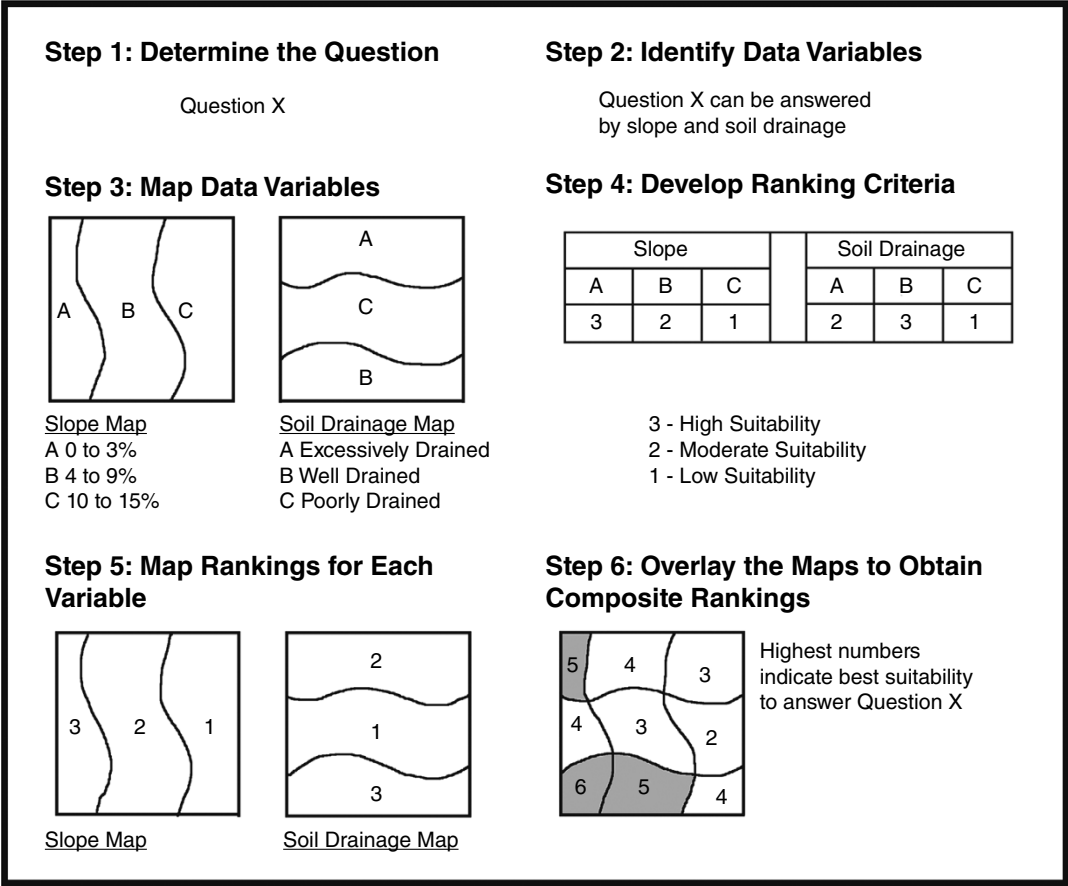


(A) The erosion reconnaissance survey map depicts erosion types and severity; **(B)** summer wind direction is illustrated using wind roses. The boundary line outlines the 100-mile-wide and 1150-mile-long project area that roughly follows the 99th meridian.

One of the innovative aspects of the PSFP was the use of biophysical and economic spatial data to determine where to locate the windbreaks. Planners concentrated efforts within a 161-km (100-mile) wide zone running from North Dakota to the Brazos River in Texas based on a minimal annual precipitation of 51 cm (20 inches) needed to establish the plantings. Within this zone, 14 resource maps were used to identify high-priority target areas for windbreak plantings. The resource maps included soils and natural vegetation, seasonal wind direction, erosion reconnaissance, regional farming systems, and land values. This suitability assessment process represents one of the earliest examples of analyzing landscapes for the placement of an agroforestry practice.



(A) A dust storm rolls across eastern Colorado during the 1930s (photo from the USDA–NRCS), and **(B)** landowners tending to their windbreak planted with the Prairie States Forestry Project (photo from the U.S. Forest Service).



For biodiversity functions, riparian assessments can be used to identify locations where riparian buffers can enhance wildlife movement (Bentrup & Kellerman, 2004) and determine what plant species may be most optimal (Carver et al., 2004). Assessments can also be conducted to determine where riparian buffers can most effectively shade streams and manage water temperatures for cold-water habitat, a function that is becoming increasingly important due to climate change (Bentrup & Dosskey, 2017).

