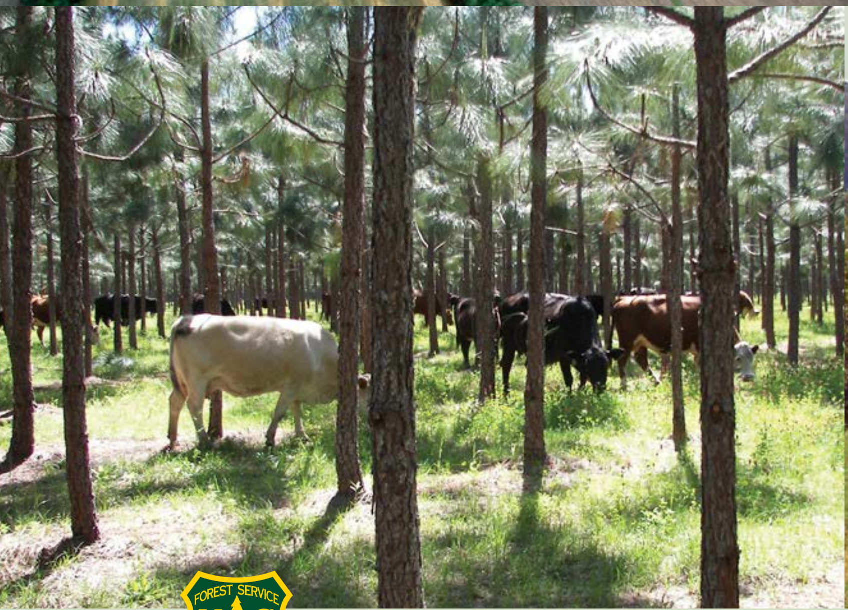
United States Department of Agriculture

# Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions

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# Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions

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**Editors**

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# Executive Summary

Toral Patel-Weynand, Gary Bentrup, and Michele Schoeneberger

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## Overview and Purpose

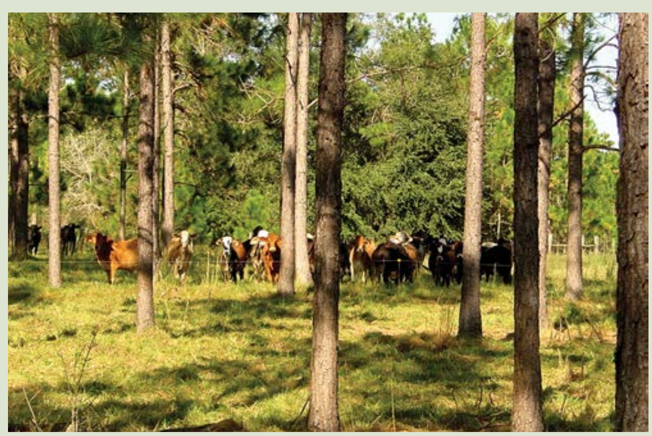
Agroforestry, the intentional integration of trees and shrubs into crop and animal production systems, is being deployed to enhance productivity, profitability, and environmental stewardship of agricultural operations and lands across the United States.

This assessment provides a science-based synthesis on the use of agroforestry for mitigation and adaptation services in the face of climatic variability and change. It provides technical input to land-use sector issues in the National Climate Assessment (NCA) and serves as a framework for including agroforestry systems in agricultural strategies to improve productivity and food security and to build resilience in these landscapes. It also provides follow-up to the technical input report by Walthall et al. (2012) that established the need for innovative strategies to address significant climatic variability challenges faced by U.S. agriculture.

The five widely recognized categories of agroforestry in the United States are (1) silvopasture, (2) alley cropping, (3) forest farming (or multistory cropping), (4) windbreaks, and (5) riparian forest buffers. Such practices can help to mitigate greenhouse gas (GHG) emissions and increase the resiliency of agricultural lands to address impacts from climatic variability. They can also enhance agricultural production; protect soil, air, and water quality; provide wildlife habitat; and allow for diversified income.

This report provides a science-based assessment of adaptation and mitigation mechanisms that agroforestry can confer, all of which are important for food security. It reviews social, cultural, and economic aspects of agroforestry and the capacity of agroforestry systems to provide multipurpose solutions. In addition, it presents a comprehensive North American perspective on the strengths and limitations of agroforestry through U.S. regional overviews as well as overviews for Canada and Mexico.

A range of national stakeholder perspectives was included, with participation from Federal and State governments, tribal lands, nongovernmental organizations, academic institutions, and professional organizations. Their input throughout the process has ensured up-to-date and relevant subject matter information for decisionmakers, practitioners, and researchers.



Agroforestry is the intentional blending of trees and shrubs into crop and livestock systems to increase production and environmental services we derive on our Nation's farms and ranches.

*Photo credits (from left to right): Gary Wells, USDA Natural Resources Conservation Service. Jim Robinson, USDA Natural Resources Conversation Service.*

Climatic variability poses significant challenges for farmers and ranchers. This report assesses how agroforestry practices can add structural and functional diversity to boost resiliency of U.S. agriculture in face of these challenges.

*Photo credits (from left to right): Lynn Betts, USDA Natural Resources Conservation Service. Beverly Moseley, USDA Natural Resources Conservation Service.*

This report provides an in-depth assessment of agroforestry as one strategy for strengthening the adaptive capacity of U.S. farms and ranches. The introduction provides an overview and addresses how agroforestry can provide adaptive and mitigative solutions for agriculture. The remaining chapters present in greater detail the biophysical dimensions, human dimensions, and regional considerations regarding the utility of agroforestry for addressing changing conditions. The chapters are—

- Reducing Threats and Enhancing Resiliency.
- Greenhouse Gas Mitigation and Accounting.
- Valuation of Agroforestry Services.
- Human Dimensions of Agroforestry Systems.
- Agroforestry Resources.
- Expanding the North American Perspective—Canada.
- Expanding the North American Perspective—Mexico.
- Challenges and Opportunities.

## Key Messages

### Ecosystem Services and Food Security Benefits of Agroforestry

Intensive (e.g., seed genetics) and extensive (e.g., landscape diversification) actions are being proposed to address extreme weather and climatic variability predicted for U.S. agriculture. Agroforestry is a unique extensive action involving the integration of woody plants with crop and livestock components. This approach has been documented to deliver a host of ecosystem goods and services, from food production to protection and enhancement of natural resources important to agriculture. Research suggests that agroforestry helps sustain these ecosystem services by increasing resilience to risks, shocks, and long-term effects from climatic variability and change. Agroforestry accomplishes these production and environmental benefits by—

- Modifying microclimate in ways that can improve crop yields from 6 to 56 percent depending on crop type.
- Reducing soil erosion from water and wind, and improving soil physical condition and fertility, thereby protecting future soil productivity.
- Modifying microclimate in ways that protect livestock productivity and well-being.
- Protecting streambanks and infrastructure, moderating water pollution, and ameliorating high stream temperatures, thus protecting water quality and aquatic ecosystems.
- Creating habitat refugia and connectivity across highly fragmented agricultural landscapes, protecting biodiversity, including pollinators and beneficial insects.
- Generating innovative food-producing systems that diversify farm portfolios and increase economic stability for the landowner.

Agroforestry practices are multifunctional strategies that can work at multiple scales to provide several benefits. A single practice can be designed to help diversify farm income, enhance production, and provide wildlife resources, while also sequestering carbon and improving water, air, and soil quality.

*Photo credits (from top to bottom): Ben Fertig, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/). USDA National Agroforestry Center.*

## Agroforestry as a Mechanism for Greenhouse Gas Mitigation

Agroforestry can be an important component of a comprehensive GHG mitigation strategy by sequestering carbon (C) in biomass and soils and reducing GHG emissions on agricultural lands, especially through avoided emissions via energy savings and fuel reductions. The lack of activity-specific data limits inclusion of agroforestry in national accounting and inventory efforts in the United States. The amounts and duration of C sequestration and reduction in GHG emissions are influenced by design specifics, local site conditions, and management activities, making agroforestry a complex but flexible mitigation option. An advantage is that C sequestration and GHG mitigation are but two of many benefits agroforestry can provide to agricultural operations and lands. Effective inclusion of agroforestry in national-level estimations for GHG emission reductions will require—

- Better understanding of soil C and other GHG dynamics across agroforestry systems and settings.
- Refined tools and methodologies for measuring the long-term potential of agroforestry systems to mitigate GHG emissions.
- A national inventory that tracks land under agroforestry, to feed into U.S. GHG inventory assessments.
- A common GHG assessment framework for national coordination of agroforestry GHG efforts.

## Economic and Sociocultural Considerations

Knowledge of the financial benefits of agroforestry to landowners, and an understanding of ecosystem service benefits to society, will be critical to agroforestry outreach efforts. The few economic studies available suggest that agroforestry offers financial benefits for producers on marginal lands. Due to the long timeframe for agroforestry plantings to mature and provide the full suite of benefits, agroforestry may be less competitive with annual cropping systems on highly productive lands. However, when ecosystem services are factored in, agroforestry can be competitive on prime agricultural lands as well.

Voluntary, conservation-based programs at the Federal, State, and local levels provide financial incentives for landowners to implement agroforestry practices. Additional economic benefits will likely be derived from the ability of agroforestry practices to mitigate and adapt to climatic variability, particularly in response to extreme weather events.

Additional considerations influencing agroforestry adoption in the United States include a long management timeframe, complex systems, a lack of information, and the need for specialized equipment. Approaches for increasing agroforestry adoption include increased education and technical support as well as innovative partnerships, such as equipment-sharing cooperatives. In response to surveys, most farmers indicated they would like to do more to protect their operations and lands from climatic variability. Such farmers may be open to new approaches, such as partnering with others, to create more resilient agricultural landscapes that include agroforestry practices.


Agricultural producers are a diverse group, and agroforestry practices can be tailored to address individual farmer and rancher objectives and situations.

*Photo credits (from top to bottom): USDA National Agroforestry Center. Ron Nichols, USDA Natural Resources Conservation Service. Bob Nichols, USDA Office of Communications.*

Indigenous and tribal agroforestry systems of the United States and U.S.-affiliated islands provide time-tested models that inform modern agroecosystem management. These systems employ agroforestry to maintain and enhance food, fiber, and medicinal resources for local livelihoods and economies. They are often locally adaptive and reflective of tribal traditions. Traditional ecological knowledge has diminished due to the declining transfer of knowledge from older to younger generations. This loss is a result of cultural and value changes and an increasing focus on other employment options. Maintenance and renewal of indigenous and tribal agroforestry practices will need to be supported by increased awareness and transfer of traditional ecological knowledge.

## U.S. Regional Summaries

An overview of regional perspectives on the status and potential future role of agroforestry in each of the NCA regions follows.

### Alaska

- Although only 0.2 percent of Alaska is actively farmed, agriculture plays an important local and regional role.
- Alaska has warmed twice as fast as the rest of the Nation and changes are so rapid that they are difficult to anticipate, even with the best models. Future increases in temperatures may result in conditions more favorable to agriculture.
- Riparian forest buffer use is increasing in southeast Alaska and may help offset some climatic variability impacts on aquatic health and fisheries.
- Forest farming opportunities exist for high-value and culturally significant understory crops, including mushrooms, berries, medicinal plants, and traditional native foods.
- Windbreak establishment may be helpful to the vegetable production now becoming possible under warming conditions, thus supporting new avenues for addressing food insecurity issues affecting Alaska Native peoples.

### Hawaii and the U.S.-Affiliated Pacific Islands

- Although arable land is limited on the islands, farming is vital to local economies and food security, particularly in areas where people rely on subsistence agriculture.
- Many climate-related stressors, including shifting rainfall patterns, changing storm and drought intensities, decreasing coastal stability, and salinization of groundwater, threaten the Pacific Islands.

- Agroforestry has been used in the Pacific Islands for centuries to produce numerous products for subsistence or sale (fruits, tubers, spices, medicines, wood, and fiber). These systems reduce rainfall intensity and erosion from tropical storms and provide efficient use of land and water resources.
- Seaside plains are important areas for traditional agriculture, and coastal windbreaks can help dissipate wind energy and storm surges, thus increasing coastal stability.

### Northwest

- Nearly one-fourth of the region's land area is agricultural, providing 52 percent of the Nation's potato crop, 17 percent of the Nation's wheat, 11 percent of the Nation's milk, and a diversity of fruit and nut crops.
- Heat stress, decreased chilling hours, increased drought, and reduced snowmelt are some of the challenges that farmers and ranchers in the Northwest face.
- The region's tribal communities have historically practiced agroforestry, and some of these practices continue today. Silvopasture, windbreaks, and alley cropping may offer the most potential to modify microclimates in support of livestock and crop production.
- Riparian forest buffers are used in agricultural areas to lower stream temperatures to protect salmon and other cold-water species. A warming climate and reduced snowmelt will likely increase the need for riparian forest buffers.

### Southwest

- More than one-half of the Nation's high-value specialty crops come from the southwest region, which includes California. These crops are predominantly irrigation-dependent and vulnerable to water availability and temperature extremes. Extensive forested rangelands generate revenue through livestock and dairy production.
- Predicted changes in climate pose daunting challenges for an already parched region that is expected to get hotter and, in its southern half, significantly drier.
- Many specialty crops in the region require insect pollination, and agroforestry practices can create more diversified and resilient foraging and nesting habitat.
- Opportunities exist to manage forested rangelands as silvopasture systems that reduce fuel loads and severity of forest fires while enhancing forage and livestock production. Improved irrigation technologies may provide a means for increasing nut production from key agroforestry trees (e.g., pinyon pine, pecan) valued and grown in this region.

### Great Plains

- More than 80 percent of the land area in the Great Plains is dedicated to cropland, pasture, and rangeland, with the total market value split about equally between crop and livestock production.
- Known for its historic weather extremes, the Great Plains region expects hotter temperatures with higher likelihood of heavy rain and snow events in addition to more intense droughts.
- Windbreaks have long played a role in combatting impacts from adverse climatic variability in the region, beginning with the 1930s Dust Bowl, and remain a logical choice for building greater resiliency in Great Plains agriculture and livestock production.
- Awareness of water quality and streambank stability issues in the region is increasing the use of riparian forest buffers and will likely continue as these issues intensify.

During the 1930s Dust Bowl, windbreaks were planted in the Great Plains to control soil erosion and protect crops, and they remain a logical choice for building greater resiliency in agriculture and livestock production.

*Photo credits (from top to bottom): USDA Natural Resources Conservation Service. USDA Forest Service.*

### Midwest

- More than two-thirds of the land in the Midwest is in agricultural use, with corn and soybean constituting 85 percent of crop receipts.
- Increased heat stress, alternating flooding and drought cycles, and higher populations of harmful insects are major climatic challenges faced by producers in the region.
- Riparian forest buffers are used to reduce water-quality problems, and this need is expected to grow as extreme rainfall events increase.
- Expanding the use of windbreaks and alley cropping could buffer the effects of warmer temperatures on crops and livestock and help boost populations of beneficial insects.

### Northeast

- About 21 percent of the region is in agricultural use, with the most prevalent commodities being dairy and poultry production and perennial fruits.
- Increasing heat waves, heat stress, extreme precipitation events, and flooding pose challenges for growing traditional crops and may lead to decreases in milk production. Warmer and wetter winters may impact survival and production in fruit- and nut-bearing plants.
- Riparian forest buffers have been used extensively in the Chesapeake Bay watershed and other areas to address water quality issues. Buffers will play an increasingly important role in mitigating the impacts of extreme precipitation events and flooding.
- Well-managed silvopasture systems could reduce heat stress on livestock while maintaining forest health. Forest farming may reduce the conversion of forest cover to other cover types less resilient to the effects of climatic variability and environmental change.

### Southeast and Caribbean

- The Southeast is a diverse agricultural region, producing the majority of U.S. broiler chickens and peanuts (66 and 62 percent, respectively) and one-third of cotton and tomatoes (37 and 33 percent). The Caribbean islands have limited arable land and depend on imported food.
- Extreme heat events, decreases in fresh water availability, and sea-level rise are some of the challenges faced by the region's farmers and ranchers.
- Silvopasture, alley cropping, and forest farming are the most commonly used agroforestry practices, providing high potential for microclimate modification and efficient water resource use.
- In the Caribbean, the use of forest farming and other agroforestry practices to produce fruits, vegetables, and nuts on steep slopes can increase food security and reduce soil erosion.

## Perspectives From Canada and Mexico

The challenges and opportunities for agroforestry to address climate-related impacts are similar in Canada and Mexico to those in the United States. A review of approaches taken in each country provides new insights for each and can help to identify additional opportunities for collaboration and partnerships.

Canadian agroforestry systems are similar to those found in the United States, with windbreaks and shelterbelts being the most widespread. Greater attention is being given to the use of agroforestry to address and mitigate environmental impacts of modern agriculture, including GHG emissions. Through the Agricultural Greenhouse Gases Program, the Canadian government is documenting the C sequestration potential of agroforestry across provinces, which may feed into future inventory reports. Conservation programs such as the community-developed, farmer-delivered Alternative Land Use Services provide important financial support for agroforestry adoption. To maximize efforts between Canada and the United States, a memorandum of understanding was signed in 2012 between the Agroforestry Development Centre of the Department of Agriculture and Agri-Food Canada and the National Agroforestry Center of the Forest Service, an agency of the U.S. Department of Agriculture (USDA). It called for collaborative activities on temperate agroforestry systems, with an emphasis on climatic variability and change.

In Mexico, many agroforestry systems are derived from traditional land-use systems developed by indigenous people over long periods of time and are well adapted to local conditions. These systems play an important role in food security by integrating a diversity of edible species, notably fruit trees, with perennial food crops and by providing fuelwood for cooking. Despite their value, Mexican agroforestry systems are suffering production declines due to disease, changes in climate, and land abandonment. Policies and incentive programs do not often include agroforestry because they are outside the mission of government agencies responsible for agricultural- or forestry-related programs. Agroforestry practitioners and advocates, however, are placing greater attention on agroforestry in promoting sustainable land use. Focusing on production of ecosystem goods and services provides options for addressing climatic variability and change.

## Addressing the Challenges

The potential for agroforestry to provide mitigation and adaptation services in the face of climatic variability and change is documented by research. In addition, agroforestry plays a prominent role in the history of U.S. efforts to combat climate-related impacts to agriculture. In 1935, the Prairie States Forestry Program began planting more than 200 million tree seedlings as shelterbelts, to reclaim land ravaged by the Dust Bowl. Today the range of climate-related impacts to U.S. agriculture is greater, and so is the potential for agroforestry to address them. Agroforestry represents a promising management option, but critical challenges still exist for successful promotion, adoption, and long-term maintenance. The obstacles to adoption (e.g., lack of information, awareness, and technical and policy support) are recognized and will need to be addressed at appropriate scales.

Although the implementation of agroforestry systems can alleviate climate-related stressors to agriculture, they too may be vulnerable to climate-related impacts. The long-term benefits of agroforestry systems may be affected by stresses resulting from future climatic conditions. Future success may require development and introduction of new species and cultivars better adapted to current and future climatic conditions. Time and resources will need to be invested in improved seed sourcing, field evaluation trials, and enhanced predictive capability for modeling shifts in growing zones.

Although the practice of agroforestry involves considerable uncertainty, scientific principles and decision-support tools are available for taking action now. Technical assistance offered through Federal and State conservation programs provides planning and design processes for implementation. Transfer of technical knowledge can promote an adaptive management approach to addressing uncertainty and modifying management options. Adaptive management can reduce the risks of climatic variability in agriculture and forestry by improving planning, preventing maladaptation, and informing investment and management of resources (Peterson et al. 2014, Vose et al. 2016, Walthall et al. 2012). By tracking the successes and failures of different adaptation actions, including agroforestry, landowners, practitioners, researchers, and institutions can produce more robust adaptation strategies over time.

U.S. and global communities will continue to experience challenges from climatic variability and change, and the potential effects on agricultural production pose a serious threat to food security around the world. Improving adaptive capacity in agricultural systems, while meeting food-security needs and enhancing C sequestration, is challenging. Agroforestry is a multipurpose option for farmers and ranchers to address adaptation, food security, and GHG mitigation concerns and to build the resilient agricultural landscapes needed under changing conditions.

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# Chapter 1
# Introduction

Gary Bentrup, Michele Schoeneberger, Toral Patel-Weynand, Shibu Jose, Tara Haan Karel

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Enhancing food security and preserving vital ecosystem services from agricultural lands are critical issues for the United States and have become increasingly important globally. Addressing these issues requires that forestry and agricultural systems become even more productive while ensuring that the other environmental services provided by these landscapes are available to future generations. To achieve higher levels of productivity and ensure long-term sustainability, these landscapes and production systems will need to use inputs more efficiently; have less variability and greater stability in outputs; and be more resilient to risks, shocks, and long-term climatic variability (Tilman et al. 2011). To achieve these goals will require a major shift in the way land, water, soil nutrients, and genetic resources are managed. In general terms, agroecological principles and practices that capitalize on greater multifunctionality also build in greater resiliency within the agricultural operations and landscapes in which they are applied (Beddington et al. 2012, Tomich et al. 2011).

As a multifunctional management strategy, agroforestry provides an intentional blending of forestry and agricultural practices that can address food security and stability in managing for other ecological and environmental services provided by these landscapes. As an agricultural management option, agroforestry is unique in that it is tree based, adding strategic diversity at various scales in ways that can reduce threats and build resiliency under changing conditions. Agroforestry, as defined within the United States, is "intensive land-use management that optimizes the benefits (physical, biological, ecological, economic, and social) from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock" (Gold and Garrett 2009). Better recognized within tropical agricultural strategies (Verchot et al. 2007), agroforestry is now emerging as a viable resiliency strategy for the United States and other temperate regions, especially in regards to helping producers deal with the impacts from the increasing erratic and extreme weather events (Delgado et al. 2011, Jose et al. 2012, Schoeneberger et al. 2012, Smith et al. 2013). A brief overview of the five main categories of agroforestry practices used in the United States, with a growing sixth category—special applications—for agroforestry technologies being adapted to address emerging needs across rural/urban landscapes, is presented in figure 1.1 and table 1.1.

Although practice categories offer a useful frame of reference for describing agroforestry, in application it can take on many variations and combinations—from only a few trees within a crop field to highly integrated, multistoried food forests—depending on the products and functions being sought. The permutations and the terminology used to describe them are often quite varied, especially for agroforestry within tribal and island communities. To illustrate the large continuum of agroforestry practices, examples in box 1.1 show the different combinations of practices in greater detail. Additional information on these agroforestry practices within North America can be found in Garrett (2009).

Agroforestry has been identified as a multifunctional land-use approach that can balance the production of commodities with noncommodity outputs such as environmental protection and cultural and landscape amenities (McIntyre et al. 2009). Evidence suggests that agroforestry can sustainably increase production per unit of land area while maintaining or enhancing other economic, social, and environmental services (Asbjornsen et al. 2014, Olson et al. 2000, Smith et al. 2013). Evidence also suggests that agroforestry can build adaptive capacity within agricultural operations and support greenhouse gas (GHG) mitigation (CAST 2011, FAO 2013b, Matocha et al. 2012, van Noordwijk et al. 2014, Watson et al. 2000).

Like many other management options for building resiliency, agroforestry needs to be implemented proactively to reduce vulnerability to weather extremes and other climatic variability-driven impacts when they occur. Tree-based practices have

**Figure 1.1.** Five main categories of agroforestry practices are used in the United States: (A) alley cropping, (B) windbreaks, (C) riparian forest buffers, (D) silvopasture, and (E) forest farming. An emerging sixth category is (F) special applications (e.g., short-rotation woody crops). (Photos by USDA Forest Service and USDA Natural Resources Conservation Service [A, B, C, D, F], and Catherine Bukowski, Virginia Tech [E]).


longer establishment periods, requiring planting several years before large-scale disturbances occur. The potential benefits currently valued by farmers and ranchers (e.g., enhanced yields and livestock production, water quality protection, biodiversity, productive soils, and diversification of production) are derived from the same agroforestry functions that are important for reducing threats and enhancing resiliency under changing conditions. These many benefits provide a mechanism for producers to offset any lost opportunity costs as they work towards building more resilient operations.

Agroforestry practices in the United States are not as well-studied and well-established as more conventional agronomic and forestry practices and will require some investment to further our understanding of the impacts of changing conditions on agroforestry health and performance (Luedeling et al. 2014). Most of our knowledge of agroforestry is derived from site- and field-scale studies at limited numbers of locations. Agroforestry systems are complex assemblages of ecosystem components, each of which may respond differently to climatic variability and other environmental changes. Although we

**Table 1.1.** Categories of agroforestry practices in the United States.

| Practice | Description[a] | Primary benefits and uses[b] |
|---|---|---|
| Alley cropping (also called tree-based intercropping) | Trees or shrubs planted in sets of single or multiple rows with agronomic crops, horticultural crops, or forages produced in the alleys between the trees that can also produce additional products. | • Produce annual and higher value but longer term crops.<br>• Enhance microclimate conditions to improve crop or forage quality and quantity.<br>• Reduce surface water runoff and erosion.<br>• Improve soil quality by increasing utilization and cycling of nutrients.<br>• Enhance habitat for wildlife and beneficial insects.<br>• Decrease offsite movement of nutrients or chemicals. |
| Windbreaks (also includes shelterbelts) | Single or multiple rows of trees or shrubs that are established for environmental purposes; depending on the primary use, may be referred to as crop or field windbreak, livestock windbreak, living snow fence, farmstead windbreak, or hedgerow. | • Control wind erosion.<br>• Protect wind-sensitive crops.<br>• Enhance crop yields.<br>• Reduce animal stress and mortality.<br>• Serve as a barrier to dust, odor, and pesticide drift.<br>• Conserve energy.<br>• Manage snow dispersal to keep roads open or to harvest moisture. |
| Riparian forest buffers[c] | An area of trees, shrubs, and herbaceous vegetation established and managed adjacent to streams, lakes, ponds, and wetlands. | • Reduce nonpoint source pollution from adjacent land uses.<br>• Stabilize streambanks.<br>• Enhance aquatic and terrestrial habitats.<br>• Increase C storage in plant biomass and soils.<br>• Diversify income either through added plant production or recreational fees. |
| Silvopasture | Trees combined with pasture and livestock production. | • Produce diversification of livestock and plant products in time and space.<br>• Produce annual and higher value but longer term products.<br>• Reduce nutrient loss. |
| Forest farming (also called multistory cropping) | Existing or planted stands of trees or shrubs that are managed as an overstory with an understory of plants that are grown for a variety of products. | • Improve crop diversity by growing mixed but compatible crops having different heights on the same area.<br>• Improve soil quality by increasing utilization and cycling of nutrients.<br>• Increase C storage in plant biomass and soil. |
| Special applications | Use of agroforestry technologies to help solve special concerns, such as disposal of animal wastes or filtering irrigation tailwater, while producing a short- or long-rotation woody crop. | • Treat municipal and agricultural wastes.<br>• Manage stormwater.<br>• Produce biofeedstock. |

C = carbon.

[a] Descriptions follow USDA Natural Resources Conservation Service Practice Standards. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/cp/ncps/.

[b] All agroforestry plantings add diversity within the agricultural landscape. In general, such plantings will enhance wildlife habitat in agricultural settings and are often designed or managed with doing so as a secondary benefit.

[c] Riparian forest buffer refers to the planted practice. This category does not include naturally established riparian forests.

capitalize on it to attain agroforestry's benefits, this inherent complexity makes it difficult to accurately predict, at this time, impacts from changing conditions. A broader understanding of how these agroforestry practices function is needed to enhance our ability to provide reliable regional and local assistance, and gaining that understanding will require an adaptive management approach.

This report offers a first-ever scientific assessment of agroforestry's potential in the United States to provide mitigation and adaptation services under changing conditions. Based on available scientific evidence, agroforestry can contribute to these services by sequestering carbon, reducing GHG emissions, enhancing resiliency, and reducing threats while facilitating migration of wildlife and aquatic species to more favorable conditions (table 1.2). One of the primary strengths of agroforestry that emerged from this assessment is the opportunity to provide integrated mitigation and adaptation services in a synergistic manner (Duguma et al. 2014) while also supporting expanding food security goals and limiting environmental impacts. Agroforestry-induced diversification of income streams and other ecosystem services can help safeguard agricultural production under the many uncertainties from climatic variability to shifting markets.

## **Box 1.1.** The Practice of Agroforestry

Agroforestry represents a wide-ranging continuum of managed woody plant, herbaceous crop, and livestock combinations—from a few trees planted within industrial, commodity operations to stratified native forests manipulated for food and other products. This diversity can create some confusion regarding what agroforestry actually is and what it means.

As a general rule, when agroforestry is placed into a land use, it does not convert the land use. It is not considered afforestation (based on its small size); rather, it is the use of tree-based plantings in support of agricultural land use or, in the case of forest farming, in support of forest land use. Agroforestry within U.S. farm or ranch operations, in general, is only a few plantings, comprising a small portion of the land area.

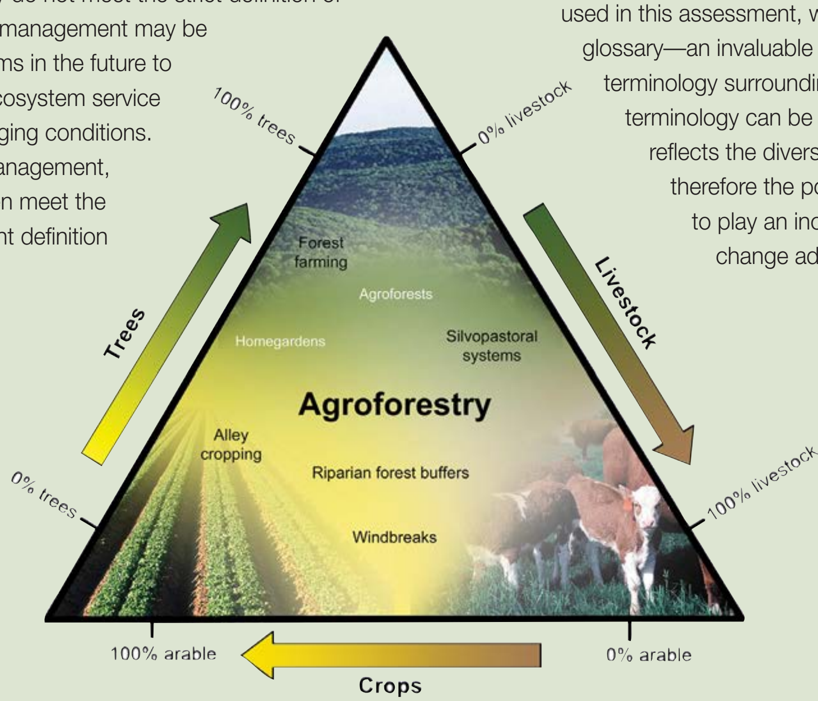
The definition of agroforestry implies deliberate and integrated management of tree, crop, and livestock components. Therefore low- to no-management applications, such as tribal and island plantings or Southwest woodland grazing, represent a gray area (see chapter 5 and box A.1). Some of these systems currently do not meet the strict definition of agroforestry. However, management may be required in these systems in the future to enhance or maintain ecosystem service production under changing conditions. With this addition of management, those systems may then meet the criteria under the current definition of agroforestry.

**Is it an agroforestry system or practice?**

Agroforestry is often described in many ways; as a *system*, a *practice*, and even a *management activity* and a *planting*. Although these terms are used interchangeably, a distinction between a system and a practice is worth mentioning. *System* connotes the many parts, arrangements, and interactions created by integrating these parts; it is a familiar term within the scientific community. In the agricultural community, however, the use of *practice* is better understood and more compatible with other agricultural practices (Gold and Garrett 2009).

Agroforestry category and practice, while also used interchangeably, can provide a means for acknowledging subgroups. In this case, the five main agroforestry *practices* (table 1.1) can be referred to as *categories*, allowing some groups, like windbreaks, to be further defined based on specific use (e.g., field windbreaks, farmstead windbreaks, livestock windbreaks).

Additional terms such as *agroforest* and *homegarden* are used in this assessment, which also includes a glossary—an invaluable tool for navigating the terminology surrounding agroforestry. The terminology can be confusing; however, it reflects the diversity, the versatility, and therefore the potential of agroforestry to play an increasing role in climate change adaptation strategies.




Agroforestry represents a fluid continuum among trees, crops, and livestock, ranging from a few trees established within a field or pasture to multistory forests managed for a variety of products. The five agroforestry categories are well-established terms in the conterminous United States, with each practice having the potential to vary depending on its design within these continuums. Terms, such as *homegarden* and *agroforest*, which are more commonly used and recognized outside the conterminous United States (e.g., the islands and Mexico), are slowly growing in use in the United States. (Figure adapted from den Herder et al. 2015.)

**Table 1.2.** Agroforestry functions that support climate change mitigation and adaptation.

| Climate change activity | Major climate change functions | Agroforestry functions that support climate change mitigation and adaptation |
|---|---|---|
| **Adaptation** | | |
| Actions that reduce or eliminate the negative effects of climate change or take advantage of the positive effects. | Reduce threats and enhance resilience. | • Alter microclimate to reduce impact of extreme weather events on crop production.<br>• Alter microclimate to maintain quality and quantity of forage production.<br>• Alter microclimate to reduce livestock stress.<br>• Provide greater habitat diversity to support organisms (e.g., native pollinators, beneficial insects).<br>• Provide greater structural and functional diversity to maintain and protect natural resource services.<br>• Create diversified production opportunities to reduce risk under fluctuating climate. |
| | Facilitate plant species movement to more favorable conditions. | • Assist in plant species migration through planting decisions. |
| | Allow species to migrate to more favorable conditions. | • Provide travel corridors for species migration. |
| **Mitigation** | | |
| Activities that reduce GHGs in the atmosphere or enhance the storage of GHGs stored in ecosystems. | Sequester C | • Accumulate C in woody biomass.<br>• Accumulate C in soil. |
| | Reduce GHG emissions | • Reduce fossil fuel consumption:<br>o with reduced equipment runs in areas with trees.<br>o with reduced farmstead heating and cooling.<br>• Reduce $N_2O$ emissions:<br>o by greater nutrient uptake through plant diversity.<br>o by reduced N fertilizer application in tree component.<br>• Enhance forage quality, thereby reducing $CH_4$. |

C = carbon. $CH_4$ = methane. $CO_2$ = carbon dioxide. GHG = greenhouse gas. N = nitrogen. $N_2O$ = nitrous oxide.

Source: Modified from Schoeneberger et al. (2012).

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# Chapter 2
# Reducing Threats and Enhancing Resiliency

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## Adaptive Capacity of U.S. Agriculture

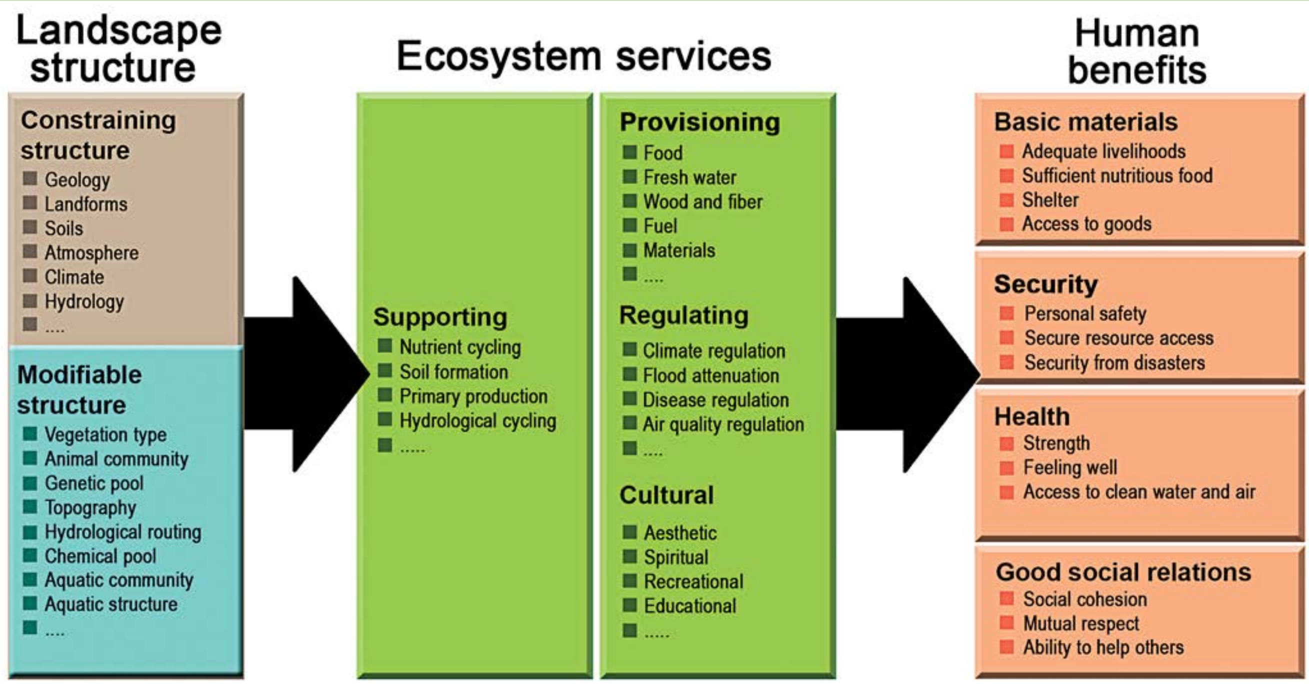
Assessments of climate change in the United States and of its impacts on U.S. agriculture (Melillo et al. 2014, Walthall et al. 2012) conclude that it is very likely that climate is changing in the United States and will continue to change throughout the 21st century. According to those assessments, temperatures will become generally warmer, but variability within seasons will become greater in some regions; precipitation patterns will change, becoming generally wetter or drier, depending on the region; and a higher incidence of extreme weather events, including drought, heat waves, and periods of intense rainfall, is likely.

Changes in climate patterns and weather variability pose substantial hazards for current U.S. agricultural systems and the resource base (fig. 2.1). According to an assessment of U.S. agriculture (Walthall et al. 2012), yield of crops and livestock will decline in some regions and increase in others due to changes in regional average climate conditions, extreme weather events outside optimum growth and reproductive ranges, and shifting ranges of damaging pests; crop growth (and that of weeds, too) may increase in response to higher atmospheric carbon dioxide ($CO_2$), but the quality of some crops may be reduced; soil erosion and water pollution will increase; and the quality of habitat for supporting beneficial biodiversity such as pollinators will decline.

The pace and complexity of changing conditions are likely to overwhelm the ability of current systems to adapt and sustain current levels of output in the long term (Walthall et al. 2012). New technologies will be needed to avoid significant disruptions in agriculture. This chapter assesses the potential for agroforestry to help adapt agriculture and agricultural lands to threats from climate change. Agroforestry practices blend trees and shrubs into the agricultural landscape to modify landscape structure in specific ways (fig. 2.2). Structure provided by agroforestry practices can be designed to modify microclimate to ameliorate direct impacts of weather extremes on production systems; to provide additional opportunities for crop production; and to protect and enhance key resources such as soil, water, and biodiversity on which agricultural production and other ecosystem services depend.

**Figure 2.1.** Agricultural productivity in the United States faces the potential for severe disruption because of climate change. To sustain a high level of productivity and a healthy resource base, agricultural systems will need to adapt to changing conditions. (A) Rice harvest in California. (Photo by Gary Kramer, USDA Natural Resources Conservation Service). (B) Cattle grazing in Alabama. (Photo by Steven Kirkpatrick, USDA Natural Resources Conservation Service).


**Figure 2.2.** Agroforestry reduces climate-related threats to agriculture by modifying the structure of agricultural landscapes. Through landscape structure, agroforestry practices modify microclimate, stabilize soil, protect water and air quality, and provide for biological diversity, including the diversity of agricultural crops. Each general type of agroforestry practice (see chapter 1) represents a different structural template for emphasizing certain benefits over others. All agroforestry practices, however, are capable of providing, and likely will provide, multiple benefits in any agricultural landscape. (Figure from Dosskey et al. 2012, as modified from MEA 2005).




## Commodity Production

Many benefits of agroforestry are derived from how it modifies local environmental conditions (e.g., air and soil temperatures, humidity, evaporation, windspeed, turbulence). Through agroforestry, local microclimate can be manipulated to enhance productivity of adjacent agricultural fields and pastures and to provide other environmental benefits.

Incorporating woody vegetation into the landscape reduces windspeed across the land surface, provides shade from solar radiation during the day, reduces radiative cooling at night, and recycles water from the soil (Brandle et al. 2009, Stigter 2010). These effects lead to physiological and ecological changes in the biological components of the agricultural landscape.

The structure of the agroforestry practice determines the magnitude of change in windspeed or radiation load (Barnes et al. 1998, Heisler and Dewalle 1988, Zhou et al. 2005). By manipulating the density and arrangement of the tree canopy, the wind flow patterns and radiation loads can be modified for the benefit of nearby crop fields and pastures (Brandle et al. 2009, McNaughton 1988). Evaporation from the soil surface is reduced, leaving more moisture for crop growth (Brandle et al. 2009). Water use efficiency is increased (Davis and Norman 1988). Soil temperatures tend to be warmer (Hodges et al. 2004) and humidity tends to be higher (McNaughton 1988). Daytime air temperatures tend to be warmer near the trees because of disruption of large-scale turbulence but tend to be cooler farther away (Cleugh 2002, McNaughton 1988). Agroforestry systems capitalize on these effects to benefit both crop and livestock production.

Future climate is expected to be warmer and drier in many agricultural regions; drought is a major concern (Walthall et al. 2012). Irrigation restrictions already are common in the Western United States (Schaible and Aillery 2012). Through microclimate modification, agroforestry practices, such as windbreaks, alley cropping, and silvopasture, can help crops and livestock use limited water more efficiently and thus ameliorate the effects of climate change.

Agroforestry practices vary in structure and design and, consequently, in their effects on microclimate. Garrett (2009) provides a comprehensive and detailed review of different agroforestry practices and their associated microclimate effects. Chapters include discussions of windbreaks (Brandle et al. 2009), silvopasture systems (Sharrow et al. 2009), and alley cropping systems (Garrett et al. 2009). The major conclusions of these chapters regarding how agroforestry practices affect crop and livestock production are presented in the following sections.

## Crop Production

The effect of windbreaks (fig. 2.3) on the yield of conventional crops has been well documented worldwide (Baldwin 1988, Brandle et al. 2009, Kort 1988). Yield improvements can be substantial, although results vary by crop, location, and year (table 2.1). For example, under windy conditions, when moisture is limited, shelter provides positive benefits for both quality and quantity of grain, forage, and vegetable crops. The yield benefit from a windbreak to crops in the field area more than offsets the decrease in yield from the area planted to trees (fig. 2.4). The precise mechanisms that produce this benefit can vary, but all are related to wind reduction and radiation control by the windbreak. For example, in Nebraska, overwintering wheat plants (*Triticum aestivum*) are protected from winter desiccation (Brandle et al. 1984, 1992). In Mediterranean environments, wheat yield increases are attributed to improvement in water use efficiency (Campi et al. 2009). In Australia,

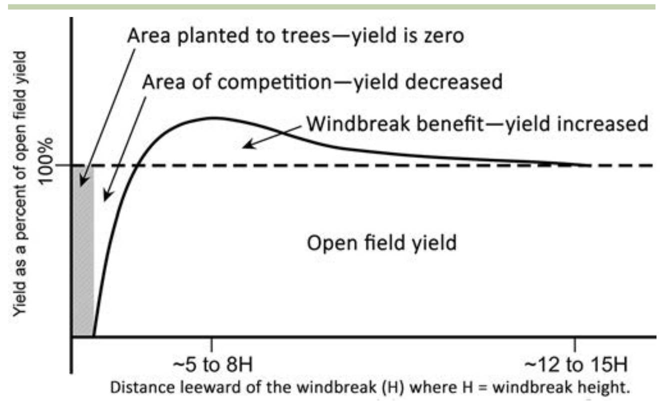
**Figure 2.3.** A windbreak of conifer trees provides year-round protection from wind for this cropland in Indiana. (Photo by Erwin C. Cole, USDA Natural Resources Conservation Service).

**Table 2.1.** Yield of many different crops can be increased by providing shelter with windbreaks.

| Crop | Average yield increase (%) |
|---|---|
| French beans | 6 |
| Oats | 6 |
| Potatoes | 6 |
| Spring wheat | 8 |
| Dry beans | 10 |
| Maize | 12 |
| Soybeans | 15 |
| Tomatoes | 16 |
| Rye | 19 |
| Grass hay | 20 |
| Winter wheat | 23 |
| Barley | 25 |
| Raspberry | 40 |
| Snap beans | 40 |
| Millet | 44 |
| Strawberry | 56 |

Source: Data from Baldwin (1988), Brandle et al. (2009), and Kort (1988).

**Figure 2.4.** The generalized profile of crop yield response to field windbreaks in the Great Plains. (Figure adapted from Read 1964 and Brandle et al. 2009).



the principle benefit of windbreaks was their ability to reduce wind erosion and subsequent crop damage (Sudmeyer et al. 2002, Sudmeyer and Flugge 2005).

Modeling studies by Easterling et al. (1997) using the Erosion-Productivity Impact Calculator and Mize et al. (2008) using the Shelterbelt Agroforestry Modeling System indicate that windbreaks have the potential to increase yields over unprotected fields under all but the most extreme scenarios predicted by climate models. Lower nighttime temperatures resulting from reduced windspeed, less mixing of the air, and reduced evapotranspiration are thought to account for most of the yield gains in sheltered crops (Easterling et al. 1997, Hatfield et al. 2011).

High winds during drought periods can also decrease yields because of abrasion to crop plants from blowing soil (Armbrust 1982, Finch 1988, Sudmeyer et al. 2002, Sudmeyer and Flugge 2005). Under a future warmer and drier climate, drought periods are expected to become more frequent and more extreme (Vose et al. 2016). Abrasion damage is a particular problem with production of fruit and vegetable crops (Norton 1988). In many cases, replanting becomes necessary, requiring additional inputs and expense. Wind control by agroforestry practices (windbreaks, riparian buffers, and alley cropping systems) can be effective at minimizing blowing soil. Properly designed windbreaks, for example, are effective to a distance from the windbreak of 10 times the height of the trees (USDA-NRCS 2014). Windblown soil particles in the air (dust) also degrade air quality and can create serious health issues for people, livestock, and wildlife (Williams and Young 1999), as explained in the section on Air Quality in this chapter.

In the longer term, erosion of soil by wind removes the finer soil particles, organic matter, and nutrients, which leads to reduced soil health. Furthermore, soil that is blown off site is deposited in lakes, reservoirs, and road ditches, requiring mitigation efforts. The economic costs associated with offsite impacts of blown soil can exceed the onsite costs of yield reduction from crop damage and soil loss (Huszar and Piper 1986).

Shade from agroforestry practices can help limit heat stress and improve yields of some crops. Crops such as cotton (*Gossypium hirsutum*) and soybean (*Glycine max*) have higher rates of field emergence when grown under moderated temperatures. Cotton exhibits earlier germination and higher survival rates when grown in the shade of pecan trees, where conditions are cooler and moister (Jose et al. 2004). Moderate shade can also improve growth in some crops; for example, two species of woody ornamentals, American beautyberry (*Callicarpa americana* var. *lactea*) and parsley hawthorn (*Crataegus marshallii*) have higher survival and faster growth under pecan alley cropping compared with monoculture (Fletcher et al. 2012). Warm-season legumes, hoary ticktrefoil (*Desmodium canescens*) and panicledleaf ticktrefoil (*D. paniculatum*) produce significantly greater dry weight and some forage species contain more crude protein when grown at 50 percent and 80 percent shade than in full sunlight (Lin et al. 1999, 2001). Shading and competition with trees for water and nutrients, however, can also negatively affect the yield of some crops. On the balance, Gillespie et al. (2000) saw no effect on corn yield in two alley cropping systems in Indiana. To adapt to future hotter climate, it will be important to identify and select effective combinations of agroforestry tree and crop species that capitalize on microclimate modification.

## Livestock Production

Predicted higher temperatures may pose a significant challenge in animal production systems. Elevated temperatures, especially when combined with high humidity, will reduce weight gain, pregnancy rates, and milk production and will also lower overall animal health (Walthall et al. 2012). In beef cattle operations, heat is a significant factor in biological efficiency (Gaughan et al. 2010, Tucker et al. 2008). For example, a reduction in deep body temperature of beef cattle by as much as 0.77 °C can improve gain rates by as much as 0.57 kilograms per day during summer heat stress periods (Higgins et al. 2011).

Providing shade is a recommended strategy for reducing summertime heat stress on livestock under a warming climate (Rowlinson 2008). Shade also helps improve milk yields, increase conception rates, and decrease mastitis in dairy cattle (Gregory 1995, Tucker et al. 2008). Shade is important for reducing heat load from direct sunlight, particularly in cattle with dull, dark hair coats (da Silva et al. 2003). Provision of shading using agroforestry practices may offset the effects of projected temperature increases on livestock production. By providing shade, silvopasture and livestock windbreaks can reduce the energy expended for thermoregulation, leading to higher feed conversion and weight gain (Brandle et al. 2009, Sharrow et al. 2009). Mitlöhner et al. (2001) found that cattle provided with shade reached their target body weight 20 days earlier than those without shade.

Increasing atmospheric $CO_2$ concentration may reduce the quality of livestock forages produced on grazing and pasture lands (Walthall et al. 2012). Higher levels of $CO_2$ will increase forage production but reduce overall forage quality because of the effects on plant nitrogen and protein content (Morgan et al. 2004). Shading, however, can increase forage quality, depending on the forage species (Lin et al. 2001). For instance, the shading component in silvopasture systems has been shown to improve forage quality in cool-season grasses by increasing protein content while reducing fiber (Bambo et al. 2009, Kallenbach et al. 2006). Higher forage quality combined with shading to reduce animal heat stress suggests that silvopasture systems can be a viable strategy to sustain livestock production under climate change (Schoeneberger et al. 2012).

In some regions, such as the Central United States, periodic winter cold events are likely to become more extreme under a future climate (Kim et al. 2014) and threaten livestock production. Low temperatures, especially when combined with wind, decrease livestock production efficiency by requiring greater feed intake to maintain body temperature. The consequences of extreme cold events can create challenges to producers, exemplified by the October 2013 storm that resulted in the deaths of more than 45,000 livestock in South Dakota (Edwards et al. 2014). Reducing windspeed in winter by using agroforestry practices, particularly windbreaks, can lower livestock stress, improve livestock health, and increase feeding efficiency (Brandle et al. 2009, Gregory 1995). Winter protection can be especially critical for young lambs and calves during lambing or calving season. Cattle producers in Kansas indicate, on average, calving success increases by 2 percent if a windbreak protects the cows (Quam et al. 1994).

### Key Findings

Agroforestry practices can improve the productivity of conventional agricultural crops and livestock by enhancing the microclimate around them and, thereby, may ameliorate negative effects of climate change on agricultural production.

### Key Information Needs

- Improved models for predicting effects of agroforestry practices on crop yields under future climate scenarios.
- Identification of agroforestry tree and crop combinations that capitalize effectively on microclimate modification.
- Better documentation of forage and livestock yield responses in silvopasture systems.
- Revised agroforestry designs tailored to modern field geometries and management practices.

## Crop Diversity

Annual grain and oil-seed crops comprise the bulk of U.S. food and feed crop production and will continue to do so for much of the 21st century (Malcolm et al. 2012). In response to climate change, shifts in acreages for specific crops, changes in management decisions, and expansion of irrigation may compensate for some loss in yields in the short term (Walthall et al. 2012). Advances in plant breeding and development of genetically modified crops offer opportunities to develop crops more tolerant of drought and heat stress; however, most of our annual crops will remain particularly vulnerable. Maintaining annual crop production will become increasingly problematic, and the combined stresses associated with climate change are expected to decrease overall agricultural productivity in the second half of this century (Pryor et al. 2014, Walthall et al. 2012) (table 2.2).

**Table 2.2.** Percent change in U.S. production (averaged across climate change scenarios) relative to reference conditions.

| Crop | Average percent change in production | | | |
|---|---|---|---|---|
| | 2020 | 2040 | 2060 | 2080 |
| Barley (bushels) | – 1.9 | – 0.6 | – 3.5 | 1.0 |
| Corn (bushels) | – 8.1 | – 8.7 | – 13.8 | – 16.2 |
| Cotton (bales) | – 7.9 | – 6.1 | – 5.6 | – 5.9 |
| Hay (dry ton) | – 4.0 | – 0.6 | 2.7 | 4.2 |
| Oats (bushels) | – 8.7 | – 10.7 | – 16.1 | – 20.8 |
| Rice (cwt) | – 2.2 | – 2.5 | – 4.2 | – 6.1 |
| Silage (dry ton) | – 6.9 | – 9.5 | – 13.1 | – 14.4 |
| Sorghum (bushels) | – 15.1 | – 5.4 | – 14.0 | – 17.0 |
| Soybeans (bushels) | – 8.1 | – 8.8 | – 11.9 | – 14.3 |
| Wheat (bushels) | – 2.8 | 1.3 | 5.6 | 11.6 |

cwt = hundredweight.
Source: USDA-ERS (2015b).

Agroforestry practices may be capable of both mitigating the negative impacts of climate stressors on annual crop production and serving as resilient food production systems (Lin 2011, Matocha et al. 2012, Schoeneberger et al. 2012, Van Noordwijk et al. 2014, Verchot et al. 2007). Agroforestry food crops offer opportunities to replace production of annual grain and oil-seed crops on acres converted to agroforestry practices (fig. 2.5).

Agroforestry systems are multispecies mixes of perennials and annuals that are inherently more resilient to environmental stresses than annual-only cropping systems (Leakey 2014, Malézieux 2012, Smith et al. 2013). They have a higher degree

**Figure 2.5.** Agroforestry practices providing protection for annual crops and natural resources can be implemented with species that produce an additional crop, like this cherry crop in Michigan. (Photo by Lynn Betts, USDA Natural Resources Conservation Service).

of species diversity, larger root systems that hedge against climate extremes, and the ability to tolerate increased disturbance (Helzer 2010, Jose et al. 2009). Where winter chilling requirements do not become limiting, food-producing perennial crops such as fruits, nuts, and berries can provide resilience to climate extremes. Species mixes spread biological and financial risks across crops and seasons. Many agroforestry crops are also better suited to being grown on marginal lands than are annual crops (MacDaniels and Lieberman 1979, Molnar et al. 2013, Smith et al. 2013).

The production of specialty crops that can be grown in agroforestry systems is increasing in direct response to increasing demand for locally sourced foods (Johnson 2014, Low and Vogel 2011, USDA-ERS 2015a). Fruit, nut, and vegetable farms are eight times more likely to sell locally than are other farms (Low and Vogel 2011). According to statistics collected by the USDA Agricultural Marketing Service, the number of farmers markets has increased from 1,755 to more than 8,284, reflecting a 372-percent increase since 1994 (fig. 2.6) (USDA-ERS 2014). Agroforestry food crops can contribute to increasingly popular direct-to-consumer food systems.

**Figure 2.6.** Growth of local farmers markets are increasing the demand for specialty food crops, including agroforestry crops, and creating new marketing opportunities. (From USDA Economic Research Service using USDA Agricultural Market Service's Farmers Market Survey).


Agroforestry food systems are notable historically for their sustainability and resilience. For example, multistory food-producing systems have sustainably produced fruit, nuts, leafy vegetables, and other staple foods since ancient times (Ewel 1999, Wiersum 2004); tropical and subtropical agroforestry homegardens have demonstrated sustainable production for thousands of years (Torquebiau 1992, Vandermeer et al. 1998); and multistory agroforestry homegardens have been traditionally cultivated in temperate environments for at least two millennia (Clark and Nicholas 2013, Lelle and Gold 1994, Smith 1950).

Agroforestry is a form of multifunctional agriculture (Jose 2012, Leakey 2014, McIntyre et al. 2009, Picasso et al. 2011, Quinkenstein et al. 2009, Robertson et al. 2014, Van Noordwijk et al. 2011). When properly designed and maintained, food-producing agroforestry systems can simultaneously provide ecological services that annual crops do not, such as reducing nonpoint source pollution, sequestering carbon, sustaining long-term soil fertility, and enabling biological control through crop and ecosystem diversity (Batello et al. 2014, Clough et al. 2011, Davis et al. 2012, Ewel 1999, Jose 2012, Robertson et al. 2014, Schoeneberger et al. 2012).

The integration of food- and commodity-producing perennials into agroforestry practices has the potential to add millions of hectares to the production base of the United States without loss of protection of environmentally sensitive lands (Jose et al. 2012). Agroforestry practices like alley cropping, windbreaks, and riparian forest buffers can be designed to include food-producing species (e.g., fruits, nuts) (Schultz et al. 2009, Smith et al. 2013). Nonfood crops such as floriculture, biomass, and timber crops can also be incorporated into these practices (Schultz et al. 2009). Agroforestry production systems can produce greater total yields per unit area as compared with monocultures of the individual crops they include (Dupraz et al. 2005). The combination of diversified food and commodity production and provision of ecosystem services can impart greater economic and biological resilience to the effects of climate change than can conventional annual cropping systems.