Marginal Land

For the placement of many agroforestry practices, a common strategy is to target lands that are considered sensitive or “marginal” for conventional crop production (Lovell et al., 2018; Tsonkova, Bohm, Quinkenstein, & Freese, 2012). Lands with highly erodible soils, for example, are more sensitive to the loss of topsoil, a problem that could be reduced substantially by converting the land into the perennial continuous cover of agroforestry (Garrett, McGraw, & Walter, 2009). Trees and shrubs would reduce environmental impacts and economic risks, as these woody systems can stabilize the soil and retain nutrients (Molnar, Kahn, Ford, Funk, & Funk, 2013). The use of marginal lands also makes sense from an economic perspective because marginal lands are often lower yielding and higher risk for conventional crop production (Rhoads, Lewis, & Andresen, 2016), so the landowner might be more open to alternative land use systems (Lovell et al., 2018).

A number of approaches and data are available for identifying marginal lands for the placement of agroforestry practices (Gopalakrishnan, Negri, & Snyder, 2011; Holzmüller & Jose, 2012; Mattia, Lovell, & Fraterrigo, 2018). With the high resolution and accuracy of modern maps, these spatial analyses could also identify problem “wet spots” within a field that can be sources of water quality problems as well as be low performing (Agnew et al., 2006; Brandes et al., 2016). Maps of crop productivity are also available for most regions, as with the cropland data layer provided by the USDA. In some cases, these analyses may yield small marginal areas in the middle of fields or other locations that can make management difficult and that will require an iterative design process with producers to develop a workable solution (Mattia, Lovell, & Fraterrigo, 2018).

Woody Crop Optimization

For agroforestry systems that contain a productive tree or shrub crop (e.g., timber, nuts or berries, woody florals, bioenergy, bio-oils), an

entirely different approach to placement might be used. Geospatial tools and economic analyses can be combined to determine the best areas for optimizing the products derived from woody plants used in agroforestry practices (Bentrup & Leininger, 2002). Several woody crop optimization assessments are available to serve as examples (Ahmad, Goparaju, & Qayum, 2019; Reisner, de Filippi, Herzog, & Palma, 2007; Wallace & Young, 2008), and this landscape strategy can be particularly valuable because woody crop suitability will probably shift under climate change (de Sousa et al., 2017). These types of spatial assessments could help guide the creation of nutrient-rich landscapes that focus less on crop volume and calorie production and more on the nutritional content of a diverse set of plants for improved human health (Wood, 2018).

This approach could particularly make sense for an alley cropping system in which the tree productivity would be added onto the yield of the alley crop. Wolz and DeLucia (2019) tested this approach for the U.S. Midwest, modeling black walnut (*Juglans nigra* L.) systems grown for timber as a plantation (trees alone) or as rows in an alley cropping system with existing crops compared with the current corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.] rotation. Alley cropping systems had the highest economic rates of return on 23% of the land, some of which would not be considered marginal (Wolz & DeLucia, 2019). The approach is currently limited by the availability of high-resolution data on all of the necessary variables—soil suitability, timber prices, crop productivity, cash rents, and land cover.

Alley Crop Compatibility Zones

In a similar vein, agroforestry practices (particularly alley cropping) might be placed in regions with existing crops that are most compatible with trees, the distribution of which could be analyzed and mapped. For example, cool-season crops such as wheat (*Triticum aestivum* L.) have been successfully integrated with tree rows due to less competition for light during the active growing season between trees and the alley crops. Long-term studies in France have demonstrated the success of growing winter wheat in combination with hybrid walnut trees (Lovell et al., 2018). Forage hay crops also have good potential for the alley plantings, although less information is available on how the trees impact the productivity of the forage (Garrett et al., 2009). Also worth noting is the incompatibility of certain crops for use in an alley cropping system due to competition for resources or management constraints.

Understanding the spatial distribution of genetically modified, herbicide-resistant crop cultivars could be useful because these crops allow applications of various broad-spectrum herbicides late in the season, which could severely damage trees and shrubs grown in close proximity (Garrett et al., 2009).