If widely deployed, agroforestry practices scattered across the agricultural landscape can function as a patchwork of mosaics at different stages of maturity (early, mid, late) (Robertson et al. 2014, Subler and Uhl 1990), adding further resilience to the agroecosystem. Well-designed landscape mosaics can further spread economic and ecological risk and may lower some costs of production (Clark and Nicholas 2013, Smith et al. 2013).

## Key Findings

- Agroforestry systems incorporating appropriate species can be significant food production systems.
- Food-producing agroforestry systems are more resilient to climate stressors than are annual cropping systems.
- Agroforestry systems can diversify farm portfolios, spread risk, and increase both the economic and environmental resilience of farms.

## Key Information Needs

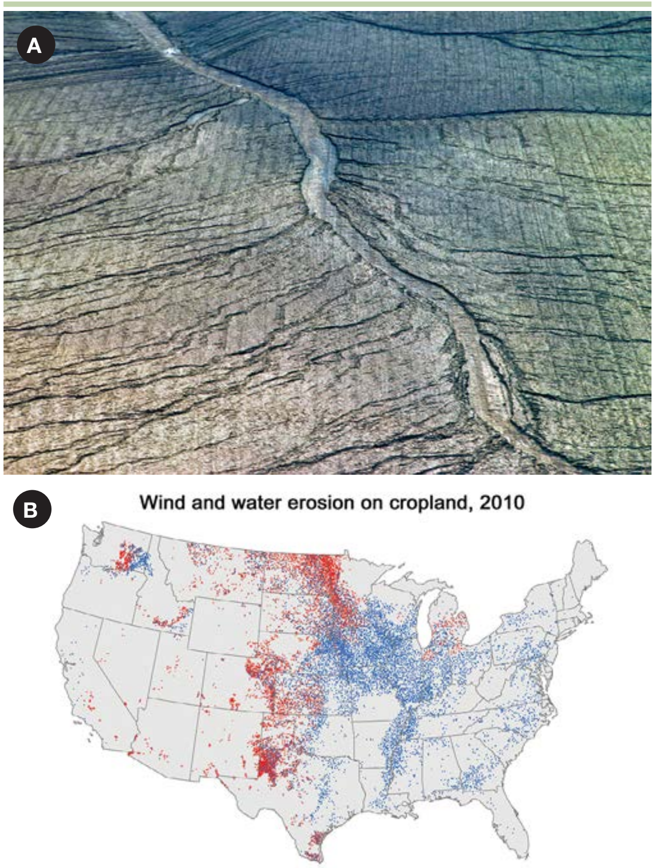
- Improved agroforestry systems for marginal and degraded lands.
- Identification of agroforestry tree and crop combinations that maximize positive interactions while minimizing competitive interactions between crops and trees.

- Better strategies for producing, distributing, and marketing food and nonfood products from agroforestry systems.

## Soil Resources

Climate change is predicted to include more frequent extreme rainfall events and longer drought periods, which would affect soil resources (Melillo et al. 2014). Increased precipitation intensity will lead to an exponential increase in the potential for soil erosion by water runoff (Garbrecht et al. 2014). Longer drought periods will increase the period of susceptibility of soils to erosion by wind (Nordstrom and Hotta 2004). Topsoil loss to erosion will reduce the health and productivity of the remaining soil resource and threaten the sustainability of agricultural production (Walthall et al. 2012) (fig. 2.7).

**Figure 2.7.** Soil erosion by water and wind jeopardizes soil health and the sustainability of agricultural productivity. Climate change is predicted to exacerbate conditions that lead to soil erosion. (A) Severe sheet and rill erosion on highly erodible soils in Iowa after heavy rains. The spring rains fell on soils that had no protection against soil erosion. (Photo by Lynn Betts, USDA Natural Resources Conservation Service). (B) Some agricultural regions currently experience high rates of soil erosion by water (blue dots) and wind (red dots). Each dot represents 100,000 tons per year. Soil erosion is expected to accelerate in response to climate change in most regions. (Data and map from 2010 USDA National Resources Inventory, USDA Natural Resources Conservation Service).




Appropriate agroforestry practices can reduce these threats by protecting soils from water and wind erosion and by rebuilding soil health in eroded soils (Jose 2009, Young 1989).

### Soil Erosion

Most soil erosion in agricultural fields occurs during large rainfall events. When the rainfall rate exceeds the infiltration capacity of soil, the excess water drains overland, dislodging topsoil and carrying it off the field. Soil erosion is accentuated by annual tillage that loosens the topsoil, reduces infiltration capacity, and removes surface debris that protects soil from being dislodged by raindrops and overland flow. Under current climate conditions, the average rate of soil erosion from tilled agricultural fields is much greater than the rate of soil regeneration leading to a substantial net loss of soil (Montgomery 2007). Under a future climate, greater frequency of extreme rainfall events will exacerbate this problem. At a national scale, soil erosion by rainfall is estimated to increase between 16 and 58 percent during the 21st century because of climate change (Nearing 2001, Nearing et al. 2004). Others have predicted similarly large increases in erosion rate (O'Neal et al. 2005, Segura et al. 2014).

Agroforestry practices such as alley cropping can markedly reduce the rate of soil erosion from crop fields and potentially counteract the increasing risk of erosion posed by climate change. An alley cropping system can be oriented and designed to stabilize soil and promote infiltration within the tree strips and to reduce the erosive force of overland flow across the cultivated field. Sediment outflow from fields with alley cropping has been measured to be 28 to 30 percent less than from fields without alley cropping (Udawatta et al. 2011b).

In drier regions of the United States, like the Great Plains, soil erosion by wind can be significant during drought periods. This region historically has experienced severe soil loss by wind erosion, such as experienced during the Dust Bowl years in the 1930s. The prospect of increasing length and severity of drought periods due to climate change raises the risk that periods of severe wind erosion may recur with greater frequency.

Of all the potential benefits of a windbreak agroforestry practice, wind erosion control is the most widely recognized and accepted (Brandle et al. 2009). The link between windspeed and wind erosion is well established. Properly designed windbreaks reduce windspeed near the ground surface (as described previously in the Commodity Production section) and significantly reduce wind erosion. In response to the Dust Bowl experience, soil conservation efforts established nearly 19,000 miles of windbreaks in the Great Plains (Droze 1977) (box 2.1). The success of that program led to similar efforts elsewhere in the United States and Canada and also in Argentina, Australia, China, New Zealand, and Russia (Cleugh et al. 2002, Mattis

1988, Miller et al. 1995, Peri and Bloomberg 2002, Sturrock 1984, Zhao et al. 1995). In the United States, however, most of the original windbreaks have been, and continue to be, removed as modern fields have increased in size and have changed shape to accept pivot irrigation systems. Where windbreaks have been removed, other techniques, such as conservation tillage and residue management, would be needed to limit wind erosion on a short-term basis, but they cannot replace the benefits of long-term perennial plantings.

## **Box 2.1.** Prairie States Forestry Project

Current wind erosion and airborne dust problems are likely to increase under climate change (see Soil Resources and Air Quality sections). The U.S. Government used agroforestry to address these same issues during the Dust Bowl period of the 1930s on the Great Plains, when millions of acres of farmland were literally being blown away. The persistent drought, poor soil management, and subsequent wind erosion in the region had far-reaching social, economic, and environmental impacts. Soil was lost at a tremendous rate and many farmers and ranchers were forced from their land, leading to the largest human migration in American history within a short period of time. Between 1930 and 1940, approximately 3.5 million people moved away from the Plains States (Worster 1979). Dust pneumonia, a form of lung disease, affected many residents in the region. The worst duststorms reached the east coast and blanketed cities such as Chicago and New York in “black snow.”

*A giant duststorm rolls across eastern Colorado during the 1930s. (Photo by USDA Natural Resources Conservation Service).*

In 1935, President Franklin D. Roosevelt initiated the Prairie States Forestry Project to combat the severe soil erosion. For the next 8 years, the U.S. Department of Agriculture, Forest Service, working with the Works Progress Administration (WPA) and Civilian Conservation Corps (CCC), planted windbreaks throughout the Great Plains States of Kansas, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas. Although WPA and CCC workers planted the trees and shrubs, landowners were responsible for long-term care and maintenance of the windbreaks. Most of these windbreaks were 10 to 16 rows wide and a mile long. Even under the dry conditions of the time, most seedlings survived and, for the next 30 to 40 years, provided protection to the agricultural lands of the region. Nearly 220 million seedlings were planted, creating 18,600 miles of windbreaks occupying 240,000 acres on 30,000 farms (Williams 2005). Although many of these original windbreaks still exist around farmsteads, most of the wide-row field windbreaks have been removed to make way for center-pivot irrigation systems or field consolidation.

*Workers planting a windbreak in the Great Plains during the mid-1930s. (Photo by USDA Forest Service).*

*Landowners tending to their windbreak planted as part of the Prairie States Forestry Project during the 1930s. (Photo by USDA Forest Service).*

The Prairie States Forestry Project represents one of the largest and most focused efforts of the U.S. Government to address an environmental problem and is considered by some as a potential model for an effective climate change strategy (Sauer 2010). Viewed by modern standards, the project was conceived, designed, and implemented in a short period of time and incorporated effective top-down and bottom-up management styles. Although climate change is a more complex and global phenomenon than was the Dust Bowl, this past experience may hold important lessons for the current climate change problem.

## Soil Health and Productivity

The erosion of fertile topsoil reduces soil productive capacity. Eroded topsoil consists of fine soil particles containing organic matter and nutrients. What remains is subsoil that has poorer physical, chemical, and microbiological properties for crop growth (Pimentel et al. 1995, Williams et al. 1981). Trees, shrubs, and grasses within agroforestry systems affect properties of soil directly beneath and adjacent to them. Compared with monocultured annual crops, perennial agroforestry vegetation can more quickly build and sustain higher levels of soil organic matter and nutrient content and create more favorable soil physical conditions for plant growth (Berg and Laskowski 2006, Cadisch and Giller 1997, Udawatta and Anderson 2008, Udawatta et al. 2009). All these soil improvements link to recycling of organic matter provided by plant litter, roots, and root exudates and to decomposition processes influenced by agroforestry shading and wind reduction that alter soil temperature and water regimes.

Soils in agroforestry systems often have better structure for infiltration and water storage capacity than do soils in annually cultivated fields (Bharati et al. 2002; Seobi et al. 2005; Udawatta et al. 2006, 2011a). These characteristics will be critically important under a drier and warmer climate. Improved soil porosity is consistently observed within agroforestry systems that include riparian buffers, field windbreaks, alley cropping, and silvopasture practices (Bharati et al. 2002, Kumar et al. 2010, Sauer et al. 2007, Seobi et al. 2005). Improved soil pore size distribution associated with perennial vegetation increases infiltration and water-holding capacity (Udawatta and Anderson 2008, Udawatta et al. 2011a). These changes in soil structure and porosity are resilient to disturbances such as raindrop impact (Amezketa 1999, Bronick and Lal 2005).

Soil fertility and nutrient-use efficiency of crops can be improved by the presence of nearby agroforestry trees. Nutrients are captured from the subsoil by roots of trees and recycled to the soil surface through tree litter and, along with additional nitrogen fixed by leguminous agroforestry trees, can be recaptured by nearby crops (Blazier et al. 2008, Karki et al. 2009, Nair 1993). This process can reduce the need for intensive and frequent fertilizer additions. Reestablishment of nutrient-cycling processes creates a more diverse and resilient soil fertility system.

Microbial communities and soil enzymes under trees are functionally different than those under annual crops, which may improve nutrient availability and plant growth in alley cropping systems (Lacombe et al. 2009, Mungai et al. 2005, Rivest et al. 2010, Udawatta and Anderson 2008, Udawatta et al. 2009). Emerging research suggests that agroforestry systems can support higher microbial diversity than annual monocropped fields (Unger et al. 2013) and may have a positive effect on soil biochemical properties and microbial resilience that results in higher crop productivity and tolerance to severe water stress (Rivest et al. 2013).

### Key Findings

- Agroforestry practices such as alley cropping and windbreaks can reduce soil erosion by water and wind and, thereby, protect long-term soil productivity.
- Agroforestry systems can enhance soil health by improving soil physical condition and fertility and by diversifying soil biological functions.

### Key Information Needs

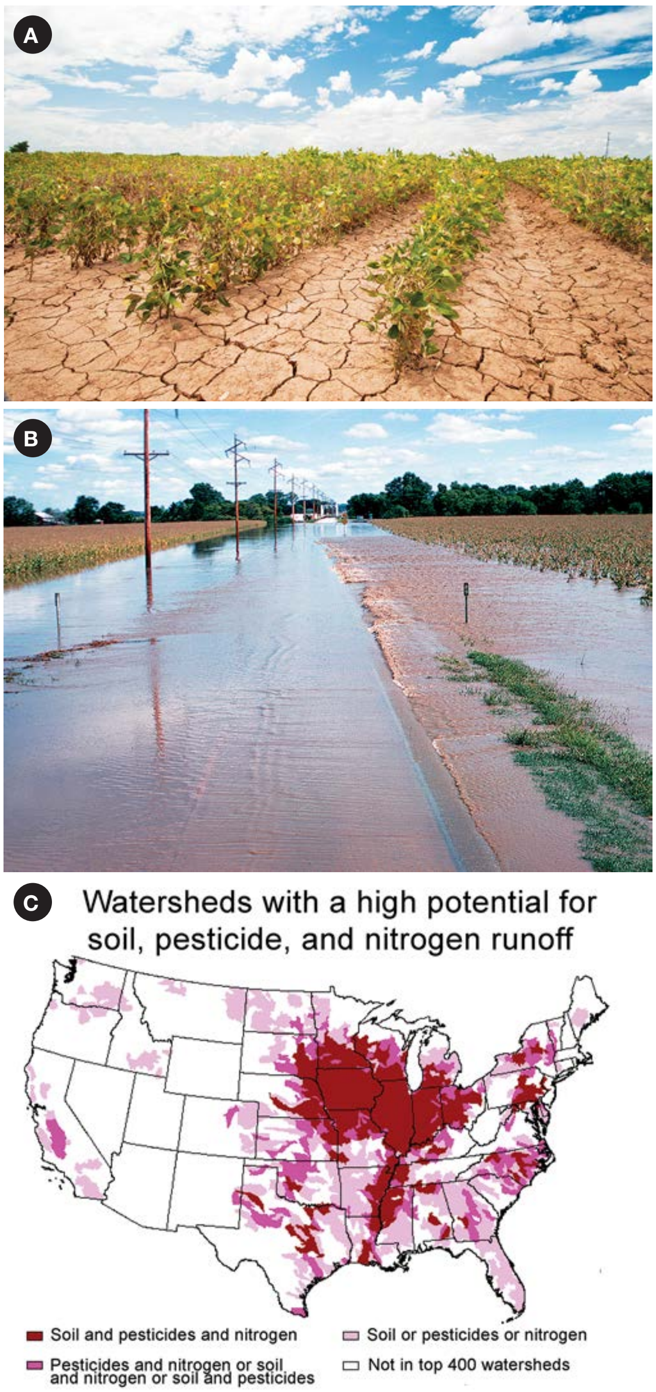
- Identification of optimal combinations of tree and crop species and spatial configurations for improving soil health, particularly on marginal or degraded lands.
- Better understanding of how to capitalize on below-ground structure and processes for improving water and nutrient uptake, especially under drought conditions.
- Documentation of crop productivity responses to agroforestry-related soil improvements.

## Water Resources

Water resources support crop and livestock production, and agricultural lands supply water for other uses, including wildlife and aquatic species, domestic consumption, energy production, and industrial and recreational purposes. Predicted increases in weather variability, including increasing frequency and intensity of heavy rainfall events and extended heat and drought periods, will affect water supply in ways that directly threaten agricultural production, infrastructure, and environmental quality (Melillo et al. 2014). Major impacts will include increasing drought stress on crops and livestock while water supplies for irrigation diminish, increasing flood and erosion damage to crops and supporting infrastructure, increasing water pollution by sediments and agricultural chemicals, accelerated sedimentation and diminishing water storage capacity in reservoirs for supply during drought and for flood control during storm events, and increasing water temperatures that degrade aquatic habitats (Bates et al. 2008, Brewer et al. 2014, Kundzewicz et al. 2014,Walthall et al. 2012, Whitehead et al. 2009, Wilbanks and Fernandez 2012) (fig. 2.8).

Agroforestry practices can reduce drought stress and demand for irrigation water by moderating water use by crops and livestock, lessen the severity of flooding and stream channel erosion by moderating stream discharge and peak stormflows, reduce water pollution by sediments and agricultural chemicals by protecting soils in fields from erosion and by filtering these

**Figure 2.8.** Water resources are expected to be affected by climate change in several ways. (A) Drought and heat stress in crops is expected to increase in severity. (Photo by Bob Nichols, USDA Office of Communications). (B) With climate change, flood damage to crops and transportation infrastructure is expected to become more frequent and severe. (Photo by Keith McCall, USDA Natural Resources Conservation Service). (C) Risk for water pollution by sediment, pesticides, and nutrients is high in many agricultural areas and is expected to increase with climate change. (Map by USDA Natural Resources Conservation Service, Resource Assessment and Strategic Planning Division, Map ID:BMW.1731, October 1997).




pollutants out of runoff from agricultural fields, and moderate excessively high stream temperatures that threaten aquatic biota by providing shade to stream channels (Schoeneberger et al. 2012, Walthall et al. 2012). Each of these benefits is described in more detail in the following sections.

## Drought

Agroforestry practices can reduce agricultural demand for water during drought. Windbreaks reduce crop water stress and conserve soil moisture by reducing windspeed across adjacent crop fields, thereby reducing evaporation losses from soil and transpiration by crops (Brandle et al. 2009). Silvopastures provide wind control and shade for livestock, thereby reducing heat stress and water needs (Sharrow et al. 2009). The benefits of wind control are described in greater detail in the Commodity Production section in this chapter.

Tree crops are more drought hardy than most herbaceous annual crops (Atkinson 2011, Fereres 1984). Drought hardiness is attributed to better stress tolerance and to extensive root systems that explore more soil for water (Chaves et al. 2002, Turner and Kramer 1980,). Agroforestry practices can increase soil porosity, reduce runoff, and increase soil cover, leading to increased water infiltration and retention in the soil profile, which can reduce moisture stress during low rainfall years (Anderson et al. 2009, Udawatta and Anderson 2008, Udawatta et al. 2002, Verchot et al. 2007). Under certain conditions, trees interspersed with crops can make more water available for use by adjacent crop plants. Through a process called hydraulic lift, deeper rooted trees can redistribute deep soil water supplies upward into the crop root zone and sustain crop plants during drought (Horton and Hart 1998, Yu et al. 2013). Under less extreme conditions, however, trees growing in close proximity to crop plants, such as along the edges of windbreaks or in closely spaced alleys, will compete with the crop plants for soil moisture and limit crop yield (fig. 2.4).

In many northern semiarid areas, such as the northern Great Plains, snow is a critical source of soil moisture for crop and forage production during the following growing season (Brandle et al. 2009). Without windbreaks, much of windblown snow is blown off the field and deposited in road ditches and gullies or behind fence rows or other obstructions (Greb 1980). Field windbreaks can help capture the moisture available in snow by slowing the wind and distributing the snow across the field. Snow capture and protection of crop plants from winter desiccation by windbreaks can increase wheat yields by 15 to 20 percent (Brandle et al. 1984, Kort 1988, Lehane and Nielson 1961).

## Flooding

Increasing rainfall intensities will produce larger stormflows in streams and rivers (Vose et al. 2016). In response, flooding will increase and stream channels and banks will experience accelerated erosion as waterways adjust to the new flow regime. Flooding and stream channel erosion will damage crops and nearby transportation infrastructure such as roads, railways, and bridges (Kundzewicz et al. 2014, Walthall et al. 2012, Whitehead et al. 2009, Wilbanks et al. 2012).

Increasing forest cover in watersheds can reduce the total amount of runoff and lessen peak stormflows (Vose et al. 2016). Forest clearing increases total stream discharge and peak stormflows (Andréassian 2004, Bosch and Hewlett 1982, Mao and Cherkauer 2009, Twine et al. 2004). Reestablishing forest cover reverses this trend by a combination of increasing rainfall interception and evapotranspiration, increasing rainfall infiltration, and retarding the velocity of overland runoff flow toward stream channels (Anderson et al. 2009, Bartens et al. 2008, Johnson 1998, Kumar et al. 2008, Seobi et al. 2005, Trimble et al. 1987). This watershed-scale effect can be significant, even if trees are reestablished only in narrow strips in uplands or in streamside riparian zones (Salemi et al. 2012; Smith 1992; Udawatta et al. 2002, 2011b). In arid regions such as the desert Southwestern United States, however, establishment of streamside forest can reduce critical summer base flows because water uptake and transpiration rates by trees is greater than by other types of vegetative cover (Scott et al. 2000, Shafroth et al. 2005, Wilcox et al. 2007).

Forest vegetation on streambanks and floodplains provides better protection from the erosive forces of stormflow than do annual crops and natural herbaceous cover. Forested banks and floodplains experience much lower rates of erosion than those that are unforested (Allen et al. 2003; Beeson and Doyle 1995; Geyer et al. 2000; Hession et al. 2003; Laubel et al. 2003; Micheli et al. 2004; Thorne 1990; Zaimes et al. 2004, 2006). Along unstable streams, forest is more effective than herbaceous vegetation alone at reducing high bank erosion rates (Geyer et al. 2000; Harmel et al. 1999; Simon and Collison 2002; Zaimes et al. 2004, 2006). Computer models can reveal specific sites along stream courses where bank erosion is more likely to occur and where establishment of riparian forest buffers would be most effective at controlling the erosion (Tomer et al. 2003).

Streamside trees can have some negative local effects on flooding and erosion. Debris from trees can clog small streams and drainage ways, retarding storm drainage and worsening farmland flooding. Toppling of large trees can be a localized source of accelerated bank erosion (Montgomery 1997, Thorne 1990). The conversion of herbaceous vegetation on streambanks to forest may cause some limited channel widening (Davies-Colley 1997, Lyons et al. 2000, Stott 1997, Sweeney et al. 2004, Trimble 1997).

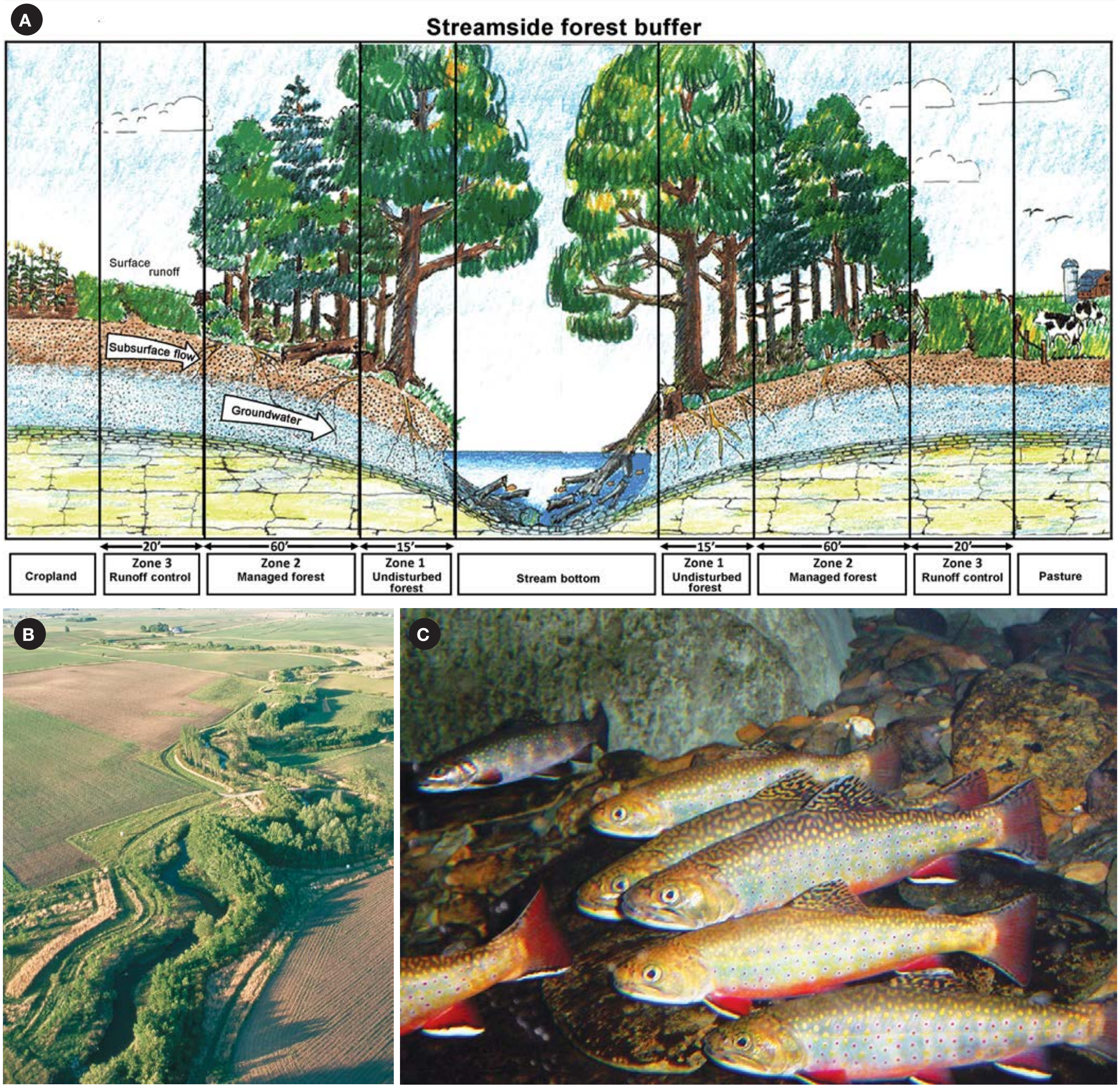
## Water Pollution

Nonpoint source water pollution by eroded sediments, fertilizers, and other agricultural chemicals contributes substantially to the impairment of U.S. waters (EPA 2013). Increasing rainfall intensities under climate change will produce even greater amounts of runoff, leading to accelerated soil erosion and chemical transport from agricultural fields and also from streambanks and channels (Walthall et al. 2012).

Establishing permanent vegetation in and around annually cultivated crop fields can reduce the amount of runoff and associated erosion from the fields (Dosskey 2001; Reeder and Westerman 2006; Renard et al. 1997; Udawatta et al. 2002, 2011b) and function to filter sediments and chemicals from runoff before they reach waterways (Baker et al. 2006; Dosskey 2001, 2010; Helmers et al. 2008; Lin et al. 2011; Lowrance et al. 1997; Mayer et al. 2007). The impact of permanent vegetation, such as in agroforestry practices, on pollutant runoff can be substantial. For example, nitrogen removal by a riparian forest buffer (fig. 2.9) can be as high as 90 percent or more of the runoff load from an adjacent crop field (Anderson et al. 2014, Dosskey 2001, Lowrance et al. 1997, Mayer et al. 2007). Similar levels of sediment removal are also possible (Dosskey 2001). Phosphorus removal will be somewhat less than that for sediment (Dosskey 2001, Hoffman et al. 2009, Lowrance et al. 1997, Schmitt et al. 1999). The level of impact achieved, however, depends strongly on where buffers are planted relative to agricultural source areas (Dosskey et al. 2002, 2013; Tomer et al. 2003; Walter et al. 2000, 2007). Greater reduction will be achieved where permanent cover is interspersed with crops (e.g., alley cropping) on more erodible lands and where positioned in the path of runoff flow (e.g., riparian forest buffer). Technical tools have been developed that can identify the most effective sites in cultivated watersheds for pollution control using agroforestry practices (e.g., Dosskey et al. 2011, 2013). Even greater impact can be achieved by converting marginal cultivated land to a permanent silvopasture agroforestry system.

Several agricultural practices, however, can lead to underperformance of agroforestry practices for pollution control. Agricultural drainage practices, such as building ditches and subsurface tile drains, transport pollutants directly from fields into streams without the benefit of filtering through riparian forest buffers (Dosskey et al. 2002, McClellan et al. 2014). Special buffer designs have been developed for these pathways and also for redirecting such flows back into a riparian buffer system (Schultz et al. 2009). Filtering of large amounts of pollutants by riparian buffers, whether sediments or nutrients, cannot continue indefinitely without maintenance actions because sediment and nutrient accumulation can eventually saturate the retention capacity of a buffer (Dillaha et al. 1989,

**Figure 2.9.** Riparian forest buffer is an agroforestry practice that protects water quality and aquatic habitat. (A) A generic design for a riparian forest buffer was developed in the early 1990s by the USDA Forest Service. (Welsch 1991). This model was later modified and adopted as a conservation practice by the USDA Natural Resources Conservation Service. (B) A riparian forest buffer recently established among cropland in central Iowa. (Photo by Lynn Betts, USDA Natural Resources Conservation Service). (C) A clear stream with healthy brook trout. (Photo by U.S. Fish and Wildlife Service, Southeastern Region).




Dosskey et al. 2010). Maintenance actions include the periodic removal of accumulated sediments and the harvest and removal of vegetation and its accumulation of nutrients.

Increasing sediment loads under climate change likely will produce a compounding negative effect on water supply in irrigation-dependent agricultural regions such as the Great Plains. More intense rainfall events will accelerate soil erosion and subsequent sedimentation in water storage reservoirs and more quickly diminish the capacity to supply water during intervening drought periods (Kundzewicz et al. 2014, Whitehead et al. 2009, Wilbanks et al. 2012). Longer, hotter drought periods will reduce soil cover by crop and pasture vegetation and leave the soil increasingly vulnerable to accelerated erosion (Walthall et al. 2012) and sedimentation during subsequent rainfall events. Permanent vegetative cover in the form of drought-hardy agroforestry practices can maintain soil protection through drought periods and storm events and can filter sediments from runoff, thereby maintaining the functional lifespans of water supply reservoirs.

### Water Temperature

A predicted rise in stream water temperature may be one of the more significant effects of climate change on stream biota (Mohseni et al. 1999, Rieman et al. 2007, Wenger et al. 2011b, Wu et al. 2012). Elevated water temperature threatens the sustainability of existing aquatic communities, particularly cold-adapted fish species such as salmon and trout (Caissie 2006; Dunham et al. 2007; Mohseni et al. 2003; Poole and Berman 2001; Rieman et al. 2007; Wenger et al. 2011a, 2011b). Higher water temperature can also spur the growth of toxin-producing algal species (Whitehead et al. 2009).

Shade provided by riparian forest buffers can moderate increases in stream water temperature. Removal of the stream-side forest, which is common in agricultural landscapes, is a major stressor of stream health in the United States (EPA 2013, Sweeney and Newbold 2014). Unshaded streams, especially smaller streams, experience higher summer temperatures than those under full shade (Sweeney and Newbold 2014). Stream-side forested buffers of at least 30 meters (m) in width may be sufficient for providing maximum thermal protection in small streams (Sweeney and Newbold 2014). The degree to which a rise in water temperature can be moderated, however, will also depend on other factors, such as the size of the stream, relative contribution of groundwater to total streamflow, other land uses in the watershed, and their cumulative effects throughout the stream network (Beschta and Taylor 1988, Callahan et al. 2014, Groom et al. 2011, Luce et al. 2014, Sweeney and Newbold 2014). Mathematical modeling has been used to integrate effects of multiple factors and to predict stream temperatures under future climate scenarios (e.g., Arismendi et al. 2014, Daraio and Bales 2013, Luce et al. 2014).

Most water resource benefits of agroforestry have a lag time between installation and impact. Functions such as providing shade, wind protection, restoring soil permeability, and developing surface debris will accrue slowly as trees grow (Dosskey et al. 2010). As a consequence, many benefits to water supply and to pollution, flood, and temperature control likewise will accrue slowly. Furthermore, benefits to streamflow, pollution control, and temperature accrue at the watershed scale so that their level of benefit will depend largely on the extent of land coverage by appropriately designed agroforestry practices.

### Key Findings

Implementation of agroforestry practices on otherwise cultivated annual cropland and herbaceous pastures can offset threats to water resources by—

- Reducing water stress in nearby crops and livestock through microclimate (wind, shade) modification.
- Protecting streambanks and engineered infrastructure from erosion damage during stormflows.
- Moderating water pollution.
- Moderating high stream temperatures and protecting cold water-dependent biota.

### Key Information Needs

- Enhanced planning tools to assist managers with optimum placement and design of agroforestry practices for effective control of erosion and water pollution.
- Documentation of impacts of agroforestry implementation on water resources at the watershed scale.

## Air Quality

Weather and climate factors such as temperature, humidity, and wind influence the emissions, transport, dilution, transformation, and eventual deposition of air pollutants (Kinney 2008). Changes in these variables due to climate change will influence air quality, contributing to potential impacts on public health, safety, and quality of life. For instance, more than 20 million people in the Midwestern United States experience air quality that fails to meet national ambient air-quality standards (Pryor and Barthelmie 2013). Climate change is expected to exacerbate human health problems by increasing air pollution (Melillo et al. 2014).

Agricultural operations can be a significant source of air pollutants (Aneja et al. 2009). For example, particulate matter emitted from agricultural lands in the Columbia Plateau region of the Pacific Northwest is a major contributor to poor air quality (Sharratt et al. 2007). Other air pollution concerns arising from agriculture include odor and ozone. Agroforestry may reduce the effects of climate change on ambient air quality by buffering and protecting agricultural lands. The capacity for these services is described in the following sections for each type of air pollutant.

### Dust

Particulate matter (PM) emissions from agriculture in the United States contribute about 14 percent of $PM_{2.5}$ emissions and approximately 22 percent of $PM_{10}$ emissions (EPA 2011). A significant portion of these emissions consists of dust from cropping systems and livestock operations (EPA 2011). Airborne dust is a human health concern across many agricultural areas in the United States (Gares et al. 2006, Sharratt et al. 2007, Stout 2001) (fig. 2.10). Elevated dust in the atmosphere

**Figure 2.10.** Blowing dust is a continuing air-quality problem in semiarid regions and is likely to worsen with climate change. A duststorm engulfs Brownfield, TX, on June 22, 2006, reducing air quality and harming public health. This storm caused several traffic accidents, resulting in a fatality and several injuries. (Photo by David Drummond).

can lead to skin and eye irritations, shortness of breath, asthma, and other respiratory disorders that contribute to significant healthcare costs (Clausnitzer and Singer 2000, Smith and Lee 2003, Williams and Young 1999). Poor visibility due to windblown dust also contributes to highway accidents and traffic fatalities.[1] Dust can be transported from regional to intercontinental scales, creating problems and hazards well beyond the source (Chin et al. 2007).

Predicted hotter, drier summers under climate change will likely lead to increased drying of soils, wind erosion, and airborne dust (Lee et al. 1996, Zobeck and Van Pelt 2006). Under higher greenhouse gas emission scenarios, drought is projected to become more common throughout most of the Central and Southern United States, contributing to higher airborne dust levels due to a reduction in vegetative cover (Lee et al. 1996, Melillo et al. 2014). Bioaerosols, such as fungal spores and endotoxins, are likely to be more of a problem under drier conditions (Boxall et al. 2009). Duststorms associated with drought conditions have been associated with increased incidence of Coccidioidomycosis (an infection referred to as valley fever, which is caused by a soil-borne fungal pathogen) in Arizona and California (Comrie 2005). Although the capacity of current climate models to predict future windspeeds is limited, estimated reduction in windspeeds in some U.S. regions due to climate change may offset some of the increased wind erosion potential (Breslow and Sailor 2002, Sailor et al. 2008, Segal et al. 2001).

Windbreaks, through a variety of physical processes, can reduce windspeed over the land surface and thereby reduce the mobilization and transport of dust and associated particulates (Heisler and Dewalle 1988, Tibke 1988). The zone of reduced windspeed typically extends a distance equivalent to 10 to 20 tree heights downwind of a windbreak, so multiple barriers are often required to effectively control wind erosion from large fields (Tibke 1988). Trees can also filter the air by intercepting airborne particles (Hill 1971). Trees have been observed to reduce dustfall by 30 to 42 percent and total suspended particles by 11 to 13 percent (Dochinger 1980) (see box 2.1 describing agroforestry's role in mitigating the 1930s Dust Bowl). The perennial vegetation used in agroforestry practices can also reduce the area of farm soil exposed to erosion (Asbjornsen et al. 2014).

## Odor

Odor emitted from livestock and poultry production facilities can be a significant problem for human health, quality of rural life, and local economies (Donham et al. 2007, Palmquist et al. 1997, Wing and Wolf 2000). Odors from these facilities can be offensive and cause eye, nose, and throat irritations; headaches; nausea; palpitations; and other symptoms (Heederik et al. 2007, Schiffman and Williams 2005, Thu 2002). Odors arise primarily from manure decomposition and consist of a complex mixture of gaseous and particulate compounds (Bottcher 2001). Depending on weather conditions, odorous compounds can be perceived by residents more than 5.5 kilometers (km) from their source (Guo et al. 2005).

Predicted warmer temperatures will increase the production of odorous compounds through faster anaerobic decomposition of manure (Miner 1995). Odor transport is also favored by stable atmospheric conditions, low windspeed, and high ambient temperature (Xing et al. 2007), conditions likely to increase under projected climate scenarios (Melillo et al. 2014).

Evidence suggests that windbreaks located adjacent to livestock production facilities can help mitigate odors through a mix of physical and social dynamics. Trees and shrubs can filter and intercept odor-causing particulates and gases, in part, because of the large surface area provided by plant foliage (Hill 1971, Khan and Abbasi 2000). Windbreaks can lift the odor plume into the lower atmosphere, aiding in dilution and dispersion (Lin et al. 2006). Land deposition of odorous particulates and aerosols can occur downwind of the windbreaks due to reduced windspeeds (Laird 1997, Thernelius 1997). Trees may serve as a biological sink for the chemical constituents of odor after interception (Hill 1971, Tyndall and Colletti 2007). Enhancing

[1] KOAA Channel 5: January 13, 2014. http://www.koaa.com/news/blowing-dust-causes-multiple-accidents-on-i-25/. *Lincoln Journal Star*: April 29, 2014. http://journalstar.com/news/local/dust-storm-chokes-i--traffic-in-panhandle/article_f92ddcd6-b48f-5469-a462-1c5dcab11355.html?comment_form=true. KSAL: April 30, 2014. http://www.ksal.com/drought-wind-causing-big-dust-storms/.

the aesthetics of livestock production sites with vegetation such as windbreaks has also been shown to reduce the perception of odor (Kreis 1978, Mikesell et al. 2001, Tyndall and Colletti 2007).

Odor concentrations can be reduced by 6 to 66 percent when measured downwind from windbreaks (Hernandez et al. 2012, Lin et al. 2006, Malone et al. 2006, Parker et al. 2012). Although windbreaks can contribute to reducing concentrations of odorous compounds, it is recommended that windbreaks be viewed as complementary technology to be used with a suite of odor management strategies (Tyndall and Colletti 2007).

### Ozone

Ground-level ozone causes respiratory problems for humans and damages sensitive vegetation, including crops and forests. Climate change is expected to increase summertime ground-level ozone in polluted regions by 1 to 10 parts per billion during the coming decades (Jacob and Winner 2009). Nonattainment of ozone air-quality standards is typically an issue in urban areas; however, some U.S. agricultural regions, such as the San Joaquin Valley in California, also suffer from high ozone levels (Yates et al. 2011). Although ozone is not emitted directly from agricultural operations, it is formed through the chemical reactions of nitrogen oxides (NOx) and volatile organic compounds (VOCs) that are considered to be ozone precursors. These ozone precursors can be produced by agricultural processes such as decomposition of plant and animal wastes, combustion engines in farm equipment, burning of crop residue, and applications of pesticides and nitrogen fertilizer (Yates et al. 2011).

Agroforestry can help reduce ground-level ozone indirectly by reducing NOx and VOC emissions. Agricultural pesticide applications are a significant source of VOC emissions and methods to reduce the number of applications will reduce the concentration of VOC emissions (Yates et al. 2011). Biological pest control provided by agroforestry practices may reduce pesticide applications that contribute to VOC emissions. Agroforestry practices can facilitate beneficial insect dispersal into fields and predation on pest species, reducing pesticide use (Bianchi et al. 2006, Chaplin-Kramer and Kremen 2012, Griffiths et al. 2008, Holland and Fahrig 2000, Morandin et al. 2014) (see Biodiversity section for additional information). Increasing the area occupied by woody vegetation can reduce the number of equipment passes, reducing fuel use and emissions (Brandle et al. 1992). Vegetation can intercept and serve as a sink for VOCs and NOx (Nowak et al. 2000, 2006); however, trees can also emit VOCs and may offset some of the trapping benefit (Nowak et al. 2000). Selecting tree species that are low emitters of VOCs may reduce this effect (Taha 1996). The overall net impact of agroforestry on ozone precursors is still unknown and requires further investigation.

### Key Findings

- Agroforestry practices are an effective means to reduce human health impacts from windblown dust and other particulate matter.
- Windbreaks can aid in reducing odors from livestock production facilities.
- Agroforestry practices can decrease ozone precursors.

### Key Information Needs

- Enhanced tools for locating and designing agroforestry practices to improve air quality.
- Better understanding of how to reduce odor using agroforestry practices.
- Documentation of the effectiveness of agroforestry practices on mitigating ground-level ozone.

## Biodiversity

Biodiversity provides the fundamental building blocks for the many goods and services that are derived from agroecosystems (Altieri 1999). Declines and changes in biodiversity can have direct or indirect impacts on ecosystem function, persistence, and services (Cardinale et al. 2012). Many stressors, such as habitat loss and degradation, invasive species, overuse, pollution, and disease, currently are impacting biodiversity (MEA 2005). Climate change is another stressor that will exacerbate many of these problems, affecting the services that biodiversity provides to society (Staudinger et al. 2012). Climate change likely will reduce crop pollination by animals by increasing phenological mismatching between pollinators and plants (Kjøhl et al. 2011, Polce et al. 2014), compound existing stressors on managed honey bee colonies (Reddy et al. 2013), displace native pollinator species by invasion of incompatible alien plants (Staudinger et al. 2012), and result in other impacts (Melillo et al. 2014, Staudinger et al. 2012). Climate change is expected to accelerate insect resistance to pesticides because of longer growing seasons yielding more generations per year (Walthall et al. 2012). Habitat conditions, both terrestrial and aquatic, will be altered by changes in precipitation and temperatures (Staudinger et al. 2012). Species that are unable to shift their geographic distributions or have narrow environmental tolerances will be at an increased risk of extinction (Mantyka-Pringle et al. 2012, Staudinger et al. 2012).

Agroforestry has the capacity to conserve biodiversity while promoting agricultural production (Jose 2012) and can be used to enhance resilience to climate change (Schoeneberger et al. 2012). Agroforestry plays five major roles in conserving biodiversity by providing (1) perennial habitat for species in otherwise monocultured annual croplands; (2) preservation of germplasm for sensitive species; (3) a productive alternative to land clearing for monocultured annual crops; (4) corridors between habitat remnants needed for conservation of area-sensitive plant and animal species; and (5) erosion control and water quality protection, among other services, that prevent the degradation and loss of habitat (e.g., Jose 2009, 2012). The following sections summarize the important benefits and tradeoffs of using agroforestry practices to mitigate some climate change impacts on biodiversity.

## Pollination

More than 30 percent of food production relies on insect pollination, overwhelmingly provided by both European honey bees and wild native bees (Klein et al. 2007). Pollination services by managed honey bee colonies are expected to decline under predicted climate change scenarios due to impacts on their biology, behavior, and distribution (Reddy et al. 2013). Given the challenges facing managed honey bee colonies, it is important to diversify the pollinators on which growers rely. Wild native bees, which number more than 4,000 species in North America, pollinate crops worth at least $3 billion annually in the United States (Losey and Vaughan 2006). Conserving a diverse assemblage of pollinators, with different traits and responses to ambient conditions, is considered one of the best ways to minimize risk due to climate change (Kjøhl et al. 2011, Rader et al. 2013, Winfree et al. 2007). Native bees and other pollinators can benefit from agroforestry in several ways.

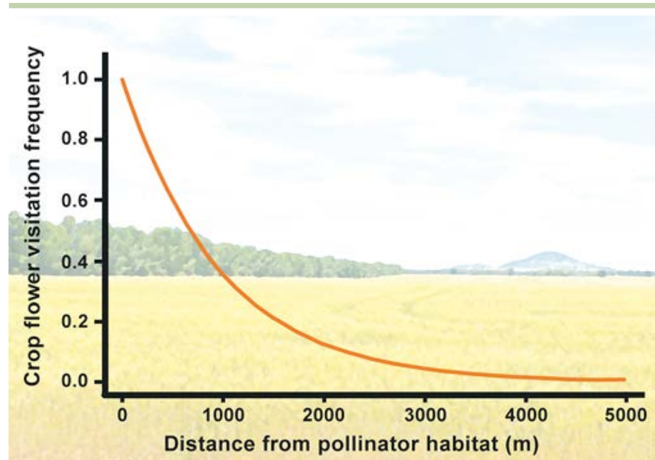
When appropriate tree and shrub species are used in agroforestry practices, these woody plants can provide important sources of pollen and nectar for pollinators, especially when crops are not in flower (Hannon and Sisk 2009, Miñarro and Prida 2013). These species can provide flowers of various sizes, shapes, and colors that support a diverse community of bees and other pollinators (Nicholls and Altieri 2013, Potts et al. 2003, Roulston and Goodell 2011). Enhancing plant diversity through agroforestry can alleviate the potential spatial and phenological mismatch between pollinators and plants by offering a variety of resources to enhance pollinator stability under climate variation (Kjøhl et al. 2011, Polce et al. 2014). Providing substantial floral resources throughout the growing season is critical to sustaining an adequate population of pollinators that can effectively pollinate a crop (Morandin and Kremen 2013, Morandin et al. 2011). For instance, agroforestry practices incorporating early flowering species like willows (*Salix* spp.) can provide some of the first pollen and nectar resources of the season, boosting early-season pollinator populations (Ostaff et al. 2015).

Agroforestry practices can provide nesting habitat for native bees. Approximately 30 percent of native bees are solitary woodnesters that require trees and shrubs for nesting (Cane et al. 2007, Grundel et al. 2010, Potts et al. 2005). Some build their nests inside hollow tunnels provided by soft, pithy centers of branches or tunnels left behind by wood-boring beetle larvae; others excavate their own tunnels. About 70 percent of native bee species create nests under ground and require undisturbed ground such as that under trees and shrubs not subject to tillage or soil disturbance (Cane et al. 2007, Potts et al. 2005). Bumble bees (*Bombus* sp.), some of the most effective native pollinators, often construct ground-level nests at the interface between fields and linear woody habitat such as hedgerows and windbreaks (Kells and Goulson 2003, Svensson et al. 2000). Bumble bee nest densities can be twice as high in these linear woody habitats compared with grassland and woodland habitats (Osborne et al. 2008).

Agroforestry practices can offer habitats with favorable microclimate conditions for pollinator activity. The practices can provide numerous niches that allow pollinators to find suitable sites for thermal regulation (Kjøhl et al. 2011, Pollard and Holland 2006). Windbreaks and other practices reduce windspeeds in fields, minimizing the desiccation of petals and loss of pollen viability (Wilcock and Neiland 2002) while also allowing pollinators to forage during high wind events that would normally reduce or prohibit foraging (Brittain et al. 2013).

Agroforestry practices can provide pollinator habitat close to crops. Pollinator visits to a crop drop off dramatically when the pollinator habitat is not located nearby (Dramstad 1996, Klein et al. 2012, Morandin and Kremen 2013, Morandin et al. 2014, Ricketts et al. 2008) (fig. 2.11). Fruit set of pollinator-dependent crops is estimated to decrease by 16 percent at 1 km distance from the nearest pollinator habitat (Garibaldi et al. 2011). Reducing the distance between pollinator habitat at the field and landscape scales can result in greater pollination and yield production (Benjamin et al. 2014, Holzschuh et al. 2012).

**Figure 2.11.** The effectiveness of pollination declines with increasing distance that pollinators must travel from their natural habitat. Agroforestry practices such as hedgerows and windbreaks can provide the critical habitat at field margins that native pollinators require. (Data from Ricketts et al. 2008).



Pollinators, particularly bumble bees, use linear habitat features to travel from field to field, increasing pollination activity and seed set (Cranmer et al. 2012, Van Geert et al. 2010). Agroforestry practices can provide pollinator habitat and travel corridors at these spatial scales while simultaneously offering other services, such as microclimate benefits, to crops and soil protection.

Bees can be negatively affected by exposure to many agricultural pesticides, ranging from direct contact to inadvertent spray drift (Arena and Sgolastra 2014). Agricultural spray drift is predicted to rise due to increased pesticide volatility under predicted warmer temperatures (Bloomfield et al. 2006). Windbreaks, hedgerows, riparian forest buffers, and alley cropping can reduce pesticide spray drift from coming onto or leaving a farm. Branches, leaves, and stems of woody plants can capture pesticide particles, and the windspeed reduction at the application site can reduce movement of pesticides off their target (Kjær et al. 2014, Lazzaro et al. 2008, Otto et al. 2009, Richardson et al. 2004). Spray drift reductions of 80 to 90 percent can be achieved with woody buffers; however, because data gaps for using this method accurately still exist and buffer vegetation can be harmed by pesticides, plant species selection is critical (Ucar and Hall 2001). Agroforestry practices can also serve as safe havens for pollinators if adequately protected from spray drift (Davis and Williams 1990, Lazzaro et al. 2008, Longley et al. 1997).

## Biological Pest Control

Insect pests are responsible for 18 percent of the loss in crop production globally (Oerke 2006), and this loss is expected to increase under a warmer climate (Walthall et al. 2012). Beneficial insects, such as arthropod predators and parasitoids, suppress populations of insect pests in agricultural crops, an ecosystem service that has been estimated at $4.5 billion annually in the United States (Losey and Vaughan 2006). Supporting biological pest control through agroecosystem diversification may be a strategy for suppressing pest outbreaks under a changing climate (Lin 2011). Diversification at the farm and landscape level has been shown to increase beneficial insect abundance and diversity in crops, although the overall impact on pest control is less well documented (Chaplin-Kramer and Kremen 2012, Chaplin-Kramer et al. 2011, Shackelford et al. 2013). Increasing habitat diversity with agroforestry practices can support biological pest control in several ways.

Agroforestry practices can provide a food supply for beneficial insects when crop pests are not available (Gareau et al. 2013, Morandin et al. 2011, Stamps and Linit 1998). In annual cropping systems, beneficial insects lack continuous sources of alternative prey. Agroforestry practices also offer stable habitat that benefits reproduction, overwintering, and refuge from perturbations of farming practices (Pywell et al. 2005, Varchola and Dunn 2001).

Agroforestry practices within fields (e.g., alley cropping) or adjacent to fields (e.g., windbreaks, hedgerows, riparian forest buffers) facilitate beneficial insect dispersal into fields (Bianchi et al. 2006, Chaplin-Kramer and Kremen 2012, Griffiths et al. 2008, Holland and Fahrig 2000). Pest control from parasitism has been found to extend 100 m from hedgerows (Morandin et al. 2014). Reducing wind in fields can also significantly aid beneficial insects in finding and consuming pests. Wind barriers can improve crop pest reduction by beneficial insects by up to 40 percent (Barton 2014). In some cases, however, trees and shrubs may inhibit movement of certain beneficial insects, potentially limiting their effectiveness for controlling crop pests (Mauremooto et al. 1995).

Birds also use the woody habitat in agroforestry practices and can contribute to pest control, although the impact of this service is still unquantified (Kirk et al. 1996, Puckett et al. 2009, Tremblay et al. 2001). Bats may also provide pest control (Boyles et al. 2011), but this service has been explored primarily in tropical regions (Maas et al. 2013). The role of birds and bats in controlling pests warrants further investigation.

In some cases, agroforestry practices may exacerbate pest problems by protecting insect pests, allowing them to maintain and rebuild populations to reinvade crop areas (Slosser et al. 1984). Certain plant species might also provide a host for crop pests. For example, European buckthorn (*Rhamnus cathartica*), a species historically used in agroforestry plantings, has proven to be invasive and an overwintering host for the Asian soybean aphid (*Aphis glycines*) (Heimpel et al. 2010). Choosing the right practice for a particular location and carefully selecting and managing plants will be critical to minimize potential problems (Griffiths et al. 2008).

## Corridors

Climate change is intensifying the negative cumulative effects of habitat loss and fragmentation on biodiversity (Staudinger et al. 2012). Habitat fragmentation will likely impede the ability of many species to respond, move, and/or adapt to climate-related impacts (Mantyka-Pringle et al. 2012). Enhancing connectivity between remaining habitat fragments across landscapes may reduce population fluctuations and extinction risk and promote gene flow and adaptation (Heller and Zavaleta 2009, Mawdsley et al. 2009). Connectivity can be enhanced by establishing corridors and stepping-stone reserves or by taking management actions that enhance landscape permeability (Krosby et al. 2010). Although corridor benefits are species dependent, corridors are most likely to benefit species with slow-growing populations that have low survivorship when dispersed through fragmented landscapes (Hudgens and Haddad 2003).

Agroforestry practices such as windbreaks, hedgerows, and riparian forest buffers can function as forest corridors in the agricultural landscape (e.g., Haas 1995, Hilty and Merenlender 2004). Corridors can be effective for species movement although evidence for supporting population viability is currently limited (Davies and Pullin 2007, Gilbert-Norton et al. 2010). Minimal migrations (i.e., one individual per generation) between habitat patches, however, may minimize loss of genetic diversity (Mills and Allendorf 1996). For example, in the intensely farmed Tensas River Basin, threatened Louisiana black bears (*Ursus americanus luteolus*) use riparian forest buffers to travel between forest patches to forage and breed (Anderson 1997) (fig. 2.12). Agroforestry practices like alley cropping, silvopasture, and forest farming also create landscape structure similar to natural forest and increase permeability of agricultural landscapes to animal movement and population persistence (Eycott et al. 2012, Watling et al. 2011). In some regions, however, forest corridors and habitats may be detrimental to grassland species (Pierce et al. 2001).

Farmers often view corridors and other noncropped habitat as a reservoir for problem species, such as weeds, that can invade their fields—a perception that may increase due to the prediction that weed populations will increase under climate change (Walthall et al. 2012). Corridors can provide habitat for weed species and may function as invasion conduits, but they are not a major source of weeds in agricultural fields (Boutin et al. 2001, Devlaeminck et al. 2005, Reberg-Horton et al. 2011, Wilkerson 2014). Through management such as mowing and maintaining perennial vegetative cover, potential weed issues can be minimized and, in some cases, corridors may serve as barriers to weed invasion (Boutin et al. 2001, Wilkerson 2014). Some have expressed concern that providing wildlife corridors such as riparian forest buffers and hedgerows in the vicinity of fruit and vegetation fields can increase food safety risks if wildlife is a disease vector for pathogens such as *Escherichia coli* O157:H7 (Beretti and Stuart 2008). Current evidence, however, suggests wildlife is not a significant source of food-borne pathogens and that wildlife habitat adjacent to fields does not increase food safety risks (Ferens and Hovde 2011, Ilic et al. 2012, Karp et al. 2015, Langholz and Jay-Russell 2013).

## Key Findings

- Agroforestry practices can support crop pollination and biological pest control by providing the habitat needs of native pollinators and beneficial insects.
- Pollinators, beneficial insects, and other flora and fauna species can be protected from pesticide applications through the use of agroforestry practices.
- Habitat connectivity may be augmented with agroforestry practices, potentially enabling flora and fauna species to adapt to climate change.

**Figure 2.12.** The Louisiana black bear was once abundant in East Texas, southern Mississippi, and all of Louisiana. Forest clearing for agricultural and urban development diminished the bear's habitat by 90 to 95 percent, leading the U.S. Fish and Wildlife Service to designate the bear as threatened in 1992 under the Endangered Species Act. Wildlife biologists studying the bears in the Tensas River Basin in northern Louisiana determined that wooded corridors along rivers and ditches enable the bears to move between isolated patches of favorable forest habitat and have played an important role in sustaining the species in a landscape dominated by corn, soybeans, and cotton. (Source and photos from USDA Natural Resources Conservation Service 2004).

## Key Information Needs

- Better understanding of how agroforestry practices can support biological pest control by bats, birds, and other natural enemies.
- Improved models for designing agroforestry practices to mitigate pesticide impacts on flora and fauna species.
- Documentation of the effect of corridors on crop pests (i.e., weeds, insects, and diseases) and on beneficial flora and fauna populations under climate change.
- Increased capacity to manage agroforestry practices at landscape scales for enhancing pollination and biological pest control.

## Adaptable Plantings

To be an effective adaptation strategy, agroforestry plant materials must themselves be adaptable to climate change effects. Changing climatic conditions will impact plant survival and function, which, in turn, determines agroforestry's utility as an adaptation and mitigation option. Tree and shrub species have multiple points of climate vulnerability: winter chilling requirements, springtime freeze risk, heat and water stress, pollination constraints, and disease and pest damage (Winkler et al. 2013). Winter warming trends predicted for many regions of the United States (Melillo et al. 2014) may reduce chilling hours, which, along with changes in frost, drought, and heat events, will influence quality and yield from many fruit/nut-producing species (Winkler et al. 2013). Disease and pest dynamics are expected to shift and escalate, which, when combined with abiotic tree stress, will further impact performance and survival of many woody species (Ayres and Lombardero 2000).

The selection of plant materials will need to take into account changing climatic conditions altering the geographical distribution of plants (Iverson et al. 2008a, McKenny et al. 2007b). Geographic ranges where species naturally reproduce, survive, and grow will shift as thresholds of tolerance are exceeded in some current locations and new locations come to within tolerable thresholds. Planted crops and agroforestry tree species will experience a similar effect—perhaps even more so as many agroforestry species are introduced and not necessarily locally well adapted. Given that woody plant material is long lived, the success of an agroforestry practice will depend on the adaptability of the planted trees and shrubs to both current and future climate regimes (fig. 2.13). Several tools are available for identifying agroforestry species that are adaptable in specific regions.

Through informed decisions on plant selection, agroforestry may offer a way to facilitate assisted migration of plant species (Dawson et al. 2011). For temperate forest species, it has been estimated that migration rates of more than 1 km per year may be needed for tree species to keep pace with current temperature and precipitation changes, a speed of migration tenfold greater than that observed in the past under natural climate change for key taxa (McLachlan et al. 2005, Pearson 2006, Petit et al. 2008). Assisted migration is an approach to lessen climate change impacts by intentionally moving species to more climatically suitable locations (Pedlar et al. 2012, Williams and Dumroese 2013). This approach can carry potential risks, such as the creation of invasive species, hybridization with new species, and the introduction of disease to other species; therefore, strategies to minimize risks need to be considered (Pedlar et al. 2012). Species-selection frameworks and other tools are available to support decisionmaking with considerations for assisted migration (Williams and Dumroese 2013).

**Figure 2.13.** Successful agroforestry must include trees that are adapted to both present and future climatic conditions. Tree death will compromise the long-term effectiveness of this windbreak in Nebraska. Windbreak renovation, in which maladaptive trees are replaced over time, will be key in maintaining healthy and functioning plant materials. (Photo by Nebraska Forest Service).

### Model Prediction

Significant changes to plant distribution patterns are expected to occur during the next century in response to climate change. The 2007 Intergovernmental Panel on Climate Change (IPCC) predicted a mean global temperature rise of 2.4 to 6.4 °C by the end of the 21st century (IPCC 2007), an increase that has been estimated to place 20 to 30 percent of species at high risk of extinction (McKenney et al. 2007b, Warren et al. 2013). Numerous studies during the past decade have tried to predict what shifts may occur in distribution patterns and to determine what species will be lost from a particular region (Iverson et al. 2008b, van Zooneveld et al. 2009, Warren et al. 2013). Studies of native North American trees predict the future natural habitats for 134 species in the Eastern United States (Iverson et al. 2008a). Unlike natural forest lands, cultivated urban and agroforestry trees are intentionally planted and may consist of native and nonnative species. Useful lifespans of 50 years or more may be expected. Therefore, trees planted today may be coping with the altered climatic conditions predicted in the decades to come.

Many studies have used Climate Envelope Models (CEMs) to predict plant species distributions as influenced by climate change. CEMs represent a refinement of the traditional USDA Plant Hardiness Zone maps (USDA 2012) and can project distribution impacts of climate change (McKenney et al. 2007a). For example, based on climate scenarios developed by the IPCC in 2000, the Chicago Botanic Garden recently determined that many commonly planted species would become less suitable for climatic conditions that are predicted in future decades and that other species would become more suitable (Bell 2014). Although critics have raised concerns about the CEM technique, other studies have validated the results of some case studies using CEMs (Hijmans and Grahman 2006).

## Plant Evaluation Trials

Climate extremes typically limit the suitability of cultivated tree species for certain regions (McKenney et al. 2007a). Plant evaluation trials are used to test the suitability of tree species and cultivars developed from breeding and selection programs (Braun et al. 2010). These evaluations can be informative when conducted in locations frequently challenged by extremes that are expected in other regions under future climate regimes. For example, the continental climate of the Great Plains region is known for hot summers, cold winters, and rapid temperature fluctuations (Kunkel et al. 2013). Heavy rains interrupt seasonal and prolonged droughts. These conditions are expected to be accentuated by climate change and extended into adjacent regions (Karl et al. 2009, Kunkel et al. 2013). The John C. Pair Horticultural Center near Wichita, KS, conducts tree evaluations in this harsh climate. A 2-year period (2011 through 2012) brought some of the warmest temperatures on record to the Wichita area and only 75 percent of average precipitation. Under these conditions, not unlike what is predicted in future decades, a test of various cultivars of sugar maple (*Acer saccharum*), elm (*Ulmus* spp.), and assorted conifers identified some species and cultivars that are more tolerant of these conditions than others (Pool et al. 2013). In previous trials, one particular ecotype of maple native to western Oklahoma, "Caddo" maple, proved to be particularly hardy under extreme heat and drought conditions (Griffin 2005, Pair 1995). Trials with Caddo maple conducted in other regions, however, determined its suitability is geographically restricted from higher rainfall and humidity climates farther to the east because of susceptibility to disease.

A regional project to evaluate several seed sources of baldcypress (*Taxodium distichum*) from Texas and Mexico identified some genotypes having potentially better cold hardiness (Arnold et al. 2012). In addition, some baldcypress genotypes performed well during the historic heat and drought of the southern Great Plains in 2011 and 2012. Seed collected from the southwestern most populations of baldcypress in Central Texas are performing well on sites in Oklahoma and Kansas. They are cold hardy, heat and drought tolerant, and adapted to the high pH soils common in the Great Plains region (Denny et al. 2008).

Long-term, multi-State trials can produce locally relevant information regarding the geographic suitability of new cultivars. For example, the National Elm Trial is a 15-State effort to evaluate Dutch elm disease-resistant elm cultivars across the United States (Jacobi 2014). Often, cultivars that perform well in one region of the country fail to survive in another.

Conifers continue to be a challenge to grow successfully in parts of the agriculturally important Great Plains. Although they often serve as windbreaks, protect against soil erosion, and provide wildlife habitat, disease and environmental stress take their toll. Species that are known for heat and drought tolerance may not be sufficiently cold hardy. Transplant survival can also be a problem for species and cultivars that do not exhibit rapid root growth (Pool et al. 2012).

Evaluation trials and research will need to include efforts focused not only on growth and survival, but also on the resilience of fruit/nut production to climate change impacts in plant materials. The information garnered from evaluations in locations with frequent environmental challenges provides insight into various species' long-term utility in agroforestry and urban landscapes.

## Seed Sourcing

Populations of trees and other plants can become adapted to local environmental conditions (Aitken et al. 2008, Hufford and Mazer 2003, Langlet 1971, Leimu and Fischer 2008, Linhart and Grant 1996). Some of these conditions are directly influenced by climate change; for example, water availability (Dudley 1996a, 1996b; Fenster 1997), winter temperature and length (Balduman et al. 1999), competitive regime (Leger 2008), and pests and pathogens (Thrall et al. 2002). On this basis, locally sourced seed is assumed to outperform nonlocal seed for restoration, revegetation, and forestry projects, especially over the longer term. The benefit of local seed, however, is predicated on an environment that is relatively constant, which, in this era of rapid climate change, will not be the case (Havens et al. 2015). Successful tree planting must balance adaptation to current and future climate conditions (Bower and Aitken 2008). Selection of plant materials for agroforestry can hopefully benefit from lessons learned and materials identified in ongoing, broad-based assisted migration studies for forests (Williams and Dumroese 2013) as well as that from the horticultural and landscaping sectors.

One strategy to account for climate change is to use seed from a different location where current conditions are similar to those expected locally under climate change. Seed transfer zones, within which seed can be transferred with little risk of maladaptation, have been developed for several tree species (Johnson et al. 2004, Kramer and Havens 2009). They can be derived experimentally through plant evaluation trials or more quickly estimated using combinations of mapped minimum winter temperature zones, aridity, and ecoregions (Bower et al. 2014, Erickson et al. 2004, Johnson et al. 2010, Omernik 1987). The estimation approach has been modified to account for climate change, such as warmer temperatures (Kramer and Havens 2009, Vitt et al. 2010, Ying and Yanchuk 2006), but this approach, like plant evaluation trials, likely will yield only approximate results because of uncertainty in both the prediction of future local climate conditions and the ability to find those conditions currently at a different location. Seed transfer zones that account for climate change have been under development for economically important tree species for more than two decades (Billington and Pelham 1991, O'Brien et al. 2007, Potter and Hargrove 2012, Rehfeldt 2004, Rehfeldt et al. 1999, Ying and Yanchuk 2006). These strategies might also be useful for identifying multiple species that have developed mutualisms through co-evolution and are suitable for transferring as a group (Gallagher et al. 2015).

Agroforestry tree species may be more tolerant and resilient than the herbaceous agricultural crops they protect, but they are not immune to the adverse impacts of climate change. New management practices will need to be developed and, in some cases, more resilient germplasm or new species altogether will need to be considered. Climate Envelope Modeling, if applied correctly, could be a valuable tool for determining which species will continue to be suitable for a specific region, identifying other regions that may possess hardier germplasm for seed sourcing, and identifying potential breeding opportunities that will yield climate change-adapted plant material for the future.

## Other Adaptation Issues and Strategies

Along with seed source and plant material considerations in developing resilient plantings, belowground aspects, especially those related to the mycorrhization of plants, need to be considered (Compant et al. 2010, Johnson et al. 2013). For instance, the ability of southern California oaks to form both vesicular-arbuscular and ecto-mycorrhizae provides added diversity to help buffer against adverse conditions (Allen 2015). Not taking into account the belowground conditions, like mycorrhizal diversity and suitability, may impair plant performance such as found by Kranabetter et al. (2015) in their assisted migration studies with Douglas-fir. Management activities, ranging from mycorrhizal inoculation to the use of tree shelters, application of hydrogels and organic amendments, and planting methods, can impact seedling establishment success under changing conditions (Piñeiro et al. 2013) and therefore provide additional strategies to establish and grow more resilient agroforestry plantings.

Given the complexity of factors affecting plant performance and persistence, additional research is needed to fully understand climate change impacts on agroforestry plant materials (Ayres and Lombardero 2000, Luedeling 2012). In the meantime, adaptation strategies for agroforestry can be pulled from existing information generated in other sectors, such as horticulture. Orchard production research has identified varieties of plant materials with lower dormancy requirements and has also provided information for in-field management options. One of the most effective adaptation strategies is simply increasing the plant diversity within a planting, which broadens the mix of genetic, phenological, and biophysical attributes (Altieri 1999, Lin 2011). Using a wide range of plant materials can reduce herbivory by pests (Jactel and Brockerhoff 2007, Aitken et al. 2008), decrease disease transmission (Lin 2011), minimize phenological mismatching between pollinators and plants (Polce et al. 2014), and decrease risk from extreme weather events (Altieri 1999, Lin 2011). Because agroforestry is a designed planting, it offers opportunity for using a variety of species and arrangements within a planting. More innovative practice designs, such as using resilient woody species to provide microclimate benefits to fruit/nut-producing species through a mixed-use windbreak or alley cropping system, can also offer a way forward while new plant materials and management guidance are being developed.

## Key Findings

- Agroforestry species currently used in a specific region may not tolerate stresses brought on by future climate conditions, thus jeopardizing long-term benefits of these practices.
- Successful agroforestry practices may require the introduction of new species and/or cultivars that are better adapted to both current and future climatic conditions.
- Models, field evaluation trials, and seed sourcing will likely be required to develop suitable species and cultivars.

## Key Information Needs

- Better understanding of the impact of future climate conditions and interrelated stressors on agroforestry species.
- Improved modeling for predicting species suitability under future climatic regimes.
- Refined plant species options for agroforestry practices in different regions of the United States under climate change.

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# Chapter 3
# Greenhouse Gas Mitigation and Accounting

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It is well documented that forests provide significant carbon (C) sequestration (McKinley et al. 2011). In the 2013 U.S. Department of Agriculture (USDA) Greenhouse Gas Inventory, forests, urban trees, and harvested wood accounted for the majority of agricultural and forest sinks of carbon dioxide ($CO_2$) (USDA-OCE 2016). Trees outside of forests (TOF; assemblages of trees not meeting the definition of forest based on area, width, and/or canopy coverage criteria) also play an important role in C sequestration as well as in the reduction of greenhouse emissions but do so within agricultural and urban lands. While the positive contributions of these forest-derived mitigation services within U.S. agricultural lands have been documented, the lack of inventory- and activity-specific data limits our ability to assess the amount and therefore significance of these contributions (Robertson and Mason 2016, Schoeneberger 2009). Recent international studies, however, indicate these contributions can be very significant in regards to overall global and national C budgets (Schnell et al. 2015, Zomer et al. 2016).

According to the most recent U.S. Agriculture and Forestry Greenhouse Gas Inventory (1990–2013), agriculture in the United States contributed 595 million metric tons of $CO_2$ equivalents in 2013, with nearly one-half (45 percent) of these emissions coming from soils, 28 percent from livestock production (enteric fermentation), and the rest from energy use and managed livestock waste (USDA-OCE 2016). Agriculture also has the ability to offset these emissions through the use of management practices, of which TOF-based practices and, specifically, the TOF practice of agroforestry, are now included (CAST 2011, Denef et al. 2011, Eagle and Olander 2012, Eve et al. 2014). Agroforestry is the intentional integration of woody plants into crop and livestock production systems to purposely create a number of forest-derived services that support agricultural operations and lands, including those services that can directly address greenhouse gas (GHG) mitigation and adaptation needs related to food security and natural resource protection under changing conditions (see chapter 2 in this assessment, Nair 2012a, Plieninger 2011, Schoeneberger et al. 2012, Verchot et al. 2007, Vira et al. 2015). It is because of this capacity to simultaneously provide C sequestration and other GHG mitigation services, along with adaptation, that interest is growing in the use of agroforestry and other TOF systems (e.g., woody draws, woodlots, fencelines) in U.S. agricultural climate change strategies (CAST 2011, Ogle et al. 2014). The discussions and relevance of GHG mitigation accounting methodologies and research needs presented in this chapter therefore have significance beyond just agroforestry and beyond just U.S. boundaries.

The GHG mitigation capacity of agroforestry will be influenced by how the trees, crops, livestock components, or a combination of the three are assembled into the many different agroforestry practices. The five main categories of agroforestry practices used in the United States are (1) riparian forest buffers, (2) windbreaks (including shelterbelts), (3) alley cropping (tree-based intercropping), (4) silvopasture, and (5) forest farming (multistory cropping), with a sixth category capturing adaptation of agroforestry technologies to address emerging issues such as biofeedstock production and stormwater management. A brief description of each agroforestry practice is provided in table 1.1 in chapter 1, along with a list of many potential benefits these practices may confer to the land and the landowner. Additional details on each of these practices and their potential benefits are available at the USDA National Agroforestry Center Web site (http://nac.unl.edu).

Approaches for assessing the GHG contributions at both entity (individual field or farm) and national scales are presented in this chapter. Relatively well defined and appropriate for forest and cropping/grazing systems, these approaches meet current Intergovernmental Panel on Climate Change (IPCC) *Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) and provide a solid basis for constructing the consistent accounting methodologies across spatial scales needed in the more variable agroforestry systems. Although information is limited, agroforestry's other direct and indirect effects on GHG emissions (nitrous oxide [$N_2O$], methane [$CH_4$], and avoided emissions) are presented to inform future research and assessment activities required to build a more comprehensive understanding of agroforestry's contributions to agriculture's net GHG footprint and therefore how these practices can best be used within GHG mitigation strategies.

## Potential Greenhouse Gas Mitigation Roles of Agroforestry

Temperate agroforestry is recognized as a viable land-management option for mitigating GHG emissions in the United States and Canada (CAST 2011, Eve et al. 2014, Nair et al. 2010, Schoeneberger et al. 2012). Agroforestry contributes to agricultural GHG mitigation activities by (1) sequestering carbon (C) in terrestrial biomass and soils, (2) reducing GHG emissions, and (3) avoiding emissions through reduced fossil fuel and energy usage. These GHG mitigation benefits are derived via the diversity of ecological functions created by and management activities used within agroforestry operations, both of which translate into greater C capture and tighter nutrient cycling in agroforestry compared with conventional operations under comparable conditions (Olson et al. 2000).

As a GHG mitigation tool, agroforestry can also provide additional ecosystem services and goods that producers and society value (see table 1.2 in chapter 1), including adaptive capacity for building added resiliency of operations and lands to changing climate (see chapter 2 of this assessment, ICF 2013, Nair et al. 2009, Plieninger 2011, Schoeneberger et al. 2012). As practiced in the temperate United States (with most practices, especially windbreaks and riparian forest buffers, comprising less than 5 percent of the field area), agroforestry can deliver these services while leaving the bulk of land in agricultural production. A large agricultural land base within the United States that could benefit from agroforestry includes nearly 22 percent of the cropland currently classified as marginal (ICF 2013). Even if only a small percentage of this area were converted, the potential C sequestration, along with other GHG reductions, could become noteworthy. When appropriately located, designed, and managed, agroforestry should not result in the conversion of additional lands into agricultural operations to replace these generally small portions of land now occupied in trees (see chapter 2 of this assessment, Schoeneberger 2009). For example, the 3 to 5 percent of a crop field put into a windbreak should result in increased yield (into the field up to a distance of 15 times the height of the trees), providing equal to greater returns from putting that small amount into trees (see the Commodity Production section in chapter 2).

### Carbon Sequestration

Agroforestry's potential for sequestering large amounts of C is well recognized in both tropical and temperate regions (IPCC 2000, Kumar and Nair 2011, Plieninger 2011, Udawatta and Jose 2012). For example, 13-year-old poplar and spruce alley cropping systems in Canada had approximately 41 and 11 percent more total C, respectively, than accounted for in adjacent sole-cropping systems (Peichl et al. 2006). Positive trends in C sequestration have been documented in temperate regions, and the number of these studies is growing (see Kumar and Nair 2011). Tree-based agricultural practices tend to store more C in the woody biomass and soil compared with their treeless/more conventional agricultural alternatives under comparable conditions (table 3.1) (Lewandrowski et al. 2004, Nair 2012a). Similar to that observed in afforestation and reforestation activities (Gorte 2009), this C potential per unit area in agroforestry systems can be substantial, largely because of the amount of C sequestered in the woody biomass, with stem wood accounting for up to 90 percent of the new C (Hooker and Compton 2003).

**Table 3.1.** Estimated carbon sequestration rates for four main categories of U.S. agricultural land use.

| Practice category | C sequestration rate (Mg of $CO_2$ eq $ha^{-1}$ $year^{-1}$) |
|---|---|
| Afforestation (previously cropland or pasture) | 6.7–19.0 |
| Herbaceous riparian or conservation buffers | 1.2–2.2 |
| Conservation tillage (reduced to no-till) | 0.7–1.7 |
| Grazing management | 2.7–11.9 |

$CO_2$ = carbon dioxide. eq = equivalent. ha = hectare. Mg = megagram.
Source: Data from Lewandrowski et al. (2004).

Based on U.S. land area that would be suitable for and benefit from the non-GHG mitigation services provided by agroforestry, such as soil- and water-quality protection (see chapter 2), estimates of agroforestry's C sequestration potential range from 90 teragrams (Tg) C per year (yr) (soil + biomass based at approximately 15 years into establishment) (Nair and Nair 2003) to 219 Tg C $yr^{-1}$ (soil + biomass based at variable years [20 to 50 years] into establishment and depending on practice) (Udawatta and Jose 2012).

The range in estimates that have been reported over the years, from Dixon et al. (1994) to Udawatta and Jose (2012), vary substantially because of differences in (1) the assumptions used regarding C sequestering rates, (2) which pools were included in the estimate, (3) presumed project lifespans, and (4) the assumptions each study used to determine land area, where that land was, and how much of it would support each agroforestry practice type. The lack of national agroforestry inventory information in the United States limits our ability to estimate land area already under agroforestry and, therefore, current C sequestration contributions at regional and national scales (Perry et al. 2005, 2009; Robertson and Mason 2016). Regardless of the limited information, the data continue to affirm that we know enough to assess the direction of agroforestry's impact on C sequestration within an operation; that we know these impacts, in general, will be neutral to highly beneficial in comparison with more conventional operations; and that we know enough to estimate the larger C sinks in these systems (see CAST 2011, Kumar and Nair 2011, Schoeneberger 2009).

Because agroforestry is a combination of agricultural and forestry activities, the C stocks from which sequestered C is estimated should include the various pools from each of these activities. The size of these stocks (and sequestered C) will vary by agroforestry practice (fig. 3.1). These stocks will also vary with age and/or development of the woody component. Adding to the complexity of C fluxes within these system are the many interactions generated by the agroforestry plantings on other C components within the system, as illustrated in the windbreak example in figure 3.2. Recent work, such as by Wotherspoon et al. (2014), is helping to build a more comprehensive understanding of C fluxes generated by agroforestry—in this case, alley cropping; however, most studies to date report on only a portion of these pools. The lack of national inventory information (Perry et al. 2005) and the high cost and difficulty of collecting measurement information for all these pools have led to more pragmatic approaches for C research and accounting in agroforestry (Brown 2002, Schoeneberger 2009) (see discussion in table 3.2).

Carbon accounting within agriculture and forestry needs to consider five main pools: (1) live biomass (above ground), (2) live biomass (below ground), (3) dead biomass (dead

**Figure 3.1.** Continuum of agroforestry practices from agricultural field to forest stand, with relative carbon stocks by ecosystem pool associated with each practice. Note: This figure is for illustration purposes only; actual carbon stocks may vary widely, depending on the agroforestry prescription.

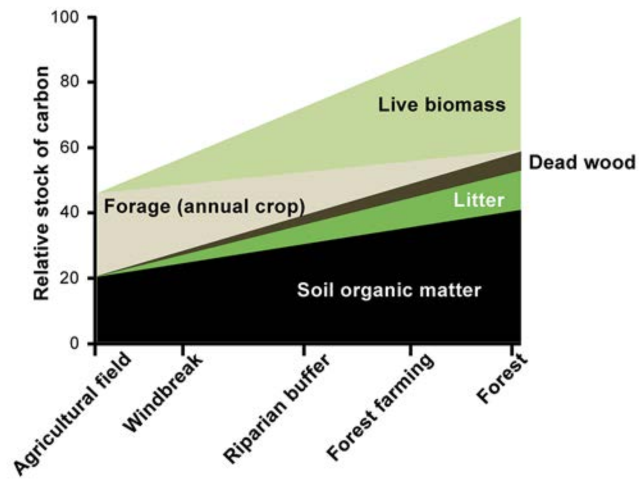
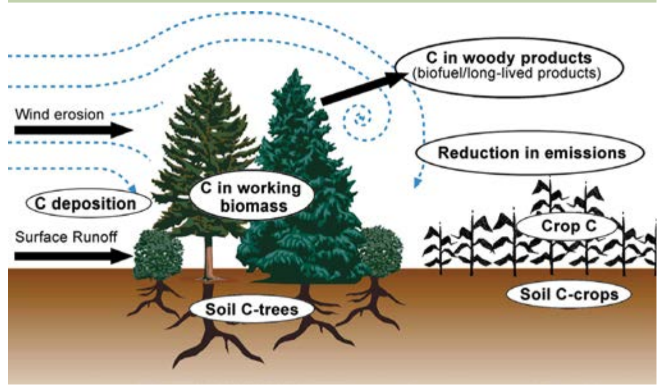



**Figure 3.2.** Major carbon sinks and sources that can be affected by a field windbreak. (Schoeneberger 2009).




wood), (4) dead biomass (forest floor), and (5) soil organic matter (Eve et al. 2014, IPCC 2006). Table 3.2 provides a brief overview regarding the feasibility of accurately and cost-effectively accounting for these various pools in agroforestry systems. Table 3.3 provides definitions for these pools, with references to estimation approaches for agricultural and forested systems. Depending on the level of specificity required for reporting, these pools may be further delineated, especially within forest land use (e.g., dead wood may be divided into standing and downed dead biomass; live biomass may be divided into live trees and understory biomass).

The majority of new aboveground C in agroforestry plantings is predominantly contained in the standing woody biomass, as documented in afforestation and reforestation plantings (Hooker and Compton 2003, Niu and Duiker 2006, Vesterdal et al. 2002). This component is the most readily visible, easily measured, and easily verified portion and, therefore, generally tends to be the more studied and reported component. Depending on the objectives, measures and/or estimates of belowground woody C and/or soil C may or may not be included with the agronomic component (Eagle and Olander 2012, Nair et al. 2010, Udawatta and Jose 2012).

Regarding the woody biomass component, Zhou et al. (2015) and Kort and Turnock (1999) demonstrated that use of existing allometric models obtained from forest-grown trees generally resulted in the underestimation of woody biomass and C in agroforestry plantings. Zhou et al. (2011, 2015) found that growth differences in specific gravity and architecture (both taper and ratio of stem to branch biomass) created in the more open canopies of agroforestry practices compared with forests contributed to this underestimation.

Less is known regarding C allocation to belowground woody biomass in agroforestry plantings. Estimation of this pool currently is accomplished pragmatically using forestry-derived protocols (Hoover et al. 2014). Ritson and Sochacki's work (2003) found more open-grown trees may have greater root biomass compared with close-spaced trees due to increased light and/or more root thickening in response to greater mechanical stress from wind sway. Taking these findings—for aboveground and belowground woody biomass and, therefore, C estimates—into account means that the generally neutral to very positive amounts of sequestered C reported to date for agroforestry practices in temperate regions may not fully reflect the whole contribution of this pool but can be considered a conservative assessment of agroforestry's C sequestration contribution.

**Table 3.2.** Accounting considerations for carbon sequestration pools in agroforestry plantings.[a]

| Project effects | Ecosystem component | Contribution to reduction[b] | Flux[c] | Ability to measure or estimate[d] |
|---|---|---|---|---|
| **Live biomass** | | | | |
| Above ground | Trees | ++ | L | **R—**Represents largest pool (Hooker and Compton 2003). Biomass equations should be modified for agroforestry plantings (Zhou et al. 2015) or regional biomass equations should be derived from forest stand data. The latter are currently available for most agroforestry species and will provide conservative (underestimated) values. |
| | Understory | + | S–M | **M—**Some plantings may potentially have a large shrub component, especially by design, so inclusion in accounting should be considered. Work is ongoing in the development of biomass estimation models for a few of the key species of shrubs used in agroforestry. |
| Below ground | Trees—coarse roots | ++ | M | **R—**Allometric equations should be used with root/shoot estimates (e.g., Birdsey 1992, Cairns et al. 1997). Increased partitioning of biomass/C to roots is observed in open-grown trees (Ritson and Sochacki 2003), so forest approaches will give conservative (underestimated) values for this component. |
| | Trees—fine roots | + | S–M | **N—**Turnover is extremely high, creating high variability and large error. Positive impact of this pool will be reflected, if at all, in the soil organic matter over time. |
| | Understory | + | S–M | **M—**Some plantings have the potential of having a large enough shrub component that inclusion in accounting should be considered. Work is ongoing in the development of biomass estimation models for a few of the key species of shrubs used in agroforestry. |
| **Dead biomass** | | | | |
| Dead wood<br>Forest floor | | + | S | **N—**In an afforestation activity, like agroforestry, these components do not accumulate to significant levels until late in a practice's lifespan. Turnover of litter, in general, is higher in these more open systems. Variability and difficulty in estimating litter component is extremely high. |
| **Soil organic matter** | | | | |
| Soil—carbon from biomass turnover | | + | S | **M—**This matter can represent a pool that is influenced just under the tree component; variable distance from the tree over time (assuming main input from tree litter) or a combination of tree and crop management influences. Variability/error very high and with less certainty other than number will be positive in the long term. Soil accrual pool significantly smaller than that in woody biomass within row type plantings but could become quite significant in the plantings that occupy larger areas (i.e., alley cropping and silvopasture). |

[a] Takes into account the woody portion of an agroforestry practice and the understory created by it. Does not include agricultural components altered by the integration of woody plants. Currently limited ability to account for the interactions between the agricultural and forestry components so are assessed separately. See discussion in the later part of this chapter.

[b] + and ++ = increasing positive net C potentially sequestered.

[c] S = small, M = medium, and L = large contribution to C sequestered in that pool, with S and M relative to the proportion the aboveground woody biomass comprises.

[d] R = recommended, M = maybe, and N = not recommended, based on lack of ease and reliability of getting the value and cost of measurement.

Source: Adapted from Schoeneberger (2009).

**Table 3.3.** Definitions of carbon pools that may exist in agroforestry practices and the data sources.

| Carbon pool | Definition | Estimation approaches: Agricultural fields | Estimation approaches: Forest stands |
|---|---|---|---|
| Live biomass | **Live trees:** Large woody perennial plants (capable of reaching a height ≥ 15 feet) with a d.b.h. or at root collar (if multistemmed woodland species) ≥ 1 inch. Includes the C mass in roots (with diameters > 0.08 inches), stems, branches, and foliage. | Parton et al. (1987)<br>Parton et al. (1998)<br>Zhou (1999)<br>Zhou et al. (2011)<br>Zhou et al. (2015) | Smith et al. (2006)<br>Jenkins et al. (2003)<br>Woodall et al. (2011)<br>Hoover et al. (2014) |
| | **Understory:** Roots, stems, branches, and foliage of tree seedlings, shrubs, herbs, forbs, and grasses. | | Smith et al. (2006)<br>Russell et al. (2014)<br>Hoover et al. (2014) |
| Dead wood | **Standing dead:** Dead trees of ≥ 1 inch d.b.h. that have not yet fallen, including C mass of coarse roots, stems, and branches, but that do not lean more than 45 degrees from vertical, including coarse nonliving roots > 0.08 inches in diameter. | | Smith et al. (2006)<br>Harmon et al. (2011)<br>Domke et al. (2011)<br>Hoover et al. (2014) |
| | **Downed dead:** Nonliving woody biomass with a diameter ≥ 3 inches at transect intersection, lying on the ground. Also includes debris piles (usually from past harvesting) and previously standing dead trees that have lost enough height or volume or lean > 45 degrees from vertical, so they do not qualify as standing dead trees. | | Smith et al. (2006)<br>Hoover et al. (2014) |
| Litter | The litter layers and all fine woody debris with a diameter < 3 inches at transect intersection, lying on the ground above the mineral soil. | | Smith et al. (2006)<br>Hoover et al. (2014) |
| Soil organic matter | All organic material in soil to a depth, in general, of 3.3 feet, including the fine roots (< 0.08 inches in diameter) of the live and standing dead tree pools, but excluding the coarse roots of the pools above. | Del Grosso et al. (2001)<br>Del Grosso et al. (2011)<br>Ogle et al. (2003)<br>Ogle et al. (2010)<br>Parton et al. (1998) | Smith et al. (2006)<br>Hoover et al. (2014) |

d.b.h. = diameter at breast height. C = carbon.

Sources: Adapted from Eve et al. (2014); IPCC (2006).

Soil C stocks are likely to be altered in agroforestry plantings compared with conventional cropping or grazing systems in the United States, but the direction and magnitude of change will depend on the ecological context of the site and the type of agroforestry system implemented (see the Soil Resources section in chapter 2). Inherently highly variable, soil C has been found to be even more variable in agroforestry systems (e.g., Bambrick et al. 2010, Sharrow and Ismail 2004) compared with nearby forest-only plantation and treeless operations and may well explain the variability of agroforestry findings reported thus far. Methodological difficulties, including differences in sampling depth and selection of the site to provide comparative baselines, further limit discussion to qualitative rather than more quantitative comparisons, especially across regions, conditions, and different types of agroforestry practices (Nair 2012b). Results to date from agroforestry and afforestation studies in the United States indicate soil C sequestration under agroforestry may actually be negligible/undetectable to possibly negative for several years after initial establishment (Nave et al. 2013, Paul et al. 2003, Peichl et al. 2006, Udawatta et al. 2009).

Erosion control in agroforested areas also confounds easy and accurate assessments of C sequestration in the soil pool. Many agroforestry plantings, particularly windbreaks and riparian forest buffers, are purposely designed to intercept soil eroding from adjacent sources. These transported soils, either from wind erosion (Nuberg 1998, Sudmeyer and Scott 2002) or surface runoff (McCarty and Ritchie 2002), tend to be higher in C and other nutrients. The patterns of soil parameter data (i.e., litter mass, soil pH, and texture) measured by Sauer et al. (2007) from under a 35-year-old windbreak in Nebraska documented this deposition. Use of stable C isotope analysis is one means of separating out that C that is transported in and that C sequestered in situ. Hernandez-Ramirez et al. (2011), using this method, identified approximately 50 percent of the larger soil organic C (SOC) pool found beneath afforested areas versus adjacent cropland in Iowa was tree derived (1.73 kilograms [kg] C square meters [$m^{-2}$]), with an estimated mean residence time of 45 years and an estimated annual accrual rate of 10.6 grams C $m^{-2}$ $yr^{-1}$. The cotransport of nitrogen (N) with eroded materials into the agroforestry planting may also cause confounding impacts. Although the addition of N via erosion has not been found to increase soil C efflux or deplete soil C stocks (Grandy et al. 2013, Janssens et al. 2010, Ramirez et al. 2012), it may be impacting soil C stocks in ways not yet identified or understood and requires further investigation.

Perhaps more substantial than the estimation of total SOC are the findings that these tree-based systems, compared with their treeless counterparts, tend to store significantly more C deeper in the profile and in the smaller sized fractions, all of which contribute a greater stability to this sequestered C (Haile et al. 2008, 2010; Howlett et al. 2011). Soils under the woody component of hedgerows, windbreaks, and silvopasture were found to consistently have greater total SOC and SOC in all size fractions when compared with the treeless agricultural component (Baah-Acheamfour et al. 2014).

## GHG Mitigation of Other GHGs

Understanding agroforestry's broader role in GHG mitigation beyond the C sequestration described previously entails knowledge of its impacts on the other major GHGs of concern in agriculture, namely $N_2O$ and $CH_4$. Research is limited regarding the impacts of agroforestry on these two GHGs. The tighter nutrient cycling created by the greater spatial and temporal diversity in agroforestry plantings (Olson et al. 2000) would support the premise that agroforestry should have neutral to beneficial effects in reducing emissions of these two GHGs when compared with conventional treeless practices under similar conditions. In addition, how other management activities, especially those involving the management of fertilizers and grazing, are implemented in the various agroforestry practices will also influence the direction and magnitude of this mitigation potential (box 3.1). The data and means for accurate estimates of these contributions are not available yet for building a quantitative understanding. Enough is now known, however, to identify the relative magnitude and direction of trends and also the mechanisms at play in the various agroforestry practices under different settings. Such information can assist in establishing improved design and management guidance that better optimize agroforestry's beneficial GHG functions.

### GHG Mitigation of Nitrous Oxide

The potential to lower $N_2O$ emissions in an alley cropping system (also referred to as tree-based intercropping system) was estimated at 1.2 kg $N_2O$ hectare$^{-1}$ yr$^{-1}$ (Evers et al. 2010). Amadi et al. (2016) found $N_2O$ emissions were about 4 times lower in shelterbelts, a factor they attributed to the exclusion of N fertilization and also possibly due to greater soil aeration under shelterbelt trees. Other studies have also documented $N_2O$ emission reductions in tree plantings into crop and pasture lands; e.g., afforestation plantings (Allen et al. 2009), windbreaks (Ryszkowski and Kedziora 2007), and riparian forest buffers (Kim et al. 2009). Data regarding the magnitude of these trends are insufficient to judge the significance of these reductions at broader scales at this time (Ogle et al. 2014).

The elimination or reduction of N-fertilizer inputs on that portion of land planted to the agroforestry tree component will reduce $N_2O$ emissions from that source. This amount can be estimated using methodologies described in Ogle et al. (2014). Tighter nutrient cycling that is generally observed in multistrata/multispecies plantings, such as agroforestry (Olson et al. 2000), should also play a role in reducing emissions, both on and off site. Observations of N conservation in agroforestry plantings as compared with treeless cropping and grazing systems have been documented (Allen et al. 2004, Bambo et al. 2009, López-Díaz et al. 2011, Nair et al. 2007). This effect will be altered depending on the various types and amounts of management activities implemented within the agroforestry system, as well as by the age of the woody plants (box 3.1).

$N_2O$ emissions are influenced by many different factors and are highly variable in agricultural soils (Butterbach-Bahl et al. 2013, Eve et al. 2014). The additional complexity of spatial and temporal factors created in agroforestry, such as influence of tree development on nutrient cycling, is expected to play a role in reducing net $N_2O$ emissions through greater soil N uptake; however, it will also make it more difficult to quantitatively assess. Riparian forest buffers warrant special attention regarding $N_2O$ emissions. Although naturally occurring riparian forests have been identified as being potential $N_2O$ hotspots—a function of intercepting additional N from runoff and having conditions conducive for denitrification (Groffman et al. 2000)—riparian forest buffers are those conservation plantings purposely designed and used to intercept field runoff, especially nitrates ($NO_3$), to protect water quality. Increased uptake of $NO_3$ by riparian forest buffer vegetation has the potential to reduce the amount of $NO_3$ that would otherwise be available for denitrification and subsequent $N_2O$ emission (Kim et al. 2009, Tufekcioglu et al. 2003). Harvesting of plant materials in the riparian forest buffer zones closest to the fields would remove N from the site and help maintain more actively growing plant materials and therefore nutrient uptake, especially for N. To offset harvesting costs, these plant materials could be specifically selected for and then used/sold as a source of biofeedstock (Schoeneberger et al. 2008).

## **Box 3.1.** Management activities within agroforestry practices that can potentially alter the magnitude and direction of carbon sequestration and other greenhouse gas fluxes.

**Practice** | **Management activities**

### Windbreaks

- Disturbance to soil by site preparation during establishment.
- Deposition of wind- and water-transported sediments, nutrients, and other agricultural chemicals into the planting.
- Windbreak renovation (removal and replanting of dead and dying trees over time).

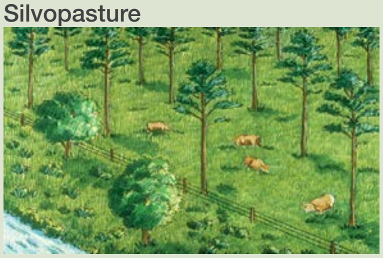
### Riparian forest buffers

- Disturbance to soil by site preparation during establishment.
- Deposition of wind- and water-transported sediments, nutrients, and other agricultural chemicals into the planting.
- Harvesting of herbaceous materials planted in Zone 3 (zone closest to crop/grazing system) and of woody materials planted in Zone 2 (middle zone).

### Alley cropping

- Disturbance to soil by site preparation during establishment.
- Weed control (mechanical or chemical).
- Pruning, thinning, and harvesting of woody material (amount and frequency vary greatly depending on short- and long-term objectives of practice).
- Fertilization for alley crop and possibly also occasionally for trees in rows (i.e., fruit/nut trees).
- Pesticides as needed for alley and row crops.
- Tillage in alleys (frequency and intensity).
- Crop species used in alley production.
- Complex harvesting schedules stratified in space and time.

### Silvopasture



- Disturbance to soil by site preparation during establishment.
- Weed control (mechanical or chemical).
- Pruning, thinning, and harvesting of woody material (amount and frequency vary greatly depending on short- and long-term objectives of practice).
- Harvesting of needles for pine straw.
- Fertilization of forage component.
- Tillage in forage component (frequency and intensity).
- Crop species used in forage component.
- Grazing management (timing, intensity, frequency).
- Complex harvesting schedules stratified in space and time.

### Forest farming

- Activities will be predominantly alterations of overstory for canopy manipulation and modification of understory as required for specific understory crop being grown and from harvesting of crops.

### Special applications

- Special applications are essentially modifications of the above agroforestry practices to address issues such as urban stormwater treatment, biofeedstock production, and waste treatment and will entail similar activities as listed above but to varying levels and frequencies of applications.

Source: Adapted from Ogle et al. (2014).

### GHG Mitigation of Methane

The second most prevalent GHG emitted in the United States from human activities, $CH_4$, is 25 times more efficient at trapping radiation than $CO_2$ (USDA-OCE 2016). The largest sources of $CH_4$ from agricultural activities are from livestock and manure management. The major strategies for reducing these emissions are therefore focused on altering how livestock and manure are managed; however, assessment of $CH_4$ flux in agroforestry is important to obtain a full GHG accounting of these systems within farm and ranch operations. Agroforestry can potentially alter the $CH_4$ emissions, albeit to only a small extent, by influencing microbially mediated soil activities responsible for $CH_4$ oxidation and reduction, with the latter most likely to occur at any measurable extent in well-aerated soils under upland practices and the former in periodically flooded soils that tend to occur in riparian environments. Agroforestry, specifically silvopasture, also can potentially influence $CH_4$ emissions but, in this case, through management and rotation of livestock.

Research findings for soil-mediated impacts in agroforestry systems at this stage are contradictory. Allen et al. (2009) and Priano et al. (2014) found $CH_4$ uptake to be greater in afforested ex-pasture sites than in pasture, suggesting that agroforestry that is afforestation-like could potentially influence $CH_4$ uptake positively. In a Canadian study, soil $CH_4$ oxidation potential under shelterbelts was 3.5 times greater than in cultivated soils, which was attributed to the trees creating more favorable moisture, soil organic matter, and infiltration conditions for $CH_4$ uptake (Amadi et al. 2016). Upland soils in general, particularly under forests, are identified as providing a $CH_4$ sink; however, this function generally is reduced by soil disturbance, such as tillage and N-fertilization (Dutaur and Verchot 2007, Suwanwaree and Robertson 2005, Topp and Pattey 1997). These findings would suggest that agroforestry practices, at least in the early years after establishment, may have only limited capacity for $CH_4$ oxidation activity. Soils in riparian forest buffers generally are found to be a $CH_4$ source due to anaerobic conditions created by periodic flooding. $CH_4$ flux in soils under established riparian vegetation in Iowa, however, did not differ from adjacent upland crop soils (Kim et al. 2010), most likely due to the altered hydrology generally encountered in these Midwest agricultural landscapes.

Silvopasture may have the greatest potential among the agroforestry practices to reduce $CH_4$ emissions. Livestock are the key $CH_4$ producers in silvopasture systems, and silvopasture affords several management opportunities to influence this production. Silvopasture introduces a grazing strategy of moving cattle in a rotational stocking system and has the potential to produce more digestible feed and greater overall gain from feed efficiency due to shade-induced microclimate changes (Cuartas et al. 2014, Lin et al. 1998, Mitlöhner et al. 2001) (see the Livestock Production section in chapter 2). Little GHG work has been done with all three silvopasture components in place (trees, forage, and livestock). Most studies have focused predominantly on only the C sequestering and nutrient uptake capacity of the tree and forage components in this system (e.g., Haile et al. 2010, Nair et al. 2007). Further work to integrate the animal component in the GHG modeling and accounting of silvopasture should be a priority, given the potential implication to reduce $CH_4$ emissions by improving forage quality via tree-based shading.

## GHG Mitigation Through Emission Avoidance

Trees planted on agricultural lands and around farmsteads and facilities can increase feed efficiency, reduce the area of land tilled, and modify microclimate both around buildings—reducing heating/cooling needs—and near roads—reducing snow deposition and, therefore, snow removal on roads (Brandle et al. 1992, DeWalle and Heisler 1988, Kursten and Burschel 1993). These activities lead to reduced consumption of fossil fuels, chemical inputs that include N-fertilizer, and electricity and natural gas usage on farms and ranches, all of which lead to a reduction in GHG emissions. These reductions are also referred to as avoided emissions. Machinery fuel and oil, N, and herbicides, expressed in terms of kg of C equivalent (CE), have been estimated at 0.94 kg CE per kg fuel, 1.3 kg CE per kg of N-fertilizer, and 6.3 kg CE per kg of herbicide, respectively (Lal 2004). As proposed by Lal (2004), inclusion of energy use within the net GHG assessment of an operation provides a more complete picture for comparing farm and ranch management decisions.

Brandle et al. (1992) estimated potential C storage (sequestered carbon dioxide [$CO_2$]) and conservation ($CO_2$ avoided emissions) that might be realized in a United States-wide windbreak-planting program. Their findings indicate avoided emissions can play a greater role in GHG mitigation in agriculture than that realized from direct C sequestration via biomass. These estimates were based on broad assumptions and energy-efficiency conditions different from today. Further, they did not include a complete accounting of other potential contributions to avoided emissions (e.g., reduction in feed quantity required because of increased feed efficiency from livestock windbreaks). The magnitude of the estimated contributions found by Brandle et al. (1992), along with estimates from a more recent study (Possu 2015) strongly supports additional research in this area.

## Emissions and Sequestration Accounting Methods

The IPCC (2006) *Guidelines for National Greenhouse Gas Inventories* presents two basic approaches—(1) the stock-difference method and (2) the gain-loss method—to emissions accounting and recommends using the method or combination of methods that provides the highest levels of certainty, while using the available resources as efficiently as possible. With the stock-difference method, mean annual net C emissions or sequestration for land subject to human activities is estimated as the ratio of the difference in C stock estimates at two points in time and the number of intervening years. With the gain-loss method, which is a process-based approach, annual changes in C stocks are estimated by summing the differences between the gains (e.g., increase in biomass) and losses (e.g., biomass decomposition) in a C pool. In the United States, both approaches are used to estimate C stock changes for different land uses, depending on the availability of inventory data. When inventory data exist (e.g., the national forest inventory from the USDA Forest Service Forest Inventory and Analysis [FIA] program), the stock-difference method is used. When inventory data are sparse, the gain-loss method or a combination of the two methods is used. In agroforestry systems, in which data are often limited, it is likely a combination of the two accounting methods will be used to obtain estimates of C stock changes in the woody and crop-related components. COMET-Farm (http://cometfarm.nrel.colostate.edu), a USDA Web-based tool for assessing GHG and C sequestration within farm and ranch operations, currently uses a stock-difference method in its Quick Agroforestry tool (for further discussion see box 6.1 in chapter 6 of this assessment).

### Uncertainty

There is a need to develop agroforestry models with less uncertainty regarding C stocks and the other GHGs. The factors contributing to uncertainty in GHG accounting in agroforestry include measurement and sampling error, modeling error, and interpretation of the protocols one follows. Lack of data at both the entity and national scales is the primary source of uncertainty associated with estimates of GHGs in agroforestry systems (Nair 2012b). As new data become available, models specific to agroforestry systems may be developed that better reflect C stocks and stock changes in these environments.

Monte Carlo methods are often recommended for estimating the statistical uncertainty associated with GHG estimates (IPCC 2006). Although the methods may vary based on data availability, simulations generally are run many times (e.g., 1,000 to 10,000 times) to obtain a probability distribution around the GHG estimate of interest that can then be used to estimate statistical uncertainty. Part of the GHG research strategy for temperate agroforestry will need to take into account input requirements for such exercises.

## Carbon Accounting at the Entity Level

One of the many potential benefits of agroforestry systems is the sequestration of $CO_2$ from the atmosphere in herbaceous and woody biomass and the accumulation of C in live and dead organic matter (IPCC 2000, Kumar and Nair 2011). Carbon accounting in agroforestry systems represents a challenge because of its mix of land use and management practices that intersect three distinct land-use categories: (1) forest land, (2) cropland, and (3) grassland (table 3.4) (EPA 2014). This section provides an overview of carbon pools and accounting approaches in agroforestry at the entity level (see Hoover et al. [2014] and Ogle et al. [2014] for a full description), with an emphasis on woody vegetation and associated ecosystem pools. The inventory and accounting methods described in this section are consistent with national and international protocols.

**Table 3.4.** Land-use categories used in GHG accounting in the United States that may include agroforestry practices.

| Land-use category | Defining agency | Description |
|---|---|---|
| Forest land | USDA Forest Service (FIA program) | Land areas ≥ 36.6 m wide and 0.4 ha in size with ≥ 10 percent cover (or equivalent stocking) by live trees able to attain an in situ height of 5 m, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Areas between forest and nonforest lands that have ≥ 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up land are also included. Areas such as shelterbelt strips of trees ≥ 36.6 m wide or 0.4 ha in size are also classified as forest. |
| Cropland | USDA Natural Resources Conservation Service (NRI program) | Land areas used for the production of agricultural crops for harvest, including both cultivated and noncultivated lands. Cultivated cropland includes row crops or close-grown crops and also hay or pasture in rotation with cultivated crops. Noncultivated cropland includes continuous hay, perennial crops (e.g., orchards), and horticultural crops. Cropland also includes land with alley cropping and windbreaks, and also lands in temporary fallow or enrolled in conservation reserve programs (i.e., set-asides), as long as these areas do not meet the forest land criteria. |
| Grassland | USDA Natural Resources Conservation Service (NRI program) | Land area composed principally of grasses, grass-like plants (i.e., sedges and rushes), forbs, or shrubs suitable for grazing and browsing and includes both pastures and native rangelands. Includes areas where practices such as clearing, burning, chaining, and/or chemicals are applied to maintain the grass vegetation; savannas, some wetlands, deserts, and tundra; woody plant communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, if they do not meet the criteria for forest land; and land managed with agroforestry practices such as silvopasture and windbreaks, assuming the stand or woodlot does not meet the criteria for forest land. |

FIA = Forest Inventory and Analysis. GHG = greenhouse gas. ha = hectare. m = meter. NRI = Natural Resources Inventory. USDA = U.S. Department of Agriculture.

## System Boundaries and Scale

The inventory and accounting methods described in this section have been modified from strategic level guidelines (IPCC 2006, Smith et al. 2006) for use at the entity level.

C fluxes will occur across the system boundary; however, they are not typically estimated, with the exception of harvested wood products. Given the array of agroforestry practices, trees on a property may not fit a particular land-use definition, creating complexities in inventory and accounting. Methods from multiple land-use categories (i.e., forest land, cropland, and grassland) will likely be required—with care taken to avoid double counting—to obtain a comprehensive estimate of C stocks and stock changes for the entity (see Eve et al. [2014] for complete descriptions of accounting techniques for different land-use categories).

Unlike annual crops, which are considered by the IPCC (2006) and the U.S. Environmental Protection Agency (EPA 2014) to be ephemeral with no net emission to the atmosphere (West et al. 2011), perennial woody crops have the potential to sequester large amounts of C per unit area (Dixon et al. 1994, Kumar and Nair 2011, Nair et al. 2010). To account for C stocks and stock changes in agroforestry systems, measurements collected as part of a field inventory may be used to meet the necessary data requirements for C accounting purposes. In most cases, repeated annual measurements are not practical, nor are the changes in C stocks sufficiently different from year to year to support such remeasurements. Instead, models and/or lookup tables from the IPCC (2006) and Eve et al. (2014) may be needed to account for temporal changes in vegetation and associated ecosystem pools when longitudinal datasets are not available.

## Summary of Inventory and Data Requirements

Inventories of natural resources contribute to the accounting of various products and/or services (e.g., C sequestration) those resources provide. In agroforestry systems, C pools may be broadly or narrowly defined, depending on the size of the entity and type of management practice. Systems (e.g., forest farming) that resemble forest stands may include all ecosystem pools typically associated with forest land, but practices in which trees are a minor component (e.g., alley cropping and windbreaks) may include only certain ecosystem pools common in forest stands (fig. 3.1). The type of agroforestry system will dictate which accounting methods are used to obtain C stock and stock-change estimates and the inventory information necessary to compile those estimates (Eve et al. 2014).

## Estimation of C Pools

Obtaining sound estimates of C stocks and stock changes in agroforestry systems requires balancing data availability with the entity's resources and needs. Explicitly establishing system boundaries and the C in ecosystem pools to be included in the accounting framework will help identify possible gaps or overlaps between pools or methods, particularly when combining methods across land-use categories. Furthermore, consistent definitions and estimation methods must be used for each pool to ensure valid estimates of C stock changes (Eve et al. 2014, IPCC 2006).

Many of the estimation and sampling approaches used to account for C in agroforestry systems come from the forestry and agricultural literature. As such, it may be helpful when identifying estimation and sampling strategies to think about agroforestry practices and, even just within an agroforestry practice, as occurring within an agriculture and forestry continuum (figs. 3.1 and 3.2). Carbon in agroforestry practices that are dominated by agricultural crops (e.g., windbreaks) may be best accounted for using approaches developed for agricultural applications. Carbon in agroforestry practices that more closely resemble forest conditions (e.g., forest farming) may be best accounted for using methods developed in forestry. In other words, the distribution of C from agricultural fields to forest will dictate which models, measurements, and sampling design one chooses to quantify C stocks and stock changes.

This section focuses on C in perennial crops and soil organic matter as annual crops (i.e., most food crops and some forages, such as rye, oats, and wheat) are not typically included in C accounting. Live perennial biomass therefore includes live trees (above and below ground), shrubs, seedlings, and herbaceous vegetation (table 3.4). Some or all of these components of the live biomass pool may exist in agroforestry practices and in forest conditions; this pool accounts for as much as one-half of the C storage (EPA 2014). Dead wood includes standing dead trees and downed dead wood (table 3.4). Dead wood may be a negligible component of many agroforestry practices, but, in systems managed to more closely resemble forest conditions, one or both of these components may exist and be important contributors to the C stocks and fluxes. Litter and fine woody debris (table 3.4) are small but important components in forests and, although they may be minor components in agroforestry systems, approaches for estimating this ecosystem pool exist. Finally, SOC (table 3.4) is a major component in forests and agricultural landscapes and accounts for a substantial amount of C storage in these systems (EPA 2014).

Although inventory and sampling methodologies are beyond the scope of this chapter (see Pearson et al. [2007] for a description of C inventories), each ecosystem pool mentioned may exist in an entity-level accounting framework in agroforestry systems. For a complete description of entity-level accounting in agroforestry systems as it currently stands, see Eve et al. (2014).

## Carbon Accounting at the Regional and National Levels

This section provides an overview of the assessment of C emissions and sinks resulting from the uses and changes in land types and forests in the United States, with emphasis on agroforestry systems. The IPCC *Guidelines for National Greenhouse Gas Inventories* (IPCC 2006) recommends reporting fluxes according to changes within and conversions between certain land-use types termed forest land, cropland, grassland, and settlements (and also wetlands). Agroforestry practices under the current organization of land-use categories in the U.S. National Greenhouse Gas Inventory (NGHGI) report are not explicitly characterized and, given the complex of land uses, may not be included in the national inventories used to compile C stocks and stock-change estimates for the United States (Perry et al. 2005, 2009). That said, agroforestry systems may be represented within the forest land (e.g., shelterbelts), cropland (e.g., alley cropping, windbreaks), or grassland (e.g., windbreaks, silvopasture) land-use types in the NGHGI if they meet the minimum definitions for each land use defined by the national inventories.

### Land Representation in National Accounting

In accordance with IPCC (2006) guidelines for reporting GHG fluxes to the United Nations Framework Convention on Climate Change, the United States uses a combination of approaches and data sources to (1) determine areas of managed and unmanaged lands, (2) apply consistent definitions for the land-use categories over space and time, and (3) account for all C stock changes and non-$CO_2$ GHG emissions on all managed lands (EPA 2014). Aspatial data from the Natural Resources Inventory (NRI) and FIA programs are used with spatially explicit time series land-use data from the National Land Cover Database (NLCD) to provide a complete representation of land uses and land-use change for managed lands. In general, land in the United States is considered managed if direct human intervention has influenced its condition and all other land is considered unmanaged (EPA 2014).

IPCC (2006) identifies six main land-use categories. In the United States, land-use definitions are country specific and are consistent with those used in the NRI and FIA programs. Agroforestry systems represent a complex of land use and management practices that intersect three distinct land-use categories in the NGHGI: (1) forest land, (2) cropland, and (3) grassland (table 3.4).

### National Accounting Data Sources

The different land uses are monitored by national inventory programs that focus primarily on forest lands and agricultural lands. Because certain agroforestry practices may not meet the definitions of the different land uses used in national inventory programs, they may not be monitored (Perry et al. 2005). As a result, there is not sufficient data to characterize C stocks and stock changes at a national scale for certain agroforestry practices as required in national and international C reporting instruments. That said, the FIA program has several pilot studies currently under way to evaluate novel approaches to monitoring remote areas (e.g., interior Alaska), urban ecosystems, and tree cover in agricultural landscapes (Liknes et al. 2010, Meneguzzo et al. 2013).

#### Natural Resources Inventory

The NRI is the official source of data on all land uses on non-Federal lands in the conterminous United States and Hawaii (except forest land), and it is also used as the resource to determine the total land base for the conterminous United States and Hawaii. The NRI is a statistically based survey conducted by the USDA Natural Resources Conservation Service and is designed to assess soil, water, and related environmental resources on non-Federal lands. The NRI survey uses data obtained from remote-sensing imagery and field visits to provide detailed information on land use and management, particularly for croplands and grasslands, and is used as the basis to account for C stock changes in agricultural lands (except Federal grasslands).