Sensitive and Drought-Prone Areas

The placement of agroforestry practices can also be considered on a broader regional scale. For example, practices such as windbreaks can be particularly valuable in regions that are prone to drought or other severe conditions because the woody vegetation provides more favorable microclimate conditions. Windbreaks can offer an economic advantage for sensitive crops, as demonstrated in the arid cold temperate region of southern Patagonia, Argentina. In this very windy region, dense windbreaks reduce the wind speed by 85% at a ground distance equivalent to the height of the trees. Protection of sensitive crops such as strawberry (*Fragaria* sp.) and cherry (*Prunus avium* L.) can increase production substantially (Peri & Bloomberg, 2002). A shelterbelt system has also been developed for the Three-North Region of northern China. Initiated in 1978 and intended to go through 2050, the program covers about 40% of China's territory, providing windbreaks to improve microclimate conditions for sensitive crops, particularly to reduce drought stress in zones that are most limited by moisture (Zheng, Zhu, & Xing, 2016). The assessment process in the Prairie States Forestry Project (Box 2) offers a conceptual framework of what a regional-scale analysis could look like for addressing drought-prone areas.

Livestock Considerations

Just as sensitive crops can benefit from the protection of trees in harsh climates, the performance and comfort of livestock can also be improved. Silvopastoral systems are particularly valuable in areas where heat stress reduces livestock productivity. In the U.S. Southeast, for example, the addition of trees has been shown to provide a milder microclimate than open pasture (Karki & Goodman, 2015), and grazing is more consistent across the land (Karki & Goodman, 2010). The shading component in silvopasture systems has also been shown to improve forage quality, for example in cool-season grasses by increasing protein content while reducing fiber (Kallenbach, Kerley, & Bishop-Hurley, 2006). Windbreaks can also reduce stress on sensitive animals by providing more comfortable conditions (Dronen, 1988). Rows of trees can be placed so they shelter

pastures, feedlots, and other livestock holding areas from cold winter winds, hot summer winds, or both. Windbreaks provide an additional benefit of mitigating odors and reducing the movement of particulate matter when placed downwind of livestock areas (Tyndall & Colletti, 2007; Willis et al., 2017). The prevailing winds, topographic setting, canopy cover, and other biophysical and social data can be used to locate and manage agroforestry practices to address livestock considerations (Adhikari et al., 2018; Hung et al., 2005; Mor-Mussery, Leu, & Budovsky, 2013).

Case Study: Application of Agroforestry in the Upper Sangamon River Watershed

A case study of the Upper Sangamon River Watershed (USRW) in Illinois demonstrates the potential application of agroforestry at the landscape scale. This research was conducted by a team at the University of Illinois from 2013–2018. The USRW study site is located in central Illinois, where intensively managed field corn and soybean occupy the majority of the landscape. The multistep study included a survey of stakeholders to examine adoption potential, mapping of marginal lands that would be targets for a transition to agroforestry, and development of design scenarios for individual landowners (Fig. 14–6). From this work, various solutions emerged for supplying food and promoting healthy land through agroforestry applications that included trees and shrubs that were themselves productive.

The landowner survey was designed to investigate motivators and barriers for implementing new multifunctional perennial cropping systems, including agroforestry, on marginal land. While the survey was sent to the majority of landowners in the counties of the USRW, the response rate was relatively low (9.2%), probably resulting in a sample somewhat biased toward an interest in these systems. Of those who responded, approximately one-third indicated they would be willing to convert their marginal land to multifunctional perennial cropping systems. The most popular perennial cropping options were bioenergy crops, hay, and fruit and nut trees. To follow up the results of the survey, a focus group revealed important barriers including the need for markets and infrastructure, as well as a labor force to manage the systems (Mattia, Lovell, & Davis, 2018).

Data from the survey were used to classify different types of landowners for predicting the potential to adopt multifunctional perennial cropping systems. Multivariate analysis revealed six categories of landowners from the pool of