#### Forest Inventory and Analysis

The FIA program, conducted by the USDA Forest Service, is another statistically based survey for the United States; it is the official source of data on forest land area and management. The FIA program employs a three-phase annual inventory, with each phase contributing to the subsequent phase. Phase 1 is a variance-reduction step in which satellite imagery is used to assign Phase 2 (P2) plots to strata (Bechtold and Patterson 2005). P2 plots are distributed approximately every 2,428 ha across the 48 conterminous States of the United States and are visited every 5 to 10 years (i.e., 10 to 20 percent of plots are remeasured in each State each year). Each P2 permanent ground plot comprises a series of smaller fixed-radius plots (i.e., subplots) spaced 36.6 m apart in a triangular arrangement, with one subplot in the center. Tree- and site-level attributes—such as diameter at breast height and tree height—are measured at regular temporal intervals on P2 plots that have at least one forested condition (USDA Forest Service 2013). Every 16th P2 plot is a Phase 3 plot where additional attributes on live and dead trees, forest floor, understory vegetation, and soils are sampled. This information is used to estimate C stocks and stock changes on managed forest land (i.e., direct human intervention has influenced its condition) in the United States.

### National Land Cover Database

The NLCD is used as a supplementary database to account for land use on Federal lands (e.g., Federal grasslands) that are not included in the NRI and FIA databases. The NLCD land-cover classification scheme, available for 1992, 2001, 2006, and 2011, has been applied over the conterminous United States (Homer et al. 2004) and also for Alaska and Hawaii in 2001. For the conterminous United States, the NLCD Land Cover Change Products for 2001 and 2006 were used to represent both land use and land-use change for Federal lands (Fry et al. 2011, Homer et al. 2004). The NLCD products are based primarily on Landsat Thematic Mapper imagery. The NLCD is strictly a source of land-cover information and does not provide the necessary site conditions, crop types, and management information from which to estimate C stock changes or GHG emissions on those lands.

## Carbon Stocks and Stock Changes

The relevant land-use categories that may include agroforestry systems or the C pools that comprise agroecosystems include forest land, croplands, and grasslands. This section provides an overview of the estimation methods for C stocks and stock changes within the C pools relevant in agroforests by land-use category.

### Forest Land

Five C pools are defined by the IPCC (2006) for estimating C stocks or stock changes in forest ecosystems. These pools are consistent with the pools defined in table 3.3, although live biomass is separated into aboveground and belowground components for national reporting. Forest ecosystem stock and flux estimates are based on the stock-change method, and calculations for all estimates are in units of C. Separate estimates are made for the five storage pools. All estimates are based on data collected from FIA plots and from models employed to fill gaps in field data (USDA Forest Service 2013). Carbon-conversion factors are applied at the disaggregated level of each inventory plot and then appropriately expanded to population estimates. A combination of tiers as outlined by IPCC (2006) is used. The Tier 3 biomass C values are calculated from FIA tree-level data. The Tier 2 dead organic and soil C pools are based on land use, land-use change, and forestry empirical or process models from FIA data. All C-conversion factors are specific to regions or individual States within the United States, which were further classified according to characteristic forest types within each region.

### Croplands

Changes in soil C stocks due to agricultural land use and management activities on mineral soils and organic soils are estimated according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2009). An IPCC Tier 3 model-based approach (Ogle et al. 2010) was applied to estimate C stock changes for mineral soils used to produce most annual crops (e.g., alfalfa hay, barley, corn, cotton, dry beans, grass hay, grass-clover hay, oats, onions, peanuts, potatoes, rice, sorghum, soybeans, sugar beets, sunflowers, tomatoes, and wheat) in the United States in terms of land area. The model-based approach uses the DAYCENT biogeochemical model (Del Grosso et al. 2001, 2011; Parton et al. 1998) to estimate soil C stock changes and soil $N_2O$ emissions from agricultural soil management. Coupling the two source categories in a single inventory analysis ensures a consistent treatment of the processes and interactions between C and N cycling in soils. The remaining crops on mineral soils were estimated using an IPCC Tier 2 method (Ogle et al. 2003). The Tier 2 method was also used for very gravelly, cobbly, or shaley soils (greater than 35 percent by volume). Mineral SOC stocks were estimated using a Tier 2 method for these areas because the DAYCENT model, which is used for the Tier 3 method, has not been fully tested for estimating C stock changes in certain cropping systems. An additional stock-change calculation was estimated for mineral soils using Tier 2 emission factors to account for enrollment patterns in the USDA Conservation Reserve Program after 2007, which was not addressed by the Tier 3 method.

Annual C emissions from drained organic soils in cropland are estimated using the Tier 2 method provided in IPCC (2006), with U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates.

### Grasslands

Changes in soil C stocks due to agricultural land use and management activities on mineral and organic soils for private grasslands are estimated according to land-use histories recorded in the USDA NRI survey (USDA-NRCS 2009). Land use and some management information (e.g., crop type, soil attributes, irrigation) were originally collected for each NRI point on a 5-year cycle beginning in 1982. In 1998, the NRI program initiated annual data collection, and the annual data are currently available through 2010. NRI points were classified as "grassland remaining grassland" back to 1990 (the baseline year) if the land use had been grassland for 20 years. Grassland includes pasture and rangeland used for grass forage production, where the primary use is livestock grazing. Rangelands are typically extensive areas of native grassland that are not intensively managed, while pastures are often seeded grassland, possibly following tree removal, that may or may not be improved with practices such as irrigation and interseeding legumes.

An IPCC Tier 3 model-based approach (Ogle et al. 2010) is applied to estimate C stock changes for most mineral soils in non-Federal grasslands remaining grasslands. The C stock changes for the remaining soils are estimated with an IPCC Tier 2 method (Ogle et al. 2003), including gravelly, cobbly, or shaley soils (greater than 35 percent by volume) and additional stock changes associated with sewage sludge amendments. Annual C emissions from drained organic soils in grasslands are estimated using the Tier 2 method provided in IPCC (2006), which uses U.S.-specific C loss rates (Ogle et al. 2003) rather than default IPCC rates, as described in the Cropland Remaining Cropland section for organic soils (IPCC 2006).

## Advancing Greenhouse Gas Performance and Accounting in Agroforestry Systems

Agroforestry systems are purposely diverse and complex, deliberately mixing both forestry and agriculture components into a variety of practices, a variety of designs (e.g., species compositions, arrangements), and a variety of settings, and involving a variety of other forestry and agricultural management activities (i.e., fertilization, harvesting, grazing, and tillage) (box 3.1). The ability of agroforestry to confer its many ecosystem benefits from production to landscape health is attributable to this high functional and structural diversity (Olson et al. 2000). All these factors influence how much C can be sequestered and GHGs emitted or avoided, which means agroforestry affords us a very flexible and potentially powerful arrangement of options to improve GHG mitigation performance, along with other functions being sought from agriculture by producers and society.

### Capitalizing on Agroforestry's Complexity

Understanding how best to utilize these plantings in GHG mitigation strategies requires that we can understand, document, and account for all of agroforestry's GHG impacts. Agroforestry practices are expressly designed to capitalize on the beneficial interactions generated among the tree, crop, and livestock components, the impacts of which may occur well beyond the area occupied by the agroforestry planting itself. For example, a crop windbreak is designed to favorably modify microclimate on the adjacent crop field, an impact that can extend up to a distance of 15 times the windbreak tree height (Brandle et al. 2009). Windbreak-induced shifts in crop growth and soil microclimate in the field adjacent to the practice can then potentially further alter soil C fluxes and $N_2O$ emissions in the field. We must actually look beyond the C sequestered in the wood and soil just under the trees, as is done now, to fully capture agroforestry's C benefits (fig. 3.2).

Interpractice soil C transfers also need to be considered in agroforestry GHG accounting. Many agroforestry plantings are explicitly designed to intercept or alter wind- and water-borne soil erosion, a climate change adaptive function that is predicted to become more critical under future weather events (see the Soil Resources section in chapter 2). Higher levels of soil C under windbreaks in the Great Plains and elsewhere are partially attributable to this interception of wind-blown soils (Sauer et al. 2007). These windbreak-intercepted soils have also been generally found to be richer in C (Sudmeyer and Scott 2002). Increased soil movement from upland fields into a riparian wetland area was associated with increased C sequestration rates in a riparian wetland (McCarty and Ritchie 2002). The more limited management and therefore more limited disturbance within riparian areas also suggest riparian forest buffers can serve as a longer term sink for C in this landscape. These erosional processes also deliver N into agroforestry practices, which is expected to influence $N_2O$ flux in many different ways, depending on landscape position, site conditions, and vegetation and to also then impact C dynamics.

Species selections and planting configurations and densities are key considerations in designing for GHG mitigation-enhanced services from agroforestry. For instance, use of fast-growing species such as hybrid poplar can provide rapid C sequestration and N uptake, albeit with a shorter project duration than using slower growing species. Slower growing species, on the other hand, may be selected for the very purpose of longer function, such as in a windbreak, and thus have a longer project duration in which to sequester C. Mixtures of species, such as the herbaceous and woody plants used in riparian forest buffers, may be selected to optimize these GHG factors on site and also to provide other opportunities like biofeedstock production, which, in turn, would have additional GHG benefits (fig. 9.1 in chapter 9 of this assessment) (Schoeneberger et al. 2008). Other considerations can involve timing, placement, and type of N-fertilizer in agroforestry practices, where needed, and animal stocking numbers and rotation lengths in silvopasture systems (table 3.3). Many considerations can go into the planning and design of agroforestry, GHG mitigation being potentially one of them.

The various roles agroforestry can play in both GHG mitigation and climate change adaptation in U.S. agriculture—all depending on design and management—affords us the opportunity to rethink these practices in terms of optimizing benefits across the multiple objectives being sought for these lands (Schoeneberger et al. 2012). Waterbreaks are one example. A waterbreak is a planned floodplain system of linear woody buffers oriented to reduce flooding impacts (Wallace et al. 2000). Properly designed and located, waterbreaks could help address the potential impacts of the increased frequency and intensity of flood events being predicted under climate change and can also provide enhanced GHG mitigation services and many other nonflood-related services (fig. 9.3 in chapter 9 of this assessment). Other examples are presented in chapter 9.

## Accounting Needs

Advancements are being made in the approaches for determining relative values and directions of GHG impacts from agroforestry (see Ogle et al. 2014). Tools, like USDA COMET-Farm (http://www.cometfarm.nrel.colostate.edu), now available for entity-level C reporting and planning, have incorporated modules for agroforestry and other woody plantings. These tools can help land managers compare the relative amounts of GHG mitigation from the many different climate-smart management options available, including agroforestry.

As mentioned previously, although current GHG accounting in agroforestry is focused on C in the woody biomass and in the soil under the woody plants, full GHG accounting will need to take into account that (1) the agroforestry-influenced unit may be greater than just the agroforestry-planted area (fig. 3.2), and (2) spatial and temporal factors will need to be considered for the mixture of components (fig. 3.1 and fig. 3.3). For example, silvopasture requires not only the modification and coupling of crop and forestry accounting approaches, but also inclusion of accounting for the livestock. Again, at this time, accounting can essentially only be done for each individual component as if no interactions occur among the components. Work by Dube et al. (2011) in silvopasture, which involves the co-management of trees, forage, and animals, provides us a glimpse of the many integrated GHG dynamics in these highly integrated systems.

As an agricultural management activity, agroforestry GHG information needs are similar to those already identified for agriculture in general (Olander et al. 2013) and include—

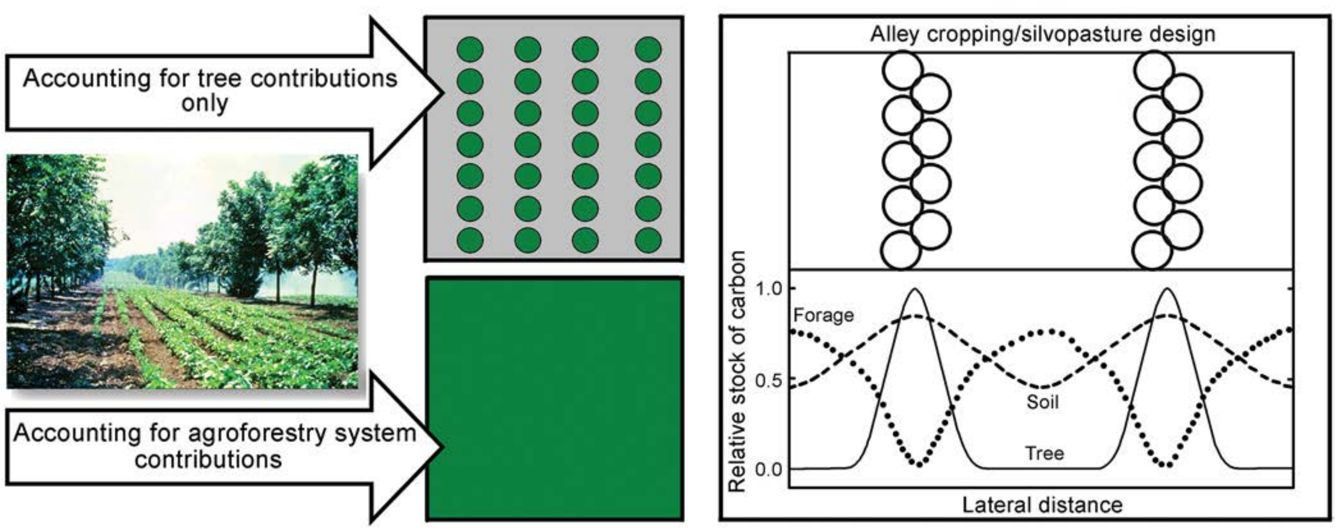
- User-friendly methods that work across scales, regions, and systems.
- Lower cost, feasible (end users' willingness to use) approaches.
- Methods that can crosswalk between emission-reduction strategies and inventories for reporting.
- Easily understood and common metrics for policy and market users.
- Continued research to account for and address the uncertainties in all the previous needs.

Although agroforestry practices have been part of the landscape for hundreds of years, they now reflect a wide variety of forms, management activities, and geographic settings. Performing the number of studies needed to adequately describe the performance of an agroforestry practice is physically and economically difficult. Regional and national coordination of agroforestry studies provides a more effective means to generate the necessary data. Standardization of measurement and modeling protocols would allow studies to be directly compared and the data then to be aggregated for additional research analyses and modeling efforts.

## A Common Framework for Greenhouse Gas Accounting in Agroforestry

GHG assessments of agriculture's many activities, including agroforestry, need to be compatible for maximum use of the data collected (i.e., to compare between activities and to aggregate the contributions of many activities into a whole-farm context) (Olander et al. 2013). To this end, the report *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory* was developed to create an

**Figure 3.3.** Complexities of carbon sequestration accounting within an agroforestry practice as illustrated by an alley cropping/silvopasture design. Accounting must be pragmatic, however, with the acknowledgment that accounting in agroforestry is not a 1+1=2 system but rather one in which 1+1 may be either greater than or less than 2, depending on the spatial and temporal factors influencing these interactive and long-lived systems.



updated standard set of GHG estimation methods for use by USDA, landowners, and other stakeholders to assist in GHG management decisions (Eve et al. 2014). Key considerations are consistent with IPCC (2006) and include—

- ***Transparency.*** Clearly explained assumptions and methodologies to facilitate replication.
- ***Consistency.*** Methods and estimates internally consistent between years and, to the extent possible, with other USDA inventory efforts.
- ***Comparability.*** Estimates of emissions and sequestration reported by one entity should be comparable to those reported by others.
- ***Completeness.*** Must account for all sources and sinks and also for all GHG to the greatest extent possible.
- ***Accuracy.*** Accurate estimates that are systematically neither over nor under true emissions or removals as far as can be judged.
- ***Cost-effectiveness.*** Balance between the relative costs and benefits of additional efforts to improve the inventory or reduce uncertainty.
- ***Ease of Use.*** Level of complexity of the user interface and underlying data requirements.

These considerations are especially relevant to agroforestry efforts in the United States. Efforts to build regional understanding and GHG accounting of agroforestry in the United States are currently limited by not only a lack of data but also by disparate sampling protocols and designs used between studies (Nair 2012b). A more coordinated approach that could be used among the agroforestry researchers within the United States, other North American countries, and other temperate regions would create a more cost-effective strategy for generating the data needed to inform GHG and climate change decision-making (Nair 2012b, Schoeneberger et al. 2012).

A logical place to begin framing a common approach to GHG assessment in agroforestry is perhaps best placed in the land use into which it is primarily deployed—agriculture. Such a coordinated approach is the USDA Agricultural Research Service's GRACEnet (Greenhouse gas Reduction through Agricultural Carbon Enhancement network) effort (Liebig et al. 2012). GRACEnet provides a national framework for standardized approaches to assess C sequestration and GHG emissions from different cropping and rangeland systems, using common measurement protocols and coordinated regional experimental design (Walthall et al. 2012). By capitalizing on GRACEnet's already-established framework and protocols, data generated should be readily comparable across agroforestry studies and practices as well as across the many other agricultural management practices, thereby enabling a more accurate whole-farm accounting.

## Capitalizing on Agroforestry's GHG and Adaptation Benefits

Pursuing agroforestry-derived GHG mitigation and climate change adaptation services simultaneously has technical and financial advantages (Duguma et al. 2014, Motocha et al. 2012, Plieninger 2011). GHG mitigation by agroforestry is dependent on having the plantings in place; however, adoption of agroforestry will be dependent on its cost-effectiveness, for whatever reason. Capitalizing on both the mitigation and adaptation services agroforestry can provide may help tip the balance in terms of cost-effectiveness for establishing new plantings. Carbon payments alone may influence adoption of agroforestry. However, the additional incentives tied to attainment of the adaptive services and goods agroforestry can also provide, such as protecting soil and air quality and providing critical wildlife habitat (e.g. pollinators), could lower the break-even prices even further and lead to greater adoption by farmers and ranchers (ICF 2013). Agroforestry also has the potential to generate additional income through diversified production and through hunting and other recreational fees, providing additional incentive. Use of these plantings as GHG mitigation strategies will ultimately hinge on the economics of agroforestry use (see chapter 4 in this assessment for further discussion of financial considerations regarding agroforestry) and on other producer values (see chapter 5 in this assessment for further discussion regarding adoption of agroforestry).

## Key Findings

- Agroforestry plantings can sequester C in soils and biomass and mitigate other GHG emissions while leaving the bulk of land in agricultural production and providing other production, natural resource, and climate change adaptation services.
- The C sequestration and indirect C (emission avoidance) benefits from agroforestry systems are generally comparable or larger in magnitude than many other agricultural management activities. With high rates of C sequestration per unit area, even small plantings like windbreaks can provide substantial contributions to whole-farm GHG mitigation.
- Agroforestry's other GHG mitigation services, while not all fully understood, appear to also contribute to the improvement of the GHG footprint of individual farm and ranch operations.
- The specifics of agroforestry design and management activities influence the amounts and duration of C sequestration and potential reduction in GHG emissions. As such, agroforestry, with its many components, provides a highly flexible and versatile management option to improve GHG mitigation and production services.

## Key Information Needs

- Identification of land in the United States suitable, both biophysically and cost-effectively, for establishing the various agroforestry practices to optimize GHG benefits along with other services agroforestry can provide.
- A national inventory to cost-effectively track land currently in agroforestry with a description of plantings (e.g., practice, age, condition) over time to evaluate contributions and include within U.S. GHG inventory assessments.
- A common GHG assessment framework to efficiently advance measurement, understanding, and predictive capacity of agroforestry's GHG services across the range of spatial and temporal settings in which agroforestry can be placed in the United States.
- Refined tools and methodologies for cost-effective and verifiable measurements/estimations of agroforestry's long-term potential to mitigate GHG emissions within the many agricultural production systems across the United States.
- Criteria and design tools to assist producers in developing appropriate configurations, species selections, and planting densities in the various agroforestry practices that optimize GHG mitigation along with other ecosystem services, including adaptation of and by the plantings to extreme weather events and other climate change impacts.

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# Chapter 4
# Valuation of Agroforestry Services

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Rural communities and lands are particularly vulnerable to climate change (Lal et al. 2011). Changes in the viability of plants and animals; arid land expansion; reductions in water quantity and quality; increased threats from pests, diseases, and wildfire; and more frequent extreme weather events may induce a variety of economic and social impacts on rural communities. These impacts include increased uncertainty of food and fiber production, reduced supply of ecosystem services, changes in employment opportunities, and human (and nonhuman) population relocations (Lal et al. 2011). Reducing the vulnerability of rural communities requires developing agricultural and forestry production systems that are resilient to changing environmental conditions (Lin et al. 2008, Verchot et al. 2007). Chapters 2 and 3 of this assessment demonstrate the potential for agroforestry to mitigate climate change (through increased carbon sequestration and reduced greenhouse gas [GHG] emissions) and assist rural communities in adapting to climate change by providing alternatives to conventional agricultural that are more resilient to the impacts of extreme weather events, changes in rainfall patterns, and increased risks from pests and diseases. Agroforestry, however, will make a significant contribution to mitigating or adapting to climate change only if landowners across the landscape adopt it in the United States (Scherr et al. 2012).

Economic theory predicts that farmers (who are price sensitive) will invest in agroforestry when the expected returns from the new system are higher than all other alternatives for the use of their land, labor, and capital. A large empirical literature confirms that a host of other factors also determine the extent of agroforestry adoption; these factors include household preferences, resource endowments, market incentives, biophysical factors, and risk and uncertainty (Mercer 2004, Mercer and Pattanayak 2003).[1] The role of risk and uncertainty, in particular, appears to be more important in agroforestry-adoption decisions compared with annual cropping innovations because of the long periods before the returns to tree growing are realized (Pannell 2003, Pattanayak et al. 2003).

Agroforestry systems also produce a number of important ecosystem services, such as carbon sequestration, biodiversity conservation, soil enrichment, and protection of air and water (Jose 2009). The value of these services to society is potentially quite high, but rarely are landowners paid for them. In many cases, agroforestry systems will be economically viable only when landowners are paid for producing these nonmarket services (Frey et al. 2010). Under these circumstances, it may be optimal for society to provide incentives to adopt agroforestry as evidenced by a number of Federal programs promoting agroforestry adoption (Godsey et al. 2009). Determining the optimal size of these incentives requires estimates of the value of the ecosystem services produced by agroforestry systems.

This chapter provides an overview of research on the economic valuation of agroforestry in North America. Economists have two approaches for valuing land-use systems: (1) financial analysis examines returns to investments from the landowner's perspective and typically focuses on enterprise- or farm-level outcomes and (2) economic analysis expands the analysis to include societal impacts beyond the farm boundaries (i.e., externalities) (Thompson and George 2009). We organize this chapter using this typology. First, we examine the current literature on the valuation of agroforestry from the landowner's perspective focusing on this question: "Under what conditions is agroforestry a viable financial enterprise for landowners?" We briefly review the various tools used for this type of analysis, including capital budgeting, production frontier analysis, and linear programming and their application to agroforestry. The second section of the chapter synthesizes the literature on the value of agroforestry from society's perspective, emphasizing the valuation of the ecosystem services and both positive and negative externalities associated with agroforestry. Then, we review the recent literature on the role and impact of risk and uncertainty on the adoptability of agroforestry in the United States and end with a summary of key findings and information needs.

[1] Economic theory can also be used to explain the impact of these factors.

## Valuation of Financial Returns to the Landowner

A range of methods and analytical tools has been used to estimate the financial returns to landowners from adopting agroforestry systems. These tools are summarized in table 4.1 and discussed individually in the following paragraphs.

### Capital Budgeting

Capital budgeting (cashflow or cost-benefit analysis) is the most widely used method for comparing the efficiency (profitability) of alternatives with different inputs and outputs (Klemperer 1996). Net present value (NPV), the sum of the discounted periodic net revenues per unit of land during a given period, is the most common decisionmaking criteria in capital budgeting studies. When the NPV is higher for agroforestry than are all feasible alternatives, it is potentially adoptable. The soil expectation value (SEV), the net return per acre assuming perpetual rotations, is more appropriate when the time horizons of alternatives vary (for example, when comparing annual cropping to agroforestry). Multiplying SEV by the interest rate gives the annual equivalent value, which can be used to compare alternatives yearly. Other capital budgeting criteria include the benefit-cost ratio, which compares discounted benefits to costs as a ratio rather than a difference, and the internal rate of return, which is the discount rate at which the present value of benefits equals the present value of costs (i.e., the discount rate that makes the NPV equal zero).

Frey et al. (2010) applied capital budgeting techniques to compare financial returns from eight agroforestry and seven forestry systems with annual cropping on marginal lands in the Lower Mississippi Alluvial Valley. With few exceptions, annual cropping produced higher returns than agroforestry and forestry, even in the absence of Federal agricultural support payments. A few forestry and agroforestry systems, however, were competitive on marginal agricultural lands, assuming landowners could sell carbon sequestration credits. Holderieath et al. (2012) developed cashflow models to assess the adoptability of silvopasture and alley cropping in Missouri, with and without payments for carbon credits. They found that additional incentives from selling carbon credits were not sufficient to encourage adoption of silvopasture or alley cropping practices because the financial returns were so much lower than annual cropping. Godsey et al. (2007) applied cashflow analysis to compare the costs of converting upland hardwood forests in the Missouri Ozarks to silvopasture with the cost of traditional improved pasture and found that silvopasture can produce positive NPVs. Ares et al. (2006) examined nut, timber, and forage production and the economics of managed pecan silvopasture in southeastern Kansas. They estimated discounted cashflows and NPVs from 20-year Monte Carlo simulations of four agroforestry scenarios for pecan/cattle silvopasture operations. Using current nut and beef prices and discount rates of 6 and 8 percent, cashflows were positive during the 20-year simulation, but NPVs were negative; however, adding timber production to the system produced positive NPVs.

Stamps et al. (2009) used cashflow analysis to compare alley cropping alfalfa with black walnut to conventionally grown alfalfa in Missouri. Although cashflows for black walnut plantations were negative for decades, adding alfalfa production in wide alleys between the walnut trees produced positive cashflows. The annual equivalent value for alfalfa monoculture, however, was almost 50 percent higher than for the agroforestry system, and, without payments for the ecosystem services produced from the agroforestry system, widespread adoption was deemed unlikely.

**Table 4.1.** Financial valuation methods.

| Methods | Definition | Agroforestry examples |
|---|---|---|
| Capital budgeting | Economic analysis to determine the relative profitability of investment alternatives. Decision criteria include net present value (NPV), soil expectation value (SEV), and annual equivalent value (AEV). | Frey et al. (2010)<br>Holderieath et al. (2012)<br>Godsey et al. (2007)<br>Ares et al. (2006)<br>Stamps et al. (2009)<br>Benjamin et al. (2000)<br>Graves et al. (2007, 2011)<br>Susaeta et al. (2012) |
| Linear programming | Optimization of an outcome based on some set of constraints using a linear mathematical model. | Stainback et al. (2004)<br>Wojtkowski et al. (1988)<br>Mudhara and Hildebrand (2004)<br>Thangata and Hildebrand (2012)<br>Dhakal et al. (2012) |
| Production frontier analysis | Parametric and nonparametric econometric techniques for measuring the technical efficiency of alternative production systems. | Frey et al. (2012)<br>Pattanayak and Mercer (1998)<br>Yin and Hyde (2000)<br>Lindara et al. (2006)<br>Gockowski et al. (2010)<br>Jahan et al. (2013) |

Benjamin et al. (2000) used a discounted cashflow analysis to compare returns to hardwood (walnut) alley cropping systems with traditional forest plantation, row crop monoculture (corn), and annual crop rotations (corn-soybean-wheat) in the U.S. Midwest. During a 68-year rotation, widely spaced alley cropping systems produced the highest NPVs (with a 5-percent discount rate) followed by traditional walnut plantations, both of which were more than twice as high as the returns for annual crops during the same period.

### Linear Programming

Linear programming (LP) models differ from capital budgeting in two important ways: (1) they analyze the entire farm, not just the activity of interest, and (2) they can account for farm diversity. Farm types are modeled separately and aggregated to evaluate potential adoptability across a landscape. When the landowners' objective is to maximize long-term profits from the entire farm under multiple constraints, LP is usually the preferred analytical tool. LP models have been widely applied to agroforestry systems in the tropics (examples include Dhakal et al. 2012, Mudhara and Hildebrand 2004, Thangata and Hildebrand 2012, Wojtkowski et al. 1988), but we could find only one study that applied LP in temperate zones. In this study, Stainback et al. (2004) used dynamic optimization models to compare the profitability of silvopasture with conventional cattle ranching in southern Florida, with and without taxes on phosphorous runoff and payments for carbon sequestration. In the absence of taxes and carbon payments, traditional ranching produced higher SEVs than the silvopasture systems. Although phosphorous taxes alone were not enough for silvopasture to compete economically with traditional ranching, payments for carbon sequestration with or without phosphorous taxes could make silvopasture competitive.

### Production Frontier Analysis

The production frontier, the maximum output that can be produced for any given level of input, is used to measure technical efficiency (TE). In one input/one output cases, TE is simply the slope of the line through the origin to any point on the production frontier. Measuring relative efficiency when faced with multiple inputs and outputs, however, is much more difficult. One approach is to use the ratio of the weighted inputs to weighted outputs. If all outputs and inputs have market values, the prices are the weights and TE is equivalent to the benefit-cost ratio. For situations in which markets are thin (small number of buyers and sellers), prices do not exist, and/or farmers may lack access to markets, benefit-cost ratios may not be comparable between farms. In these cases, two methods (parametric and nonparametric) are available. Although a large and growing literature is applying parametric methods to analyze agroforestry in the tropics (e.g., Gockowski et al. 2010, Jahan et al. 2013, Lindara et al. 2006, Pattanayak and Mercer 1998, Yin and Hyde 2000), we were unable to find any studies applying this approach to agroforestry in temperate regions.

Data envelopment analysis (DEA), the most common nonparametric alternative, uses LP to calculate the weights that maximize technical (or profit) efficiency. DEA is suited for comparing the efficiency of alternatives, even when market prices are not available for all inputs and outputs. DEA determines the weights (relative shadow prices) for each input and output that maximize efficiency. Although no studies in the United States using DEA could be found, Frey et al. (2012) applied DEA to compare the relative efficiency among silvopasture, conventional pasture, and plantation forestry in Argentina, after which, they applied nonparametric statistical analysis to compare the systems within farms. Silvopasture was found to be more efficient than conventional cattle ranching, but results were inconclusive for conventional forestry.

## Valuation of Ecosystem Services and Externalities From Agroforestry

In addition to providing financial benefits to landowners, agroforestry can also generate substantial ecosystem services to the public, including carbon sequestration; biodiversity conservation; and protection of soil, air, and water (Jose 2009). Ecosystem services, however, typically are not sold in markets and, therefore, cannot be valued directly with market prices. Designing optimal agroforestry policies (from society's perspective) for mitigating and adapting to climate change requires estimating the value of these nonmarket ecosystem service benefits and applying them in benefit-cost analyses.

Nonmarket valuation methods have been widely used to estimate the value of ecosystem services, such as biodiversity, water quality, and recreation. Valuation methods are usually based on either stated or revealed preferences. Stated preference approaches, including contingent valuation and choice modeling, rely on surveys to directly elicit values from respondents. Revealed preference approaches like hedonic analysis use actual choices people make in real markets to infer how much they are willing to pay for environmental goods and services associated with those choices. Although demand for nonmarket valuation studies of ecosystem services from agroforestry is increasing, only a limited number of studies applied to U.S. agroforestry currently exist. Table 4.2 summarizes the available methods.

**Table 4.2.** Nonmarket valuation methods.

| Methods | Definition | Agroforestry examples |
|---|---|---|
| Contingent valuation | Stated preference method that asks the respondents whether they would like to pay (or accept) a set amount of money for certain environmental condition. | Grala et al. (2012)<br>Shrestha and Alavalapati (2004a)<br>Qiu et al. (2006) |
| Choice experiments | Stated preference method that asks people to make choices based on two or more hypothetical conditions. A set of attributes, including environmental conditions, is described in each choice. | Shrestha and Alavalapati (2005)<br>Mercer and Snook (2004) |
| Hedonic analysis | Revealed preference methods based on the assumption that the prices of household properties represent the sum of values associated with property attributes, including the environmental assets. | Bastian et al. (2002)<br>Shrestha and Alavalapati (2004b)<br>Vanslembrouck et al. (2005) |
| Benefit transfer | Transfer of available information from existing literatures conducted in another location or conditions to estimate the benefit value of the current research condition. | Porter et al. (2009)<br>Kulshreshtha and Kort (2009) |

## Contingent Valuation

Contingent valuation is a survey method for estimating nonuse and passive use values in which respondents are asked how much they would be willing to pay or willing to accept for changes (positive or negative) in ecosystem service production under alternative land-use scenarios (Bateman et al. 2002, Mitchell and Carson 1989). Grala et al. (2012) employed contingent valuation to estimate the willingness of Iowa's residents to pay for the aesthetic benefits associated with field windbreaks. Depending on their perceptions about the visual appeal and abundance of field windbreaks, Iowa residents were willing to donate on average from $4.77 to $8.50 to a fund to pay landowners to plant windbreaks. Qiu et al. (2006) valued the benefits of riparian buffer zones in a suburban watershed of St. Louis, MO. Respondents were willing to pay an additional $1,400 to $1,625 to live in a community accessible to a riparian buffer and $6,100 to $6,858 for properties adjacent to a riparian buffer. The above two cases showed that residents are willing to sacrifice part of their income to support the establishment of agroforestry for the externalities provided, such as aesthetic values.

Contingent valuation surveys also have been used to estimate farmers' willingness to accept payments to supply various ecosystem services. For example, Shrestha and Alavalapati (2004a) investigated incentives for ranchers to adopt silvopasture in Florida. They found that natural attributes, such as wildlife presence, recreational hunting opportunities, and the presence of creeks increased the probability that ranchers would adopt silvopasture. To adopt silvopasture, however, ranchers would require an average price premium of $0.15 per pound for beef or a direct payment of $9.32 per acre per year. Buckley et al. (2012) investigated the willingness of farmers in the Republic of Ireland to install 10-meter-wide riparian buffer zones over 5 years. Of farmers surveyed, 47 percent were willing to adopt the proposed riparian buffer zone if paid, on average, $1.51 per linear meter per year.

## Choice Experiments

In contrast with contingent valuation, in which people are directly asked to state their willingness to pay (or accept; WTP) for changes in ecosystem services, choice experiments require respondents to choose from a series of two or more choice sets with options that contain various combinations of attributes for each choice (Hanley et al. 2001). Based on the statistical analysis of the respondents' sets of choices, the impact of each attribute on willingness to pay for an ecosystem service can be estimated. The WTP for a specific policy scenario is the sum of the WTP for all its attributes. Choice experiments can be especially useful in evaluating policies with a varying set of possible characteristics.

Two studies employed the choice experiment method to evaluate the preferences for several agroforestry attributes from the public's and landowners' perspectives. In the first study, Shrestha and Alavalapati (2005) used a choice experiment to estimate how much households in south-central Florida would be willing to pay for environmental goods and services produced by installing silvopasture systems in the Lake Okeechobee watershed of Florida. Three attribute levels were provided for each of the following environmental characteristics: (1) water-quality improvement, (2) carbon sequestration, and (3) wildlife habitat protection. The results indicated that an average household in south-central Florida would be willing to pay $30.24 to $71.17 per year for 5 years for the environmental benefits produced by silvopasture adoption. In the second study, Mercer and Snook (2004) describe a choice experiment to assess how different attributes of an agroforestry system influenced farmers' willingness to adopt agroforestry in Campeche, Mexico. The attributes included labor requirements, technical assistance, forest conservation, plant availability, and production resources. The results showed that farmers had a strong preference for increasing forest cover to bequeath a better world to their children and that important factors for adopting agroforestry included technical assistance; accessibility of tree seedlings; and a mix of products, including timber, crops, and fruit trees. Choice experiment studies are able to estimate the respondents' preferences toward both negative and positive attributes associated with agroforestry land—essential information for balancing different impacts in policy design.

## Hedonic Analysis

The hedonic price method is a revealed preference method based on the assumption that the prices of real estate are determined by the values associated with property attributes, including environmental amenities (Palmquist 1991). The hedonic method has been used to estimate economic damages associated with air pollution or water pollution, the economic benefits of aesthetic views, and the value of nearby recreational opportunities. For instance, if people who live near agroforests value increased wildlife habitat or the aesthetics of including trees in an agricultural landscape, the property values of nearby residences would be higher than more distant residences.

Three studies estimated the benefits from agroforestry generated by the price premium in real markets, such as land value, rent, or hunting license revenues. In the first study, Bastian et al. (2002) employed a hedonic model to examine the impact of wildlife habitat, angling opportunities, and scenic vistas on the value of agricultural land in Wyoming. The results showed that visually diverse lands generate higher prices relative to those landscapes dominated by agricultural production. In the second study, Shrestha and Alavalapati (2004b) investigated the effect of ranchland attributes, such as parcel size, tree cover, and proximity to urban centers, on recreational hunting in Florida. The results suggest that the additional tree and vegetation cover for silvopasture practices could increase hunting revenues. For example, maintaining 22 percent tree cover on ranchlands could increase hunting lease revenues by $16.15 per acre per year, an opportunity to supplement income from cattle. In the third study, Vanslembrouck et al. (2005) analyzed the effect of rural landscapes on the demand for rural tourism in Flanders, Belgium. Results indicate that some agricultural activities, such as meadows and grazing cattle, have a positive impact on how much tourists are willing to pay for rural accommodation, but intensive annual crop cultivation has a negative impact.

## Benefit Transfer

Benefit transfer techniques are commonly used to indirectly estimate values for ecosystem services when it is not feasible (because of time or resource constraints) to conduct studies on the site in question. A benefit transfer study collects data and results from previous studies performed in other locations or under different sets of conditions. The values of the benefits under study are then estimated by adjusting the results from the previous studies based on the similarities and differences between the studies' geographic and socioeconomic focus and methodological approaches.

Although the benefit transfer method is much less costly than conducting new research, care must be taken when extrapolating results from one setting to another. Both the geographical and socioeconomic characteristics of study sites may influence the estimates of values for ecosystem services (De Groot et al. 2012, Smith and Kaoru 1990). Instead of applying per-unit value estimates directly from the existing literature, it is preferable to use the functional forms and parameter estimates in a meta-analysis to derive values specific for the new study.

Porter et al. (2009) estimated the value of pollination, biological control, and food production from a combined food and energy agroforestry system in Taastrup, Denmark, based on previous estimates for agricultural ecosystem services by Costanza et al. (1997). Kulshreshtha and Kort (2009) employed the benefit transfer method to estimate the value of soil-erosion reduction, air-quality improvements, GHG-emission reductions, improved water quality, enhanced biodiversity, and enhanced recreation activities in prairie shelterbelts in Canada based on information in published literature. The total benefits for the external value from shelterbelts were found to be more than $140 million Canadian ($90.5 million U.S.) at 2001 exchange rates (OZF Foreign Exchange Services 2016). The previous two studies employed benefit transfer to value ecosystem services from agroforestry; however, the value used from previous literature may have been based on agricultural or forest land. The study did not distinguish between different land scenarios.

Choosing which nonmarket valuation techniques to use to value ecosystem services from agroforestry should be based on the available information and program circumstances. Stated preference techniques usually rely on surveys to investigate hypothetical scenarios of agroforestry programs. Conversely, revealed preference techniques use observations on actual choices that people made in existing markets to measure preferences. Contingent valuation and choice experiments are usually used to evaluate the nonconsumptive value of ecosystem services, such as biodiversity or cultural values. By contrast, the hedonic method is usually used to evaluate the consumptive values of agroforestry, such as aesthetic value or recreation. The limitation with stated preference methods is that the results are sensitive to numerous sources of bias in survey design and implementation. Although hedonic models avoid the potential problem with hypothetical responses, it requires a large amount of data that is largely limited to observable states of the world. In addition, hedonic results may be of limited value when markets are distorted, choices are constrained by income, or information about environmental conditions is scarce. Benefit transfer methods are used when resources and time are limited, such as when a large number of ecosystem services are being valued over a large area, and when sufficient numbers of previous studies are available to draw on.

## Risk and Uncertainty

Variability in returns and the ability to change or postpone decisions when conditions change are important decision criteria for landowners. Because deterministic models assume that landowners/managers have perfect foresight of future conditions, they are not appropriate in the face of risk or uncertainty. A variety of stochastic models, however, can be used to incorporate risky or uncertain future conditions. Using both stochastic and deterministic models can provide important insights about financial decisions (Frey et al. 2013). Table 4.3 lists the available methods with examples from the agroforestry literature.

### Mean-Variance Analysis

Mean-variance analysis (often referred to as E-V for "expected value/variance") can identify the set of "efficient" alternatives that either minimize risk for any given level of returns or maximize returns for any given level of risk. Although E-V is a powerful tool for decisionmaking, the underlying assumptions about utility functions and distributions of returns often conflict with economic theory. Nevertheless, E-V is appropriate under a wide variety of utility functions and common levels of risk aversion (Kroll et al. 1984). Lilieholm and Reeves (1991) used E-V to model the efficient allocation of agroforestry within the whole farm and used simulation to show that adopting agroforestry can be optimal for certain levels of risk aversion.

Frey (2009) applied E-V to examine the tradeoffs between returns and risk in the Lower Mississippi Alluvial Valley and the potential for reducing risk by adopting agroforestry systems. He found that diversifying annual row crop production with cottonwood, pecan, and silvopasture can reduce whole-farm risk substantially, particularly on marginal land. The farmers, however, face a tradeoff between reducing variation of returns (with agroforestry) or maximizing the expected value of the returns (annual cropping). Additional research is needed to determine when, where, and why farmers would be willing to choose agroforestry in these circumstances. We could find no other temperate zone E-V analyses of agroforestry. Analyses for tropical agroforestry include Ramirez and Sosa (2000) and Babu and Rajasekaran (1991).

### Stochastic Dominance

Because of less restrictive assumptions, stochastic dominance (SD) can be used when E-V is inappropriate (Hadar and Russell 1969). Results are less deterministic than E-V but typically provide only a partial ranking of efficient and inefficient alternatives. Therefore, SD is commonly used to estimate a partial ordering based on partial information for initial screenings of alternatives (Hildebrandt and Knoke 2011). No examples of studies assessing temperate zone agroforestry with SD were found; however, Castro et al. (2013) and Benítez et al. (2006) applied SD to analyze the uncertainties associated with using conservation payments to preserve shade coffee in Ecuador.

### Real Options

Management flexibility varies widely between land-use alternatives, and the ability to change or postpone actions can be crucial to the decision to adopt one system rather than another. One approach for incorporating uncertain future conditions is to apply real options (RO) techniques to estimate the value of flexibility for the alternatives. The key difference between RO and capital budgeting is the recursive nature of the RO decisionmaking process; i.e., RO provides an estimate of the value of being able to delay current-year decisions until future conditions are known (e.g., timber harvest and reforestation decisions).

Frey et al. (2013) used RO to analyze how the variability of returns and the flexibility to change or postpone decisions (option value) affect the returns to forestry and agroforestry systems, the adoption potential, and disadoption risk of agroforestry and production forestry in the Lower Mississippi Alluvial Valley. Due to the higher opportunity costs associated with converting from forests to agriculture, the option value provided by agriculture outweighed the forestry and agroforestry systems. The adoption potential of forestry and agroforestry was reduced when landowners took into account the flexibility provided by annual cropping systems as compared with tree-based systems, suggesting that simple cashflow analyses may overstate the adoptability of agroforestry in some cases.

**Table 4.3.** Incorporating risk and uncertainty.

| Methods | Definition | Examples |
|---|---|---|
| Mean-variance analysis | Mathematical analysis of effects of risk and expected returns to a portfolio of investments to identify the set of "efficient" alternatives that either minimize risk for any given level of returns or maximize returns for any given level of risk. | Frey (2009)<br>Lilieholm and Reeves (1991)<br>Ramirez and Sosa (2000)<br>Babu and Rajasekaran (1991) |
| Stochastic dominance | Method for comparing different distributions of outcomes among alternatives. | Castro et al. (2013)<br>Benítez et al. (2006) |
| Real options | Method that takes into account strategic management options of alternatives and the flexibility to exercise or abandon the options at different points in time. | Frey et al. (2013)<br>Behan et al. (2006)<br>Isik and Yang (2004)<br>Wolbert-Haverkamp and Musshoff (2014) |

Using RO models, Behan et al. (2006) also found that Irish farmers would wait longer to reforest/afforest than suggested by standard discounted cashflow analyses because of high establishment costs and the relative irreversibility of switching to forestry. Isik and Yang (2004) applied RO to examine participation in the Conservation Reserve Enhancement Program in Illinois. Although option values, land attributes, and farmer characteristics significantly influenced participation, uncertainties in crop prices and program payments and irreversibility associated with fixed-contract periods were also crucial. Wolbert-Haverkamp and Musshoff (2014) applied RO analysis to examine farmers' options to integrate short rotation woody crops into traditional agricultural cropping systems in Germany. They found that the conversion triggers calculated with RO analysis are higher than predicted with classical investment theory and that risk-averse farmers would be expected to convert earlier from rye production to short rotation woody crops than risk-neutral farmers.

## Summary and Conclusions

Research suggests that agroforestry systems may help mitigate climate change through carbon sequestration, rehabilitation of degraded lands, and stabilization of ecosystems by increasing resilience to climate change impacts through soil and water conservation, nutrient recycling, food security, biodiversity, and climate regulation (Lasco et al. 2014). The impact of agroforestry, however, will be limited by the extent of its adoption across the landscape, which currently remains quite low in the United States. This chapter examines the available economics literature on the value of agroforestry from both a landowner (net revenues) and a societal perspective (value of externalities). Although the literature is very thin, most of the economic studies of agroforestry in the United States that we were able to locate suggest that financial returns to adopting agroforestry are rarely competitive with modern annual agriculture unless incentives or payments for carbon sequestration and other ecosystem services are included. From a societal perspective, a few studies have applied nonmarket valuation techniques to value ecosystem services associated with agroforestry and have found significant willingness to pay by U.S. residents for the external ecosystem services produced by agroforestry. The available literature, however, is too small to make definitive statements concerning the economics and adoptability of agroforestry in the face of climate change.

### Key Findings

- Under current policy and economic conditions in the United States, agroforestry has the most promise for soils that are marginal for annual monocultures. It is unlikely to compete financially with modern monocultures on highly productive lands.
- The role of risk and uncertainty appears to be more important for adopting agroforestry than for annual cropping innovations, given the longer planning horizons required for implementing and managing agroforestry. Studies used to assess risk suggest that diversified systems like agroforestry may reduce whole-farm risk but at a cost of lowering total expected returns to the farm.
- An increasing number of studies are employing nonmarket value evaluation methods to measure the value of biodiversity, water quality, recreation, and other ecosystem services from agroforestry systems. Studies indicate that, when incentives or payments for ecosystem services are included, agroforestry can be competitive with conventional cropping and livestock systems.

### Key Information Needs

- The literature on the economics of agroforestry in temperate zones and, particularly, in the United States is very limited. Additional information is needed on financial and economic valuation, risk analysis, and how they influence adoptability of agroforestry in the United States.
- More nonmarket valuation studies of ecosystem services produced by agroforestry are needed, especially for those services benefitting society (biodiversity, water quality).
- More studies are needed to compare the ecosystem service benefits of agroforestry ecosystems with modern annual agriculture, plantation forestry, or forested ecosystems.
- Research is needed to quantify and understand future adoptability of agroforestry under a changing climate.

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# Chapter 5
# Human Dimensions of Agroforestry Systems

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The success of agroforestry in adapting and mitigating climate change depends on many human dimensions surrounding agroforestry. This chapter reviews research on the adoption of new practices by landowners and examines cultural perspectives on agroforestry. Diverse and complex motivators for conservation decisionmaking reflect the diversity of landowners, land management practices, and ecosystems and provide a variety of opportunities to encourage agroforestry adoption.

The chapter also reviews tribal and indigenous systems as models for modern resiliency. Affirmation of time-tested traditional agroforestry practices will help raise awareness and appreciation of traditional knowledge, with due respect to its indigenous origins. These diverse practices can play a vital role in reducing food insecurity, particularly on U.S.-affiliated tropical islands where the majority of food is imported. Practices by American Indians across the United States and practices on U.S.-affiliated tropical islands are highlighted and discussed in terms of building resilient operations, landscapes, and communities.

## Agroforestry Adoption Constraints and Opportunities

Land managers are the gatekeepers to the realization of agroforestry's climate mitigation and adaptation potential. Understanding how land managers make decisions is central to determining what role agroforestry can and will play in climate-smart strategies. Few studies focus on the adoption of agroforestry practices in the United States (e.g., Raedeke et al. 2003, Valdivia et al. 2012). Information can be gleaned, however, from research on land managers' decisionmaking regarding other types of conservation practices. This research suggests diverse and complex motivators and factors for conservation decisionmaking, reflecting the diversity of landowners and land managers, land management practices, and ecosystems involved (e.g., Baumgart-Getz et al. 2012, Knowler and Bradshaw 2007, Napier et al. 2000, Pannell et al. 2006, Prokopy et al. 2008). The decision to adopt and implement conservation practices is made by land managers for economic and cultural objectives and is influenced by knowledge from other practitioners and available technical guidance. Several models that describe the adoption of conservation practices and can help to explain agroforestry adoption are presented in the ensuing paragraphs.

Climatic variability and climate change make conservation-related decisionmaking more complex. Understanding farmers' attitudes toward climate change-motivated adoption of conservation practices has been found to be important in the United States (Barnes and Toma 2011, Prokopy et al. 2015). Farmers, in general, are more interested in adapting to climate change than mitigating greenhouse gases (Prokopy et al. 2015). Arbuckle et al. (2013) found that farmers may be willing to adapt to climate change, even though they may not think it is human caused or may not think it is happening at all. In their study, 62 percent of Iowa farmers surveyed said they would need to do more to protect their land from climate change in the future, but only 33 percent thought the government should do more to reduce greenhouse gases and other causes of climate change (Arbuckle et al. 2013). These findings suggest that farmers and other land managers could be better engaged by focusing on the impacts of climate change (and agroforestry's adaptive capacities) rather than on mitigation.

## Practitioner Motivations To Use Agroforestry

When discussing how adoption of agroforestry practices happens, it is important to consider who makes the decisions to implement these practices. Current and potential adopters of agroforestry practices are not a uniform group (fig. 5.1). Climatic variability and climate change are only two of many possible motivators and considerations that influence a land manager's decision to change his or her practices. Other factors in conservation practice adoption models include landowner and land manager demographics, farm characteristics, and landowner attitudes (Skelton et al. 2005). Farm structure, with variables such as the size of the farm, crop and product diversification, land tenure, and existing conservation practices, drives other models of adoption of conservation practices (for American Indians, see Mondou 1998). Landowners' economic bottom lines and climate change mitigation are among many factors of adoption. Categorizing potential agroforestry adopters can offer basic guidance for targeting adoption strategies (table 5.1).

## Barriers to Agroforestry Adoption

Many of the barriers to agroforestry adoption by land managers in the United States are the same as the barriers to other types of change. Theories about adoption of conservation practices are typically focused on economics (for more information on economics and agroforestry, see chapter 4). Although profit is a key motivator (Cary and Wilkinson 1997), profit maximization alone is not a reliable predictor of implementation of a particular agroforestry practice (Skelton et al. 2005). Decisionmaking about profit is mediated by other considerations, such as income diversification and reducing income risk (Zinkhan and Mercer 1997). Other factors besides economic considerations can be barriers to adoption (table 5.2).

Lack of information about how to implement and integrate agroforestry systems into their existing enterprises may be one of the most significant barriers for landowners. Survey results in Pennsylvania revealed that, although many landowners were interested in agroforestry (90 percent), most respondents did not have enough information about implementation, management, and marketing to follow through with adoption (Strong and Jacobson 2005). In a survey of U.S. extension professionals with responses from 32 States, about one-half of respondents (23 of 45 respondents), representing 16 States, provided programs in agroforestry (Jacobson and Kar 2013). These survey results suggest many States lack capacity in agroforestry. Information on revenue-generating specialty crops within agroforestry systems is also lacking (Gold et al. 2004a, 2004b). Enterprise budgets and decisionmaking models for these specialty crops are also limited, which makes it harder to get loans from traditional farm lending organizations.

**Figure 5.1.** Agricultural producers are a diverse group, each with their own motivations, characteristics, resources, and attitudes that can influence decisionmaking regarding agroforestry. (Photos (L-R) courtesy of Lynn Betts, Bob Nichols, Ron Nichols, Ron Nichols, Tim McCabe, Bob Nichols, USDA Natural Resources Conservation Service and USDA Office of Communications).

**Table 5.1.** Generalized list of potential agroforestry adopters and some of their common motivations and characteristics that can influence adoption of agroforestry practices.

| Potential adopters | Common motivations and characteristics | Reference |
|---|---|---|
| Large-acreage farmers | • Avoid potential environmental regulation by using practices to reduce negative offsite impacts.<br>• Increase yield and profit. | Skelton et al. (2005) |
| Small-acreage farmers | • Diversify farm operations and income sources.<br>• Lower risk to volatile markets and extreme weather events.<br>• Meet increasing interest in local and organic markets.<br>• Often have nonmanaged woodlands with agroforestry potential. | Jordan (2004),<br>Lasco et al. (2014),<br>Raedeke et al. (2003),<br>Workman et al. (2004) |
| Limited-resource farmers | • Increase food security.<br>• Diversify farm operations and income sources.<br>• Reduce input costs by relying on agroforestry practices to provide biological services. | Raedeke et al. (2003) |
| Beginning farmers and ranchers | • Easier to integrate agroforestry into new operations.<br>• More likely to participate in cost-share programs that can be used to implement agroforestry practices.<br>• More likely to implement agricultural best management practices. | Mishra and Khanal (2013),<br>Prokopy et al. (2008),<br>USDA NASS (2014) |
| Tribes and indigenous groups | • Sustain culturally significant food and fiber systems.<br>• Diversify farm and ranch operations and income sources.<br>• Encourage economic development.<br>• Increase food security. | Mondou (1998) |
| Ranchers, confined animal operations | • Avoid potential environmental regulation by using practices to reduce negative offsite impacts.<br>• Enhance public relations by using sustainable practices.<br>• Increase production and profit. | Gillespie et al. (2007) |
| Ranchers, free-range or pasture-based operations | • Diversify ranch operations and income sources.<br>• Increase interest in local and organic markets.<br>• Lower risk to volatile markets and extreme weather events. | Gillespie et al. (2007),<br>Workman et al. (2004) |
| Woodland owners | • Provide income independent of timber harvesting activities.<br>• Diversify income for part-time or nontraditional owners. | Valdivia and Poulos (2009),<br>Vaughan et al. (2013) |
| Public and nonprofit land managers | • Accomplish public goals for natural resources.<br>• Provide demonstration sites and opportunities for learning. | Garrett and Buck (1997),<br>Garrett et al. (2004),<br>USDA (2015) |

**Table 5.2.** Barriers to agroforestry adoption by land managers.

| Barrier | Description | Reference |
|---|---|---|
| Cost | • Tree and shrub establishment is perceived to be costly. | Valdivia et al. (2012) |
| Labor | • Agroforestry practices can involve more labor to manage. | AFTA (2000) |
| Lack of crop insurance | • Crops produced from agroforestry systems may be perceived as riskier than commodity crops if crop insurance is not available for the agroforestry crops. | Young et al. (2001) |
| Lack of support for traditional tribal agroforestry systems | • Government programs have favored intensive commodity crops rather than tribal agroforestry practices. | Cleveland et al. (1995),<br>Teel and Buck (1998) |
| Time | • Agroforestry practices require a longer management timeframe and have a longer expected period for return on investment. | Raedeke et al. (2003),<br>Valdivia et al. (2012) |
| Climate change impacts | • Uncertainty about future climate can inhibit landowners from investing in longer term agroforestry systems. | Kirilenko and Sedjo (2007) |
| Uncertain land tenure | • Land renters have less incentive to install practices that take time to return benefits of which they may not receive value. | Raedeke et al. (2003) |
| Complexity | • Agroforestry increases agricultural production system complexity and landowners are generally averse to adding complexity.<br>• Agroforestry practices may be incompatible with farmers' existing equipment or other fixed capital assets.<br>• Adding complexity is particularly challenging when existing production systems are fairly simple. | Valdivia et al. (2012) |
| Lack of information | • Agronomists and farmers generally have little experience in planning and managing agroforestry practices. | Coggeshall (2011),<br>Finn et al. (2008),<br>Gold et al. (2004a),<br>Gold et al. (2004b),<br>Jacobson and Kar (2013),<br>Warmund et al. (2010) |

## Support for Agroforestry Adoption

Significant support exists for increasing agroforestry adoption. Some of this support directly addresses barriers discussed in the previous section, and other support provides a starting point for addressing those barriers. The various types of support include—

- Policy support.
  - U.S. Department of Agriculture (USDA) Agroforestry Strategic Framework.
  - USDA Departmental Regulation on agroforestry.
  - Whole-Farm Revenue Protection (WFRP) pilot program.
- Partnerships.
  - Association for Temperate Agroforestry (AFTA).
  - Landowner associations.
  - Tribes and intertribal consortia.
  - Crop-processing cooperatives.
  - Crop-specific support groups.
- Agroforestry education and technical support.
- Incentives.

### Policy Support

Policy support for agroforestry at the Federal level is primarily through the USDA and its agricultural and forestry-based agencies. Increasing support from the USDA has been helpful in addressing the cost, time, complexity, and information constraints to agroforestry adoption. In 2011, the USDA released its *USDA Agroforestry Strategic Framework Fiscal Year 2011–2016*, which outlines the USDA's approach to agroforestry (USDA 2011). This framework created the Agroforestry Executive Steering Committee (which includes eight USDA agencies) to guide framework implementation. These actions increased Department-wide knowledge of agroforestry, enhancing the accessibility of agroforestry-related USDA lending and cost-share programs as USDA employees grow more knowledgeable about the risks and benefits of agroforestry. The USDA Departmental Regulation on agroforestry also created a consistent definition of agroforestry for all agencies to refer to, allowing for more programs to explicitly mention agroforestry in their guidance (Vilsack 2013).

As an outcome of this strategic framework, the first comprehensive report on agroforestry was released by USDA in 2013—*Agroforestry: USDA Reports to America, Fiscal Years 2011–2012* (USDA 2013b). A more comprehensive version was released in 2015 (USDA 2015). This report quantifies current agroforestry activities taking place both on the American landscape and within USDA, creating a baseline of information on agroforestry at the Federal level. One question in the 2012 Census of Agriculture addressed the adoption of silvopasture and alley cropping (USDA Census of Agriculture 2014). Inclusion of this question adds to the baseline information about agroforestry adoption in the United States. Other Federal policy changes, such as the WFRP pilot program—a USDA Risk Management Agency program for specialty and diversified crop producers—may also decrease risks for agroforestry producers with multiple crops. This program provides insurance coverage for the whole-farm enterprise, rather than for a single crop. It also insures farms with specialty or organic commodities (both crops and livestock) and those marketing to local, regional, farm-identity preserved, specialty, or direct markets (USDA RMA 2014). This coverage may be useful for agroforestry producers, who tend to have diversified operations.

In other instances, Federal policies affecting tribes have pushed for commercialization and modernization of tribal agriculture, which has been at the serious detriment of traditional and sustainable agroforestry systems (Cleveland et al. 1995, Mondou 1998). The American Indian Agricultural Resource Management Act (AIARMA 1994) has implications regarding how tribes maintain traditional and adopt modern agricultural systems (Mondou 1998). This act, which defines "agricultural product" to include crops, livestock, forage and feed, grains, and any other marketable or traditionally used materials, may be a vehicle to support tribal agroforestry (Mondou 1998). The U.S. Department of the Interior (DOI) Secretarial Order 3289, *Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources* details governmental programs that might be used to support tribal agroforestry under climate change (Salazar 2009).

### Partnerships

Social networks are known to play a significant role in the diffusion of agricultural innovations (Jackson-Smith and McEvoy 2011, Prokopy et al. 2008). Factors affecting diffusion include exposure to information from institutional and noninstitutional sources, including opinion leaders in the farm community and extension agents (Skelton et al. 2005). Agroforestry proponents and practitioners have embraced this social network-based approach by forming a variety of partnerships through peer-to-peer networks of either agroforestry landowners or agroforestry extension professionals or both.

Some of these networks and working groups exist at the regional level, sharing information on crop varieties, markets, policies, and programs that come from a shared political, ecological, and economic situation. Like organic producers, agroforestry producers have developed this knowledge collaboratively (Parker and Lillard 2013). Farmers get most of their important information about agricultural conservation practices from family, friends, and neighbors (Jackson-Smith and McEvoy 2011) and are more dependent on farmer-to-farmer networks than information that comes from the top down from organizations (Valdivia et al. 2012).

This peer-to-peer approach can be effective in facilitating farmers' decisionmaking by helping to diffuse information about particular practices and support (Ingram 2008). Many of the peer-to-peer networks related to agroforestry advocate for a variety of conservation practices. This approach is helpful because landowners tend to integrate agroforestry into their existing operations in conjunction with other conservation practices and maintain nonagroforestry systems on their farms. Many of these national networks are connected to one another through national and international organizations, such as AFTA, that seek to promote the wider adoption of agroforestry by landowners in temperate regions of North America.

Landowner associations, specialty crop-processing cooperatives (i.e., cooperatives that share processing infrastructure), and crop-specific support groups (e.g., North America Aronia Cooperative, the Upper Midwest Hazelnut Development Initiative) can also be helpful to landowners interested in agroforestry. Many specialty agroforestry products are economically viable only with processing, which can require equipment a single landowner may not be able to afford.

Many programs seek to improve conservation outcomes at a landscape scale across "all lands" (including public, tribal, and private lands). At the Federal level, some of these programs include the Two Chiefs' Joint Landscape Restoration Partnership, the Collaborative Forest Landscape Restoration Program, and the Joint Fire Science Program. Agroforestry provides a way for these programs, which are often primarily focused on forest lands, to achieve conservation outcomes on private agricultural lands as well.

### Agroforestry Education and Technical Support

Along with increasing information shared through partnerships, technical capacity related to agroforestry can be increased through education supported by Federal, State, tribal, and academic programs (e.g., Cooperative State Research, Education, and Extension Service, Federally Recognized Tribes Extension Grant Program). These programs generally target landowners and technical service providers. Deficiencies in the availability of formal and informal agroforestry training in temperate areas have long been noted (Nair 1993). Numerous training events have taken place during the intervening years that address this issue of increasing technical capacity (USDA 2015). Many of these training events target technical service providers who work with landowners. AIARMA (1994) provides opportunities for Federal training of tribes and members interested in an agricultural study program. Programs include, but are not limited to, agricultural economics, animal science, biological sciences, geographic information systems, horticulture, range management, soil, and veterinary science, all of which pertain to agroforestry practices and systems (Mondou 1998).

Although some studies have shown that education may be a more effective motivator than financial assistance for some landowners, the overall efficacy of education campaigns on the adoption of best management practices is still inconclusive (Prokopy et al. 2008, Skelton et al. 2005). Lassoie et al. (1994) noted the importance of education that not only addresses the mechanics of "how to" but also includes information on landowner motivations and effective integration of agroforestry into existing systems. Additional understanding related to how educational efforts should be structured to impact agroforestry adoption is needed and is being carried out through existing Sustainable Agriculture Research and Education grants.

Postsecondary education and training in agroforestry are available, though limited, with fewer than 20 colleges and universities offering graduate coursework in the field (Gold and Jose 2012, USDA 2015). Increasing postsecondary education capacity may be necessary. A need also exists to support tribal colleges to increase agricultural, forestry, and range educational programs as a means for expanding tribal agroforestry opportunities (Mondou 1998: 410):

> Unless the education of Native American Indians in all facets of agriculture is made available and accessible, the possibility of revenue generating agricultural enterprises is remote for tribes that lack sufficient capital to fund the education of willing and able students.

Creating a certification program for agroforesters has been proposed to address the lack of information among technical service providers (Mason et al. 2012). This proposed program would be developed jointly among the Society of American Foresters, American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

### Incentives

Because cost is an important constraint to the adoption of agroforestry systems, financial assistance programs have been developed for conservation practices, including agroforestry practices. Although financial assistance alone is not enough to motivate farmers to adopt conservation practices, conservation practices that are profitable are more likely to be implemented (Napier et al. 2000). A variety of government incentive programs support agroforestry practices at the Federal, regional, and State levels. Details about Federal incentive programs are described in chapter 6. At the regional level, additional incentives may exist to address particular natural resource concerns, such as the Chesapeake Bay Program that provides implementation funds for riparian forest buffers to address nutrient management problems in that region. Market incentives through ecosystem services markets may also encourage agroforestry practice adoption.

## Indigenous Systems as Models for Modern Resiliency

Although agroforestry is a relatively new scientific field, indigenous agroforestry systems have been cultivated for centuries—if not millennia—in much of the world, including in North America, the Pacific Islands, and the Caribbean (Clark and Nicholas 2013, Clarke and Thaman 1993, Ffolliott 1998, Lepofsky 2009, Smith 1929) (fig. 5.2). There is much to be learned from the adaptation strategies of indigenous peoples that have been developed in response to environmental changes over millennia and not just decades (Wildcat 2014). The long-term presence of agroforestry in much of the world is indicative of its resilience to extremes in temperature, precipitation, and storm wind, all of which are projected to become more frequent (Australian Bureau of Meteorology and CSIRO 2011, 2014; Keener et al. 2012; Kirilenko and Sedjo 2007).

Traditional indigenous multistrata agroforestry systems are models for sustainable agroecosystems (Kumar and Nair 2007, Soemarwoto 1987, Torquebiau 1992). Indigenous multistrata homegardens, which provide family food security throughout the tropics, are considered to be "the epitome of sustainability" (Kumar and Nair 2004). These multistrata systems that include a multitude of crop species and cultivars with varying tolerances to drought, waterlogging, wind, salt spray, and other climatic variables increase the resilience of their overall productivity when impacted by episodic environmental stressors (Barnett 2011). Crop and cultivar selection is crucial for the ability of the practice to tolerate sporadic environmental extremes. For example, in coastal buffer agroforestry for windbreak, erosion control, and food production, plants are chosen for their high tolerance to salt spray and storm surges (Wilkinson and Elevitch 2000).

After European/Western contact, colonization destroyed many of these traditional agroforestry systems, or they became neglected in favor of plantation-type agriculture in a process known as "agrodeforestation" (Thaman 1992). Today, up to 90 percent of food consumed in the previously self-sufficient island states of the Pacific and Caribbean is imported (FAO

**Figure 5.2.** Indigenous agroforestry systems have a long history in North America, the Pacific Islands, and the Caribbean. (A) A multistory cropping agroforestry system in Palau. (Photo by J.B. Friday, University of Hawaii). (B) Agroforestry system with coconut and taro on an atoll in the Pacific Islands. (Photo by John Quidachay, USDA Forest Service). (C) Ron Reed of the Karuk Food Crew collects gooseberries. (Photo by Colleen Rossier, University of California, Davis). (D) A member of the Alabama-Coushatta Tribe harvests longleaf pine needles for basket weaving. (Photo by Beverly Moseley, USDA Natural Resources Conservation Service).

2005). Loss of indigenous systems has led to environmental degradation and food insecurity for many developing small island states (Pelling and Uitto 2001). Residents of some low islands of the Pacific are some of the first climate change refugees in the world due to rising sea levels and amplified storm surges (Park 2011).

These threats, combined with rising awareness of the expected climate-related stressors, have resulted in renewed interest in protecting, expanding, and reestablishing agroforestry systems modeled after local indigenous systems (fig. 5.3). Trosper and Parrotta (2012: 1) wrote, "The role of traditional knowledge—and the bio-cultural diversity it sustains—is increasingly recognized as important by decision makers, conservation and development organizations, and the scientific community." Historical forced displacement, land seizure/cessions, and migration of indigenous people combined with social, economic, and land-use alterations with modernization have led to losses in traditional knowledge of systems and cultivars (Clarke and Thaman 1993, Falanruw 2009). Conversely, the remnants of traditional systems—and even virtually intact indigenous systems—that still exist represent a widespread and diverse reservoir of experience, species, and knowledge from which to draw in building adaptive responses to climate change.

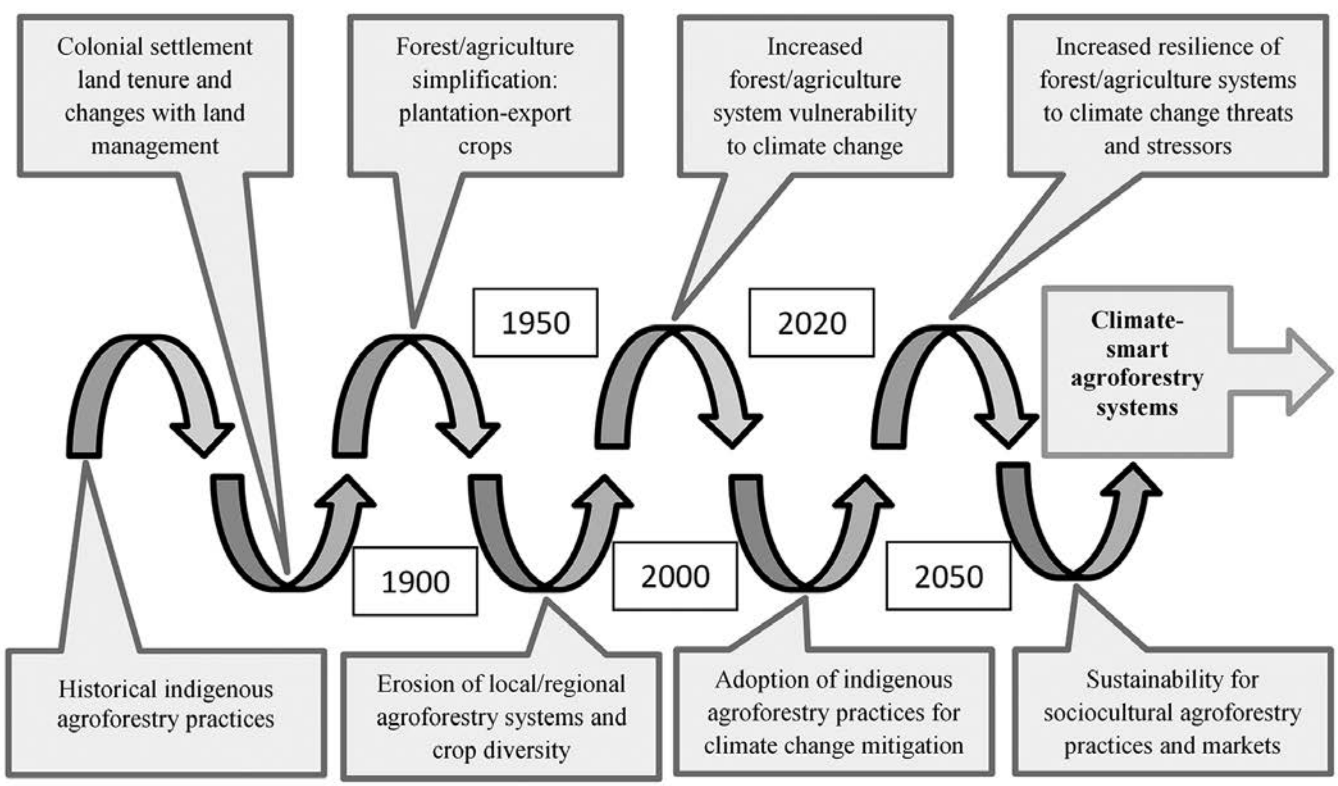
Affirmation of traditional practices, based on cultural aesthetics combined with scientific and economic validation of their productivity and practicality as an adaptation strategy, will help raise awareness and appreciation by producers, researchers, policymakers, and the general public. This increased awareness and appreciation will, in turn, lead to retention and use of traditional knowledge with due acknowledgment of its indigenous origins (Williams and Hardison 2013) as a viable and important component of climate change adaptation.

## Agroforestry Practices, American Indians, and Climate Change

American Indians across North America have been using and adapting traditional management practices to maintain and enhance food, fiber, and medicinal resources over millennia for their livelihoods and economies (Anderson and Parker 2009, Cleveland et al. 1995, Parlee et al. 2006). Many tribal programs and communities are implementing agroforestry practices to achieve resource objectives that integrate local values. These practices are locally adaptive and responsive to particular agricultural, range, and forestry systems that reflect tribal traditions (Mondou 1998).

American Indian land tenure arrangements are diverse. Tribal trust lands broadly include an array of designations ranging from reservations, rancherias, and individual allotments. Tribes also hold lands in fee, lease private property, and, in turn, lease tribal lands to nontribal entities, or they have arrangements and agreements to work on public lands within their ancestral territory. During early European settlement and development,

**Figure 5.3.** Timeline depicting influences on indigenous agroforestry systems and their adaptive responses to change.



many tribes were displaced, relocated, or moved out of their ancestral territory. Engaging in agroforestry practices can foster the integration of traditional values with modern resource management on tribal lands (Mondou 1998, Teel and Buck 1998). As Norton-Smith et al. (2016) indicate, adaptation methods may include initiatives that foster cultural identity and connection to place.

Agroforestry land management practices implemented by tribes and tribal members include forest farming, alley cropping, riparian forest buffers, windbreaks, and silvopasture. Other land management practices implemented by tribes and tribal members include forest/woodland grazing; fuelwood, biofuel, and fiber production from agricultural land, forest land, and rangeland; wild harvest (pine nuts, acorns, berries, mushroom, etc.); edible landscaping; intercrops as beneficial insect refuges; and groundwater and irrigation drainwater management (Bainbridge 1995, Rossier and Lake 2014). Tribes or tribal individuals use these practices to produce traditional foods, fibers, basketry/art materials, and medicinal plants or to maintain traditional customs and practices. These practices are often at a small scale, however, when compared with tribal work on conventional forestry, range, or agricultural operations. The distribution of many traditional food, fiber, and other species is shifting as the climate changes, accelerating the complexity of access and making traditional subsistence harvesting and storage practices more challenging (Norton-Smith et al. 2016). Adaptation strategies should recognize the cultural importance of these species as well as their political context (Lynn et al. 2013). This context is important when considering agroforestry as an adaptation strategy as well.

### Tribal Examples of Agroforestry

Many tribes across the United States have established a range of different agroforestry systems that integrate indigenous knowledge and stewardship practices with contemporary restoration and economic development opportunities (Cleveland et al. 1995; for tribal agriculture, see Mondou 1998; Rossier and Lake 2014). (Several regional examples are provided in boxes 5.1 to 5.4.) Peer-reviewed literature that describes these systems, particularly in the context of climate change, is sparse. As a result, these examples outline a limited set of known examples of agroforestry systems based on the information that is available. Tribal agroforestry pilot projects that started in the past 20 years could be evaluated for the potential success as applicable climate change adaptation strategies (Luna 2000, Rossier and Lake 2014, Mondou 1998).

In addition, many tribes across the United States are engaged in nursery greenhouse projects to support restoration of culturally valued plants (Dumroese et al. 2009). For example, Blackfeet Community College has a tribal nursery greenhouse project in which horticultural trials with traditionally used native plants species were conducted. More than 50 native plants were propagated for restoration and cultural education activities, especially for activities related to history and language associated with native plants (Luna 2000). Some of this restoration work is designed to create systems that include agroforestry practices.

## **Box 5.1.** Winnebago Reservation in Nebraska

Members of the Winnebago Reservation in Nebraska started a project to integrate forestry and agricultural management to meet local tribal food, land restoration, and soil conservation needs. They implemented a multicropping system by converting some commercial agricultural land into crops of traditional food species integrated with cultivars (Szymanski and Colletti 1999). They planted clover, corn, and soybeans between black walnut trees in an alley cropping system. They reforested areas between fields creating windbreaks and riparian forest buffers along streams. These efforts also were intended to improve wildlife habitat (Szymanski et al. 1998). The goal of the multicropping system was to produce shorter rotation cover crops and annual food crops and to foster longer lived species that provide food and wildlife habitat. No published research on the outcomes of this project was located nor was a response received from the tribe when an effort was made to contact them.

## **Box 5.2.** Mississippi Band of the Choctaw

A cooperative effort among the Mississippi Band of the Choctaw Tribe; the U.S. Department of Agriculture, Natural Resources Conservation Service; and others in Neshoba County, MS, sought to restore riparian and wetland systems to support cultural basketry traditions (Luna 2000). The tribal greenhouse was used for propagating plants that were of cultural and ecological importance. Focal plant species included Nutall oak (*Quercus texana*), mockernut hickory (*Carya tomentosa*), and switchcane (*Arundinaria gigantea*). Switchcane is one of the largest native grasses in North America, and the fiber is used in Choctaw basketry. The production of these baskets provides income for the tribe. Restored riparian and wetland areas with switchcane patches are harvested for use in traditional tribal basketry.

## **Box 5.3.** Seminole Tribe of Florida

The Seminole Tribe of Florida is carrying out silvopasture and other agroforestry practices in several States of their ancestral territory on tribal reservation and other trust lands and also on purchased private lands. The Seminole historically raised cattle and integrated range management with traditional burning of forests and grasslands (Sievers et al. 1985). The tribal silvopasture program integrates cattle range improvement with prescribed fire and other agricultural and farming needs of the tribal community. The tribe is also leasing lands, implementing agroforestry and restoration practices, and generating revenue from land leasing for farming and hunting.

## **Box 5.4.** Karuk, Yurok, and Hoopa Valley Tribes in California

In northern California, the Karuk, Yurok, and Hoopa Valley Tribes are integrating traditional forest management with agroforestry practices to reduce hazardous fuel loads, reintroduce fire, and enhance traditional foods (Rossier and Lake 2014). Tribes historically managed Douglas-fir-tanoak forests with fire to promote access for gathering different food resources. Fire reduces understory vegetation, improves tribal gatherer mobility, improves nutrient cycling, reduces nut and other insect pests, and enhances food quantity and quality (Anderson 1994). The benefits of agroforestry practices on valued tribal food and basketry plants are being studied in collaboration with Federal agencies, watershed and fire safe councils, and academic researchers. This work has the potential for application on National Forest System lands.

### Projected Impacts of Climate Change on Tribally Valued Resources and Tribal Agroforestry Practices

Ecological disturbances, such as flooding, drought, fire, and extreme weather events (e.g. temperatures) affect agroforestry practices and resources used for a range of tribal purposes (Cleveland et al. 1995, Mondou 1998, Voggesser et al. 2013). These disturbances directly and indirectly affect ecosystem goods and services and valued habitats and resources such as traditional and cultivated food crops; basketry materials/fiber resources; ranching, farming, and hunting practices; wildlife habitat quality that is of spiritual, cultural, and economic importance; public/tribal municipal water and air quality; and community recreational activities (Burger et al. 2008, Lynn et al. 2013). Downscale climate models and specific species climatic resilience studies have general application to tribes (Liverman and Merideth 2002, Vose et al. 2012).

The effects of climatic variability and climate change on American Indians and affiliated indigenous people and the Federal policies and authorities that are applicable are not well understood by resource managers and others working with tribes (Cordalis and Suagee 2008). A limited number of Federal policies and authorities pertain to tribal agroforestry and climate change. Currently, these polices address tribal agroforestry and climate change as separate issues, which may limit the use of indigenous agroforestry as an adaptive strategy for climate change. For instance, Section 105(a)(4) of AIARMA (1994) has implications for tribal agroforestry, but it lacks specific mention of climate change. Native Hawaiians and Pacific Islanders of U.S.-affiliated territories have other local authorities such as Act 234 (State of Hawaii 2007), which addresses climate change but does not specifically address Native Hawaiians or agroforestry.

### Considerations for Tribal Agroforestry

Many indigenous and tribal communities desire land, resource management, and agroforestry management tools that provide access to and improve the quality of valued habitats necessary to perpetuate traditional customs and knowledge systems in their ancestral homelands (Jones 2000, Rossier and Lake 2014). The adoption of traditional stewardship methods and related tribal agroforestry practices by nonindigenous/nontribal entities may have benefits ecologically and for food and fiber production systems, but it can create other concerns or pose threats for indigenous/tribal communities (Altieri and Nicholls 2013, Dixon et al. 1994). The misappropriation of traditional knowledge and tribal agroforestry practices by nonindigenous resource managers or industry is a concern and sensitive issue (Williams and Hardison 2013). Many anthropologists documented historical tribal harvesting practices and uses of food, fiber, and medicinal plants (Moerman 1998), from which many commercial enterprises benefit without any direct compensation back to tribes as the original holders of that knowledge and practice (Tedder et al. 2002). Many agricultural systems benefit from cultivars that originate from tribal sources, yet no recognition of or compensation for this indigenous/tribal legacy is formalized (Thrupp 2000). Mondou (1998: 407–408) states—

> Many Native American Indian farmers are striving to bring [traditional] farming back as an integral part of their respective culture by using modern technologies, while at same time trying to protect the folk variety seeds from mass marketing. With the advent of sophisticated biotechnologies and markets that are

worldwide in scope, notwithstanding intellectual property rights of the particular tribe, folk variety seeds of the indigenous people are in demand.

In addition, the commercial production, management, and wild harvesting of berries originates from tribal stewardship (Moore 1994), but commercial harvesting interest has affected tribal gathering.

The formulation of Federal policies and authorities that protect traditional knowledge, stewardship methods, and agroforestry practices consequently are limited. The Cultural and Heritage Cooperation Authority authorized in the Food, Conservation, and Energy Act of 2008 (also known as the 2008 Farm Bill) provides specific authority to the USDA Forest Service to protect tribal information about resources, cultural items, uses, or activities that have a traditional and cultural purpose from release under the Freedom of Information Act (CHCA 2008). Desai (2007) provides international examples for protecting traditional knowledge. Furthermore, many indigenous and tribal governments and community members will want assurances that their knowledge, traditional customs, and agroforestry practices will not be co-opted by nontribal members without permission or will not be inappropriately applied, which could result in the further disenfranchisement, marginalization, or exclusion from resource management, food and fiber production, and scientific research (Williams and Hardison 2013). Research can examine and provide evaluation for understanding at which scale or landscape condition indigenous and tribal agroforestry practices would increase the resilience of agricultural, range, and forestry production systems against changing conditions.

## U.S.-Affiliated Tropical Islands

The U.S.-affiliated tropical islands of the Pacific and Caribbean comprise hundreds of islands of varying sizes, elevations, climates, peoples, and histories. Agroforestry was, and on many islands is still, the predominant form of agriculture, using species and techniques introduced and developed before contact with European/Western culture. On various islands, these techniques include shoreline plantings and windbreaks, intensive mulching, shifting agriculture followed by forest fallow with varying degrees of enhancement, and multistory agroforestry (see the section on Hawaii and the U.S.-Affiliated Pacific Islands in appendix A). Colonization and subsequent cultural change have affected land tenure; shifted subsistence agroforestry toward cash economies and monocrop agriculture; and interrupted the transmission of traditional ecological knowledge, including agroforestry.

Climate change impacts on these islands, which vary depending on the region and local topography, include drought, increased storm intensity (wind and rainfall), sea level rise and coastal erosion, and salinization of groundwater. High sea levels have been especially pronounced in the western Pacific in recent years because of prevailing La Niña conditions, with coastal erosion and groundwater salinization being exacerbated on atolls by development impacts (Keener et al. 2012; Hawaii and the U.S.-Affiliated Pacific Islands in appendix A). Current-day island experiences of storms, inundation events, drought, and degradation of freshwater resources heighten public awareness and anticipation of climate change in the Pacific and Caribbean. These experiences seem to accelerate Pacific migration trends (already occurring because of aspirations for education, health care, and employment) from atolls to "high" (volcanic) islands and from remote islands to U.S. domestic areas (Hezel 2001). At the same time, communities and governments assert the desire for "future generations living productive lives on these islands" despite climate change, prioritizing the need for adaptation of agricultural policies and practices (RMI 2011).

Practitioners of agroforestry in the islands are diverse and include—

- Indigenous Pacific people who follow practices passed down to them by centuries of common tradition and by guarded family secrets, as in the case of prestige crops like yams in Pohnpei (Raynor and Fownes 1993). Their traditional ecological knowledge encompasses practices that effectively conserve soil and water and provide nutritious subsistence produce. A serious constraint to the continuation of these systems has been the interruption of passing traditional ecological knowledge to younger generations. With cultural change, family members who move away, focus on paid employment, or do not value the old ways, do not acquire the knowledge of their elders.
- Pacific Island residents practicing agroforestry with less benefit of traditional ecological knowledge. This group of practitioners includes younger generations; farmers affected by new pests or diseases that are unknown in traditional systems; inter-island migrants, who now practice on a different island (with different soils or climate); and migrants and contract laborers (primarily from Asia), who bring their own cultural practices and crop preferences.
- Small- and large-acreage landowners who grow coffee and other row or orchard crops with overstory shade (coffee and cacao) or windbreaks, particularly in the Caribbean, Hawaii, and Guam.
- Ranchers who incorporate agroforestry techniques (windbreaks, shade trees, living fences, alley cropping, and/or protein banks), particularly in the Caribbean, Hawaii, and Mariana Islands.
- Families of any description who have homegardens, including tree and nontree crops.

### Learning Networks

Changes in hydrology, variable weather conditions, and climate change and the introduction of invasive plants, insects, pests, and diseases constrain the success of traditional agroforestry systems. The variety of island ecosystems, indigenous systems, and species provides an opportunity for one island with changing conditions to look to another island for potential solutions. Pacific Island forestry agencies (USDA Forest Service grantees) welcome USDA technical assistance, even for traditional systems, to cope with new and unfamiliar weather/climate conditions and pests, as long as the advice and advisor respect the local context and knowledge (Friday 2011). In the Caribbean, associations for shade coffee and agroecology actively promote and support agroforestry, in collaboration with the USDA Natural Resources Conservation Service, U.S. Fish and Wildlife Service, university agricultural extension services, local governmental agencies, and environmental organizations that seek benefits for biodiversity and watersheds.

### Food Security, Ethnoagrobotany, and Cultural Pride

In the Pacific, a constraint to sustaining subsistence agroforestry and expanding it into the commercial realm has been the relative inconvenience of agroforestry products to consumers. They tend to be perishable, unfamiliar to new residents, and/or not marketed through commercial channels (Hollyer 2014). The counterbalancing opportunity is increasing awareness of the nutritional value of fresh, local island produce, especially starches with high fiber and vitamin content (e.g., breadfruit, taro, yam, sweet potato) relative to processed carbohydrates (white rice and flour), and of traditional or introduced species and cultivars with high vitamin content (e.g., the Karat banana) (Englberger and Lorens 2004). Campaigns for food security have tapped cultural pride, as with the Waianae Diet (Shintani et al. 1994) and documentation of ethnoagrobotanical heritage (Balick 2009). Initiatives have included policies favoring local food, promotional festivals, and projects in food processing and marketing improvements. Demand and markets for subsistence products vary by island and time period. The Caribbean likewise has a wealth of tropical fruits and special varieties (e.g., the West Indian avocado) through homegardens and local markets that can enrich diets.

### Economic Valuation

Another constraint to the use of agroforestry on the islands has been a historic focus by governments on cash crops and "modern" systems. This constraint in part stems from insufficient awareness and appreciation of traditional agroforestry. Many tropical agroforestry systems are still partially or wholly for subsistence use and their products are seldom included in agricultural and economic statistics. Past colonial or government decisions have resulted in land-use conversions to pasture and monocrop plantations (notably sugar and pineapple) and in a lack of institutional and extension support to validate and expand agroforestry. Valuation of agroforestry products, in terms of cash value of products (including import substitution) and per-acre values of agroforestry as a land use, provides an opportunity to increase recognition of agroforestry, leading to more supportive policies (ADB 2005; Drew et al. 2004, 2005).

### Economic Viability at Farm Level

Coffee grown under partial tree canopy shade (considered a multistory agroforestry practice) was once common in Puerto Rico until government subsidies and technical assistance promoted a transition to higher yielding, full-sun (nonagroforestry) systems. Coffee production then encountered labor constraints, low incomes, and catastrophic hurricanes, resulting in marked declines between 1982 and 2007. Problems of full-sun systems include shortened life span of coffee shrubs, high erosion rates, water-quality problems, and destruction of habitat for wildlife species. Growers' preference for shaded coffee systems provides an opportunity to return to agroforestry practices that afford more biodiversity and watershed environmental services, especially if incentives and support are provided for shade coffee as they were for sun coffee (Borkhataria et al. 2012). Likewise, some coffee farmers in Hawaii prefer shade coffee because of its more pleasant work environment and wildlife habitat (Elevitch et al. 2009). Many of the U.S.-affiliated islands have important tourism industries that provide opportunities for additional farm income through tourist experiences with coffee and other exotic agroforestry products.

### Land-Use Planning and Land Tenure

Migration and land tenure sometimes affect agroforestry in the context of the whole-island landscape. In the Pacific, as people move from distant to central islands or from coasts to interiors (because of climate change impacts or for other reasons), they seek land for food production. Sometimes native primary forest is converted to agroforest (FSM 2010), and sometimes agroforestry is intensified by using fewer trees (ASCC 2010). Where the practice of agroforestry or the planting of certain species signifies a claim to the land, that tradition thus encourages clearing native forest for agroforest. Changes in historic land tenure systems have resulted in weaker community and familial regulation of resources, often leading to exploitation and overuse (Falanruw 1992). The opportunities, therefore, are for governments to encourage agroforestry development in the most appropriate locations available—for example, by considering slope and erodibility when regulating land distribution and allowable uses (FSM 2010, KIRMA 2003), siting road development to enable access to suitable lands (Ramsay et al. 2013), providing grassland or secondary vegetation areas to migrants or other residents for agroforest development

(FSM 2010), reviving traditional conservation authorities, and providing extension support to influence choices (Shed 2012). In the Caribbean, historical changes in land tenure, industrialization, and recent urbanization disrupted family farming. Now, former agricultural land reverting to secondary forest in Puerto Rico and the U.S. Virgin Islands (Brandeis and Turner 2013a, 2013b) may provide an opportunity to expand agroforestry land uses, although the fertility of much of that land is constrained by soil degradation (Lugo and Helmer 2004).

## Conclusions

Farmers, ranchers, tribes, and other land managers are the gatekeepers to realizing agroforestry's potential for climate mitigation and adaptation. Because agroforestry is primarily conducted on private lands, human dimensions must be considered in the development of policies, programs, and outreach efforts. Potential agroforestry adopters are diverse—they differ in respect to their needs, types and conditions of their resources, social and cultural backgrounds, and the landscapes in which they operate. Agroforestry practices are also site specific, modified to suit the physical resources and ecology of the site. As a result, no one route will effectively encourage agroforestry adoption. Different strategies are needed to address the different challenges that land managers face in managing their operations and resources under climate change. Research on human dimensions in agriculture and resource management provides a beginning foundation on which to effectively advance agroforestry outreach and adoption. Increased educational opportunities, policy support, and partnerships may also encourage agroforestry implementation. Renewed interest in protecting, expanding, and reestablishing agroforestry systems modeled after local indigenous systems has emerged because of the resilience of those systems to climate change threats. The adoption of these traditional stewardship methods should be done with care to protect and respect the autonomy of tribal and indigenous sovereignty.

### Key Findings

- Factors influencing agroforestry adoption are similar to the factors that influence other conservation practices and, as such, agroforestry programs can build off information generated through research in these other areas.
- The various demographic groups in agriculture (e.g., small farms, tribes, limited-resource producers) have diverse motives and characteristics that can contribute to the adoption of agroforestry. Targeting adoption strategies based on these motivations and characteristics may enhance adoption.
- Addressing extreme weather and climate change impacts is but one of many reasons that landowners may adopt agroforestry practices.
- Common barriers to agroforestry adoption include implementation costs, labor requirements, longer timeframe for return on investment, uncertain land tenure, lack of information, and increased complexity.
- Traditional agroforestry systems of the United States and the U.S.-affiliated islands are important to indigenous populations, particularly for food security and cultural resources under the uncertainty of climate change. These time-tested models can inform solutions for building modern-day resilient agroecosystems, but few Federal policies specifically support indigenous agroforestry systems.
- Support for agroforestry adoption exists through various policies, partnerships, educational and technical assistance opportunities, and incentives and other financial assistance programs.

### Key Information Needs

- A greater understanding of land managers' perceptions of climatic variability and change and how it influences their decisionmaking, particularly concerning use of conservation practices (including agroforestry practices).
- More information regarding how agroforestry can fit into different types and scales of agricultural operations and marketing systems, including financial and labor requirements and economic values.
- The identification of the types of technical support and educational opportunities that are most effective at encouraging agroforestry adoption.
- A broader understanding of the additional support tribes and U.S.-affiliated island communities will require for adapting to current and anticipated climate change impacts.
- Better documentation of historical and current tribal and island agroforestry practices, with an emphasis on how these practices can be framed as or adapted for agroforestry land management.
- Evaluations on the resiliency of tribal and island agroforestry systems to disturbances, including assessments of threats and opportunities to enhance sustainability under climate change.

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# Chapter 6
# Agroforestry Resources

W. Keith Moser and Gary Bentrup

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Agroforestry has potential to serve as a climate change management option for building resilient and profitable agricultural operations and landscapes. Realizing this potential requires identifying the opportunities and tradeoffs that exist in each situation and designing an agroforestry practice that achieves the desired balance among them. The decisionmaking process must incorporate many considerations, not only at the field scale but also at the larger scales of farm, landscape, and watershed, while taking into account climate variability and change.

Resources for planning, designing, and implementing agroforestry systems can provide assistance in this process. Important resources for these tasks include decision-support tools and conservation programs that provide technical and financial assistance to interested landowners. This chapter presents available resources in both of these categories and identifies gaps in the suite of tools.

## Decision-Support Tools

The application of agroforestry can be greatly enhanced through the use of decision-support tools, which are any technology or resource that can be used to help integrate diverse sets of information (Ellis et al. 2004). Information gathering and analysis tools already exist at the farm ownership level, the most notable being precision agriculture systems (Mulla 2013). The focus of this section is on decision-support tools that assist implementation rather than tools that aid research in agroforestry science. Crucial differences exist between research tools and planning-and-design tools. Researchers generally seek answers to "Why?" whereas practitioners and landowners need answers to "What?" "Where?" and "How?" Useful decision-support tools for implementation should—

1. Minimize expenses.
2. Reduce dead ends.
3. Reduce anxiety of landowners and practitioners.
4. Accelerate necessary decisionmaking.

Agroforestry systems in the United States are applied in diverse geographic, environmental, and institutional contexts. In addition, each landowner has a unique set of conditions that will dictate different questions that the decision-support tools need to answer (Arbuckle et al. 2009). In light of each unique situation, practitioners and landowners will need to rely on a suite of tools throughout the planning and implementation process (Ellis et al. 2004).

Table 6.1 lists a broad cross-section of tools to support planning, design, and management of agroforestry systems. Although not an all-encompassing list, it illustrates the range and type of tools that are available. Some of these tools are specifically developed for agroforestry systems and others come from different disciplines but can be used effectively in agroforestry applications. Not every tool has a climate change focus, but most can help the user address the potential impacts of a changing climate and possible responses.

**Table 6.1.** Examples of decision-support tools to support planning, design, and management of agroforestry systems.

| Decision-support tool | Tool type | Focus | Description | End user | Reference/link |
|---|---|---|---|---|---|
| Agroforestree Database | Database | Biophysical | Provides information on the management, use, and ecology of tree and shrub species used in agroforestry. | Practitioners, landowners, researchers | Orwa et al. (2009) http://www.worldagroforestry.org/resources/databases/agroforestree |
| Agroforestry Species Switchboard 1.0 | Database | Biophysical | Documents the presence of more than 22,000 plant species in 13 Web-based databases and, when available, provides hyperlinks to information on the selected species. | Practitioners, landowners, researchers | Kindt et al. (2013) http://www.worldagroforestry.org/products/switchboard/ |

**Table 6.1.** Examples of decision-support tools to support planning, design, and management of agroforestry systems (continued).

| Decision-support tool | Tool type | Focus | Description | End user | Reference/link |
|---|---|---|---|---|---|
| Forestry Compendium | Database | Biophysical, economic, social | Offers a compilation of knowledge on forestry, agroforestry, and tree plantations, including decisionmaking information for tree management. | Practitioners, researchers | http://www.cabi.org/fc/ |
| Agroforestry Suitability Assessments | GIS | Biophysical, economic | Provides instruction for developing GIS-based suitability assessments for agroforestry. | Practitioners | Bentrup and Leininger (2002) |
| Target Regions for Silvoarable Agroforestry in Europe | GIS | Biophysical | Identifies regions where productive growth of trees in agroforestry systems could be expected and where these systems could reduce soil erosion and nitrate leaching and increase landscape diversity. | Practitioners, researchers, policymakers | Reisner et al. (2007) |
| Agroforestry Development Production Tool | Model | Biophysical, economic, social | Helps assess many levels of new agroforestry endeavors, including environmental, social, and economic considerations; labor; and cashflow planning. | Practitioners, landowners | http://agroforestry.ubcfarm.ubc.ca/agroforestry-production-development-tool/ |
| COMET-Farm™ | Model | Biophysical | Enables farmers and ranchers to estimate carbon sequestration and GHG emissions related to crop and livestock production and on-farm energy use. | Practitioners, landowners | http://comet-farm.com |
| HOLOS Farm Greenhouse Gas Calculator | Model | Biophysical | Estimates GHG emissions based on information entered for individual farms (calibrated for Canada) using whole-farm modeling software program. | Practitioners, landowners | http://www.agr.gc.ca/holos-ghg |
| FALLOW (Forest, Agroforest, Low-Value Landscape or Wasteland) | Model and GIS | Biophysical | Evaluates impacts of shifting cultivation and fallow rotations at a landscape scale, evaluating transitions in soil fertility, crop productivity, biodiversity, and carbon stocks. | Practitioners, researchers | http://worldagroforestrycentre.org/regions/southeast_asia/resources/fallow-forest-agroforest-low-value-landscape-or-wasteland |
| AgBufferBuilder | Hybrid GIS and model | Biophysical | Designs buffers around agricultural fields using terrain analysis to account for spatially nonuniform runoff. | Practitioners, researchers | http://nac.unl.edu/tools/AgBufferBuilder.htm |
| Water Erosion Prediction Project (WEPP) | Model | Biophysical | Predicts soil erosion and the effects of conservation practices on soil erosion. | Practitioners, researchers | http://www.ars.usda.gov/Research/docs.htm?docid=10621 |
| Riparian Restoration to Promote Climate Change Resilience Tool | Hybrid GIS and model | Biophysical | Identifies areas in the riparian zone that would benefit most from increased shading produced by planting trees. | Practitioners, landowners | http://applcc.org/plan-design/gis-planning/gis-tools-resources/riparian-restoration-decision-support-tool-1 |
| Economic Budgeting for Agroforestry Practices | Model | Economic | Provides guidance for developing agroforestry enterprise budgets. | Practitioners, landowners | http://www.centerforagroforestry.org/pubs/economichandbook.pdf |
| Simulation Tool to Assess Economic Impacts of Agroforestry Practices | Model (Excel based) | Economic | Evaluates the economic impacts of installing riparian forest buffers and windbreaks for crop, building, and road protection. | Practitioners, landowners | http://www.wbvecan.ca/anglais/coutspdf.html |
| Farm-SAFE | Model (Excel based) | Economic | Compares arable, forestry and silvoarable systems across four areas of a farm in order to determine the feasibility of silvoarable systems. | Practitioners, landowners, researchers | Graves et al. (2011) https://www.agforward.eu/index.php/en/web-application-of-yield-safe-and-farm-safe-models.html |
| Elderberry Financial Decision Support Tool | Model (Excel based) | Economic | Assists with establishment and management decisions. | Practitioners, landowners | http://www.centerforagroforestry.org/profit/elderberryfinance.php |
| Black Walnut Financial Model | Model (Excel based) | Economic | Assists with establishment and management decisions. | Practitioners, landowners | http://www.centerforagroforestry.org/profit/walnutfinancialmodel.php |
| Windbreak Economic Model | Model (Excel based) | Economic | Estimates long-term financial benefits of windbreaks on crop yields. | Practitioners, landowners | http://www.centerforagroforestry.org/profit/#budget |

**Table 6.1.** Examples of decision-support tools to support planning, design, and management of agroforestry systems (continued).

| Decision-support tool | Tool type | Focus | Description | End user | Reference/link |
|---|---|---|---|---|---|
| Midwest Hazelnut Enterprise Budget Tool | Model (Excel based) | Economic | Assists with establishment and management decisions. | Practitioners, landowners | http://midwesthazelnuts.org/ |
| Buffer$ | Model (Excel based) | Economic | Analyzes cost-benefits of implementing buffers compared with traditional crops. | Practitioners, landowners | http://nac.unl.edu/tools/buffer$.htm |
| Snow Fence Cost-Benefit Web Tool | Model | Economic | Calculates what transportation agencies can pay landowners to establish a living snow fence to reduce snow and blowing snow to highways. | Practitioners, landowners | http://snowcontroltools.umn.edu/#!/calculator |
| CanVis 3.0 Visual Simulation Kit | Model | Social | Simulates agroforestry practices with 2-D image-editing tool. | Practitioners, landowners | http://nac.unl.edu/simulation/index.htm |
| Agroecological Knowledge Toolkit (AKT5) | KBS | Biophysical, economic, social | Stores, manipulates, and analyzes a variety of information and knowledge on agroforestry agroecological systems. | Practitioners, researchers | http://akt.bangor.ac.uk/ |
| *Handbook for Agroforestry Planning and Design* | Other: handbook | Biophysical, economic, social | Assist in the planning and design of agroforestry practices. | Practitioners, landowners | http://www.centerforagroforestry.org/pubs/training/HandbookP&D13.pdf |
| *Agroforestry Tech Notes* | Other: technical note series | Biophysical, economic, social | Provides agroforestry information in a useful "how to" format. | Practitioners, landowners | http://nac.unl.edu/publications/agroforestrynotes.htm |
| *Conservation Buffers Handbook* | Other: handbook | Biophysical, economic, social | Provides design guidelines for buffers and other linear vegetative practices based on a synthesis of more than 1,400 research publications. | Practitioners, landowners | http://nac.unl.edu/buffers/index.html |
| *Silvopasture: Establishment and Management Principles for Pine Forests in the Southeastern United States* | Other: handbook | Biophysical, economic, social | Assist in managing pine silvopasture system in the Southeastern United States. | Practitioners, landowners | http://www.silvopasture.org/ |
| *Profitable Farms and Woodlands: A Practical Guide in Agroforestry* | Other: handbook | Biophysical, economic, social | Depicts step-by-step methods and principles on developing agroforestry practices for farmers and woodland owners. | Practitioners, landowners | http://nac.unl.edu/documents/morepublications/profitable_farms.pdf |
| USDA PLANTS | Other: Web site (online database) | Biophysical, economic | Provides botanical information, images, and links on plants in the United States, including crops and invasive species. | Practitioners, landowners | http://plants.usda.gov/java/ |
| Forest Farming eXtension Community of Practice | Other: Web site | Biophysical, economic, social | Consolidates resources on forest farming and offers a portal for landowners to ask questions of experts. | Practitioners, landowners | http://www.extension.org/forest_farming |
| CropScape | Other: Web site | Biophysical, economic | Provides a view of the USDA Cropland Data Layer for checking the type of crop grown in each field across the contiguous United States from 1997 to the present and a sequence of views that show how the distribution of crops has shifted over time. | Practitioners, landowners, researchers | http://nassgeodata.gmu.edu/CropScape/ |
| ClimateData.us | Other: Web site | Biophysical, economic, social | Provides comparisons of projected changes in temperature and precipitation and of conditions by decade under a mitigation scenario (reduced emissions) and a high-emissions scenario. | Practitioners, landowners, researchers | http://climatedata.us/ |

GHG = greenhouse gas. GIS = Geographic Information System. KBS = Knowledge-based system. USDA = U.S. Department of Agriculture.

Databases: Organize and facilitate the management and querying of large quantities of data and information.

GISs: Add a geographic or spatial component to a database; manage, manipulate, and analyze spatial data.

Models (mathematical): Represent real-world processes and predict outcomes based on input scenarios.

KBSs: Adopt artificial intelligence in the form of organizing, manipulating, and obtaining solutions, using knowledge in the form qualitative statements, expert rules (i.e., rules of thumb), and a computer language representation system for storing and manipulating knowledge.

Hybrid systems: Integrate two or more of the computer-based technologies listed in the table (e.g., GISs, KBSs, models) for more versatile, efficient, and comprehensive decision-support tools.

Other: Includes information resources such as Web sites and planning-and-design manuals.

Source: Adapted and updated from Ellis et al. (2004).

## Conservation Programs

Voluntary conservation-based programs at the Federal, State, and local levels provide technical and financial assistance to landowners to develop conservation plans and install conservation practices. These programs address a number of farming- and ranching-related conservation issues, including drinking-water protection, agricultural-waste management, soil health improvement, enhancement of fish and wildlife habitat, and better forest management and wetland restoration. Because agroforestry can help solve these issues, conservation programs are used as a resource for implementing agroforestry practices, particularly riparian forest buffers and windbreaks.

Federal assistance for agroforestry is primarily administered through U.S. Department of Agriculture (USDA) agencies, such as the Farm Service Agency (FSA), Natural Resources Conservation Service (NRCS), Forest Service, and National Institute of Food and Agriculture (table 6.2). The USDA programs are authorized through farm bill legislation; the programs in table 6.2 are based on the 2014 Farm Bill and may be subject to change as the details of that policy are refined during the next few years. Other Federal assistance and funding for agroforestry are available through the USDI's Fish and Wildlife Service.

Depending on the details in each program, financial assistance for landowners can come in the form of cost sharing implementation costs, incentive and maintenance payments, and land use or rental payments. In return, landowners must commit to maintaining the practice for the length of the contract period. Within these Federal programs, resource professionals with NRCS, the Forest Service, State agencies, conservation districts, universities, and technical service providers provide technical assistance for planning and designing tree-based practices. These assistance programs collectively have been an important resource in implementing agroforestry on farms and ranches. Table 6.3 summarizes agroforestry practices applied using FSA and NRCS programs. Data from the other Federal programs are not tracked in a way to easily quantify the agroforestry practices implemented.

**Table 6.3.** Agroforestry practices applied during FY 2012 to FY 2015 using all FSA and NRCS conservation programs.

| Agroforestry practice applied | Unit | FY 2012–FY 2015 |
|---|---|---|
| Windbreaks | Kilometers | 6,520 |
| Riparian forest buffers | Hectares | 30,950 |
| Alley cropping | Hectares | 110 |
| Forest farming | Hectares | 12,475 |
| Silvopasture | Hectares | 595 |

FSA = Farm Service Agency. FY = fiscal year. NRCS = Natural Resources Conservation Service.

Note: This table does not include agroforestry practices installed with other Federal or State programs or practices installed without assistance programs.

Source: USDA-NRCS (2016).

**Table 6.2.** Primary Federal conservation programs used for implementing agroforestry.

| Conservation program | Agency | Description | Eligible agroforestry practices |
|---|---|---|---|
| Conservation Technical Assistance (CTA) | USDA NRCS | Technical assistance to clients to address opportunities, concerns, and problems related to the use of natural resources. | Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming |
| Environmental Quality Incentives Program (EQIP) | USDA NRCS | Financial assistance to promote agricultural production, forest management, and environmental quality as compatible goals. | Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming[a] |
| Conservation Stewardship Program (CSP) | USDA NRCS | Financial assistance to encourage producers to undertake additional conservation activities or to improve, maintain, and manage existing conservation activities. | Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming |
| Conservation Reserve Program (CRP) | USDA FSA | Financial assistance to help agricultural producers safeguard environmentally sensitive land and to convert marginal cropland to long-term conservation cover, either grass or trees. The land is bid into the program on a competitive basis and ranked based on environmental benefits and cost. | Tree planting that can be used to support future agroforestry practices after contract period has expired |
| Conservation Reserve Enhancement Program (CREP) | USDA FSA | Special financial initiative within CRP to address agricultural resource problems, targeting priority environmental needs and providing additional incentives for conservation. | Riparian forest buffer, windbreak |
| Forest Stewardship Program (FSP) | USDA Forest Service | Technical assistance to nonindustrial private forest landowners to develop comprehensive, multiresource conservation plans for their forests. | Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming |
| Sustainable Agriculture Research and Education (SARE) Program | USDA NIFA | Competitive producer grants for landowners and practitioners who want to try new agroforestry enterprise concepts. | Alley cropping, riparian forest buffer, windbreak, silvopasture, forest farming, system research |
| Partners for Fish and Wildlife (PFW) | USFWS | Financial and technical assistance to help conserve, protect, and enhance fish, wildlife, and plants and their habitats on private lands. | Riparian forest buffer, tree planting |

FSA = Farm Service Agency. NIFA = National Institute of Food and Agriculture. NRCS = Natural Resources Conservation Service. USDA = U.S. Department of Agriculture. USFWS = U.S. Fish and Wildlife Service.

[a] Practice availability will vary from State to State, depending on each State's practice policies.

### States

Many States also have agency-supported programs that may be used to establish agroforestry practices, even if the program objectives do not have an explicit agroforestry focus. These programs are tailored to each State's conservation priorities and are too numerous to describe in this chapter. These programs, however, can be a resource for implementation because agroforestry can be used to support some State conservation goals. Although not a totally State-run program, the State of Washington Conservation Reserve Enhancement Program (CREP) is a joint Federal- and State-funded effort that restores riparian habitat for salmon. Since 1999, more than 445 hectares (1,100 acres) of riparian forest buffers and other restoration measures have been implemented on the Tucannon River with CREP. This action has reduced summer mean water temperatures by about 5.5 $^{o}$C, a valuable effect under a warming climate (Smith 2012). Young Chinook salmon (*Oncorhynchus tshawytscha*) are now using areas of the river that were previously too warm for them; the number of returning Chinook adults rebounded from a low of 54 fish in 1995 to 1,239 in 2012 (Gallinat and Ross 2013).

### Private or Other Nongovernmental Organizations

Numerous private organizations indirectly support agroforestry by offering grants, cost share, and equipment on loan for landowners who are improving wildlife habitat with timber stand improvement or by planting shrubs, trees, and forages. Examples of these private organizations are the National Fish and Wildlife Foundation (NFWF), the National Wild Turkey Federation, Quail Forever, Ducks Unlimited, and Pheasants Forever. For instance, NFWF is planning to invest $12.9 million in the Chesapeake Bay watershed between 2013 and 2025 to install 2400 kilometers (1,500 miles) of riparian forest buffers for water-quality and wildlife habitat improvement (NFWF 2012).

## Challenges and Opportunities

Although tools are available for implementing agroforestry, challenges and needs persist as we improve existing tools and develop new ones to add to the suite of tools. These broad challenges include:

- Analytical capacity.
- Scalability.
- Comparison of alternatives.
- Usability.

### Analytical Capacity

Unlike the extensive datasets that exist for agronomy and forestry in the United States, agroforestry has a less robust collection of data on which to develop decision-support tools and models (Ellis et al. 2004). The inherent flexibility of designing an agroforestry system or practice, although a highly desirable feature, can result in a number of potential agroforestry systems and combinations of plantings. The multiple possible combinations can create challenges for building tools and models capable of handling the diversity of options. As a consequence, basic models are often used to predict outcomes from agroforestry practices although these models can have high uncertainty and risk, especially due to our limited understanding of the impacts of climate change on agroforestry. Whereas climate change impacts on monoculture crops or simple livestock production systems can be reasonably predicted with process-based models, robust models for multifaceted agroforestry systems are not yet available (Luedeling et al. 2014). The challenge will be to enhance the analytical capacity of agroforestry tools for present-day decisionmaking and to refine those tools as additional information becomes available (see chapter 9).

### Scalability

In the United States, agroforestry practices are implemented at the site scale by individual landowners who make decisions based on the benefits they desire, such as income diversification and soil protection. Among the agroforestry community, the expectation is that these individual agroforestry actions by numerous landowners will collectively lead to the benefits that society values, such as water-quality protection and food security, at a magnitude that will have impact. Many agroforestry decision-support tools have focused on the landowner scale (site, field, farm) because farmers and ranchers hold the key to agroforestry adoption and implementation. Tools at landscape and watershed scales, however, are also needed to help inform placement of agroforestry practices to more effectively achieve societal benefits (Tomer et al. 2009). Targeting tools that identify areas in the landscape where agroforestry practices can achieve multiple benefits simultaneously will be valuable in accomplishing landowner and societal goals (Reisner et al. 2007). The challenge is to collect data at the appropriate scales and to build tools that can work across those scales.