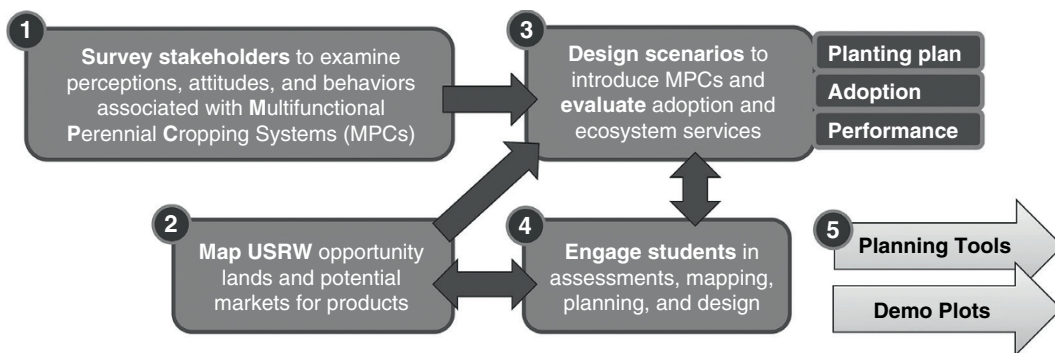


Fig. 14–6. Process for evaluating the Upper Sangamon River Watershed (USRW) in central Illinois for potential multifunctional perennial cropping systems.

survey respondents. Educated Networkers were high probability adopters, and they were characterized by high education and having farming as a secondary occupation. The Young Innovators group, which had the youngest average age but high decision-making involvement, also showed high adoption potential. Groups with medium adoption potential included Small Conventional and Large Conventional landowners, both of which identified most with conventional farming but differed in the size of operation. The lowest adoption potential was related with the Money Motivated (mostly cash rent lease arrangements) and Hands-Off (preference for low labor and time requirements) groups. From the landscape-scale perspective, focusing efforts on the needs of the high potential adopters could help with getting systems on the ground in the short term (Mattia, Lovell, & Davis, 2018).

To better understand the landscape of the USRW, the marginal land was identified and mapped using a suitability assessment model. Soil erosion potential, crop productivity, and other land traits were spatially analyzed to determine suitability. Target areas were often distributed in areas with low crop productivity and high potential for erosion. The total land classified as marginal was 7% of the agricultural land in the USRW or 18,685 ha (Fig. 14–7). Running the model with a scenario in which the identified marginal land would be converted to multifunctional perennial crops showed that simulated soil erosion could be reduced by 56% across the watershed. The approach demonstrates the potential for the conversion of a relatively small portion of land to have a large impact on the environmental health of the landscape (Mattia, Lovell, & Fraterrigo, 2018).

With the marginal land maps and survey results as a guide, 15 rural landowners were

engaged in a collaborative design process to develop potential solutions involving multifunctional perennial crops, such as agroforestry, specific to their properties. Interviews were conducted with participants at the beginning of the design process to determine their preferred locations for these systems and to explore their perceptions of different system and species types. In the next step of the design process, three scenarios were developed for each landowner, distinguished by their focus on production, conservation, or cultural functions. Each of the scenarios was developed as a scaled planting plan and visualized in color (Fig. 14–8). In the final phase of the process, landowners assessed the three scenarios, providing rankings and comments on preferences for designs, as well as ideas for motivators and barriers in implementing each alternative.

The results of the collaborative design process revealed several important findings that apply broadly to our understanding of integrating agroforestry at the landscape scale. In the pre-design interviews, landowners expressed strong interest in edible food production, even above timber production, which is a more common use of trees in agroforestry. In fact, systems that were strictly timber-based were ranked lowest by this set of landowners. In ranking the design scenarios, production scenarios were most preferred because of the profit potential, but aspects of each of the scenarios were appreciated by most landowners. In working toward a final design, landowners often included some aspects of cultural and conservation focuses, in addition to production functions. These results, therefore, provide strong support for the concept of truly “multifunctional” designs, as discussed above (Stanek et al., 2019).

The combined efforts of the work in the USRW help to distill the types of agroforestry practices