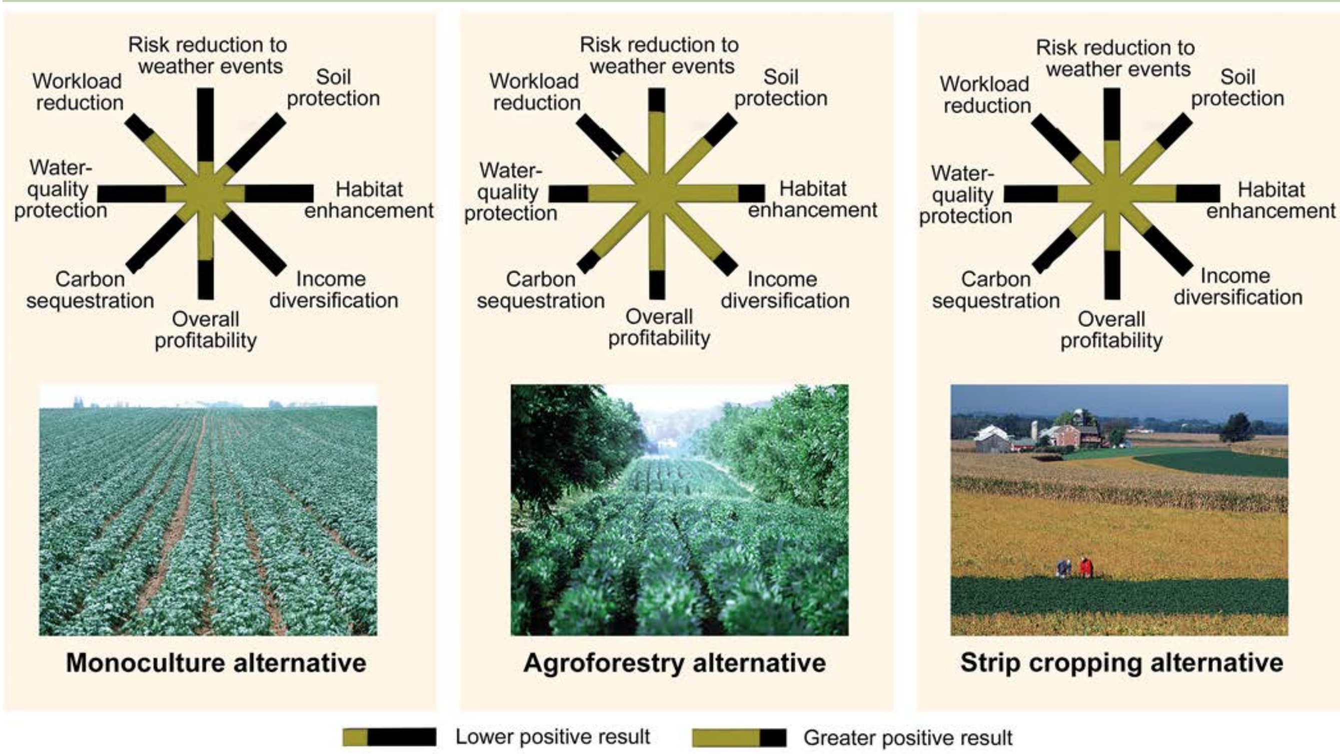
## Comparison of Alternatives

Decisionmakers often compare tradeoffs between alternative courses of action; therefore, effective decision-support tools need the capability to present the differences between the options (Ellis et al. 2004). By design, agroforestry can have numerous ecological, economic, and social effects, so the ability to compare these effects during decisionmaking is important. Placed within a larger context, agroforestry is just one option of many for transitioning to climate-smart agriculture (e.g., Delgado et al. 2011, FAO 2013). Many tools currently available for climate-smart agriculture focus on a single approach and do not facilitate cross-comparison among options (FAO 2013). Hence, the challenge is to develop tools that can compare tradeoffs among various climate-smart agricultural options at the scale of the decisionmaker (fig. 6.1).

## Usability

The usability of a decision-support tool by end users may be the most important challenge to address because, if the tool is not used, the time and cost of developing the tool is generally wasted and the scientific information underlying the tool will not aid in decisionmaking (McCown 2002). To enhance the adoption and use of agroforestry tools, end users should be consulted in tool development from start to finish, ensuring the tools match their needs and capabilities (McIntosh et al. 2011). If end users are not involved in the process of developing these tools, the resulting tools may be too complicated, too narrowly focused, and too difficult to apply in many situations (Ellis et al. 2004). Another usability consideration, particularly with erratic weather and climate change, is accommodating users with different comfort levels regarding uncertainty and risk (Willows et al. 2003). Agroforestry tools will need to incorporate innovative ways to help users evaluate risk and uncertainty in a manner that fits their decisionmaking style (see Kujala et al. 2013, Peterson et al. 2003; see appendix B).

**Figure 6.1.** A conceptual framework for comparing climate-smart agriculture options for decisionmaking. This diagram illustrates the need for decision-support tools that enable comparison of options across a variety of ecological, economic, and social considerations. This framework ideally would allow for quantitative comparisons. The longer the buff-colored bar, the greater the positive result for that resource issue. (Basic scheme from Foley et al. 2005).



## Opportunities

Decision-support tools are rarely standalone components but are used most effectively in a planning-and-design process to identify needs, develop plans, and compare tradeoffs. Technical assistance offered through conservation programs often provides a structured process in which to use decision-support tools to implement agroforestry. Among the opportunities to improve the delivery of this important service (Dosskey et al. 2012), one of the greatest is to increase awareness of these conservation programs for implementing agroforestry through promotional materials, train-the-trainer programs, and agroforestry demonstration sites (Lassoie et al. 2000).

Another opportunity is to use the planning-and-design processes provided by conservation programs as a tool to assist in adaptive management. Adaptive management is a structured, iterative process of decisionmaking in the face of uncertainty, with the goal of reducing uncertainty over time via system monitoring (Howden et al. 2007). Adaptive management has the potential to reduce the risks of climate change in agriculture by improving planning, preventing maladaptation, and informing investment and resource management (Walthall et al. 2012). By tracking the successes and failures of different adaptation actions using agroforestry and other climate-smart agriculture strategies, effective, efficient, and equitable policies and measures can be identified that can lead to more robust adaptation strategies over time (Preston et al. 2011).

## Key Findings

- The multifaceted nature of agroforestry practices and the diversity of landowner considerations require a suite of decision-support tools.
- A variety of decision-support tools addressing biophysical, economic, and social considerations are available for applying agroforestry.
- Financial and technical assistance from Federal and State conservation programs and private organizations has proven valuable in implementing agroforestry practices.

## Key Information Needs

- Strengthen the analytical capacity of decision-support tools for agroforestry.
- Continue developing targeting tools that identify locations for implementing agroforestry practices that concurrently achieve landowner and societal goals.
- Develop decision-support tools that enable comparisons of tradeoffs among climate-smart agriculture options at the scale of the decisionmaker.
- Involve end users in the development of the decision-support tools to ensure the tools match their needs and capabilities.

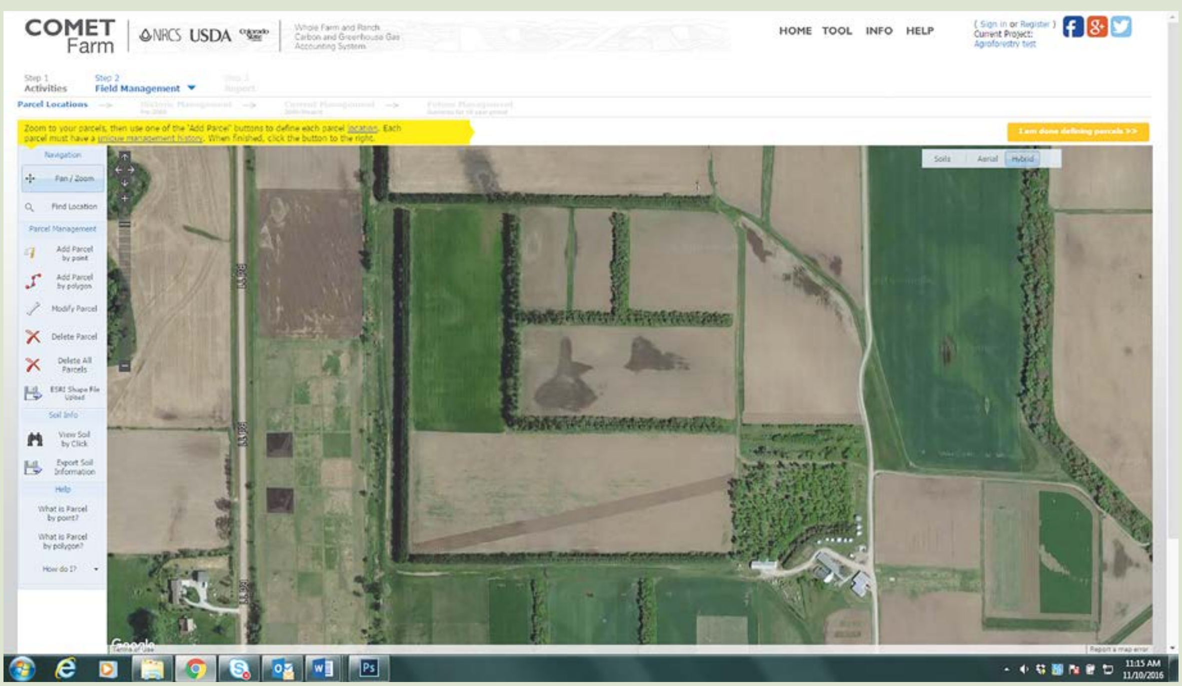
## **Box 6.1.** COMET-Farm™

COMET-Farm is a Web-based tool enabling farmers, ranchers, resource professionals, and others to assess the greenhouse gas (GHG) balance of land use and management. The tool allows for assessments of the GHG emissions and potential for carbon sequestration in farming, ranching, agroforestry, other livestock operations, and on-farm/ranch energy use. COMET-Farm estimates the GHG footprint for all or part of a user's farm/ranch operation and enables the user to evaluate the GHG benefits of conservation practices. General guidance is provided about potential changes to management practices that are likely to sequester carbon and reduce GHG emissions.

Because the tool uses detailed spatially explicit data on climate and soil conditions for a user's location and allows users to enter detailed information for field and livestock operations, it is able to produce an accurate estimate tailored to a user's specific situations. No previous training is required to run the tool, and embedded Help functions are provided. The tool guides the user through describing farm and ranch management practices, including alternative future management scenarios. After this setup process is complete, the tool generates a report comparing the carbon changes and GHG emissions between current management practices and future, alternative scenarios.

Agroforestry assessments conducted in COMET-Farm use a stock-change method. This tool enables a user to describe agroforestry practices according to the number of trees in his or her system and the sizes (diameters) of those trees; from this information, the tool calculates the biomass carbon stock now and at 10-year intervals for 50 years in the future and a yearly average. Biomass carbon stocks and change rates are calculated based on growth equations developed from the Forest Inventory and Analysis database of the U.S. Department of Agriculture (USDA), Forest Service.

COMET-Planner is another tool available within the COMET-Farm suite of tools that can be used to provide a quick and broad estimate of GHG potentials of implementing USDA Natural Resources Conservation Service conservation practice standards, including agroforestry practices. This tool considers impacts on GHG including woody biomass carbon accumulation, change in soil organic matter carbon due to cessation of tillage and increased carbon inputs from plant residues, and decreased nitrous oxide from lower synthetic fertilizer application due to the implementation of an agroforestry practice. Users need only enter location data, select the practices, and select the acreage under these practices to generate a yearly estimate of the GHG emission reductions. Both tools are available for use at http://www.comet-farm.com.




*The COMET-Farm tool enables landowners to use spatially explicit data on climate and soils for their location and to input information on their field and livestock operations to produce an estimate of GHG emissions and potential for carbon sequestration. COMET-Farm is funded by grants from the USDA Natural Resources Conservation Service and the USDA Office of the Chief Economist.*

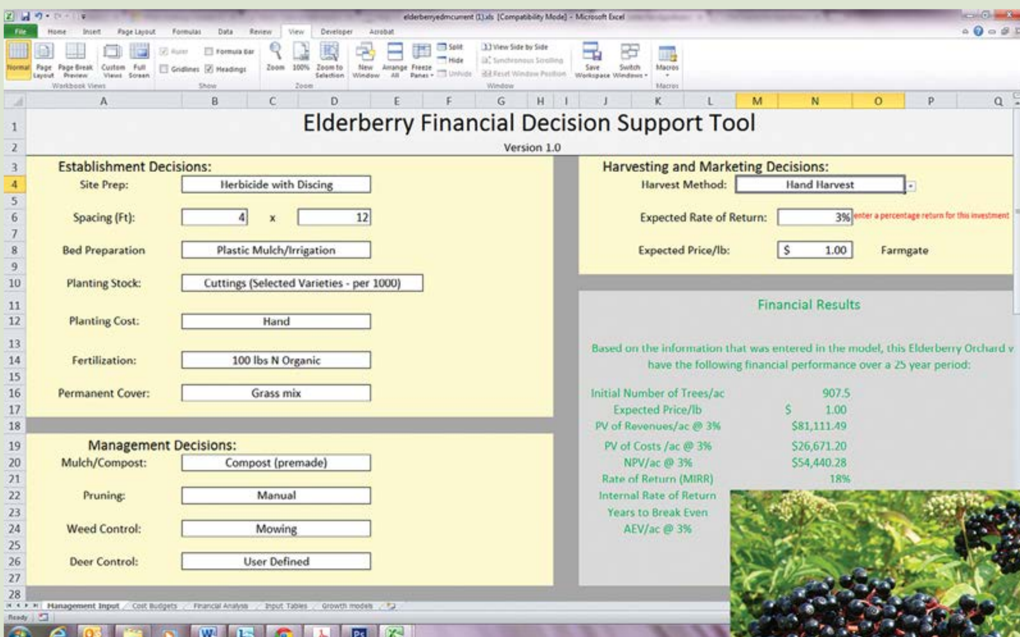
## **Box 6.2.** Economic Tools

Some of the most pressing questions for landowners wanting to know about incorporating agroforestry into their operations center on financial concerns, including costs, returns, risk, and uncertainty. Recognizing this need, the Center for Agroforestry at the University of Missouri (UMCA) developed several financial tools to help landowners explore those questions.

Agroforestry poses some unique economic budgeting challenges because it involves multiple enterprises with varying production cycles, such as trees, row crops, forages, and livestock. To help navigate these challenges, a step-by-step guide, *Economic Budgeting for Agroforestry Practices* (Godsey 2010), provides a flexible process that can be applied to any agroforestry enterprise for estimating financial needs and feasibility, highlighting tradeoffs, and monitoring economic efficiency. This tool enables landowners to develop enterprise budgets and combine these budgets into annual cashflow plans for evaluation.

Several Microsoft™ Excel-based economic tools are available from UMCA. The Windbreak Economic Model is a practice-based tool for estimating long-term financial benefits of windbreaks on crop yield. More detailed tools are available to evaluate the economic potential of black walnut (*Juglans nigra*) for nut and timber production and American elderberry (*Sambucus canadensis*) for fruit production. The Black Walnut Financial Model is a simplified model for assisting potential growers with making decisions about tree spacing, nut harvesting, and using improved (grafted) or unimproved trees.

The *Elderberry Financial Decision Support Tool* is designed to assist with elderberry establishment and management decisions. This model enables users to select options from a list of common establishment, management, harvesting, and marketing techniques to determine the mix of options that will generate the best economic returns. Each tool includes a random variable to simulate uncertainty in production due to annual weather conditions and other unpredictable events. Additional plant-specific tools are under development and soon will be released. The available tools and other financial resources are available at http://www.centerforagroforestry.org/profit/#budget.



*Elderberry is a hardy, multipurpose shrub that is suitable for many agroforestry practices. The fruit and flowers are edible and can be used for making wines, jams, syrups, and health tonics. The plant has other attributes, including attracting and benefiting birds, pollinators, and other wildlife; tolerating wet or poor soil conditions; and producing extensive root systems that can help reduce soil erosion. Photo: http://commons.wikimedia.org/wiki/File:Sambucus-berries.jpg.*

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# Chapter 7
# Expanding the North American Perspective—Canada

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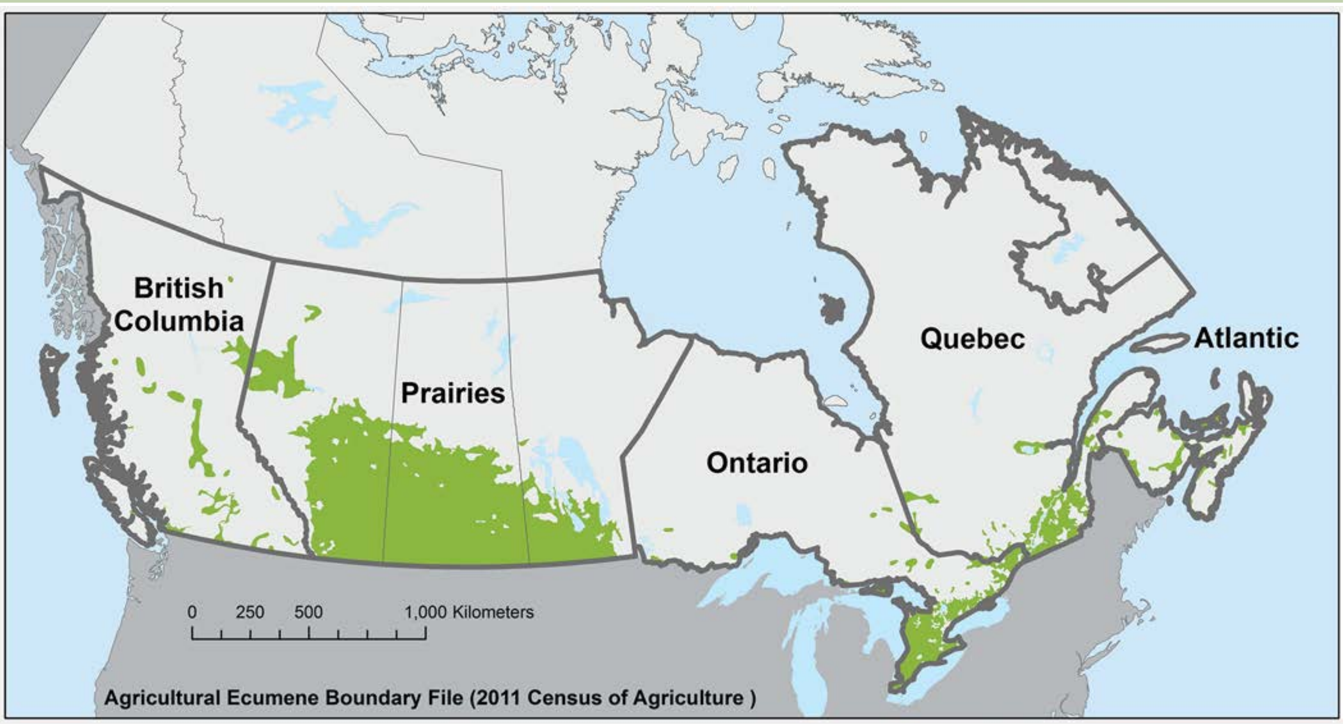
## Impacts of Climate Change on Canadian Agriculture

Canada has approximately 65 million hectares (ha) of productive agricultural land (Statistics Canada 2014), with agricultural activity generally limited to southern regions from the Atlantic Ocean to the Pacific Ocean (fig. 7.1). Assessments of climate change in Canada and its impact on Canadian agriculture conclude that most regions of Canada are projected to warm during the next 60 years (Warren and Lemmen 2014). For a high-altitude country like Canada, the warming is expected to be more pronounced than will be the global average. The results will likely be longer frost-free seasons and increased evaporation and plant transpiration. This warming may increase productivity, allow expansion of agriculture into new areas, and provide opportunities for the use of new and potentially more profitable crops (where soil conditions permit). These warmer temperatures could also benefit livestock production in the form of lower feed requirements, increased survival rates of the young, and lower energy costs.

Negative impacts from climate change also are expected, including increased intensity and frequency of droughts and violent storms. As the frequency of droughts increases, crop yields could decrease, particularly in semiarid regions of Canada. New pests and diseases will likely emerge, and more

**Figure 7.1.** This map of Canada illustrates that most agricultural land is in the southern portion of the country. (Statistics Canada 2012).



severe outbreaks of current ones will occur. Northern and remote communities are likely to see great changes in their environments—some will ease food security concerns, but others could exacerbate already decreasing food stocks and difficulties in delivering supplies into isolated areas.

## Agroforestry Across Canada

In Canada, agroforestry provides ecosystem goods and services that support integrated management of farmland and rural spaces (De Baets et al. 2007). Ecosystem services derived from agroforestry practices typically include pollination services from wild pollinators; suppression of crop pests and diseases; nutrient cycling; carbon (C) sequestration; water purification,

### **Box 7.1.** Agroforestry in Canada and Its Link to the United States

Many ecological regions of North America span the Canada/United States border, providing commonality in landscapes, climate, soils, wildlife, land management, and farming systems, including agroforestry. As such, Canada and the United States have a longstanding history of collaboration on agroforestry and formalized decades of collaboration through a Memorandum of Understanding (MOU) between Agriculture and Agri-Food Canada (AAFC) and the U.S. Department of Agriculture (USDA) in 2012. The MOU commits AAFC and the USDA to work together to accelerate the application of temperate agroforestry systems in agricultural landscapes, including research and science, outreach, education materials, and science tools for climate change mitigation that support the Global Research Alliance on Agricultural Greenhouse Gases.

USDA and AAFC jointly sponsored the Great Plains Windbreak Renovation and Innovation Conference in July 2012 at the International Peace Garden (Manitoba-North Dakota border). The event brought together scientists, natural resource professionals, and landowners to discuss renovating windbreaks, some of which were first established to slow soil erosion during the Dust Bowl era. They also discussed ways to design multifunctional windbreaks. Approximately 82 participants from 11 States and 3 Provinces attended the conference in person, and 35 joined remotely.

*Presenters and participants at the Great Plains Windbreak Renovation and Innovation Conference in 2012. Photo courtesy of Agriculture and Agri-Food Canada.*

cycling, and retention; and soil conservation and regulation of soil organic matter (Thiessen Martens et al. 2013). The ecosystem services of trees in tree-based intercropping (also known as alley cropping) have been the focus of several studies in Ontario and Quebec. Beneficial effects identified in these studies include increased soil organic C; greater C sequestration (Oelbermann and Voroney 2011, Peichl et al. 2006, Thevathasan and Gordon 2004); reduced leaching of water contaminants, including nitrate and *Escherichia coli* (Bergeron et al. 2011, Dougherty et al. 2009, Thevathasan and Gordon 2004); reduced nitrous oxide ($N_2O$) emissions (Beaudette et al. 2010); enhancement, diversification, and stabilization of arbuscular mycorrhizal fungi populations (Bainard et al. 2012, Chifflot et al. 2009, Lacombe et al. 2009); and augmentation of earthworm, bird, and insect populations (Thevathasan and Gordon 2004).

Many Canadian citizens are concerned about potential negative ecological impacts of agricultural production, and thus the role of agroforestry in Canada's agricultural landscapes has largely been linked to lessening environmental impacts of modern agriculture while balancing productivity and environmental stewardship. Adaptation and mitigation to climate change impacts are emerging concerns, and key environmental benefits sought to address these concerns include C sequestration and greenhouse gas (GHG) reductions, soil conservation, nutrient management, and water-quality protection (Van Rees 2008). Capitalizing on multiple services is a primary objective. For instance, riparian buffer zones with poplar trees can be used for water-quality protection while producing biomass that could then serve as a biofeedstock source, ultimately reducing GHG emissions (Fortier et al. 2010a).

Because the climate, soil, landforms, and resource management systems vary among Canada's five broad agricultural regions—Atlantic, Quebec, Ontario, Prairies, and British Columbia—agroforestry solutions will need to be region specific. For instance, a common agroforestry practice such as shelterbelts (table 7.1; Statistics Canada 2006) has been implemented across Canada, but the design characteristics, such as single rows versus multiple rows of trees and tree species selection, may vary from farm to farm and region to region based on agroecological conditions. The remaining paragraphs in this section summarize agroforestry trends and opportunities in each region.

### Atlantic

In Canada's Atlantic region, comprising the Provinces of New Brunswick, Newfoundland and Labrador, Nova Scotia, and Prince Edward Island, a large percentage of the land area is forested and government owned. Many agricultural producers have woodlots that generate significant income through the sale of wood as a source of fuel and pulp fiber. The purposeful integration of trees and shrubs into the agricultural landscape through the adoption of agroforestry practices has been less prevalent than farm woodlots. The interest in agroforestry, however, has grown in the region during the past 10 years.

Planting riparian forest buffers is one of the main agroforestry practices being used in this region, especially to address issues of soil erosion and contamination of watercourses by sediments, nutrients, and pesticides from intensive potato production. Each Atlantic Province has some form of environmental legislation that can affect the choice of agroforestry system that the Province adopts, particularly the use of riparian forest buffers (ADI Limited 2007). Multirow riparian forest buffers with willow (*Salix* spp.) as the primary species are being looked at for their potential to effectively buffer adjacent waterways and also to provide harvestable biomass and C sequestration (fig. 7.2). Although forest farming has only recently been introduced in the region, the potential for diversifying products and income under climate change is significant, given the number of agricultural producers that have woodlots.

**Figure 7.2.** Willow riparian forest buffer on Prince Edward Island. (Photo courtesy of Agriculture and Agri-Food Canada).

**Table 7.1.** Shelterbelt adoption in Canada's agricultural regions.

| Agricultural region | Total farms reporting | Number of farms reporting shelterbelts | Percentage of farms reporting shelterbelts |
|---|---|---|---|
| Atlantic | 8,829 | 2,525 | 29 |
| Quebec | 30,675 | 5,994 | 20 |
| Ontario | 57,211 | 19,044 | 33 |
| Prairies | 112,814 | 52,365 | 46 |
| British Columbia | 19,844 | 4,794 | 24 |
| Canada | 229,373 | 84,722 | 37 |

Source: Statistics Canada (2006).

## Quebec

Notwithstanding maple syrup production by woodlot landowners, which is a well-established industry in the Quebec and Atlantic regions, agroforestry has not been traditionally practiced in Quebec. Because of growing social pressure for sustainable management of the Province's natural resources, combined with the economic and environmental challenges that the agricultural and forestry sectors face, however, agroforestry is attracting greater attention and popularity (De Baets et al. 2007).

Planting shelterbelts is the most widespread agroforestry practice in Quebec, with approximately 400 kilometers being planted annually since the mid-1980s to protect crops, soil, livestock, buildings, and roads from the wind (De Baets et al. 2007). In the early 2000s, windbreaks began to be planted to reduce odors from intensive livestock operations. Though not as widely adopted as windbreaks, riparian forest buffers have been receiving increased attention from environmental and agricultural stakeholders (Fortier et al. 2010b).

Maintenance of a network of trees distributed throughout modified landscapes, such as those of southern Quebec, where cultivated fields form a significant component, is an option for facilitating climate change adaptation (Auzel et al. 2012).

Since 2004, provincial and Federal funding agencies have supported research on tree-based intercropping (fig. 7.3) in Quebec (Hesselink and Thevathasan 2012). Current research in Quebec and Ontario is attempting to quantify the capacity of this practice to mitigate the impact of agricultural GHGs. Several years of field trials indicate that widespread adoption of tree-based intercropping could improve current agricultural systems and also provide various social, economic, and ecosystem services to rural communities and to society as a whole. If applied on a large scale, tree-based intercropping systems could substantially reduce agricultural GHG emissions and increase atmospheric C sequestration in soils and woody biomass.

**Figure 7.3.** Young alley cropping system in southern Quebec. (Photo courtesy of David Rivest).

## Ontario

Tree-based intercropping systems have been widely researched in relation to their ecosystem services (fig. 7.4).

**Figure 7.4.** Tree-based intercropping research site at Guelph, Ontario. (Photo courtesy of Naresh Thevathasan, the University of Guelph).

The major areas of research include C sequestration, $N_2O$ reduction potentials, nutrient leaching reduction and improved water quality, enhancement of bird diversity and earthworm activity, and woody biomass production for bioenergy. It is possible for these systems to make a considerable contribution to climate change mitigation. Thevathasan and Gordon's (2004) research determined that, because of reduced fertilizer use and more efficient nitrogen-cycling, tree-based intercropping systems could contribute to the reduction of $N_2O$ emissions from agricultural fields by about 0.7 kilograms per hectare (ha) per year (1.5 pounds per acre per year).

The ecobiological processes and the combined tree and crop yields provide tangible benefits that show tree-based intercropping has increased capacity over conventional agricultural systems in terms of long-term overall productivity (Thevathasan et al. 2004). Dyack et al. (1999) determined that the low adoption rate of tree-based intercropping systems is partially due to current tax policies that do not take into consideration the numerous intangible, societal-level benefits associated with agroforestry systems. Adoption of these systems is also hindered by initial establishment costs and also by the income loss resulting from the removal of cropland from production. An economic analysis (Toor et al. 2012) found that tree-based intercropping systems in central Canada were less profitable than annual cropping systems due to reduced area for annual crops and low revenue from trees, especially when trees were slow-growing timber species such as red oak (*Quercus rubra* L.).

## The Prairies

Canada's Prairies region comprises the Provinces of Alberta, Manitoba, and Saskatchewan. Widespread agricultural settlement occurred rapidly after the railroads were built in the early 1880s. Agroforestry activities in this region began soon afterward. Many settlers acutely felt the need for shelter on the wide-open, windy, treeless southern plains, but the need was less in the more wooded northern and eastern portions of the Prairies region.

In 1886, the Federal Government adopted the Experimental Farm Stations Act; it was through this program that tree nurseries were developed to produce tree and shrub seedlings (Van Rees 2008). Early agricultural settlers, while adamant about clearing land for agricultural practices, were also cognizant of the important roles that trees play in sustaining farm systems, and they appreciated the products and services that could be derived from trees. Multirow farm shelterbelts surrounding yards and single-row field shelterbelts became the predominant tree culture practiced on the prairie landscape (Edwards 1939).

Federal programming supported the planting of shelterbelts on the prairies since 1901 (fig. 7.5), including the provision of seedlings through the Federal tree nursery at Indian Head, Saskatchewan, and, from 1935 to 1959, special support for establishing field shelterbelts for erosion control under the Prairie Farm Rehabilitation Act (Amichev et al. 2014). Throughout the period from 1901 to 2013, more than 630 million seedlings were provided for protecting farmyards and fields and were used for other environmental plantings through the Prairie Shelterbelt Program, enough seedlings to potentially sequester more than 218 megatonnes of carbon dioxide ($CO_2$) during the lifetime of the trees (Kort and Turnock 1999).

As a result of the *Saskatchewan's State of the Environment Report 1997* (Saskatchewan Environment and Resource Management 1997), which highlighted the need to support research and development in emerging value-added sectors in agriculture, the Province of Saskatchewan created the Agri-Food Innovation Fund (AFIF). Developing sustainable agroforestry economic diversification opportunities for farmers was one of the five priority areas of AFIF, with much of the emphasis on poplar-afforestation and small woodlots, with research and demonstration directed toward efforts that could supplement traditional forest products and harvest (Van Rees 2008).

**Figure 7.5.** Farmyard and field shelterbelts near Francis, Saskatchewan, established with seedlings provided through the Prairie Shelterbelt Program. (Photo courtesy of Agriculture and Agri-Food Canada).

Land tenure in the Prairies region continues to evolve toward larger specialized farms with more corporate ownership of farming operations on rented land. The predominance of large-scale agriculture and the introduction of precision farming technology have led to a noticeable reduction in habitat on marginal lands adjacent to agricultural fields. Although improved land management techniques, such as zero tillage, can help mitigate the negative impact of the loss of shelterbelts, the positive functionality of agroforestry systems cannot be adequately replaced by monoculture farming practices (Schroeder et al. 2011). The domestic market provides opportunities for more specialized, often smaller, farm enterprises, such as organic farms and market gardens. Corporate farms may be less interested in tree planting or other environmental practices that are not seen as profit-generating activities, and farming on rented land may also present obstacles to long-term conservation practices with trees. Public concern about environmental issues, however, may encourage corporate farms to make sound environmental management of the landscape an essential part of their core business.

## British Columbia

Agroforestry applications within British Columbia have evolved from efforts to integrate resource practices on public lands to, more recently, a means of economic diversification and as an approach to environmental stewardship.

Shelterbelts were reported on less than 25 percent of the farms in the Province (Statistics Canada 2006). The low percentage of adoption may be reflective of generally naturally treed landscapes of many agricultural areas of British Columbia and a need for more shelterbelt design, demonstration, assessment, and management for a variety of agricultural production systems. In British Columbia, producers rank economic efficiency and effectiveness as the most important criteria for decisionmaking, followed by adoptability, adaptability, flexibility, and independent benefits (Dobb 2013).

Various natural and land management elements—including success in using sheep grazing for silvicultural purposes since 1984, economic diversification efforts in coastal woodlots starting in the mid-1990s, and the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic in the British Columbia interior—converged, creating awareness of agroforestry's potential usefulness in British Columbia. This awareness has given rise to organized research, pilot projects, and demonstration initiatives, as illustrated in figure 7.6.

**Figure 7.6.** Silvopasture pilot site, southern interior of British Columbia. (Photo courtesy of British Columbia Ministry of Agriculture).

Significant opportunity exists in the implementation of silvopastoral systems and riparian forest buffers to address concerns related to water quality and also to provide additional economic opportunities other than those based on forestry products. Development of agroforestry in British Columbia is driven by partnerships among producers and industry associations; First Nations; academic institutions; nongovernmental organizations; and municipal, provincial, and Federal Government agencies (Dobb 2013).

## Overview of Existing Policies and Programs

"Climate change is perhaps the greatest environmental policy challenge of the 21st century" (Gleeson et al. 2009). Effective policies supporting agroforestry land-use systems in Canada can provide the framework for landowners and land managers who may become active agents of change through their own personal undertakings and examples. At present, few specific policies exist at any level of government that govern agroforestry practice and adoption. Policies and programs that do exist are not coordinated across provincial jurisdiction and generally are limited in the time they are available. More likely, agroforestry practices will be influenced by other agricultural policies affecting land use or, in some instances, forest management regulation changes.

To obtain successful adoption rates and well-maintained agroforestry systems across Canada, policy measures and/or tax incentives and cost-share programs will likely be required at Federal and/or provincial levels of government.

### Federal

To date, the only Federal organization that has a national agroforestry mandate is Agriculture and Agri-Food Canada (AAFC). Activities in support of agroforestry and tree planting in the agricultural landscape have existed at the Federal level of government since 1901. Activities in research, development, and tree distribution have continually evolved during the past century based on environmental and economic drivers and to meet the needs of the changing agricultural sector. Additional regional and national strategies for agroforestry, with the goal of improving the competitive position of the agricultural sector by incorporating agroforestry systems for the sustainable management of the agricultural land base, have also evolved over time (Van Rees 2008).

Federal-provincial cost-share agreements integrate environmental actions across levels of government and focus programs on helping producers reduce environmental risks and improving benefits. The current agricultural framework agreement, Growing Forward 2, continues to encourage agricultural producers to adopt management practices that benefit the environment and sustain the natural systems that provide ecosystem goods and services. For example, in Saskatchewan, eligible landowners can receive funding through the Farm Stewardship Program at a rate of $1,200 Canadian dollars (CAD) ($904 U.S. dollars [USD]) per mile to a maximum payment of $5,000 CAD ($3,769 USD) (Government of Saskatchewan, 2016). Table 7.2 lists the number and funding of projects involving agroforestry practices under the Agricultural Policy Framework.

**Table 7.2.** Agroforestry-related projects by Province funded under the Agricultural Policy Framework.

| Province | Number of projects | Funding (Canadian dollars, thousands) |
|---|---|---|
| Alberta | 98 | 250 |
| British Columbia | 29 | 207 |
| Manitoba | 73 | 139 |
| New Brunswick | 10 | 21 |
| Newfoundland | 0 | 0 |
| Nova Scotia | 5 | 6 |
| Ontario | 336 | 586 |
| Prince Edward Island | 3 | 7 |
| Quebec | 1,081 | 1,086 |
| Saskatchewan | 64 | 100 |
| **Totals** | **1,729** | **2,399** |

Source: Agriculture and Agri-Food Canada program data.

As illustrated, support and promotion at the provincial level can have a significant effect on the uptake of program initiatives by producers in a region. Projects in Alberta, Manitoba, and Saskatchewan, although lower than those in Ontario and Quebec, do not take into account most of the tree-planting activities that would have occurred under the Prairie Shelterbelt Program, which provided trees, on average, to 5,000 or more landowners annually.

## Agricultural Greenhouse Gases Program

The Canadian Government, through AAFC, has initiated and promoted a national network of agroforestry practitioners in research and development through the Agricultural Greenhouse Gases Program (AGGP). This proposal-based program is part of GHG mitigation initiatives undertaken in countries that are members of the Global Research Alliance and ran from September 1, 2010, to March 31, 2016. The AGGP supports projects that will create technologies, practices, and processes that can be adopted by farmers to mitigate greenhouse gas (GHG) emissions.

Within the priority area of agroforestry, six projects within the Agricultural Greenhouse Gases Program (table 7.3) were funded at a level of $4.85 million CAD. These projects address knowledge gaps and increase capacity in two main theme areas: (1) understanding C sequestration on agricultural land through agroforestry systems and (2) adoption and efficacy of agroforestry practices. Areas of study in the first theme encompass the understanding of C dynamics in agroforestry practices, including aboveground and belowground C pools and fluxes; quantifying the potential for agroforestry practices to store C on agricultural land; and developing methodology for the measurement, monitoring, and verification of C in agroforestry systems, all providing a basis for a national inventory of C in agroforestry systems in Canada. Areas of study under the second theme include assessments of how agroforestry practices interact with or affect agricultural practices, the quantification of co-benefits, and C sequestration from agroforestry systems. The six projects are also examining existing policies and developing policy tools that encourage sustainable and effective GHG mitigation practices, and conducting life-cycle assessments and economic analyses to assess the sustainability and performance of agroforestry systems for GHG mitigation.

## Provincial

In Quebec, in 2011, the provincial Department of Agriculture, Fisheries and Food of Quebec (MAPAQ; Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec) launched a pilot program on the multifunctionality of agriculture, specifically targeting agroforestry and tree-based intercropping systems as production systems for which the implementation of such systems may qualify for a subsidy. This pilot program ended in March 2015. Some other Quebec departments have also considered the various functions of agroforestry. For many years the Quebec Ministry of Natural Resources (Ministère des Ressources Naturelles du Québec) has provided trees for windbreaks and riparian forest buffers in collaboration with MAPAQ. Various timber-oriented agroforestry projects have also been funded through a regional forest development program, now titled the Regional and Forestry Development Program (Programme de développement régional et forestier) (Government of Quebec 2013). The Quebec Ministry of Transportation (Ministère des Transports du Québec) implements windbreaks in rural areas to reduce snow-control costs. In a perspective of regional development, the Quebec government's Ministry of Municipal Affairs, Regions and Land Occupancy (Ministère des Affaires municipales et de l'Occupation du territoire) also supported experimental agroforestry development projects, notably tree-based intercropping systems

**Table 7.3.** The six agroforestry projects funded under the Agricultural Greenhouse Gases Program.

| Lead institution | Title | Primary objective |
|---|---|---|
| Government of British Columbia | Evaluating silvopasture systems for economic and environmental performance and greenhouse gas mitigation potential | Examine how the practice of combining forestry with forage and livestock production in the southern interior of British Columbia will support greater biological and economic diversity and benefit the environment. |
| University of Alberta | Quantifying carbon sequestration and greenhouse gas emissions in planted shelterbelts, natural hedgerows and silvopastoral systems in different soil-climatic zones in Alberta | Quantify the value of shelterbelts, natural hedgerows, and silvopastoral systems for facilitating carbon storage and reducing greenhouse gas emissions. |
| University of Saskatchewan | Shelterbelts as an agroforestry management practice for the mitigation of GHGs | Determine how effective shelterbelts and other agroforestry plantings are in sequestering carbon and how they can better function as carbon sinks. |
| Upper Assiniboine River Conservation District | Demonstration and investigation into agroforestry based livestock systems adoption | Evaluate various beneficial management practices on the farm to see if they can be easily adopted by the farming community. |
| University of Guelph | Tree-based intercropping: An agroforestry land-use for greenhouse gas mitigation in Canadian agricultural systems | Assess how tree-based intercropping can mitigate greenhouse gas emissions and enhance carbon sequestration in tree biomass and agricultural soils. |
| Eastern Townships Forest Trust | Effects of hybrid poplar agroforestry systems on carbon sequestration in agricultural landscapes of Eastern Canada | Determine the potential for riparian and upland agroforestry buffers to sequester carbon in agricultural landscapes in Eastern Quebec. |

Source: Agriculture and Agri-Food Canada program data.

in the Gaspe Peninsula. Moreover, some municipalities are exploring agroforestry approaches as a means to increase the value of abandoned land, to enhance green corridor acceptance among farmers, and to offset C emissions from urban areas.

In British Columbia, the Agroforestry Industry Development Initiative (AIDI) supported the development and adoption of agroforestry practices by improving market connections, expanding partnerships, improving awareness, and establishing demonstrations. Funding for AIDI was provided by AAFC through the Canadian Agricultural Adaptation Program from 2010 to 2013 and was delivered by the Investment Agriculture Foundation of British Columbia.

### Alternative Land-Use Services

Financial incentives have become popular for protecting the environment in Canada (Lantz et al. 2012). Alternative Land-Use Services (ALUS) are community-developed, farmer-delivered programs that provide incentives to farmers and ranchers for the conservation and protection of environmental assets on privately owned land (ALUS 2016, Keystone Agricultural Producers 2011). Most of the current programs rely on grants through nongovernment funding agencies (Campbell 2014).

The goals of ALUS programs are to empower landowners in conservation, to increase the supply of environmental goods and services, and to improve land management by reducing soil erosion, improving water quality, improving and increasing wildlife habitat, and reducing the impacts of climate change (Government of PEI 2012). The current impact of ALUS programs has been minimal regarding agroforestry; approximately 243 ha (600 acres [ac]) have been planted in trees and shrubs across Canada, with most planted in Ontario. Many of these seedlings are provided by the Ontario Ministry of Natural Resources and Forestry's 50 Million Tree Program. With goals of sequestering C and of enhancing and diversifying southern Ontario's landscape to increase adaptive capacity and resiliency regarding climate change, the program substantially decreases costs of large-scale tree planting to increase the total number of trees planted (Forests Ontario 2016) In the Province of Prince Edward Island, 251 ha (620 ac) of tree planting within the 15-meter (49-foot) regulated buffer zone have been established and expanded buffer zones (beyond 15 meters [49 feet]) have been created on 553 ha (1,366 ac) (ALUS 2012) with payments of $185 CAD ($139 USD)/ha/year (Lantz et al. 2012).

### Ecosystem Goods and Services

The value that ecosystem goods and services produced from establishing agroforestry practices is significantly higher for the public than the costs they engender for farmers (EcoRessources Consultants 2011). Some of the most important benefits relate to C sequestration. Kulshreshtha and Kort (2009) estimated that the benefits of tree seedlings distributed through the Prairie Shelterbelt Program for the period from 1981 to 2001 was $73 million CAD ($47 million USD) for C sequestration. Some indications suggest that the demand for ecosystem goods and services from rural lands is growing as incomes rise and values change in Canadian society, but the supply side does not seem to be responding (Fox 2008).

Current discussions of alternative approaches to facilitating the provision of ecosystem goods and services have not made a distinction between taxpayer-funded programs and beneficiary-funded market programs (Fox 2008). To develop programs and policies that recognize and support the contributions that landowners make through agroforestry, a greater understanding of the benefits of ecosystem goods and services will be needed (Kulshreshtha and Kort 2009).

## Needs for Agroforestry in Canada

Although each Canadian Province has its own unique preference to different agroforestry systems adapted for local conditions, the challenges/constraints and potential impacts are similar across the Provinces (Thevathasan et al. 2012). Key research needs across the Provinces include understanding of the evolution of agroforestry practices in light of changing socioeconomic and environmental conditions; evaluation of the ecosystem goods and services provided by different types of agroforestry systems; accounting for potential impacts (both benefits and concerns) of agroforestry systems at the landscape level; and understanding how agroforestry can best be included in management of water quality and GHG mitigation in agricultural watersheds, and in emerging taxation and credit schemes. To address these needs, continued studies and analyses of the economics, risks, and life-cycle components of agroforestry systems currently found on the Canadian landscape will be required. The formation of a national agroforestry network would provide a means for efficiently addressing these many issues and building the scientific information needed at both the regional and national levels (Van Rees 2008).

### Adaptability of Species Used in Agroforestry

Having woody plant material that is adapted to the future climate conditions in Canada will be critical to the success of agroforestry as a climate change tool (Johnston et al. 2009, Silim 2004). Tree species currently used and potentially available for use in Canada are vulnerable to erratic and extreme weather events and also to climate-induced fluctuations in insects and pathogens (Allen et al. 2010, Fuhrer 2003). It is essential to understand the vulnerability of tree species under predicted climate change to determine reasonable options for adaptation of agroforestry plant materials.

The Agriculture Canada Balsam Poplar (AgCanBaP) program is focused on developing adaptable balsam poplar (*Populus balsamifera* L.) materials. Occurring across a wide range of North America, balsam poplar is both highly variable and capable of a broad range of adaptive physiological responses to a changing climate (Keller et al. 2011). With its natural range in Canada extending from coast to coast, balsam poplar is one of the most widely distributed poplars in Canada. Researchers at AAFC who have advanced genetic improvement on a number of species have also now assembled a balsam poplar collection. The AgCanBaP collection consists of material from throughout North America that provides germplasm for future climate change, breeding, and genomic studies (fig. 7.7). This collection is currently being screened to identify fast-growing selections that have greater C sequestration and biomass yields (Soolanayakanahally 2010).

## GHG Accounting and Inventory

Significant potential exists for agroforestry to contribute to Canada's GHG mitigation goals. Canada has an estimated 57 million ha (141 million ac) of agricultural land that have slight to significant degrees of agricultural crop production limitations. If 5 percent of this land area were converted to agroforestry, the potential for an annual C sink of 47 to 76 megatonnes of $CO_2$ (up to 30 percent of the emission reductions for Canada) would exist (Van Rees 2008).

Information on GHG accounting from agroforestry practices is not fully developed, however, and, therefore, is not currently reported in the National Inventory Report (NIR) on GHG sources and sinks in Canada. As the Canadian government's submission to the United Nations Framework Convention on Climate Change, NIR provides an annual report on GHG accounting across sectors, including agriculture and land use, land-use change, and forestry. Impacts of changes in woody biomass in the agricultural landscape is characterized under "perennial woody crops" in the NIR and includes land-use

**Figure 7.7.** Natural range of balsam poplar (*Populus balsamifera* L.) and geographic locations of 65 provenances (indicated by green dots) and common garden locations (indicated by red stars) in the AgCanBaP program (Soolanayakanahally et al. 2013). (Map created by Chris Stefner, Agriculture and Agri-Food Canada).

activities such as vineyards, fruit orchards, and Christmas trees reported under the Canadian Agricultural Census on a 5-year basis. Current estimates of sequestration from perennial woody crops account for the removal of only 10 gigagrams of carbon dioxide equivalent ($CO_2$eq) (Environment Canada 2014). Compared with sequestration from practices such as reduced fallow or tillage, woody biomass seems to have an insignificant effect on total C removals. This seeming insignificance is an accounting byproduct resulting from the lack of inventory of agroforestry practices in Canada and the lack of activity-specific data on the GHG impacts of agroforestry practices. The Agricultural Greenhouse Gases Program is addressing both deficiencies.

### Emerging Opportunities

In an increasingly complex commodities mix, it is beneficial that various economic diversification strategies be available to Canadian landowners through agroforestry systems (Gordon et al. 2008). Bioenergy from short-rotation willow and/or poplar has considerable potential for the future because economic inputs in some woody bioenergy systems are substantially less than those involved in grain-based systems used for ethanol production. Agroforestry, as stated by Gordon et al. (2008), offers long-term rural landscape sustainability and provides economic resilience through income diversification.

It has been suggested that payments in a C market or a grant/subsidy program for ecological services are necessary to encourage adoption of agroforestry practices (EcoRessources Consultants 2011, Thiessen Martens et al. 2013). It is anticipated that as C markets emerge, agroforestry plantings will generate C offsets and provide revenue for landowners. The Government of Alberta has created the Climate Change and Emissions Management Fund to establish or participate in funding for initiatives that reduce emissions of GHGs or improve Alberta's ability to adapt to climate change and has placed a value of $15 CAD ($11 USD)/tonne $CO_2$eq (IETA 2015). British Columbia has also developed a C market with offset prices being paid in the range of $9 to $19 CAD ($7 to $14 USD)/tonne $CO_2$eq (IETA 2015).

### Key Findings

- As Canadian agriculture likely expands into new areas under changing weather and climate conditions, agroforestry can be an important component in enhancing food security, particularly in northern and First Nation communities.
- Agroforestry can play a critical adaptation role in existing agricultural areas as these lands experience more extreme and variable weather events, increased pest infestations, and other climate-related stressors.
- Agroforestry systems can have a significant effect in mitigating GHG emissions from Canadian agricultural activity if agroforestry implementation is increased.
- Climate, soils, and agricultural systems vary considerably across the broad farming and ranching areas in Canada, requiring agroforestry solutions to be region specific.

### Key Information Needs

- Better understanding of GHG dynamics across Canadian agroforestry systems and regions.
- A national inventory to track land currently in agroforestry to feed into Canadian GHG inventory assessments.
- Development of a Canadian agroforestry network to help build the scientific information and support needed at both regional and national levels.
- Coordinated land-use policy between levels of government that addresses both short-term economic pressures of the landowner (private risk) and longer term public benefit.

### **Box 7.2.** Enhancing Food Security in Northern Canada With Agroforestry

Food insecurity is one challenge that First Nations people residing in northern Canada face. Warming temperatures are already creating many other challenges for these communities, especially for those in the more remote subarctic and arctic regions of northern Canada. These warming temperatures, however, also provide an opportunity to build food security through local agricultural production. Work by Barbeau et al. (2015) demonstrates that with the selection of appropriate plant materials, potatoes and bush beans could be grown successfully and used as a source of local, fresh, and nutritious foods. They also found that yields could be significantly enhanced by growing the crops in alleys between rows of willows. By capitalizing on this windbreak function and with the resiliency and potential other uses of and services from willow (i.e., biodiversity including pollinator habitat, C sequestration, soil conservation, and biofeedstock), agroforestry can be more specifically designed to better meet the needs of the people in these regions.

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# Chapter 8

# Expanding the North American Perspective—Mexico

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## Impacts of Climatic Variability on Mexican Agriculture

Based on national assessments, Mexico is expected to see temperature increases of 0.9 to 2.5 ºC by the year 2020, and it is very probable that, by the year 2050, the climate will be warmer by 2.0 to 4.0 ºC, especially in the central and northern parts of the country (MENR 2007). Rainfall is expected to decrease as much as 15 percent in the central part of the country, but the number of severe storms and the intensity of severe droughts are expected to increase nationwide (MENR 2007).

Mexican agriculture will be particularly vulnerable to these predicted changes in climate. Changes in precipitation may have the greatest impact, because most of the country's agricultural land (about 85 percent) is classified as arid or semiarid (Houghton et al. 2001). Increases in temperatures and soil moisture deficits will likely decrease land area suitable for rain-fed crops such as maize. Severe droughts will compound the situation in a country where, on average, more than 90 percent of agricultural losses are already attributed to drought events (Appendini and Liverman 1994). More intense tropical storms in the southern and coastal parts of the country are likely to cause extensive damage to crop and livestock production. It is also anticipated that changing weather and climate will increase the scale and frequency of forest fires, which may contribute to a shift from tropical forests to savannas (MENR 2007). Reducing agricultural vulnerability to climatic variability is of critical importance in the agricultural sector in Mexico, especially given the role the sector plays in support of food security and livelihoods of rural populations.

Agroforestry systems are gaining greater attention within Mexico as one strategy for mitigating and adapting to predicted climate change. Work by Locatelli et al. (2011) identified agroforestry as a tool for adaptation, enabling poor rural families, communities, and watersheds to be less vulnerable to extreme and erratic weather events by generating diverse environmental and socioeconomic benefits. This contribution by agroforestry systems was also recognized in Mexico's National Climate Change Strategy, which serves as a guide for Mexico's actions during the next 40 years (SEMARNAT 2013). This Federal strategy targets the reduction of greenhouse gas emissions, and specifically includes initiatives related to agroforestry.

In this chapter, we first provide an overview of the history of agroforestry in Mexico, focusing on the most prominent agroforestry systems and their associated tree and crop species, management practices, geographic range, and environmental and climatic conditions. When available, we also provide information about the agroforestry systems' potential for enhancing climate change mitigation (through carbon sequestration and storage) and adaptation to climate change (through improving food security and resilience). Next, we discuss the existing Government policies aimed at promoting different agroforestry practices and how these relate to important long-term goals related to climate change mitigation or adaptation. Finally, we describe some major constraints to the adoption of agroforestry systems and also the needs and emerging opportunities for agroforestry in Mexico.

## Overview of Agroforestry in Mexico

Mexico has an area of 1.97 million square kilometers (761,200 square miles) and is one of the 14 most biodiverse countries in the world (Mittermeier et al. 1998). Together with its large, diverse mosaic of climatic zones, terrestrial ecosystems, and plant and animal species, Mexico has immense cultural diversity that has contributed a wide range of different domesticated crops (e.g., corn, bean, cocoa, vanilla, pineapple, avocado, amaranth, chia) and also land-use systems that include agroforestry (Toledo et al. 2001, 2003). Agroforestry practices were known to have been implemented during pre-Hispanic times, based on evidence of production systems that combined crops and multipurpose trees (Barrera et al. 1977). According to Moreno-Calles et al. (2014), the most well-documented examples include the *chinampas* (e.g., floating gardens with trees and crops) that the Aztecs used in central Mexico and the homegardens (e.g., complex combinations of crops, livestock, and multipurpose trees established adjacent to the home) that the Mayans used in the Yucatan. Agroforestry systems are especially typical of the extensive tropical habitats, where they are characterized by complex, spatially and temporally stratified combinations of trees, crops, and animals. Combined with other production strategies, such as roza-tumba-quema (slash-and-burn), these systems were implemented extensively in pre-Hispanic times.

During the long history of agroforestry in Mexico, the most important objective has been the production of subsistence food crops and other immediate necessities, such as fiber, medicine, and fuel wood, and only more recently have other products of commercial value been included to a great extent (Moreno-Calles et al. 2014). Although most agroforestry systems have not contributed significantly to country-level agricultural production and commercialization based on volume or land cover, they have been vital to sustaining rural farmers and to retaining the cultural and biological diversity of Mexico.

Some of these agroforestry systems have been modified or expanded more recently in response to the introduction of foreign crops like coffee, the internationalization of markets, technological advances, and changing policy and economic environments, especially for valuable products such as coffee, cocoa, and vanilla.

Despite their long historical importance, agroforestry systems in Mexico first gained broad recognition and relevance in 1991, when a collaborative agreement was signed by the International Center for Research in Agroforestry and the Institute of Forest, Agriculture, and Animal Husbandry Research in Mexico. This collaboration lasted about 10 years and resulted in several long-term research programs and the creation of educational and graduate programs focusing on agroforestry at major universities in Mexico.

The seven most common agroforestry systems in Mexico in recent times are (1) homegardens, (2) improved fallows, (3) living fences, (4) shade trees for agricultural plantations (e.g., coffee, cacao, fruit trees), (5) alley cropping (both with crops and fodder/pasture), (6) windbreaks, and (7) silvopastoral systems (Bautista 2009, Budowski 1987, CONAFOR 2014, Dominguez Alvarez and Sanchez Velez 1989, Garcia 2010, Gutierrez Ramirez 2006, Musalem-Santiago 2002, Santoyo 2004, Wilken 1976).

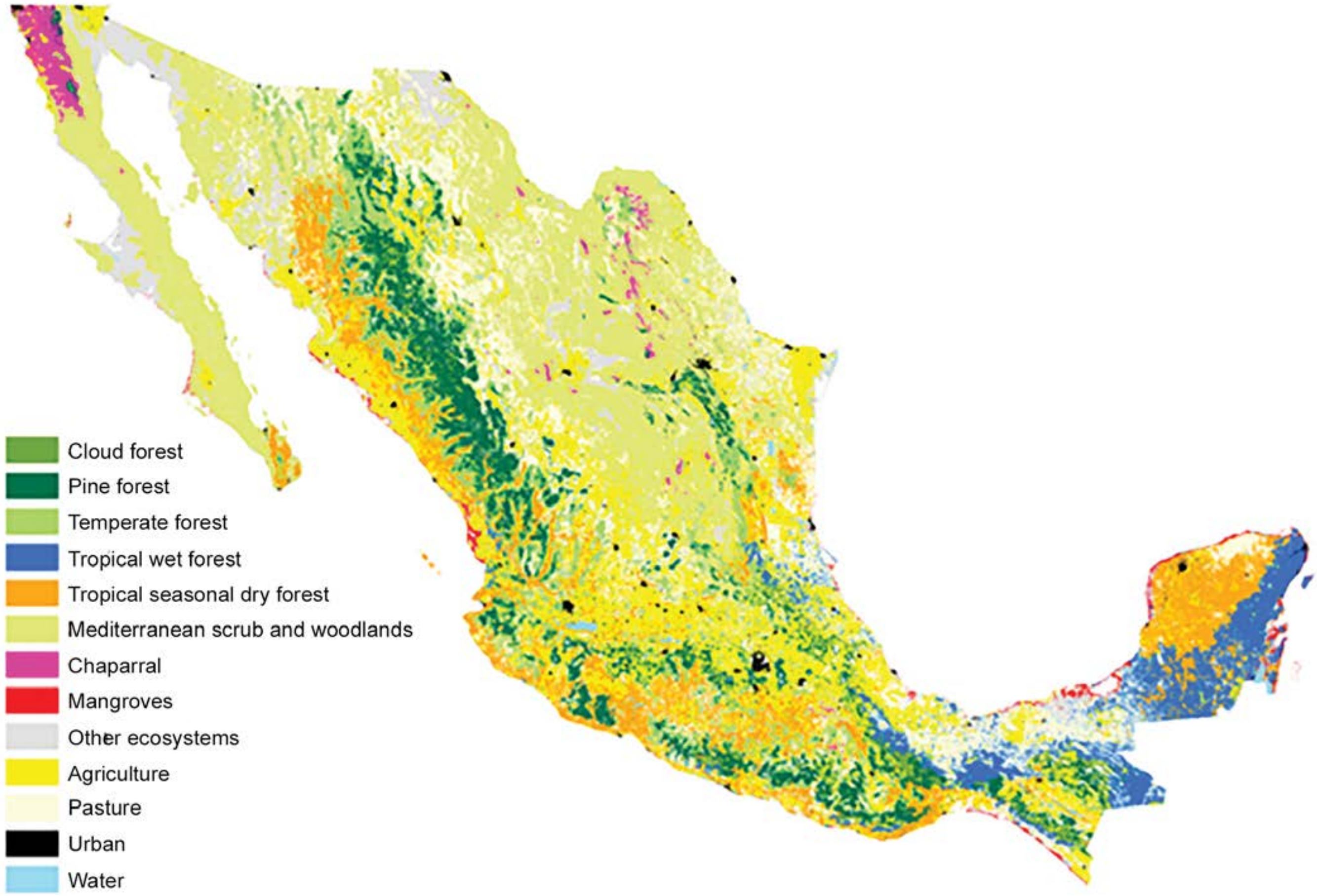
It is notable that agroforestry systems in Mexico have been intimately linked with indigenous natural resource management practices, including the rapid adoption and integration of new crops (e.g., coffee) into existing indigenous agroforestry practices having high levels of biodiversity (Beaucage 1997). Based on biocultural diversity, Moreno Calles et al. (2013) identified three main types of agroforestry systems in Mexico: (1) those associated with spaces near houses, (2) those associated with plots, and (3) those associated with forests and mountains; each has different levels of management intensity. These agroforestry systems commonly found in Mexico contribute to 15 different primary uses, most importantly, food (especially fruits), forages and medicines, ornamentals, construction materials, energy, alcoholic beverages, fibers, resins, and latex.

Also relevant for considering the role of agroforestry in land use and climate change mitigation is the land tenure system, which is unique to Mexico and differs from most other countries in Central and South America. A major land tenure reform favorable to common property management arose from the Mexican Revolution (1910–1920) (Bray et al. 2005), enabling the communal lands or *ejidos* to be established. For these reforms, the State effectively gave collective land entitlements to thousands of rural communities, resulting in more than 60 percent of Mexico's forested land currently being under communal ownership (Bray et al. 2003, FAO 2010). The internal organization of an *ejido* allows for collective activities in communal lands and family-level management in individual parcels. In total, some 60 percent of the country's forest resources are within communal lands where traditional agroforestry practices have been documented in at least 25 distinct indigenous groups scattered throughout the country, but mainly in the center and south (Boege 2009, Moreno-Calles et al. 2014). Notably, agroforestry systems in Mexico are primarily maintained at the individual-family scale. The new Agrarian Law of 1992 involved several changes in land tenure in Mexico and its Federal support. The most significant change was the possibility to obtain freehold rights of the parcels, including their privatization (Agrarian Law, Articles 81 and 82).

### Regional Adoption Trends and Constraints

Mexico consists of eight dominant ecosystem types, in addition to areas dominated by pasture or agricultural crops (fig. 8.1).

**Figure 8.1.** Distribution of major ecosystems in Mexico. (Modified from INEGI 2012).




In this chapter, we focus on a subset of these ecosystems when describing the dominant trends and constraints in adopting agroforestry systems: tropical wet forests, tropical montane cloud forests, and tropical seasonal dry forest.

## Tropical Wet Forests

Tropical wet forests are located close to the equator, where the climate is predominantly wet, with an average of more than 2000 millimeters (mm [79 inches]) of rainfall per year and uniformly high temperatures, between 20 and 35 °C. In Mexico, tropical wet forests occur primarily in the States of Chiapas, Tabasco, Oaxaca, and Veracruz and are characterized by a high diversity of plant and animal species, and by large trees—from 50 to 70 meters (m [165 to 230 feet]) tall—often supported by strong buttresses at the base of the trunk that help to stabilize them in the shallow forest soils and with abundant vines and lianas attached to their trunks. Another distinctive characteristic of tropical wet forests is the high degree of vertical stratification, often composed of several layers of vegetation, each one quite diverse in plants and animals (Rzedowski 1978).

**Cacao.** The cacao tree *(Theobroma cacao*), which grows under the canopy of tropical wet forests, has been cultivated by several cultures in Mexico and Central America for the past three millennia. Considered one of the oldest agroforestry systems in the world, the earliest evidence (1900 B.C.E.) of cacao cultivation traces to the pre-Olmec cultures known as the Mokaya. Mesoamerican people, including the Mayans and Aztecs, used the seeds of cacao fruit to make a beverage known as *xocol lt*, a Nahuatl word that means *bitter water* (McNeil et al. 2009, Young 1994). Table 8.1 provides an example of the extent and production of cacao agroforestry plantations in the State of Chiapas. Cacao trees can be productive for up to 50 years, and the older the cacao trees in the plantation are, the

**Table 8.1.** Surface area planted and harvested with cacao in the municipalities in the State of Chiapas in 2010, by municipality.

| Municipality | Surface area planted (ha) | Surface area harvested (ha) | Production (tons) |
|---|---|---|---|
| Pichucalco | 8,020 | 7,918 | 3,374 |
| Palenque | 932 | 902 | 391 |
| Tapachula | 10,159 | 10,159 | 4,415 |
| Tuxtla Gutierrez | 620 | 620 | 210 |
| **Total** | **19,731** | **19,599** | **8,390** |

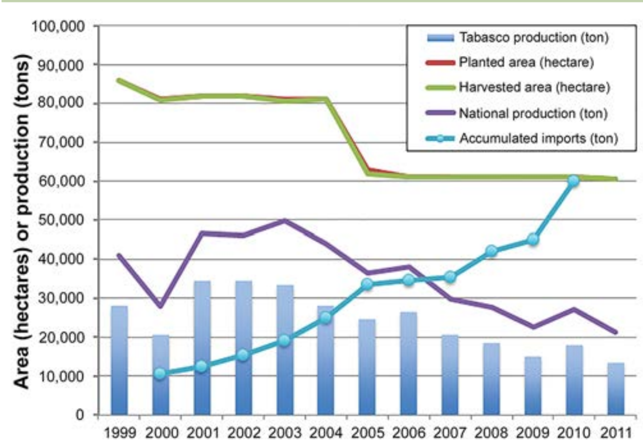
ha = hectares.

Sources: SIAP (2010); c.f. Zequeira-Larios (2014).

higher the biodiversity. A 30-year-old plantation can hold up to 500 individual plants per hectare, representing 23 families, 30 genera, and 32 species, and a 50-year-old plantation can hold 1,238 individuals representing 24 families, 40 genera, and 44 species. Cacao plantations are not only very important as biodiversity conservation areas but also as sources of timber products, fruits, and many tree species in general, and, above all, because of their ancestral origin as a cultural symbol in the tropical regions of Mexico (Ramirez-Meneses et al. 2014). A common practice today in response to declining cacao prices is the planting of valuable timber species such as *Cedrela odorata* within cacao plantations as a means of boosting revenues. Cacao trees are currently threatened by *Moniliophthora roreri*, which causes frosty pod rot, a highly destructive disease found in 11 countries in South and Central America.

Agroforestry systems based on cacao production at the national level in Mexico are declining (fig. 8.2), and often then systems are replaced by more intensive agricultural crops or livestock production. However, there is interest in stimulating cacao production in Tabasco, because it was Mexico's first global exporter of cacao.

**Figure 8.2.** Comparative historical data on the national production of cacao in Mexico, 2000 to 2010. (SIAP 2010; c.f. Zequeira-Larios 2014).




**Homegardens.** The homegarden is an integral part of smallholders' production strategies in Mexico. Although they can be found throughout all of the Mexico, homegardens are particularly common in the tropical wet forest zone. Homegardens tend to harbor high levels of biodiversity, which are maintained and enriched by farmers' practices, particularly plant and seed exchange (DeClerck and Negreros-Castillo 2000). Most homegardens are multipurpose, providing goods for home consumption, sales, environmental services, and experimentation and learning (Aguilar-Stoen et al. 2009). From a climate change perspective, homegardens provide an important strategy for increasing the resilience of small farms to a changing environment by supporting a diversity of plant (and often animal) species adapted to diverse conditions. Because homegardens often have a high proportion of woody biomass relative to agricultural systems dominated by annual crops, they also generally have higher potential for carbon sequestration.

**Vanilla.** Vanilla (*Vanilla planifolia*) is a nontimber forest product that has been managed in Mexico since pre-Hispanic times, especially among the Totonaca indigenous group in the region of Totonacapan (the States of Puebla and Veracruz) (Barrera-Rodriguez et al. 2009). Four agroforestry production systems have been recognized within Totonacan management strategies, each having different management intensities and diversity and composition of tree species: (1) secondary forests (traditional), (2) shade tree systems with *Erythrina* and *Gliricidia sepium* (technified), (3) shade tree systems with orange trees (*Citrus x aurantium* L.) (semitechnified), and (4) living fences (with 50 percent shade) (Barrera-Rodriguez et al. 2009, Hernandez-Hernandez 2011, Sanchez et al. 2001). Vanilla is cultivated within each of these four agroforestry production systems in the States of Chiapas, Oaxaca, Puebla, and Veracruz and, to a lesser extent, in Hidalgo, Michoacán, Quintana Roo, and San Luis Potosi (Damiron 2004, Hernandez-Hernandez 2011, Lopez et al. 2009). Consequently, vanilla-based shade-tree agroforestry systems typically support a high degree of species and structural diversity, which contributes to maintaining species diversity and biogeochemical cycling and providing multiple ecosystem services (Arroyo-Rodriguez et al. 2008, Hernandez-Hernandez 2011, Lopez et al. 2009, Soto-Arenas 2006). Today, vanilla is primarily produced as part of subsistence-based agroforestry systems, using a range of techniques, from traditional to more intensive-technical. The latter is characterized by greater use of chemicals to control pests, disease, and weeds and also by the use of tree species as trainers, particularly from the Leguminosae family (*Gliricidia* spp. and *Erythrina* spp.). The traditional system is characterized by the use of secondary forest species that regenerate naturally, or, in slightly more intensive systems, use of citrus trees that have been planted. Overall, vanilla production has been declining—from 445 tons in 1993 to 189 tons in 2002—largely because of the increased instability in the market price of green vanilla in recent years combined with lack of economic incentives in recent years (Barrera-Rodriguez et al. 2011); consequently, producers have been developing alternative production activities (Toussaint-Samat 2002).

**Silvopasture and agrosilvopasture.** Extensive cattle production throughout Mexico and many tropical regions in Latin America has led to the conversion of natural tropical forest to pasture. The integration of trees within pastures, referred to as silvopasture systems, has, in some cases, evolved naturally as farmers protect trees that are valued particularly for their shade, food, or other products. In other cases, this integration has been promoted specifically as a means for improving environmental quality and sustainability. Silvopastoral systems improve cattle raising because of high-quality forage provided by the trees, shade provided by timber trees, and the reduced costs of using live fences. Silvopastoral systems also increase the diversity of ecosystem services provided by cattle-raising systems, such as carbon sequestration, mitigation of methane emissions, and fixation of atmospheric nitrogen. In some Mexican States, such as Chiapas, knowledge and use of fodder trees and shrubs play an important role in the design of more environmentally sound cattle-raising systems and also provide significant income to farmers. Within the region of the Selva Lacandona, Chiapas, local people cultivate a total of 28 fodder species, representing 16 botanical families. In addition to being used for forage, most of the species are also used for shade, food, fuel wood, live fences, medicine, and construction (Jimenez-Ferrer et al. 2008).

### Tropical Montane Cloud Forests

Also known as fog forest and, in Spanish, as *bosque mesófilo de montaña*, tropical montane cloud forests are broadly characterized as ecosystems that experience frequent and persistent fog, or low-lying clouds. Because of its geographical location, this forest type is considered to be a transitional vegetation between the temperate forest and the tropical deciduous dry forest along elevational gradients. It is comprised of deciduous and evergreen trees and is covered with brilliantly colored orchids, bromeliads, mosses, and lichens. Although cloud forests occupy less than 1 percent of the country's land area, they are home to 10 to 12 percent of plant and animal species, many of which are endemics. More than 50 percent of this type of forest has been transformed to other land uses in Mexico during the past few decades, and the cloud forest is considered the most endangered type of tropical forest worldwide. Agroforestry production is an important alternative in regions of cloud forest that can help insure the socioeconomic wellbeing of landowners while simultaneously helping to protect these endangered forests by creating habitat for forest species, increasing connectivity, and minimizing edge effects along forest remnants. The main agroforestry production systems that are employed in regions of cloud forest in Mexico and that are capable of balancing conservation and development concerns include coffee, chamaedorea palm, pita, and pepper spice. These systems are discussed in more detail below.

**Shade coffee.** In areas with tropical seasonal dry forest and cloud forests, one of the most important agroforestry systems has been shaded coffee plantations. Mexico historically has been an important producer of higher quality shade coffee and currently occupies ninth place in production worldwide (Financiera Nacional de Desarrollo 2014). *Coffea arabica* dominates production in the country (97 percent of cultivated area) and grows best between 600 and 1200 m (2,000 to 4,000 ft) above sea level. Coffee is currently the most important export crop in Mexico, after grains, and is cultivated on 690,000 ha (1,700,000 acres [ac]) spread across 12 States (SAGARPA 2012). Production by some 500,000, mostly small (90 percent less than 1 ha [2.5 ac]) and indigenous (66 percent of municipalities), coffee growers provides a source of income for 3 million Mexicans.

The traditional and commercial shade polycultures that dominate (90 percent of cultivated area) coffee production in Mexico (Escamilla et al. 1994; Moguel and Toledo 1999) include a mix of native and introduced tree species that are typically nitrogen fixers and/or are useful commercially. These species include *Citrus* spp., banana (*Musa* spp.), rubber (*Castilla elastica*), pepper (*Pimenta dioica*), cedar (*Cedrela odorata*), jinicuil or chalahuite (*Inga* spp.), and colorin (*Erythrina* spp.). Coffee agroforestry systems are often enriched with chamaedorea palms, pepper trees, and pita, but in extreme cases such as the Tosepan cooperative Titataniske in the State of Puebla, such enrichment can reach 69 plant species per parcel or 250 to 300 plant species in total (Toledo and Moguel 2012). Because of the high biological diversity (an average of 29 tree species per farm) (Lopez-Gomez et al. 2008) and concomitant structural diversity, these agroforestry systems help conserve an important proportion of the fauna and flora of tropical montane cloud forests (Manson et al. 2008; Moguel and Toledo 1999; Philpott et al. 2008). These benefits, and associated ecosystem services (Jose 2009), have helped make Mexico a pioneer in the production of organic coffee (10 percent of production area), a recognized leader in other types of certification such as fair trade, and a target of payments from national and local programs focused the conservation and restoration of key ecosystem services.

Coffee production in Mexico has suffered since the early 1990s, with the collapse of international coffee agreements that regulated coffee production and stabilized prices and with the elimination of INMECAFE, which provided technical training and financing to growers and also collected, processed, and commercialized the coffee of the nation's coffee growers. Recurring international cycles of overproduction and low prices have hit Mexican growers hard (Manson et al. 2008). Coffee production in Mexico is also suffering because of pests and diseases such as broca, nematodes, and La Roya. Both the quantity and quality of coffee production may decline further because of the warmer, drier weather conditions expected under current scenarios of global climate change, unless growers implement measures to mitigate or adapt to these changes (Gay et al. 2006; Laderach et al. 2011). Two consequences of these trends have been a shift to resistant, more productive, varieties that require more agrochemicals and less shade cover, and increased rates of conversion of shade coffee plantations to other land-use systems, especially sugarcane or pasture, which typically lead to greater environmental degradation and reduce climate change mitigation potential.

**Chamaedorea palm.** The chamaedorea palm is one of the principal nontimber forest products primarily found in cloud forest ecosystems in Mexico and comprises 37 percent of the international market. Mexico is considered a center of diversification. Of the 130 species of *Chamaedorea* known on the American continent, about 50 are found in Mexico, of which 14 are native species. Planted populations of these palms do not produce seed because of a lack of pollinators, and therefore seed must be collected from natural populations found in forest ecosystems, an important factor in the conservation of forests where the plant is found. Chamedorea palm leaves (particularly from *Chamaedorea elegans*) have been exported as an ornamental internationally, especially to the United States, for more than a century, but the rate of exportation increased greatly starting in the 1940s. Palm populations overall have remained stable, although overexploitation, habitat destruction, and land-use change threaten populations in some parts of Mexico. Diverse initiatives by the National Forestry Commission (CONAFOR) of Mexico (CONAFOR 2014) and various nongovernmental organizations (NGOs) have promoted the cultivation of palm in forested areas and also as part of agroforestry systems, such as shade coffee, especially in the States of Chiapas, Oaxaca, and Veracruz. Both the chameadorea palm and pita (see details in the following section) grow well in as part of more intensively managed agroforestry systems (e.g., shade coffee), and they are especially important in providing a safety net for poor farmers to rely on when production of other subsistence or cash crops is lower than anticipated (Marshall et al. 2006).

**Pita.** Pita (*Aechmea magdalenae)* is a highly resistant fiber obtained from a terrestrial bromeliad, originally used in pre-Hispanic times primarily for fishing nets; more recently, it has been popularized through its use in artisan *charreria* with decorative borders in pita, especially in Chiapas and Oaxaca. With increasing demand, rural communities began to domesticate the pita plant by collecting cuttings to plant within their gardens, coffee and fruit plantations, and nearby forest plots. Productivity is estimated at 15 to 25 kg/ha (13 to 22 lb/ac), representing a value of $4,500 to 10,000 Mexican pesos/ha ($100 to $220 U.S. dollars/ac), which is greater than the value of coffee or cattle. Thus, the pita provides an important means of economic diversification and alternative income source when prices of other products are low, and it contributes to conservation of remaining forest patches within agricultural landscapes. Annual production of pita in Mexico varies between 30 to 40 tons.

**Pepper tree.** The pepper tree (*Pimenta dioica*), also known as the pepper spice, grows throughout Central America, the Caribbean, northern South America, and Mexico. Trees typically reach a height of 6 to 10 m (20 to 30 ft) and grow as isolated trees with open pastures, where they are valued for their shade. They are also integrated as part of home gardens and with other crops (e.g., orange, banana, cacao, coconut), where they help control weeds. The pepper spice was originally used in pre-Hispanic times and continues to be a valuable condiment internationally, with demand for dry pepper and essential oils increasing progressively. It is an important crop grown within coffee plantations in the States of Campeche, Chiapas, Oaxaca, Puebla, Tabasco, and Veracruz. Production in Mexico between 1990 and 2000 increased from 868 to 4,980 tons, with most of this product exported internationally. Mexico is the second major producer and exporter of pepper worldwide, after Jamaica.

### Tropical Seasonal Dry Forest

Tropical seasonal dry forests are characterized by pronounced seasonality in rainfall. The many deciduous species in these forests are adapted to the seasonal absence of rainfall, and plant species abundance is nurtured by the warm temperatures. Tropical seasonal dry forests have a high diversity and endemism (Trejo and Dirzo 2000). In the neotropics, these forests reach their northernmost distribution in Mexico (across the States of Baja California, Sonora, Sinaloa, Tamaulipas, all the way down to Chiapas) (Cairns et al. 1995, Ceballos and Garcia 1995, Lopez-Barrera et al. 2014).

A large portion of tropical dry forest was lost in the 1970s, when the Mexican Government supported the clearing of these forests along the Pacific coast of the State of Jalisco to be used for agriculture, cattle ranching, tourism, and housing uses (Romero-Duque et al. 2007). By 1980, human use had eliminated 44 percent of the original area of tropical dry forests in Mexico. Some of the human uses included converting the forests into grasslands for cattle grazing, employing slash-and-burn agriculture, and harvesting wood for fuel (Galicia et al. 2008). It is also important to note, however, that some of these pasture-based land-use practices may be considered agroforestry silvopastures for cases in which trees comprise integral components of the pastures, and slash-and-burn agricultural systems may be considered agroforestry if sufficient fallow periods and/or preservation of isolated trees within crop fields allow for the maintenance of permanent woody vegetation cover during longer periods.

Some tropical regions in Mexico, particularly those with dry forest, are used as silvopastoral systems, in which cattle forage on small trees and, during the dry season, on leaves and fruits that have fallen on the ground. The forage quality, in general, is higher in pastures. For example, in the Sierra de Manantlan, 19 species (herbs, shrubs, and trees) are used as forage, although in this silvopastoral system, the *Gramineae* species produced higher biomass per square meter, and *Verbesina greenmanii, Leucaena esculenta,* and *Acacia riparia* showed higher nutrient content. On the other hand, two layers—trees and herbs—in the tropical dry forest might produce more biomass than grassland alone (Montano et al. 2003), while potentially providing other diverse products, such as pitayas, honey, and spices, such as oregano and candelilla.

## Potential Carbon Sequestration From Use of Agroforestry in Mexico

Many different agroforestry systems occur in Mexico; however, only a few systems involve large-scale production of products that are supported under Government incentives or programs (e.g., shade coffee, cacao). In terms of total area covered and potential for contributing to climate change mitigation and food security, these other more traditional agroforestry systems are extremely important. Table 8.2 presents a summary of studies that have quantified contributions of different major agroforestry systems to carbon storage in Mexico, including comparisons with available global estimates and studies conducted in other Central American countries. Table 8.3 presents an overview of the distribution of major commercial agroforestry systems (e.g., shade coffee, cacao, and vanilla) by State in Mexico.

**Table 8.2.** Carbon storage in different agroforestry systems.

| System | Location | Other characteristics | Carbon T/ha |
|---|---|---|---|
| Agrosilviculture[a] | Global synthesis | Humid tropical lowlands | 39–102 |
| Silvopasture[a] | Global synthesis | Dry tropical lowlands | 39–195 |
| Silvopasture[a] | Global synthesis | Humid tropical highlands | 133–154 |
| Corn fields with trees[b] | Chiapas, Mexico | 3.7 years old | 127.9 |
| Taungya (6.8 years)[b] | Chiapas, Mexico | 6.8 years old | 109.4 |
| Natural fallow (acahual)[b] | Chiapas, Mexico | 23.7 years old | 117.6 |
| Improved fallow (acahual)[b] | Chiapas, Mexico | 7.3 years old | 150.1 |
| Homegarden[c] | Veracruz, Mexico | Citrus + coffee | 40.5–73.2 |
| Homegarden[c] | Veracruz, Mexico | Citrus + banana | 32.6–59.0 |
| Homegarden[c] | Veracruz, Mexico | Citrus + coffee + banana | 43.4–77.3 |
| Homegarden[c] | Veracruz, Mexico | Citrus + coverage | 37.9–44.8 |
| Homegarden[c] | Veracruz, Mexico | Citrus + pelibuey sheep | 63.4–94.7 |
| Pasture[c] | Veracruz, Mexico | | 1.4–2.1 |
| Shade coffee, conventional[d] | Costa Rica | | 69.0 |
| Shade coffee, organic[d] | Costa Rica | | 98.0 |
| Improved fallow[e] | Chiapas, Mexico | Low tropical agroclimatic zone | 140.8 |
| Taungya[e] | Chiapas, Mexico | Low tropical agroclimate zone | 140.8 |
| Pastures with scattered trees[e] | Chiapas, Mexico | Low tropical agroclimate zone | 129.3 |
| Pastures with live fences[e] | Chiapas, Mexico | Low tropical agroclimate zone | 118.6 |
| Pastures without trees[e] | Chiapas, Mexico | Low tropical agroclimate zone | 71.5 |
| Taungya[e] | Chiapas, Mexico | High tropical agroclimatic zone | 173.9 |
| Improved fallow[e] | Chiapas, Mexico | High tropical agroclimatic zone | 148.3 |
| Traditional fallow[e] | Chiapas, Mexico | High tropical agroclimatic zone | 157.5 |
| Inga-shade organic coffee[e] | Chiapas, Mexico | High tropical agroclimatic zone | 194.0 |
| Polyculture-shade organic coffee[e] | Chiapas, Mexico | High tropical agroclimatic zone | 151.9 |
| Polyculture-shade nonorganic coffee[e] | Chiapas, Mexico | High tropical agroclimatic zone | 173.2 |
| Traditional maize[e] | Chiapas, Mexico | High tropical agroclimatic zone | 109.7 |

T/ha = teragrams per hectare.

[a] Winjum et al. (1992); Brown et al. (1993); values standardized to a 50-year rotation and represent total carbon storage in vegetation and soils.

[b] Roncal-Carcia[Garcia? As in Lit. Cit. entry? Which spelling is correct?] et al. (2008), modified by Casanova-Lugo et al. (2011); total carbon storage in vegetation and soils.

[c] Callo-Concha et al. (2004), modified by Casanova-Lugo et al. (2011). Carbon storage in aboveground vegetation and litter.

[d] Hager (2012); total aboveground and belowground carbon.

[e] Soto-Pinto et al. (2010); total aboveground and belowground carbon.

**Table 8.3.** Current distribution and production of dominant agroforestry systems (shade coffee, cacao, and vanilla) in Mexico by State.

| State | Coffee area (ha) | Coffee value (1,000s of pesos) | Cacao area (ha) | Cacao value (1,000s of pesos) | Vanilla area (ha) | Vanilla value (1,000s of pesos) |
|---|---|---|---|---|---|---|
| Chiapas | 259,315 | 2,508,647 | 20,299 | 306,840 | 0 | 0 |
| Veracruz | 147,384 | 1,791,264 | 0 | 0 | 740 | 26,798 |
| Oaxaca | 142,766 | 481,808 | 0 | 0 | 145 | 4,195 |
| Puebla | 72,175 | 645,347 | 0 | 0 | 71 | 1,960 |
| Guerrero | 47,190 | 284,106 | 237 | 1,084 | 0 | 0 |
| Hidalgo | 25,821 | 147,266 | 0 | 0 | 0 | 0 |
| Nayarit | 17,678 | 129,113 | 0 | 0 | 0 | 0 |
| San Luis Potosi | 17,154 | 19,769 | 0 | 0 | 97 | 999 |
| Jalisco | 3,835 | 30,176 | 0 | 0 | 0 | 0 |
| Colima | 2,378 | 13,051 | 0 | 0 | 0 | 0 |
| Tabasco | 1,040 | 4,670 | 40,783 | 708,477 | 0 | 0 |
| Mexico | 479 | 2,085 | 0 | 0 | 0 | 0 |
| Queretaro | 270 | 2,066 | 0 | 0 | 0 | 0 |
| **Total** | **737,485** | **6,059,368** | **61,319** | **1,016,401** | **1,053** | **33,952** |
| *Millions of dollars* | | 459 | | 77 | | 3 |

ha = hectares.

Source: SAGARPA (2013).

## Overview of Existing Policies

In 1997, the National Forestry Commission of Mexico (CONAFOR) established the Commercial Plantations Development Program (PRODEPLAN). This program included support for establishing agroforestry systems as part of its primary goal of expanding commercial forestry plantations in Mexico. Between 2000 and 2010, 83,172 ha (205,522 ac) of agroforestry plantations were established with CONAFOR's funding support; however, the classification of these systems was based purely on the plantation density (e.g., 600 trees/ha [1,482 trees/ac]) without specifying the types of agricultural or livestock components that are managed in combination with forestry production. Thus, available information on areal extent of implementation should be interpreted cautiously (CONAFOR 2014).

The target goal of expanding forest plantations was not fully realized in this program, which was largely attributed to landowner unwillingness to invest the resources when financial returns occur on such long time scales. This lack of success led to agroforestry systems being included within PRODEPLAN in 2011, focusing on those systems having a woody component with merchantable timber as an alternative to stimulate the establishment of forestry plantations. The modification made to the operational rules for PRODEPLAN, for the first time, identified the specific agricultural, livestock, and forestry components included in the agroforestry system and the required field verification that the system was implemented according to the original proposal.

Between 2011 and 2012, 3,852 ha (9,518 ac) of agroforestry systems were supported under this program, and, in 2012, another 182 ha (450 ac) were established. Relative to the total number of hectares planted and resources distributed under this program, however, the proportion dedicated to agroforestry systems remains small. Figure 8.3 shows the distribution of agroforestry systems by State during the period from 1997 to 2012 that were implemented through CONAFOR. The program for the Production and Commercialization of Non-Timber Forest Products also provides support to certain agroforestry systems. Table 8.4 presents the agroforestry systems that have been supported as part of this new category of Agroforestry Plantations within PRODEPLAN, by bioclimatic region.

The proposal "Agroforestry-Timber Systems Most Appropriate for Mexico" calls for future CONAFOR support to target the following four systems: (1) taungya, (2) alley cropping,

**Figure 8.3.** Distribution of agroforestry systems, by State, established with support from CONAFOR's PRODEPLAN program between 1997 and 2012. (CONAFOR 2014).

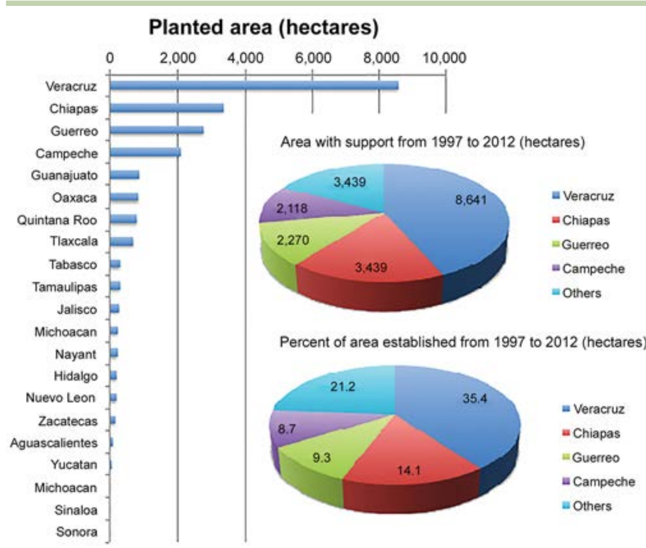


**Table 8.4.** Agroforestry-timber systems established in tropical regions in Mexico since 2011 under Comisión Nacional Forestal's Plantation Agroforestry category, by climatic zone. (1 of 2)

| State | Surface area (ha) | Agroforestry system (tree species) | Associated plant species |
|---|---|---|---|
| **Tropical zone** | | | |
| Guerrero | 25<br>25<br>60<br>50<br>50<br>50<br>100<br>124<br>50<br>169 | *1. Cedrela odorata, Swietenia macrophylla, Cordia eleagnoides*<br>*2. Cedrela odorata*<br>*3. Cedrela odorata, S. macrophylla*<br>*4. Cedrela odorata, S. macrophylla*<br>*5. Cedrela odorata, S. macrophylla*<br>*6. Cedrela odorata, S. macrophylla*<br>*7. Cedrela odorata, S. macrophylla*<br>*8. Cedrela odorata, S. macrophylla*<br>*9. Cedrela odorata, S. macrophylla*<br>*10. Cedrela odorata, S. macrophylla* | 1. Coconut<br>2. Agricultural crops<br>3. Corn, beans<br>4. Corn<br>5. Corn, beans, pasture<br>6. Corn, beans, pasture<br>7. Corn, beans, pasture<br>8. Corn, beans, pasture<br>9. Corn, beans, pasture<br>10. Corn, beans, pasture |
| Hidalgo | 100 | *Cedrela odorata* | Coffee |
| Quintana Roo | 71<br>5 | *1. Cedrela odorata, S. macrophylla*<br>*2. Cedrela odorata, S. macrophylla* | Corn |
| Chiapas | 20<br>6 | *1. Cedrela odorata, Tectona grandis*<br>*2. Tectona grandis, Tabebuia donnell-smithii, Tabebuia rosea* | Cacao<br>Mango |
| Oaxaca | 42 | *S. macrophylla, Tabebuia donnell-smithii, Cedrela odorata* | Coffee |
| Tamaulipas | 162<br>118 | *1. Eucalyptus camaldulensis*<br>*2. Gmelina arborea, Tectona grandis, Eucalyptus camaldulensis* | Sorghum<br>Pasture |
| Puebla | 50 | *S. macrophylla* | Forages |
| Tabasco | 27<br>83 | *1. Cedrela odorata*<br>2. *Eucalyptus* spp. | *1. Elaeis guineensis*<br>*2. Brachiaria brizantha* |
| Veracruz | 25 | *Gmelina arborea* | *Leucaena* spp. |
| Michoacan | 50 | *Gmelina arborea, Tectona grandis, Eucalyptus camaldulensis* | *Leucaena* spp. |
| Nayarit | 25<br>35<br>25 | *1. Tabebuia donnell-smithii, Tabebuia rosea*<br>2. *Eucalyptus* spp.<br>*3. Tabebuia donnell-smithii, Gmelina arborea, Cedrela odorata* | 1. Pasture<br>2. *Leucaena* spp.], *Brosimum alicastrum, Guasima* spp.,<br>3. *Leucaena* spp. |
| **Temperate and semiarid zones** | | | |
| Guanajuato | 50<br>200 | *1. Pinus greggii*<br>*2. Pinus greggii* | 1. Corn, beans<br>2. Corn, beans |
| Tlaxcala | 30<br>79 | *1. Pinus pseudostrobus, Pinus montezumae*<br>*2. Pinus pseudostrobus, Pinus montezumae* | 1. Rye, corn, basic grains<br>2. Wheat, corn |
| Puebla | 22 | *Pinus pseudostrobus* | Coffee |
| San Luis Potosi | 100 | *Prosopis spp.* | *Opuntia* spp. |
| Nuevo Leon | 56<br>53<br>36<br>67<br>75 | *1. Prosopis glandulosa*<br>*2. Prosopis glandulosa*<br>*3. Prosopis glandulosa*<br>*1. Prosopis glandulosa*<br>*2. Prosopis glandulosa* | 1. Pradera<br>2. Sorghum (forage), vegetable crops<br>1. Forage<br>2. Forage<br>3. Forage |
| Sonora | 44 | *Prosopis* spp. | Native grasses |
| Queretaro | 20<br>25 | *1. Pinus greggii*<br>*2. Pinus greggii, Prosopis laevigata* | 1. Rye<br>2. Alfalfa |

ha = hectares.

Source: CONAFOR-UNACH (2013).

(3) mixtures of perennial crops and trees, and (4) tree plantations with pasture and livestock (see details in table 8.5). Additional criteria for consideration include that the system should be established under areas having good agroecological conditions and with fast-growing trees with timber potential to ensure both maximum ecological and financial success for interested producers and to reduce costs to the program (CONAFOR 2014).

As part of its proposal for Agroforestry-Timber Systems Most Appropriate for Mexico, CONAFOR conducted a study to identify and prioritize potential areas for establishing agroforestry systems throughout the entire country (CONAFOR 2014). Areas with the following characteristics were excluded from the analysis: areas higher than 3000 m (9,842 ft) above sea level, areas susceptible to flooding, natural protected areas, areas with severely saline or sodic soils, areas with slopes of

**Table 8.5.** Principal characteristics of the proposed agroforestry-timber systems for Mexico.

| Agroforestry system | Principal characteristics |
|---|---|
| Taungya | Temporal combination of trees with agricultural crops; trees are planted with uniform spacing; crops are grown while there is sufficient light; crops with greater shade tolerance may be substituted as the plantation develops. |
| Alley cropping | Permanent mixture of crops or pasture in alleys; the timber trees can be established in lines of different sizes; the pasture can be for cutting or grazing. |
| Mixtures of perennial crops and trees | Permanent combination of agricultural crops and timber trees that may (or may not) provide shade for the crops; examples of tree species include rubber, coffee, cacao and coconut. |
| Tree plantations with pasture and livestock | Permanent combination of timber trees with dispersed shade within pasture maintained for livestock. |

Source: CONAFOR-UNACH (2013).

more than 25 percent (more than 20 percent for tropical lands), arid zones with less than 300 mm mean annual precipitation (MAP), tropical zones with less than 800 mm MAP, temperate zones with less than 600 mm MAP, polygons of less than 100 ha in size, areas with thin soils or soils with rocky outcroppings (lithosols), and severely degraded lands. Application of these criteria resulted in a total surface area of 13.9 million ha (34.3 million ac), distributed across 30 States, which were considered priority areas for agroforestry implementation as part of this study. The analysis (using a geographic information system) resulted in a total "potential" surface area for agroforestry of 4 million ha (10 million ac), with nearly 86 percent concentrated in eight States (table 8.6).

Data from the States of Veracruz and Tabasco show that at least one of the most common 15 genera of agroforestry species were planted outside of established priority zones (fig. 8.4). Agroforestry systems were likewise established in areas where water scarcity was considered as a fundamental limitation and potential cause of failure of agroforestry systems (CONAFOR 2014). CONAFOR's recommendation is that future agroforestry programs target the priority areas (CONAFOR 2014).

Distribution of agroforestry species and priority areas based on elevational zones; e.g., Zone A (0 to 700 m above sea level), Zone B (700 to 1500 m above sea level), Zone C (1500 to 2200 m above sea level), and Zone D (more than 2200 m above sea level) has been identified (CONAFOR 2014). Of the total area with high potential for agroforestry (i.e., 3.96 million ha [10 million ac]), the majority (82 percent) is located in Zone A, with 14 percent of the remaining area in Zone B and 4.5 percent in Zones C and D. The most frequently used agroforestry woody species and associated crops for each elevational zone were coffee and cacao and corn, beans, oats, and pasture, respectively (table 8.7)

**Table 8.6.** Distribution of potential surface area for agroforestry systems in Mexico, by State.

| State | Surface area (ha) | Percent of surface area |
|---|---|---|
| Veracruz | 1,403,500 | 35.3 |
| Chiapas | 414,871 | 10.4 |
| Oaxaca | 369,146 | 9.3 |
| Tabasco | 340,242 | 8.5 |
| Guerrero | 339.844 | 8.5 |
| San Luis Potosi | 214,664 | 5.4 |
| Puebla | 170,207 | 4.3 |
| Nayarit | 161,919 | 4.1 |
| Quintana Roo | 100,916 | 2.5 |
| Michoacan | 80,984 | 2.0 |
| Campeche | 65,981 | 1.7 |
| Tamaulipas | 57,533 | 1.4 |
| Hidalgo | 57,228 | 1.4 |
| Yucatan | 54,360 | 1.4 |
| Jalisco | 52,235 | 1.3 |
| Mexico | 46,991 | 1.2 |
| Durango | 17,3355 | 0.4 |
| Chihuahua | 13,610 | 0.3 |
| Colima | 10,353 | 0.3 |
| Sinaloa | 5,065 | 0.1 |
| Morelos | 3,315 | 0.1 |
| Sonora | 600 | 0.01 |
| Nuevo Leon | 83 | 0.002 |
| **Total** | **3,980,002** | **100** |

Source: CONAFOR 2014.

**Figure 8.4.** Comparison of identified agroforestry priority areas (orange) for the States of Tabasco and Veracruz with the areas where at least one of the most common 15 genera in agroforestry systems were planted (green). (CONAFOR 2014).

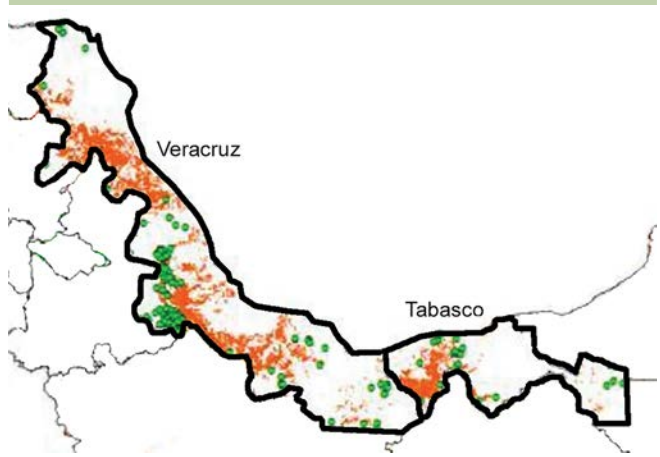


**Table 8.7.** Potential surface area for major agroforestry crops, by altitudinal zone.

| Crop | Surface area (hectares) | | | | |
|---|---|---|---|---|---|
| | Zone A (0–700 m) | Zone B (700–1500 m) | Zone C (1500–2200 m) | Zone D (> 2200 m) | Total |
| Coffee | 2,182,307 | 377,711 | 85,296 | — | 2,645,314 |
| Chocolate | 545,893 | 150,272 | 38,377 | — | 734,542 |
| Corn | 3,156,853 | 549,751 | 155,597 | 21,831 | 3,884,032 |
| Beans | 2,972,847 | 469,592 | 115,596 | 19,812 | 3,577,847 |
| Oats | 183,381 | 61,677 | 46,270 | 8,584 | 299,912 |
| Pasture | 3,193,381 | 546,487 | 142,819 | 20,795 | 3,903,482 |

Note: Zone elevations (in meters) in parentheses.

Source: CONAFOR 2014.

## Payments for Ecosystem Services Programs

Agroforestry production in Mexico has also been strengthened by the rapid growth of programs making payments for ecosystem services (PES). These programs were originally envisioned as a means for conserving and restoring the country's endangered forest and water resources, linked through the multiple services provided by these ecosystems (Manson 2004, Mora 2015, Munoz-Pina et al. 2011). There is also a growing interest for using PES programs to address the socioeconomic and cultural problems, which may be limiting their effectiveness in achieving environment goals (Alix-Garcia et al. 2012, Munoz-Pina et al. 2011). Mexico's national PES program was established in 2003 through the redistribution of 2.5 percent of water-concession payments nationwide from the National Water Commission to CONAFOR. These funds were used to establish 5-year contracts with landowners in key watersheds throughout the country for providing hydrological services. Starting in 2004, payments were authorized for additional services, including carbon sequestration, biodiversity conservation in forest plots, and improvement of shade cover in agroforestry systems (mostly shade coffee and cacao farms). Payments for carbon sequestration were eliminated in 2006. The national PES program is now one of the largest in the world, having made more than $650 million in payments covering 4.16 million ha during the period from 2003 to 2013 (table 8.8).

**Table 8.8.** Beneficiaries, area, and amount paid by year in Mexico's national program making payments for ecosystem services.

| Year | Number of beneficiaries | Area (thousands of ha) | Amount paid (millions of pesos) |
|---|---|---|---|
| 2003 | 272 | 127 | 192 |
| 2004 | 578 | 215 | 388 |
| 2005 | 302 | 196 | 310 |
| 2006 | 315 | 146 | 232 |
| 2007 | 1,447 | 610 | 1,061 |
| 2008 | 1,114 | 462 | 982 |
| 2009 | 693 | 502 | 1,096 |
| 2010 | 688 | 509 | 1,116 |
| 2011 | 558 | 465 | 980 |
| 2012 | 747 | 567 | 1,222 |
| 2013 | 637 | 471 | 1,006 |

ha = hectares.

Source: CONAFOR (N.d.).

The proportion of payments to lands in the category of PES including agroforestry systems has been growing and comprises 26 percent of all areas that have been included in the national program to date (table 8.8). To receive such payments, farmers with agroforestry production need to show that their shade cover is diversified and composed of native tree species and that cattle and other grazing animals are not part of the production system. Most payments have been made to shade coffee farms, followed by cacao, vanilla, and the chamaedorea palm.

### Reducing Emissions From Deforestation and Forest Degradation

According to CONAFOR's "Terms of Reference for the Operation of REDD+" (CONAFOR [N.d.]), one objective of REDD+ in Mexico is "to promote the establishment of agroforestry and silvopastoral systems, as well as other innovative production schemes, that simultaneously enhance food security of local people and the restoration of degraded areas." Within this program, *agroforestry* is defined as "a management system focusing on agricultural production that integrates forestry activities through productive reforestation and the management of degraded areas, with the goal of obtaining diverse benefits such as food security, production diversification, ecosystem connectivity, biodiversity conservation, among other ecosystem products and services."

Several special programs known as "early actions REDD+" have been launched recently in Mexico. In 2013, such programs were established in Campeche, Chiapas (Lacandon Forest), Oaxaca, Quintana Roo, and Yucatan. These programs support the establishment of agroforestry systems (crops plus trees) and silvopastoral systems (mostly live fences). In 2014, a new special program was launched in the coastal region of Michoacan to support the establishment and management of both agroforestry and silvopastoral systems. The only special programs that include the production of tree seedlings are the ones for Campeche, Chiapas, and Oaxaca. These special programs are administrated through the Department of Community Forestry of CONAFOR. The special programs were established as a strategy to mitigate climate change, join biological corridors, provide socioenvironmental benefits, and slow down or stop deforestation. So far, these special programs are applied only in the aforementioned States.

## Constraints to Adoption and Implementation of Agroforestry Systems in Mexico

To a large extent, adoption of different agroforestry system depends on the cultural practices of the particular indigenous groups present in each region and on the climatic constraints of the different agroforestry crops (e.g., vanilla in Veracruz, avocado in Michoacán, cacao in Tabasco). Several major threats to the future continuation or expansion of agroforestry systems in Mexico include: (1) the reduction in species and agroforestry practices represented; (2) the loss of knowledge and/or abandonment of traditional agroforestry practices, a process related to the out-migration of young men and women, along with the aging and death of the farming populations; (3) agricultural intensification that results in a reduction or loss of the fallow period, the vegetative cover, and traditional crops, along with an increase in the use of machinery, agrochemicals, and annual crops; and (4) the rental or sale of private lands for development of intensive crops or residential homes (Moreno Calles 2013).

Another factor that potentially limits the expansion of agroforestry systems to new areas is the oftentimes inadequate alignment between support and resources available from the different institutions, especially because cattle ranching and agricultural activities that are promoted by many Government programs often result in the destruction of forest resources (Moreno Calles et al. 2013). Land tenure issues may also limit agroforestry expansion. For example, cattle ranching laws in Mexico manipulate the definition of s*tocking densities* to circumvent the definition of *small property* in the redistribution of lands after the Mexican Revolution, resulting in the establishment of relatively large properties that are dedicated to cattle ranching and that do not generally favor the establishment of agroforestry or other production systems (Gonzalez-Montagut 1999).

To understand what factors influence decisions and motivations to adopt agroforestry practices, a survey of previous and current program participants was conducted (CONAFOR 2014). The following list includes some of the major findings from this study.

- The selection of a particular species to incorporate within agroforestry systems depended on familiarity, growth rates, market value, ease of propagation and management, multiple use options, interactions with crops, availability, recommendations from programs, and the environmental impacts. Although exotic species were previously favored, an increasing interest in working only with native species has recently emerged. In general, producers preferred a mixture of different species.
- In general, agroforestry projects were more useful to landowners when they were provided with information about the behavior and resource requirements for a variety of species and agroforestry designs, rather than when they were offered a single standard system. This approach enables landowners to choose which combination of species and systems best meets their available resources and needs.
- Even though agroforestry systems may be inherently profitable, the success of adoption was greatly enhanced when landowners received technical assistance that provided information about the management of tree species and agroforestry configurations, which often were unfamiliar. In particular, the involvement of local people as technicians and extensionists has proven to be a successful and low-cost method for promoting agroforestry systems and also for developing local capacities and human resources for disseminating agroforestry in the future.
- The primary four reasons for participation in CONAFOR's agroforestry program were (1) to provide a source of employment (i.e., because the program paid landowners directly to participate) (24 percent); (2) to increase the production of trees in certain areas (19 percent); to improve the environmental conditions on the land (38 percent); and to improve the economic value of the land (19 percent). Two-thirds of the participants perceived a potential for obtaining an income from the harvest of the trees as a major benefit of the agroforestry system.
- Major problems identified by the CONAFOR participants included the lack of sufficient economic resources for investing in infrastructure, labor, etc. (43 percent); biophysical limitations, such as pests and disease, lack of rain, excessive temperatures, or steep slopes (31 percent); social problems, such as vandalism, damage to plants from people (19 percent); and institutional problems related primarily to complex and slow bureaucratic requirements (7 percent).
- The subsidies provided by CONAFOR were instrumental in determining adoption of the agroforestry practices; 89 percent indicated they would not have established the practices without the subsidies. In addition, many were unwilling to implement management practices (e.g., thinning, road maintenance) because of their high cost and/or labor requirements.

A broader analysis of 21 agroforestry projects in Central America and the Caribbean by Current et al. (1995) identified several underlying themes that emerged as important factors influencing the adoption of agroforestry practices, including:

- The management intensity that is economically attractive for farmers depends on the degree of scarcity of forest resources, the level of demand, the opportunity cost of alternative uses, the availability of labor and capital, and the production costs relative to the cost of available substitutes for the products and services provided by trees. For example, this study found that, in Panama, traditional extensive land-use systems (e.g., migratory agriculture or slash-burn-fallow) were profitable in areas where land was widely available, whereas in areas with limited land area, such as El Salvador or the highlands of Guatemala, more intensive management systems such as agroforestry were more common.

- The adoption of agroforestry systems by small famers is usually most successful when it occurs gradually (i.e., during a 5-to-10 year period), taking into account the food security and risk reduction needs, especially because these producers often have limited resources and management options. The focus should be on starting with a few farmers and on agroforestry systems that offer continuous benefits during long periods. Overall, acceptance and adoption of agroforestry practices were higher among larger landowners, largely because they were able to better adapt their available resources compared with small landowners.

## Needs and Emerging Opportunities for Agroforestry in Mexico

The "Second Revision of the FAO Strategic Forestry Program 2025," conducted in 2013 in collaboration with the Autonomous University of Chapingo, Mexico, states that one of Mexico's strengths is the potential of its ecosystems to sequester carbon, which can promote conservation of resources and alternative incomes for inhabitants of forested areas (CONAFOR-FAO 2014). Despite important efforts, such as the recent PES programs, however, the generation of markets and access to international credit funds are still in their initial phases. The area incorporated within the PES programs for carbon, biodiversity, and agroforestry in 2007 was 64,835 ha (160,211 ac). The panel of experts felt that the current PES system does not constitute a true market, and they recommended that Mexico develop the PES programs so that the projects can become eligible for the global carbon credit markets. Regarding hydrologic services, the panel observed that payments are not linked with the quality or quantity of services provided, therefore becoming just a subsidy for not using the forest resources. In response to these suggestions, CONAFOR is in the process of revising its PES programs to facilitate greater contributions by public resources, international donations, and users of ecosystem services to maintain PES programs.

In terms of sustainable management, agroforestry systems are unique. Agroforestry systems can serve as an important source of income to poor rural communities and can provide a host of other important ecosystem services, such as carbon sequestration, habitat and biological corridors for wildlife, and scenic beauty (Beer et al. 2003, Jose 2009, Martinelli 2012, Moguel and Toledo 1999). Despite these many benefits, production via the principal agroforestry systems in Mexico is declining because of a host of problems, including disease, climate change, low profits, and abandonment (Bacon et al. 2008; Diaz-Jose et al. 2013; Gay et al. 2006; Tucker et al. 2009). Such trends make these agroforestry systems vulnerable to conversion to other, more intensified land uses with a concomitant loss of ecosystem services. This trend is particularly apparent in States such as Veracruz, where high population densities and a tradition as a major producer of farm produce and cattle for the country have left only a small remaining fraction of undisturbed natural vegetation (less than10 percent). Some 7,000 ha (17,297 ac) of shade coffee were converted to other land uses in central Veracruz during the past decade alone (2000 to 2010) (Cabrera Garcia 2015). In this context, agroforestry systems such as shade coffee play an even more important role by providing about 35 percent of the tree cover in mountainous regions of the State.

Major agroforestry systems in Mexico (table 8.3) are currently considered as crops and fall under the sole responsibility of the Secretariat of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA), thus facilitating shifts from shade coffee plantations to other crops (e.g., sugar cane) as a simple transition from one crop to another. On the other hand, the classification of cacao and shade coffee farms as crops also limits their inclusion in CONAFOR's forestry programs, which are designed to help promote sustainable forestry or plantations and that provide landowners with financing of up to $8,000 pesos/ha or around 20 times that for which they can currently receive in PES payments if they are within eligible areas. This situation has created a vacuum whereby neither SAGARPA (responsible for agricultural activities) nor CONAFOR (responsible for forestry activities) has a specific mandate within their mission or terms of reference to promote large-scale agroforestry practices.

To counteract these tendencies, a coalition of academics, NGOs, and regional decisionmakers is proposing a modification of national laws that would recognize and conserve the multiple cultural, socioeconomic, and ecosystem service benefits provided by agroforestry systems (Mora 2015). The proposed legal reforms would make land under agroforestry production a hybrid land use eligible to participate in all relevant SAGARPA and CONAFOR programs and thus provide additional financial incentives for this type of production system. Further, classifying agroforestry as a type of forestry system would provide additional legal protections, so that converting cacao or shade coffee into more intensified and simplified production systems as a means of short-term profit would become more difficult. Such changes would make their protection more likely in regional planning exercises. The program recently established under REDD+, called "Forests and Climate Change," proposes to create a common technical agency that would operate across both SAGARPA and CONAFOR, with the goal of facilitating agricultural activities within forested landscapes (including agroforestry practices) with an overall focus on integrated landscape management. If successful, this program has the potential for significantly increasing climate change mitigation and adaptation contributions by agroforestry systems in Mexico.

## Key Findings

- Many agroforestry systems practiced in Mexico today are derived from traditional land-use systems developed by indigenous people over long periods of time and thus are well adapted to the local climate and biophysical conditions.
- Agroforestry practices in Mexico provide opportunities for sequestering and storing larger amounts of carbon compared with other agricultural systems, such as pastures and crops.
- Existing policies in Mexico often do not adequately consider agroforestry practices as part of the country's programs that address the challenges of sustainable land-use practices and climate change, largely because these systems are outside the mission of the main Government agencies responsible for either agricultural-related or forestry-related programs.
- In recent years, greater attention has been placed on specifically identifying agroforestry systems as meeting the criteria of Government programs to promote sustainable land use, especially for those programs related to ecosystem services and climate change mitigation.
- Future success in promoting the adoption and maintenance of agroforestry practices will require more focused policy initiatives that link specific agroforestry practices with anticipated benefits and funding opportunities.
- Agroforestry contributes to food security by integrating a diversity of edible species, especially fruit tees cultivated together with perennial food crops, and by providing fuel for cooking.

## Key Information Needs

- Quantification and economic valuation of the ecosystem services provided by different agroforestry systems, especially as related to water resources, carbon storage and sequestration, biodiversity, and resilience to climate change and volatile national and global markets.
- Social, economic, and policy drivers that influence land-use change involving the establishment or conversion of agroforestry practices.

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# Chapter 9
# Challenges and Opportunities

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This assessment focuses on the capacity of agroforestry as a management option to provide critical ecosystem goods and services to farms and ranches under changing conditions. Agroforestry provides farmers, ranchers, and even communities "with [tree-integrated] strategies to manage risk, whether it stems from uncertain markets or extreme weather patterns" (USDA 2015). In addition to the benefits derived from current agroforestry use, several emerging opportunities may expand agroforestry's contributions to supporting sustainable and resilient land management. These opportunities capitalize on agroforestry's unique factors: its woody and long-lived nature; its ability to provide a variety of forest/tree-derived services of value to farmers, ranchers, and communities; and its versatility of design options.

Having been practiced throughout the world for centuries, agroforestry is not a new practice. Its use and research base, however, are relatively new within the context of modern U.S. agriculture. Research has verified the positive direction of agroforestry's mitigative and adaptive services. Based on these findings, agroforestry practices are promoted by the U.S. Department of Agriculture (USDA) through the Farm Bill and are included in USDA Natural Resources Conservation Service's conservation practice standards (USDA-NRCS [N.d.]). More research is required to meet customer demand for region-specific assistance and for the enhanced quantification of agroforestry's impacts. To this end, USDA developed the Agroforestry Strategic Framework in 2011, which provides a general roadmap for the efficient advancement of agroforestry science and adoption in the United States (USDA 2011) (box 9.1).

Key findings and needs identified in this U.S. agroforestry assessment are presented in each chapter. Looking at all these findings and needs, two overarching conclusions become apparent: (1) increasing evidence shows how the forest-derived services generated by agroforestry can contribute to food security, rural economies, and the ecological health of U.S. agricultural landscapes, and (2) additional information, especially regarding the economics of these systems, will be needed to successfully capitalize on agroforestry's benefits under changing conditions.