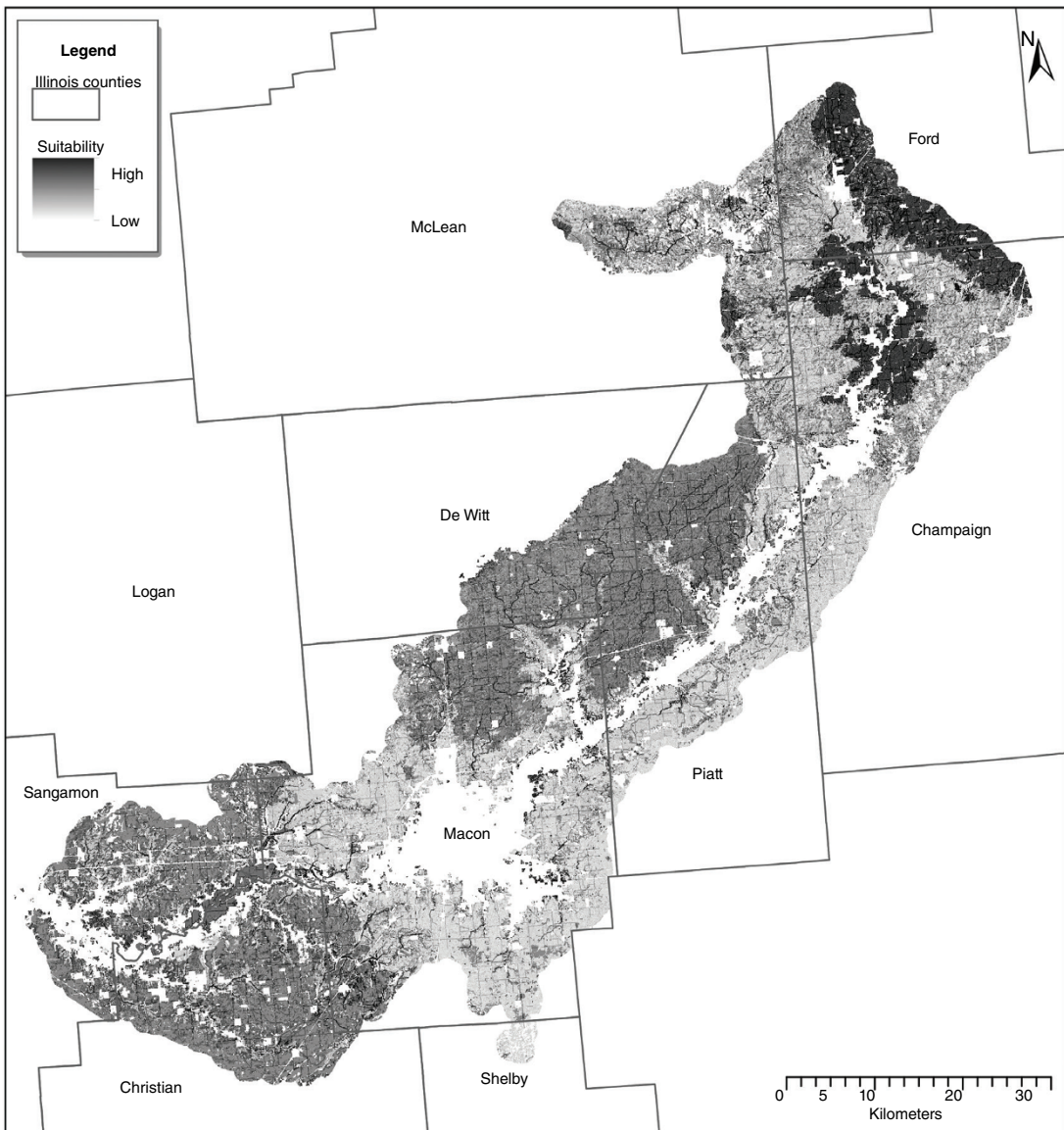


Fig. 14-7. Suitability of agricultural land in the Upper Sangamon River Watershed for multifunctional perennial cropping systems based on marginal land characteristics emphasizing areas of high soil erosion and low crop productivity.

that have the greatest potential for landscapes in which conventional annual crops dominate. Because of the strong drive for land to be productive, agroforestry solutions that offer marketable products such as fruits and nuts could be popular, particularly if they are combined with conservation goals on marginal land. Much of the land in this region could benefit from the addition of windbreaks strategically placed to protect sensitive crops, livestock, or human establishments. Typically, the windbreaks (including those established through the Conservation Reserve Program) are designed with several rows of trees

and shrubs. By selecting species that would eventually yield nuts or fruits, landowners might be more likely to retain the plantings as they become more productive over the years. Even narrowing a species list down to those native to the region still allows the production of high-value, locally specific goods. Thinking at the landscape scale allows a productive agroforestry approach that can supply healthy food and promote land stewardship, contributing to culture-based food supply. Ongoing work to establish demonstration plots and develop planning tools could support agroforestry adoption.



Fig. 14-8. Example scenario developed for a landowner depicting a multifunctional agroforestry border around a farmstead.

Conclusions

Despite the growing awareness of the importance of landscape-scale analysis and planning for agroforestry adoption and implementation, further research is needed. Of particular importance is the need to gain a better understanding of the opportunities, synergies, and trade-offs of designing for multifunctional landscapes using agroforestry. Robust but easy-to-use methods are needed to conduct these evaluations to aid in designing high-performing agroforestry systems. This is an evolving and dynamic process as new goals and objectives continually get added into the mix, such as creating culture-based food systems that support human health. In addition, emerging insights from traditional ecological knowledge should be better integrated.

Another key research area is to investigate and expand the plant material available for agroforestry using a landscape approach. Agroforestry plant species could be collected, tested, and selected across a wide range of landscape conditions including marginal lands that are typically considered less productive (Schoeneberger et al., 2017). At the same time, crop species that have not traditionally been integrated into agroforestry might be evaluated for utility and compatibility (e.g., tolerance to interspecific competition, potential synergistic relationships). New and underutilized specialty crops could be particularly appropriate for this application because they can offer an economically viable alternative (Mori, Gold, & Jose, 2017). Climate envelope models and other scenario-based strategies may be necessary to understand the suitability and viability of plant material under climate change (Schoeneberger et al., 2017). Future research will also need to include a breeding effort to improve these crops for unique situations and

changing climatic conditions. Leakey (2014) recommended collecting and selecting varieties with preferred traits from wild plants found locally, even exploring the potential to domesticate new food crops from native ecosystems.

An opportunity to broaden the implementation of agroforestry at the landscape level is to consider applications in nontraditional settings, particularly in urban areas. Agroforestry could be included as a key component of urban green infrastructure and greenway planning initiatives that are gaining attention across the globe. Opportunities exist to integrate working trees into the city landscape through applications such as urban food forests (see Chapter 10), riparian buffers along urban streams, forest farming in green spaces, and productive windbreaks to protect urban farms. Agroforestry may also be used to reduce the often common zone of conflict between urban and rural land uses by providing a buffer (Schoeneberger, Bentrup, & Francis, 2001). More research is needed, however, to better understand the potential for agroforestry to provide a wide range of ecosystem services in these nontraditional settings. In particular, social scientists should be engaged to better understand the cultural functions due to the tight connection to residents in urban areas (Lovell, 2010; Lovell & Taylor, 2013).

The potential exists to significantly expand the use of agroforestry throughout North America by strengthening and expanding landscape-scale research efforts. Particularly important is the study of agroforestry at this broader scale where connections with other land uses become relevant and comprehensive land-based solutions can be developed. Working effectively at the landscape scale will require collaboration between physical and social scientists, landowners, residents, as well as landscape designers and

planners. Experts in these planning fields are trained across disciplines to respect and reflect the value of nature and also of culture in the proposed solutions (Dramstad, Olson, & Forman, 1996). They also play an important role in developing, articulating, and communicating the range of possible solutions. Engaging this broad group of stakeholders throughout the research, planning, and design process will help identify the best solutions for agroforestry integration and ultimately improve the utility of multifunctional landscapes across the world.

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Study Questions

1. Briefly describe the differences between a landscape-level perspective and a site-specific perspective when designing agroforestry systems. How can the use of a landscape-level perspective enhance the overall delivery of ecosystem goods and services?
2. The development of the patch–corridor–matrix model in the 1980s allowed ecologists to efficiently describe landscape structure, especially within heterogeneous lands. Within the context of this model, describe the patch, corridor, and matrix elements of an example agroforestry system of your choosing and briefly list the landscape functions it provides.
3. Describe the difference between “high-quality” and “low-quality” patches in a landscape? Which agroforestry practices are most likely to serve as high-quality patches?
4. In what ways does the multifunctional landscape framework differ from traditional, widely utilized approaches to cropping systems?
5. Profitability is often the underlying measure of success for an agricultural system in modern times. When profit is the sole focus of a system, what landscape benefits may be excluded and how can a multifunctional approach avoid this?
6. What is traditional ecological knowledge? How can traditional ecological knowledge be used to improve the cultural and environmental benefits provided by agroforestry systems at a landscape scale?
7. Provide three examples of how a landscape-scale assessment can be leveraged to improve the design or function of agroforestry systems.
8. In some circumstances, a site-scale perspective is more appropriate than a landscape-scale approach when designing or assessing the use of agroforestry. Provide an example of when this may be the case and describe why a site-scale perspective is more appropriate.
9. How can the use of modern geospatial technology aid in the development and effectiveness of landscape-level agroforestry design?
10. Landscape-level agroforestry design has been acknowledged to provide a wide range of benefits, yet it is still relatively underutilized. What are some of the major challenges and opportunities for future work in this area?