## **Box 9.1.** USDA Agroforestry Strategic Framework, 2011 to 2016

Bringing together the ideas and resources of five U.S. Department of Agriculture (USDA) agencies, two key partners, and a diverse group of stakeholders, the USDA Agroforestry Strategic Framework was developed to create a roadmap for advancing the science and application of agroforestry in the United States and U.S. territories (USDA 2011). It was built around three simple goals—adoption, science, and integration—with strategies listed for accomplishing these goals. These strategies were developed with the recognition that agroforestry could play a key role in enhancing America's agricultural landscapes, watersheds, and rural communities. Addressing this diversity of issues from economic to biophysical, these strategies can help support the acceptance and adoption of agroforestry in the United States. Under the guidance of the Agroforestry Executive Steering Committee, a team of senior leaders from eight USDA agencies developed the report *Agroforestry: USDA Reports to America, Fiscal Years 2011-12* (USDA 2015). Released in July 2015, this first ever report documented USDA-supported agroforestry efforts nationwide. An in-brief version of this document is available at: http://www.usda.gov/documents/usda-reports-to-america-agroforestry-brief.pdf.

In this chapter, the key information needs for realizing greater use and benefit from agroforestry are highlighted. Emerging opportunities for an expanded and more innovative use of agroforestry in resiliency strategies are then presented: agroforestry as a means to enhance urban food security, agroforestry as a means to produce sustainable bioenergy, and agroforestry as means to create more productive floodplains.

## Information Challenges

To provide technical assistance that can encompass the many different combinations of species, arrangements, and management activities under agroforestry requires a greater understanding of the internal dynamics of these systems. For example, the ecophysiological dynamics of structure, function, and productivity are some of the parameters that play critical roles in maintaining sustainable agroforestry systems. The interactions between agroforestry plantings and the surrounding environment need to be more completely understood so we can better realize the potential benefits from expanding use. For agroforestry to be fully embraced within the United States, institutions, incentives, and motivations of landowners and other involved stakeholders need to be factored into the decision-making process. Key information challenges identified in this report have been grouped and will be discussed as follows—

- Productivity of Agroforestry Systems.
- Impacts of Agroforestry Systems on Their Surroundings.
- Agroforestry Systems and Climate Change Mitigation.
- Economic and Social Aspects of Agroforestry Systems.
- Regional U.S. and North American (Canada and Mexico) Information Needs.

### Productivity of Agroforestry Systems

To optimize productivity benefits from agroforestry, more information is needed to better tailor practices to the environment. Information and research needs include—

- Better understanding of how to capitalize on aboveground and belowground structure and processes that improve function performance, such as water and nutrient uptake.
- Better documentation of interactions in agroforestry practices over time, space, and planting options as they relate to production benefits and management strategies.
- Identification of tree and crop combinations and their management that can provide improved ecological services, including microclimate modification, pollination, and biological pest control in support of production.
- Design of innovative agroforestry-based food systems, especially those suitable for marginal lands that can expand opportunities for food production and natural resource protection.

### Impacts of Agroforestry Systems on Their Surroundings

To derive the fullest suite of ecosystem services from agroforestry, a better understanding of how these plantings interact biophysically and ecologically with surrounding environments is required. Information needs include—

- Identification of tree and crop species combinations and spatiotemporal configurations best suited for protecting and improving soil health.
- Better understanding of the impacts of agroforestry implementation on water resources, both quality and quantity, at the watershed scale.
- Improved placement and design of agroforestry practices that enhance water pollution and soil erosion control.
- Development of agroforestry practice designs that better incorporate biodiversity considerations, including corridor habitat for wildlife movement.

### Agroforestry Systems and Climate Change Mitigation

To enhance the use of agroforestry for mitigating greenhouse gases (GHGs), information needs include—

- More comprehensive data for building the scientific basis of carbon (C) sequestration and GHG emission reduction, particularly nitrous oxide, by agroforestry systems.
- Development and validation of these GHG dynamics to account for agroforestry's complex spatial and temporal interactions at entity to regional levels.
- Establishment of a common GHG assessment framework and set of protocols to advance measurement and predictive capacity of agroforestry's GHG mitigation services across the United States.

Agroforestry can also be vulnerable to changing conditions, especially climatic variability. Information needs critical to understanding and managing these impacts include—

- Better prediction of agroforestry effects on crop and livestock yields under future climate scenarios.
- Refined models for predicting tree species suitability, adaptability, and growth under future climatic regimes.
- Plant evaluation trials and seed sourcing to develop better adapted plant materials for agroforestry in different regions of the United States.

## Economic and Social Aspects of Agroforestry Systems

Current studies indicate that inclusion of agroforestry is not profitable when used on prime U.S. agricultural lands but is when used on marginal lands. Other studies suggest that the financial returns from use of agroforestry struggle to be competitive with annual agriculture. These studies, however, did not take into account the value of agroforestry's other benefits beyond production. When incentives or payments for ecosystem services have been included, agroforestry can be competitive (Kulshreshtha and Kort 2009). Nonmarket valuation of these other services provide a more complete picture of agroforestry's benefits and is particularly important in the formulation of policies and programs that encourage its use.

In addition to financial returns, other factors also determine the extent of agroforestry adoption, such as household preferences, resource endowments, market incentives, biophysical factors, and risk and uncertainty surrounding production. The role of risk and uncertainty appears to be more important for adopting agroforestry than for annual cropping innovations. Studies suggest that diversified systems like agroforestry may reduce whole-farm risk but more information is needed to better evaluate risk tradeoffs and uncertainty. Economic information needs include—

- Valuation of ecosystem services provided by agroforestry practices over multiple spatial scales and time.
- Better quantification of economic costs and benefits for producers implementing agroforestry practices.
- Understanding how agroforestry fits into production operations at different scales of production and marketing systems.

From a social science perspective, information needs include—

- Formulation of technical support and educational opportunities that are most effective at encouraging agroforestry adoption.
- Approaches that best apply that knowledge to the wide diversity of potential agroforestry adopters.
- Better understanding of landowners' perceptions of climatic variability and change as it influences their adoption of agroforestry practices.

Regarding agroforestry in tribal and indigenous communities of the United States and U.S.-affiliated islands, information needs include—

- Better documentation of tribal and island agroforestry practices, with an emphasis on how these practices can improve food security and land management.
- Evaluations of the resiliency of tribal and island agroforestry systems to disturbances, including assessments of threats and opportunities to enhance sustainability.
- Broader understanding of the additional support tribes and island communities will require for adapting to current and anticipated climate-related impacts.

## Regional U.S. and North American (Canadian and Mexican) Information Needs

Across the United States, a common information need is a better understanding of which agroforestry practices are best suited to the current climate, ecosystems, and agricultural operations within each region. In addition, we need to know which systems will be best adapted to expected climatic changes, particularly in regards to fluctuations in precipitation and temperature, pests, pollinators, and weeds. Gathering information on practices used by tribal and other indigenous groups can offer insight into specific regional agroforestry systems currently used that could be sustainably managed under evolving conditions. It is also critical to understand the associated economics, risks, and life-cycle costs and how these agroforestry systems can enhance the productivity and resilience of traditional agricultural and grazing systems.

The information gaps listed previously for U.S. regions apply to the Canadian provinces as well. Provincial support for agroforestry varies across Canada and will be a key factor in determining if agroforestry is to have an expanded role in supporting sustainable agriculture. Local conservation organizations exist in every Canadian province and can play an essential role in agroforestry adoption, especially if complemented by the creation of a national Canadian agroforestry network. Canada has an estimated 57 million hectares (approximately 141 million acres) of degraded land that have limitations for conventional agricultural crop production. If only 5 percent of this degraded land area were converted to agroforestry, a potential annual C sink of 47 to 76 teragrams of carbon dioxide equivalent (up to 30 percent of the emission reductions for Canada) could be created (Van Rees 2008).

Although Mexican agroforestry systems are primarily tropical with more subsistence-based practices than in the United States and Canada, information needs in Mexico are similar but with some additional concerns. Agroforestry systems in Mexico are suffering major declines due to disease, climate change, low profits, and abandonment. These trends render agroforestry systems vulnerable to conversion to other, more intensified land uses. Land conversions currently are facilitated by a legal system that allows for the transition from one crop to another (such as shade-grown coffee to sugar cane plantations) without any consideration of tree-derived ecosystem services from the agroforestry system. Modification of national laws that would recognize and reward these multiple benefits by agroforestry systems is being pushed forward. Proposed legal reforms would make land under agroforestry production a hybrid land use eligible for participation in national agriculture and forestry programs.

## Emerging Opportunities: Capitalizing on Agroforestry's Versatility

The versatility and flexibility of agroforestry design afford us many opportunities for addressing new and emerging challenges. Three promising and innovative applications for agroforestry use in the United States are (1) bioenergy production, (2) urban food security, and (3) productive floodplain management.

### Bioenergy Production

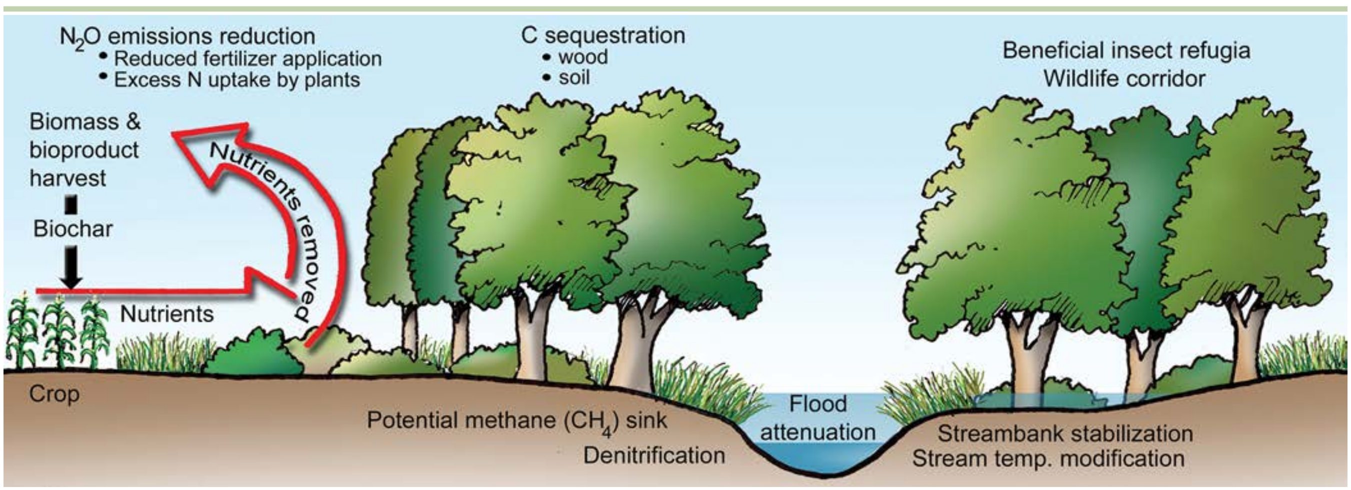
Demands on U.S. agricultural lands continue to grow for food, feed, and fiber and for other ecosystem services such as flood control, water quality protection, GHG mitigation, and wildlife habitat. With the additional demand to produce bioenergy from these lands, the sustainability and health of U.S. agricultural lands will be determined by the way in which bioenergy production and these other demands are handled, especially under conditions created by escalating extreme weather events (Gopalakrishnan et al. 2009).

Agroforestry systems can potentially augment biofeedstock production for bioenergy use, offering several advantages, especially when services for adapting to shifting weather and climate are considered. These advantages include (1) providing an environment-friendly production option for marginal lands, (2) reducing risk through diversification of income and biofeedstock sources attained by combining herbaceous and woody species into agroforestry systems, and (3) provisioning ecosystem services (i.e., protection of soil, water and air quality, and biodiversity) critical to enhancing adaptive capacity under shifting climate (Holzmueller and Jose 2012, Jose and Bardhan 2012, Thevathasan et al. 2014). Riparian forest buffers, windbreaks, and alley cropping appear to be the most promising for maximizing biomass production for bioenergy without sacrificing food production (Cardinael et al. 2012, Fortier et al. 2010, Gamble et al. 2014, Holzmueller and Jose 2012, Tsonkova et al. 2012). In the case of riparian forest buffers, harvesting biofeedstock in the zones closest to the adjacent land use can restore the nutrient uptake capacity of the plant materials, maintaining water quality functions of the system (Schultz et al. 2009) (fig. 9.1).

### Urban Food Security

More than 80 percent of the U.S. population resides in metropolitan areas. These urbanized regions face many challenges, some of which agroforestry can help address. Increasing efforts are being made to grow food within cities as a means for diversifying production sources and enhancing food security under a dynamic climate (FAO 2011). One strategy for addressing this challenge is urban food forestry or food forests, which is simply the agroforestry practice of forest farming applied in an urban environment to produce food and other ecosystem services, including air-quality enhancement,

**Figure 9.1.** A conceptual illustration of a riparian forest buffer producing biofeedstock for bioenergy while offering services, including water-quality protection, greenhouse gas mitigation, climate change adaptation, and other ecosystem services. (From Schoenberger et al. 2012).



stormwater management, and biodiversity habitat (Clark and Nicholas 2013). Urban food forestry relies on perennial woody vegetation to provide fruits and nuts while also supporting the production of other food crops (Krishnan et al. 2016, McLain et al. 2012). Targeting food forests at metropolitan locations vulnerable to flooding or urban heat island effects can help optimize the returns under climatic variability (Gill et al. 2007). Numerous urban food forestry projects are being planted in communities around the United States and offer an opportunity to use agroforestry science and technology to grow edible products while delivering other important ecosystem services in an urban environment (http://communityfoodforests.com/) (fig. 9.2).

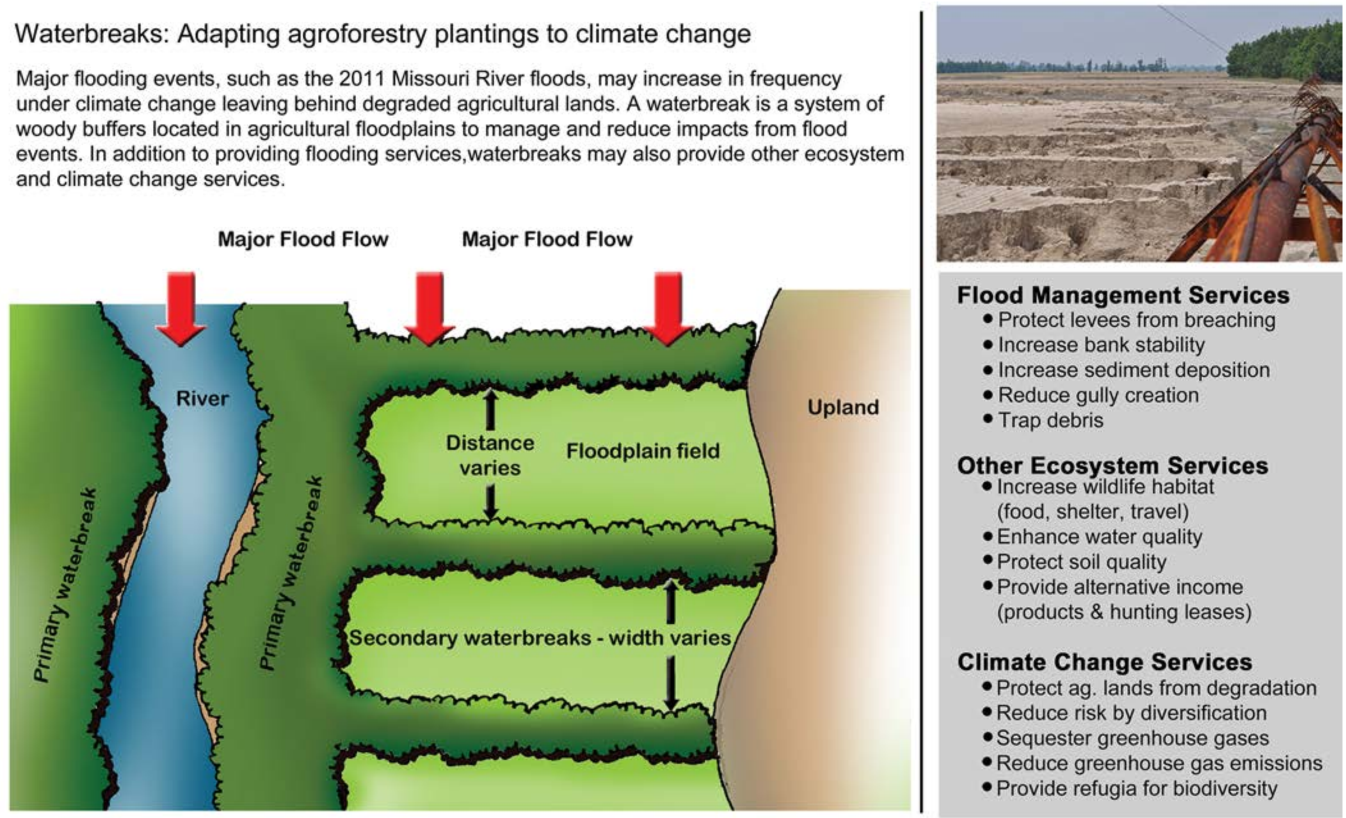
## Productive Floodplain Management

Many of the natural woody ecosystems once present in floodplains have been highly altered or removed to create productive farmland. With these alterations came extensive flood-control efforts to compensate for the loss of natural floodplains and to protect communities, roads, and agricultural fields. Even with the best available flood-control techniques, however, rivers still flood often with devastating consequences. With expected increases in flooding under climate change, a need exists for creating floodplain systems that accommodate, rather than control, flooding and that still maintain economic and biological attributes. One option for creating productive floodplains is through the establishment of carefully planned and managed waterbreaks (Wallace et al. 2000).

Waterbreaks offer a novel agroforestry system for reducing impacts from flood events by providing a series of strategically placed buffers in the floodplain (fig. 9.3). A *waterbreak* is a planned floodplain system of linear woody buffers oriented to reduce flooding impacts and to provide supplemental benefits (Wallace et al. 2000). The placement and use of waterbreaks are intended to moderate water velocity similar to the way windbreaks moderate wind velocity. Crops in floodplains have a roughness coefficient of 0.025–0.045 Manning's N, and woody vegetation can increase the coefficient to 0.08–0.16, which can reduce flood velocities by around 70 percent (Chow 1959, Fathi-Moghadam and Drikvandi 2012). Flood damage evaluation and onsite observation from the Great Midwest Flood of 1993 (a 500-year flood event) showed that fields protected with tree corridors experienced 25 to 75 percent lower reclamation costs (Wallace et al. 2000). During nonflooded conditions, waterbreaks can provide critical wildlife corridors between upland and riparian areas and improve water quality by trapping sediment and filtering chemicals from runoff. These features can also provide alternative income for landowners through hunting fees and harvesting products, such as timber, nuts, and other nontimber forest products.

**Figure 9.2.** The Dr. George Washington Carver Edible Park in Asheville, NC, is one of the oldest food forests established in the United States. Planted in 1997 on a former landfill, figs, apples, pears, chestnuts, hazelnuts, plums, peaches, grapes, and pawpaws are just some of the food producing trees that are available to the public for consumption. (Photos courtesy of Catherine Bukowski, Virginia Tech).

**Figure 9.3.** A conceptual illustration of a waterbreak producing flood management services and offering other ecosystem services. (From Schoeneberger et al. 2012).




## Conclusions

Agriculture in the United States is facing the daunting task of meeting ever-increasing production and environmental demands on a finite land base—all under the increasing uncertainty of weather and projected climate (Walthall et al. 2012). Practices are needed that can bolster the health and resiliency of U.S. agricultural landscapes today while helping producers proactively “hedge their bets” for the future. Agroforestry, a unique tree-based management activity for agricultural lands, is one such practice that offers the advantage of providing integrated mitigative and adaptive services while producing other ecosystem services of value to producers and society. As such, agroforestry can be a “no/low-regrets” option, providing near-term benefits while then being in place to address future weather and climate impacts if and when they occur.

Effective adaptation to climatic variability and change requires timely information and actionable science to assist in decisionmaking. Agroforestry, which did not begin as a science in the United States until recently (Jose et al. 2012), is lacking the robust science base traditional agricultural and forestry practices have. This assessment identified key needs for timely and actionable knowledge on the use of agroforestry as a climate-smart practice. With contributions from many experts and drawing from the rapidly growing database for agroforestry, this assessment provides the first-ever synthesis regarding agroforestry’s potential to reduce threats and build resilient agricultural landscapes in the United States. The report identifies key findings and research needs vital to optimizing these services by currently used agroforestry practices. Perhaps, more importantly, it points out the potential for a more innovative and expanded use of agroforestry as a management option for addressing the multiple challenges that our Nation’s lands face.

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# Glossary

**adaptation—**Adjustment in a natural or human system in response to actual or expected climatic stimuli or their effects that moderates harm or exploits beneficial opportunities.

**adaptive capacity—**The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

**adaptive management—**A decision process that promotes flexible decisionmaking that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process.

**afforestation—**Direct human-induced conversion of land that historically has not been forested to forested land through planting, seeding, and/or the human-induced promotion of natural seed sources. Most agroforestry plantings in temperate regions do not meet the definition of forest based on size criteria. As such, they do not qualify as afforestation practices, although ecologically they are afforestation like in their growth and ecological behavior.

**agrodeforestation—**The process of destroying or neglecting the traditional agroforestry systems in favor of plantation-type agriculture.

**agroforestry—**Intensive land-use management that optimizes the benefits (physical, biological, ecological, economic, and social) from biophysical interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock.

**agroforestry practice—**A category of agroforestry based on the type and purpose of the planting. The five categories of agroforestry practices recognized in the United States and Canada include windbreaks, riparian forest buffers, alley cropping, forest farming, and silvopasture, with a growing sixth category to capture modifications of the five practices for use in addressing emerging issues (e.g., stormwater treatment, biofeedstock production). See also box 1.1 in chapter 1.

**agroforestry system—**A land-use management system in which woody perennials (trees, shrubs, bamboos, palm trees, woody lianas) are grown on the same land management unit with crops and/or livestock to create interactions considered beneficial to the producer and/or the land. An agroforestry system can be subdivided into other systems and is a part of larger systems. See also box 1.1 in chapter 1.

**alley cropping—**The planting of trees or shrubs in two or more sets of single or multiple rows with agronomic, horticultural, or forage crops cultivated in the alleys between the rows of woody plants.

**beneficial insect—**Any of a number of species of insects that perform valued services like pollination and pest control.

**biodiversity—**The variability among living organisms from all sources, including within species, among species, and of ecosystems.

**bioenergy—**Any renewable energy made from biological sources. Fossil fuels are not counted because, even though they were once biological, they are long dead and have undergone extensive modification.

**biofeedstock—**Any renewable, biological material that can be used directly as a fuel or be converted to another form of fuel or energy product.

**biofuel—**Any liquid, gaseous, or solid fuel produced from biofeedstock.

**biological corridor—**Geographic track that allows for the exchange and migration of species within one or more ecosystems. Its function is to maintain connectivity of biological processes to avoid the isolation of species populations.

**biological pest control—**The beneficial action of predators, parasites, pathogens, and competitors in controlling pests and their damage. Biological control provided by these living organisms (“natural enemies”) is especially important for reducing the number of pest insects and mites.

**biomass—**The total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass. The quantity of biomass is expressed as a dry weight or as the energy, carbon, or nitrogen content.

**carbon allocation—**The distribution of carbon within the various components of an entity of concern (i.e., from a single tree to the whole ecosystem of which that tree may be part). In the case of this report, carbon allocation refers to the apportionment or distribution of carbon in the various components of the plants and soil system.

**carbon dioxide ($CO_2$)—**A naturally occurring gas, fixed by photosynthesis into organic matter and also a byproduct of burning fossil fuels and biomass, land-use changes, and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and, therefore, has a global warming potential, or GWP, of 1.

**carbon equivalent—**A quantity that describes, for a given mixture of greenhouse gas (GHG), the amount of carbon dioxide ($CO_2$) that would have the same global warming potential (GWP) when measured over a specified timescale (in general, 100 years). The GWPs of the three GHGs associated with forestry are as follows: (1) $CO_2$ persists in the atmosphere for about 200 to 450 years and its GWP is defined as 1, (2) methane persists for 9 to 15 years and has a GWP of 25 (meaning that is has 25 times the warming ability of carbon dioxide), and (3) nitrous oxide persists for about 120 years and has a GWP of 310.

**carbon flux—**The rate at which carbon moves to or from a particular component of an ecosystem per unit ground area per unit time.

**carbon footprint—**The total amount of greenhouse gases that are emitted into the atmosphere each year by a person, family, building, organization, or company.

**carbon sequestration—**The processes that remove carbon dioxide ($CO_2$) from the atmosphere. Terrestrial or biological carbon sequestration is the process by which plants absorb $CO_2$, release the oxygen, and store the carbon. Geologic sequestration is one step in the process of carbon capture and sequestration and involves injecting $CO_2$ deep underground where it stays permanently.

**carbon sink—**Any process, activity, or mechanism that removes carbon dioxide from the atmosphere. Carbon sinks include the oceans, plants, and other organisms that remove carbon from the atmosphere via photosynthetic processes.

**carbon stock—**The quantity of carbon held within a pool at a specified time.

**chilling requirement—**The minimum period of cold weather after which a fruit- or nut-bearing tree will break dormancy and begin flowering.

**climate—**In a narrow sense, the average weather or, more rigorously, the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. In a wider sense, the state, including a statistical description, of the climate system.

**climate change—**A statistically significant variation in either the mean state of the *climate* or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcings, or it may be due to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that Article 1 of the United Nations Framework Convention on Climate Change (UNFCCC), defines *climate change* as "…a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between *climate change* attributable to human activities altering the atmospheric composition and *climate variability* attributable to natural causes. See also *climate variability*.

**climate change adaptation—**The efforts by society or ecosystems to prepare for or adjust to the changes in climate.

**climate change mitigation—**Human intervention to reduce the human impact on the climate system, including strategies to reduce greenhouse gas (GHG) sources and emissions and to enhance GHG sinks. See also *mitigation.*

**climate smart agriculture—**An approach to developing the technical, policy, and investment conditions to achieve sustainable agricultural development for food security under climate change.

**climate variability—**Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability). See also *climate change*.

**cultivar—**A contraction of "cultivated variety," referring to a plant type within a particular cultivated species that is distinguished by one or more characters.

**ecosystem service—**An ecological process or function having monetary or nonmonetary value to individuals or society at large. Ecosystems services are (1) supporting services, such as productivity or biodiversity maintenance; (2) provisioning services, such as food, fiber, or fish; (3) regulating services, such as climate regulation or carbon sequestration; and (4) cultural services, such as tourism or spiritual and aesthetic appreciation.

**enterprise budget—**A financial management tool to estimate the costs and receipts (income) associated with the production of a specific agricultural product.

**evapotranspiration—**The sum of evaporation and plant transpiration. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

**First Nations—**The aboriginal groups formally recognized by the Canadian Government under the Federal Indian Act of 1876.

**food security—**A situation that exists when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an active and healthy life. *Food insecurity* may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level.

**forest farming—**The intentional cultivation of edible, medicinal, or decorative specialty crops beneath native or planted woodlands that are managed for both wood and understory crop production. Forest farming does not include the gathering of naturally occurring plants from native forests, also known as *wildcrafting*.

**greenhouse gas (GHG)—**Any gas whose absorption of solar radiation is responsible for the greenhouse (warming) effect. Some GHGs, such as carbon dioxide ($CO_2$), may be emitted or drawn from the atmosphere through natural processes or human activities. Other GHGs, such as certain fluorinated gaseous compounds, are created and emitted solely through human activities. The principal GHGs that enter the atmosphere because of human activities are $CO_2$, water vapor, methane, and nitrogen oxide and also fluorinated gases, such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.

**greenhouse gas mitigation—**A human intervention to reduce the human impact on the climate system, including strategies to reduce greenhouse gas (GHG) sources and emissions and to enhance GHG sinks.

**greenhouse gas sink—**Any process, activity, or mechanism that removes a greenhouse gas (GHG), an aerosol, or a precursor of a GHG or aerosol from the atmosphere.

**greenhouse gas source—**Any process activity or mechanism that releases a greenhouse gas (GHG), an aerosol, or a precursor of a GHG or aerosol into the atmosphere.

**homegarden—**A private-property garden around a house that contains various trees, crops, and animals. Homegardens exist more in tropical areas than in cooler climates.

**intercropping system—**The growing of two or more different species of crops simultaneously, as in alternate rows in the same field or single tract of land.

**living fence—**Rows of living plants, such as grasses, shrubs, and trees, that are strategically planted to work as a structural barrier.

**methane emission—**The production and discharge of methane ($CH_4$) that occur by natural sources such as wetlands and also by human activities such as leakage from natural gas systems and the raising of livestock. Agricultural emissions of $CH_4$ are caused when domestic livestock such as cattle, buffalo, sheep, goats, and camels produce large amounts of $CH_4$ as part of their normal digestive process.

**microclimate—**The local climate of a given site or habitat varying in size from a tiny crevice to a large land area, but being usually characterized by considerable uniformity of climate over the site involved and relatively local compared with its enveloping macroclimate from which it differs because of local climatic factors (such as elevation and exposure).

**multifunctional agriculture—**The practice of farming that produces various noncommodity outputs in addition to food.

**nitrous oxide emission—**The production and discharge of nitrous oxide ($N_2O$) that occur naturally through many sources associated with the nitrogen cycle, which is the natural circulation of nitrogen among the atmosphere, plants, animals, and microorganisms that live in soil and water. Agricultural emissions of $N_2O$ are caused when people add nitrogen to the soil through the use of synthetic fertilizers.

**nonpoint source pollution—**Introduced contaminants whose source is general rather than specific in location.

**nontimber forest products—**Goods harvested from woodlands, including herbal plants like ginseng and goldenseal, specialty mushrooms like shiitake and reishi, and wild foods.

**particulate matter—**Very small pieces of solid or liquid matter, such as particles of soot, dust, fumes, mists, or aerosols. The physical characteristics of particles and how they combine with other particles are part of the feedback mechanisms of the atmosphere.

**phenology—**The study of natural phenomena that recur periodically (e.g., developmental stages, migration) and their relation to climate and seasonal changes.

**resiliency—**The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change.

**riparian forest buffers—**An area of trees, shrubs, and herbaceous vegetation established and/or managed adjacent to streams, lakes, ponds, and wetlands.

**shelterbelt—**A single row or multiple rows of trees and possibly shrubs planted in a linear fashion and established upwind of the areas to be protected. Although this term is more often used interchangeably with windbreaks, some use this term to designate thicker (i.e., more plant rows) plantings to provide protection to farmsteads and livestock.

**silvopasture—**The intentional combination of trees, forage plants, and livestock in an integrated, intensively managed system.

**soil organic carbon—**The carbon occurring in the soil in soil organic matter, a term used to describe the organic constituents in the soil (tissue from dead plants and animals, products produced as these decompose, and the soil microbial biomass).

**subsurface tile drain—**A conduit installed beneath the ground surface to collect and/or convey subsurface drainage water.

**taungya—**A Burmese word that is now widely used to describe the agroforestry practice, in many tropical countries, of establishing tree plantations by planting and tending tree seedlings together with food crops. Food cropping is ended after 1 to 2 years as the trees grow.

**uncertainty—**An expression of the degree to which a value (e.g., the future state of the climate system) is unknown.

**vulnerability—**The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate and global change, including climate variability and extremes.

**weather—**The specific condition of the atmosphere at a particular place and time. Weather is measured in terms of parameters such as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation.

**windbreak—**A single row or multiple rows of trees or shrubs that are established for environmental purposes.

# Appendix A
Regional Summaries

## Alaska

Linda E. Kruger

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### Description of the Region

Alaska is a vast State covering 586,412 square miles, an area roughly one-fifth the size of the contiguous United States. It is the northernmost, easternmost, and westernmost State. Alaska has 318 different soil types and 100 volcanoes, more than 40 of which have been active in historic time, making up 80 percent of the active volcanoes in the United States.

Permafrost is thickest in the arctic, north of the Brooks Range, but it can be found in nearly 85 percent of the State. Glaciers, ice fields, high alpine tundra, moist coastlines, fjords, and rainforests limit the potential for agroforestry in much of Alaska. Forests cover approximately one-third of the total land area of Alaska (Parson et al. 2001), with 72 percent of the forest cover being in public ownership (Oswalt et al. 2014). The Federal Government is the largest owner of forest land: more than 10 million acres (ac) are within the boundaries of two national forests managed by the U.S. Department of Agriculture (USDA) Forest Service; 17 million ac are managed by the U.S. Department of the Interior, Bureau of Land Management; and 36 million ac are managed by other Federal agencies.

The State of Alaska manages 28 million ac of forest land (Oswalt et al. 2014). Only about 36 million ac of forest land are privately owned by individuals and another 33 million ac are owned by private corporations (Oswalt et al. 2014). Of the total forest acreage, 90 percent is interior boreal forest and the other 10 percent is in coastal temperate rainforest (Wolken and Hollingsworth 2012). Arable land suitable for crop production is extremely limited in Alaska; only 0.2 percent of the land is currently being actively farmed (USDA NASS 2014). For these reasons, the level of commercial forestry and commercial agriculture operations in Alaska is small when compared with many other States.

Alaska Natives have resided in the State "since time immemorial," determined to be more than 10,000 years. Today, many Alaska Natives continue to participate in traditional hunting, fishing, and gathering activities. Nonnative residents also have adopted the harvest and use of plants, animals, and fish as part of a natural resource-based lifestyle referred to in Alaska as subsistence (Berman et al. 1998). The gathering and harvesting of forest products provide an opportunity to perpetuate traditional ways; engage in recreational, social, and family activities; find spiritual connection; and acquire food and material goods to support a livelihood.

Three primary factors influence Alaska's climate. First, Alaska's high latitude, ranging from 51°N. to 71°N., results in extreme variations in solar radiation. Second, with 33,904 miles of tidal shoreline—more coastline than the contiguous United States—a significant portion of the State is influenced by ocean currents and, in the far north, by sea ice. Coastal locations are characterized by relatively small seasonal temperature variability and high humidity. Inland locations, not directly influenced by oceans, experience a climate more characterized by large daily and annual temperature fluctuations, low humidity, and relatively light and irregular precipitation (Alaska Climate Research Center 2014). The third factor, the elevation, which ranges from sea level to 20,320 feet above sea level, also influences the State's climate.

Glaciers cover approximately 5 percent of the State (29,000 square miles). Both commercial agriculture and commercial forestry are very limited compared with the same activities in many other States. As mentioned previously, forests cover only one-third of the land base (USDA NASS 2014).

Most farms in Alaska are in the Matanuska Valley northeast of Anchorage and the Tanana Valley east of Fairbanks. In 2014, 760 farms were operating on 830,000 ac (USDA NASS 2014). The top agricultural revenue producers are greenhouse and nursery products, with barley, hay, oats, and potatoes being the prevalent field crops. Having the benefit of long hours of summer sunlight, the Matanuska Valley produces world-record crops, such as a 19-pound carrot, a 76-pound rutabaga, and a 127-pound cabbage.

## Agroforestry in Alaska

Very little agriculture is mixed with forestry at this time in Alaska. During fiscal years 2010 through 2014, only 20 completed or planned agroforestry activities were documented: 4 windbreaks/shelterbelts; 4 multistory croppings (forest farming); 8 riparian forest buffers; and 4 silvopastures (Western Forestry Leadership Coalition 2012). Several nontimber specialty crops are produced in Alaska that, depending on the level of management, could be considered forms of agroforestry. Brief discussions on each of these activities are included below.

### Silvopasture

Grazing of understory vegetation in young forests and woodlands is not well documented. Although such grazing may occur on a limited basis in interior Alaska, no documentation of this activity was found, beyond the notation from the Western Forestry Leadership Coalition.

### Riparian Forest Buffers

Riparian buffers are an increasing component of forest restoration efforts in southeast Alaska and may help offset some climate change impacts on aquatic health and fisheries. Riparian buffer standards are published in Alaska Department of Natural Resources (2007), but Alaska has not adopted the USDA Natural Resources Conservation Service (NRCS) Conservation Practice Standards on Riparian Forest Buffer, Windbreak/Shelterbelt Establishment, and Windbreak/Shelterbelt Renovation (Graham 2015).

### Forest Farming

Many opportunities exist in Alaska for growing potentially high-value understory crops, including mushrooms, berries (Holloway 2006), medicinal plants, and plants used for tea and other products. DENALI BioTechnologies, Inc. (http://denalibiotech.com), located in Homer in southern Alaska, produces nutraceuticals—dietary supplements with health benefits. One product is made from wild blueberries and huckleberries harvested from around the State. Dandelions and rosehips are also harvested for other products. Many of the berries come from Kake in southeast Alaska, where Sealaska Corporation owns and manages 20,000 ac of forest land. Sealaska obtained USDA organic certification for its young growth forests and, subsequently, blueberry prices topped $3.10 per pound (Savell 2012).

At Starrigavan Creek Watershed in Sitka, also in southeast Alaska, the growth of wild berries is being encouraged through thinning and habitat improvement efforts (USDA NRCS 2014). Other plants are also harvested in the wild (see the Specialty Products section). An expansion of forest farming could provide an opportunity to increase the harvest and reliability of various crops while assuring the sustainability of the plants.

### Alley Cropping

Four Alaska farms reported that they practiced alley cropping or silvopasture in 2012 (MacFarland 2014). The potential may exist for expansion in some locations.

### Specialty Products

Spruce tips are harvested in Gustavus, in southeast Alaska, for use in a specialty beer produced in Juneau. Spruce tips are also used in jams and jellies.

Birch syrup is commercially produced in the interior of Alaska, with more than 1,500 gallons of syrup produced in 2013. In addition to producing spruce syrup, a wild medicinal Alaska tea made from Chaga mushrooms (*Inonotus obliquus*) that grow primarily on live birch trees in cold climates is also marketed.

Several studies have explored the feasibility of wood energy, including pellets and bricks, for residential heating (Nicholls et al. 2010). Wood-fired heating systems currently are being used in Juneau, Craig, and other communities and a pellet plant in Fairbanks produces wood pellets.

## Threats and Challenges to Agricultural Production and Community Well-Being

Food insecurity is a significant and growing problem in Alaska, resulting from limitations in land suitable for food production, decreasing sources and harvests of traditional foods, and a heavy reliance on imported foods. Alaska is already a region that has experienced significant warming during the past 60 years, which has led to earlier spring snowmelt, warmer permafrost, widespread droughts, and extensive insect outbreaks and wildfire (Melillo et al. 2014). These effects are reducing the growth and availability of many of the traditional foods that historically have been heavily relied on. Impact on permafrost is expected to negatively affect transportation capabilities, further exacerbating food security issues. These impacts are expected to persist and worsen under climate change, with Native Alaska communities being especially vulnerable.

## Developing Agroforestry Opportunities

Wild Alaska berries have long been important to Alaska Native people. The recognized and now documented health benefits of Alaskan berry resources are positive incentives for development of commercial production (Kellogg et al. 2011). Several opportunities exist for commercialization of berry harvest and production. A few small-scale operations around the State harvest berries and produce and sell jams, jellies, syrups, and other berry products (see the previous Specialty Products section). Expansion of a commercial berry industry would require striking “a strategic balance between the tribes and the marketplace, extraction and preservation of resources, traditional activities and modern business practices and more investigation into the interplay of these factors" (Kellogg et al. 2011). It appears this balance has been effectively achieved with wild berry harvests in Kake.

The University of Alaska Fairbanks has developed agroforestry and demonstration projects at its Matanuska Experiment Farm and Delta Junction field research site to identify plants (e.g., berries, fruit trees, medicinal plants) with agroforestry potential (Western Forestry Leadership Coalition 2012). The NRCS has published a fairly comprehensive guide for managing wild berry stands (Holloway 2006).

The predicted warming of the subarctic and arctic areas in Alaska may afford opportunities to produce food crops locally. Work by Barbeau et al. (2015) in the subarctic region of Canada demonstrated that crops such as potato and bush bean could be grown and that their yield could be increased through the use of willow windbreaks. Willow is a common and diverse species in Alaska, which suggests resilient agroforestry systems for vegetable crop production and for other products from the willow (e.g., feedstock for heat or combined heat/power generation) can be a viable component in Alaska climate-smart strategies.

The State of Alaska is expanding green firebreaks near the community of Tok in east-central Alaska to help protect the community from wildfire, while providing a source of wood for bioenergy. According to Jeff Hermanns, the Tok Area Forester, a wood-chip boiler system heats the Tok School and a greenhouse, and it generates power. The project supplies 2,000 tons of wood energy per year, saving the community \$80,000 to \$100,000 per year (Hermanns 2015). The project was described in the TimberWest journal (TimberWest Publications 2012). In addition, more than 20 wood-energy systems are operating in Alaska. The Renewable Energy Alaska Project documents several wood-energy projects on its biomass Web page (http://alaskarenewableenergy.org/why-renewable-energy-is-important/alaskas-renewable-energy-projects/). The Alaska Energy Authority also tracks wood-energy projects and administers a renewable-energy fund (http://akenergyauthority.org/AEEE/Biomass/AWEDTG).

## Key Information Needs

- Additional research is needed to help determine how agroforestry systems can be designed for use in Alaska to support the sustainable production of edible native foods and other crops and woody biomass for energy and also to maximize wildlife and fish habitat and provide other benefits.
- Locally adapted and diverse plant materials, both woody and herbaceous, need to be developed to build more climate-adapted agroforestry practices suited to Alaska's environment.

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# Hawaii and the U.S.-Affiliated Pacific Islands

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## Description of the Region

Hawaii and the U.S.-affiliated Pacific Islands (fig. A.1) include a diversity of traditional and modern agroforestry systems that have developed across a broad range of environments, from low coral atolls to high volcanic islands rising to 4,205 meters (m) (13,796 feet [ft]) in Hawaii. The peoples of Micronesia and Polynesia settled their islands as many as 4,000 years ago (Athens and Ward 2004) and brought with them a basic suite of agricultural plants. In the ensuing centuries, they developed highly sophisticated agroforestry systems tailored to meet food security needs within the local environments they inhabited. Having been developed on isolated islands and enduring for centuries or millennia, these agroforestry systems are models of sustainability (Clarke and Thaman 1993). Fertility is largely maintained by the recycling of nutrients, fallowing, and other ecosystem processes. Mulching is also practiced in many systems. Continuous soil cover prevents erosion. Because the species diversity and structure of tree-based multistory gardens are similar to native forests, these agroforests protect watersheds and water quality, both in streams and near the shore. The productivity over extremely long timeframes based only on local resources attests to their value as models for modern agroforestry systems that can be resilient to environmental stressors of the type that are projected to accompany climate change (table A.1).

The most common traditional system is a tree-based multistory system based on highly productive multipurpose species such as banana (*Musa x paradisiaca*) and coconut (*Cocos nucifera*) (fig. A.2). The traditional staple crops, in addition to breadfruit, include taros (*Colocasia esculenta*, *Alocasia macrorrhizos*, *Cyrtosperma merkusii,* and *Xanthosoma* spp.), yams (*Dioscorea* spp.), bananas (*Musa x paradisiaca*), and sweet

**Figure A.1.** Map of Hawaii and the U.S.-affiliated Pacific Islands. (Figure from http://www.PacificRISA.org, used with permission).

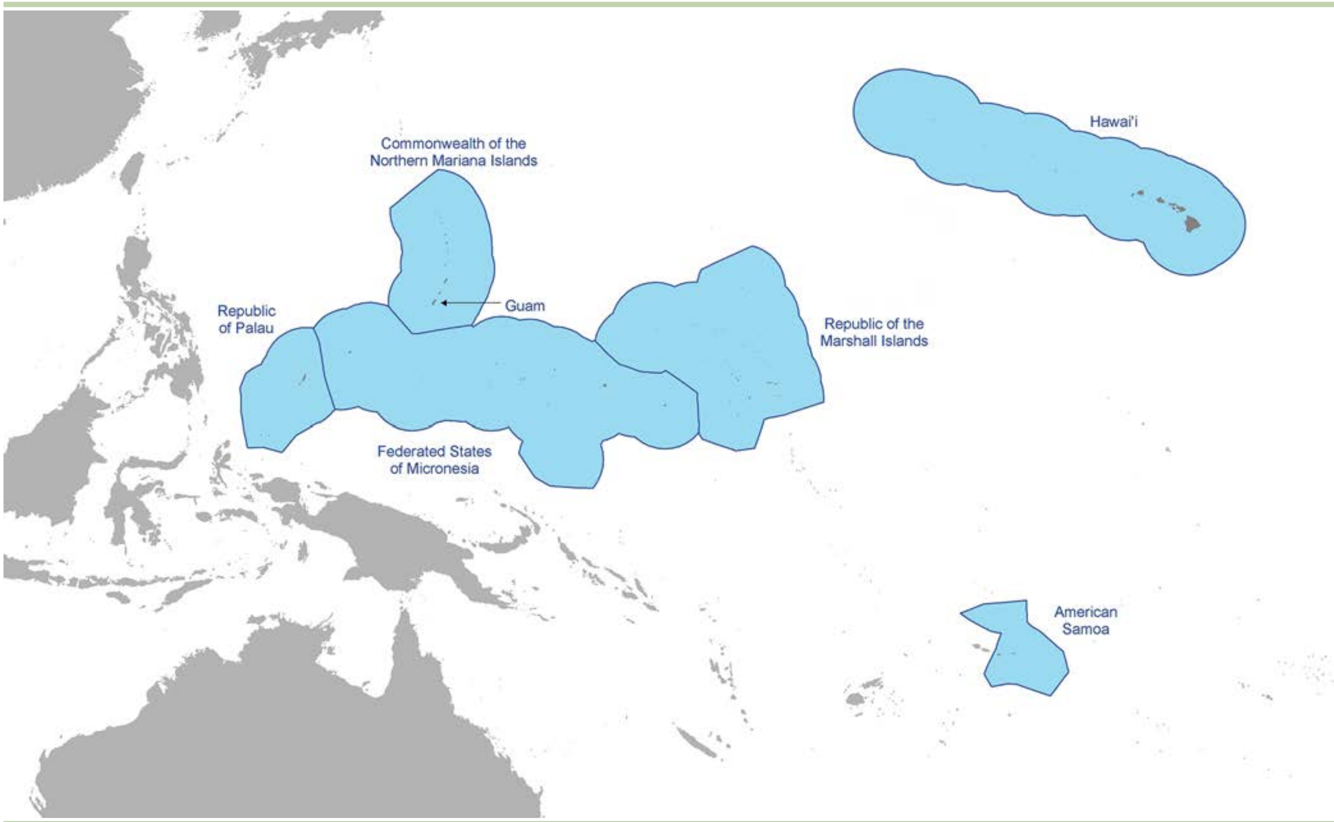

**Table A.1.** Agroforestry practices that address threats and challenges.

| Pacific agroforestry system | Threat/challenge addressed | Mechanism |
|---|---|---|
| Multistory agroforest (including homegardens, shade coffee) | Intense rainfall and soil erosion | Dissipates kinetic energy, surface litter, and tree roots with complex canopy. |
| | Drought | Provides more deeply rooted tree crops than annual crops. |
| | Sea-level rise | Allows upland agroforests to be less affected by sea-level rise than coastal farms. |
| Coastal strand windbreak (traditional) | Salt spray | Slows wind and blocks salt spray. |
| | Storm surge, wave inundation | Reinforces beach berm with roots. |
| Windbreaks in fields, orchards, pastures | Increased storm intensity and frequency | Dissipates wind energy. |
| Silvopasture | Increased temperature extremes | Provides shade for livestock. |
| Intensive tree leaf mulching to create organic soils for tree or annual crops | Drought, storm recovery | Ameliorates sandy soils with organic material. |
| Taro paddies (mulched with tree/shrub foliage) | Intense rainfall or drought | Manages water use. |

**Figure A.2.** A traditional agroforest on Palau. Crops include soft taro (*Colocasia esculenta*), giant taro (*Cyrtosperma merkusii*), avocado (*Persea americana*), banana (*Musa x paradisiaca*), papaya (*Carica papaya*), betel nut palm (*Areca catechu*), coconut palm (*Cocos nucifera*), and bamboo (*Bambusa* sp.). (Photo by J.B. Friday, University of Hawaii).

potato (*Ipomoea batatas*), with different crops being favored by different cultures and different environments (Kitalong 2008, Raynor and Fownes 1991). Medicinal plants often include kava (*Piper methysticum*), betel nut (*Areca catechu*), and noni (*Morinda citrifolia*) and a diverse array of indigenous and introduced plants (Kitalong et al. 2011). Agroforests also include other useful species such as *Pandanus tectorius*, used for food and fiber, and timber species such as *Calophyllum inophyllum*. These pan-Pacific trees and crops are adapted to a wide range of moisture regimes, although all are tropical and grow best in coastal environments. Since contact with Western civilization in the late 1700s, dozens of new species have been introduced and integrated into Pacific Island agroforests (Clarke and Thaman 1993). This additional species diversity, also called "agrobiodiversity," can strengthen resiliency of agroforestry systems (Clarke and Thaman 1997). Most modern agroforests include fruit trees such as citrus (*Citrus* spp.), mango (*Mangifera indica*), avocado (*Persea americana*), and soursop and other *Annona* spp., which were introduced in modern times. Other modern cash crops that are sometimes incorporated into agroforestry systems include black pepper (*Piper nigrum*) and cacao (*Theobroma cacao*). On atolls and coastal areas of some high islands, farmers grow giant swamp taro (*Cyrtosperma merkusii*) in sandy soils in excavated pits by mulching heavily with leaves cut from native trees (Manner 1993, 2010). Vegetation is usually preserved along coastlines (a practice now termed "coastal strand buffers") and along streams (riparian buffers). Windbreaks are also important to protect more delicate plants from wind and salt spray. Shifting agriculture, with or without an enhanced forest fallow, is also practiced for some crops on high islands of Micronesia and on American Samoa (Manner 1993, 2014).

Traditional farmers across the Pacific have developed a stunning diversity of cultivars of their main crops. On Pohnpei in Micronesia, Raynor et al. (1992) found names for 177 cultivars of yams (*Dioscorea* spp.). Islanders across the Pacific have developed hundreds of cultivars of breadfruit (Zerega et al. 2004). On Pohnpei alone, Ragone and Raynor (2009, in Balick 2009) identified 48 cultivars of breadfruit. The high agrobiodiversity of Pacific Island agroforestry systems represents adaptation to different environments and also the provision of additional uses. Fownes and Raynor (1993) found that different cultivars of breadfruit on Pohnpei fruited during different months and thus, by growing different cultivars, farmers were able to extend the breadfruit season. By having a range of varieties that can be harvested year round, it is more likely that some of the total harvest will be spared from the effects of extreme weather conditions or events. Englberger et al. (2009, in Balick 2009) estimated that about 50 cultivars of bananas are grown on Pohnpei. Englberger et al. (2004, 2006) showed that some traditional cultivars of banana were rich in carotenoids and vitamin A and could play an important role in addressing local nutrition problems caused by an overreliance on refined, imported foods. Despite the increasing importance of imported foods such as rice, bread, and canned meat, islanders still enjoy and, in part, depend on locally produced foods, which are seldom marketed commercially but are usually locally available through family connections (fig. A.3). The wide range of varieties and cultivars that still exist within and between islands provides options for changing environmental conditions.

A number of acres on the Pacific islands, representing from 2 to 85 percent of the total forest area on the islands, are dedicated to multistrata agroforests (table A.2). There are still many areas potentially suitable for agroforestry on the islands (table A.2).

**Figure A.3.** Locally grown agroforestry crops for sale at a market on Yap Island, Federated States of Micronesia. Crops include watermelon (*Citrullus lanatus* var. *lanatus*), taro (*Colocasia esculenta*), calamansi (*Citrus microcarpa*), soursop (*Annona muricata*), chili peppers (*Capsicum* sp.), pineapple (*Ananas comosus*), several varieties of bananas (*Musa x paradisiaca*), passion fruit (*Passiflora edulis*), breadfruit (*Artocarpus altilis*), and Tahitian chestnut (*Inocarpus fagifer*). (Photo by J.B. Friday, University of Hawaii).

**Table A.2.** Extent of current and potential agroforests on Pacific Islands.

| U.S.-affiliated Pacific Island jurisdiction | Total area (acres) | Population (2010) | Multistrata agroforest | | Potentially appropriate for agroforestry (not currently in forest or agroforest) (acres) | | |
|---|---|---|---|---|---|---|---|
| | | | Acres | Percent of total forest | Savanna, other shrubs and grassland, and disturbed vegetation | Cropland | Total |
| Hawaii[a] | 4,127,337 | 1,360,301 | | | 770,085 | 174,042 | 944,127 |
| American Samoa (U.S. Territory) | 49,280 | 55,519 | 15,510[b] | 35 | | | 715[c] |
| Republic of the Marshall Islands[d] | 44,800 | 67,182 | 20,000 | 85 | 1,134 | | 1,134 |
| Federated States of Micronesia[e] | 149,804 | 106,836 | 35,655 | 25 | 11,852 | 195 | 12,047 |
| Commonwealth of the Northern Mariana Islands[f] | 113,280 | 53,883 | 1,313 | 3 | 13,372 | 918 | 14,290 |
| Guam (U.S. Territory)[g] | 135,680 | 159,358 | 1,921 | 2 | 44,455 | | 44,455 |
| Republic of Palau | 114,560 | 20,956 | 2,740[h] | 4 | | | 15,329[i] |

[a] U.S. Department of Agriculture (2012).

[b] Cole et al. (1988).

[c] Donnegan et al. (2004b).

[d] Donnegan et al. (2011c).

[e] Donnegan et al. (2011b).

[f] Donnegan et al. (2011a).

[g] Donnegan et al. (2004a).

[h] Cole et al. (1987).

[i] Donnegan et al. (2007).

Note: Blank cells indicate data are not available.

## Characteristics of Agroforestry Systems

Pacific Island agroforestry systems can be highly productive. Fownes and Raynor (1993) calculated that the Pohnpeian agroforestry system produced more than 6 metric tons/hectare (ha)/year (2.7 tons/acre/year) of breadfruit alone plus significant yields of starches such as yam, taro, and other crops. Tree-based systems typically have a much higher standing biomass and total carbon storage per unit area than do annual crops. The high perennial biomass results in systems that are both more resistant to change than annual cropping systems and more resilient in the face of change. For example, fruit trees may drop fruits during a drought, but the trees will usually remain in condition to produce when rainfall returns.

The high agrobiodiversity of Pacific Island agroforestry systems also increases resistance and resiliency. Evidence indicates that those systems resist (through diversity) and recover from (through fallow) insect and disease problems better than monocultures do (Ferentinos and Vargo 1993). It is hoped that these systems will also resist and be resilient to climate change. If environmental stressors caused by climate change (changes in rainfall, temperatures, or seasonality of flowering and fruiting) cause some crops or varieties to fail, other crops in the system can take their place. For example, if increased groundwater salinity makes cultivation of *Colocasia* taro infeasible, farmers could switch to cultivating *Cyrtosperma* taro, which is generally regarded as being more salt tolerant. Agroforestry systems in the Pacific have a complex spatial structure, both vertically and across the landscape. The complex structure may lead to improved resistance to change, because the system creates the microclimates for some of the plant species (for example, shade for understory crops). The danger also exists, however, that some microclimates may disappear entirely from some islands as climates change globally, taking with them adapted crop species.

## Potential of and Limitations to Agroforestry

Hawaii has significant areas of cropland and pastureland with windbreaks and potential for additional windbreaks. Hawaii's major plantation crops (sugar and pineapple) have been greatly reduced in acreage, and the land released is still in a dynamic state, with potential for increased combinations of orchard and even multistory agroforest. Pasturelands and rangelands in Hawaii, Guam, and the Commonwealth of the Northern Mariana Islands are ecologically suitable for forest and could be restored to forest or partial forest cover with silvopastoral techniques. The potential to return savanna, secondary vegetation, and other shrubs and grasslands to productivity through agroforestry varies with land tenure, soil fertility, and slope. The "potentially appropriate" acreage figures in table A.2 have not been reduced for those factors.

Despite the productivity, resistance, and resilience of traditional agroforestry systems, a major drawback has been low-cash productivity. Most agroforestry products are subsistence foods such as breadfruit, taro, and yams. Farmers across the Pacific frequently neglect traditional agroforestry systems to seek cash employment or convert agroforests to cash crops.

Traditional agroforests can be enriched with high-value crops to perpetuate these resistant and resilient systems while increasing economic output. Examples of cash crops include black pepper (*Piper nigrum*) and sakau or kava (*Piper methysticum*) on Pohnpei (Merlin and Raynor 2005). Some traditional subsistence plants such as coconut can also be used to produce products for sale, such as oil or baskets, if markets exist. As more islanders find cash employment in the market economy, markets for traditional food crops such as yams are developing in population centers, giving farmers another way to earn some cash (Ames et al. 2009). Public campaigns to emphasize the nutritional values of traditional foods (Englberger and Lorens 2004) can also encourage farmers to perpetuate agroforestry systems, and, in some places, traditional crops have entered the cash market.

## Threats and Challenges to Agricultural Production and Community Well-Being

Climate change is expected to affect island agroforestry with higher temperatures, changes in precipitation, increased storm intensity (wind and rainfall), and salinization of groundwater, depending on the region (ABM and CSIRO 2014) and local topography. To date, the effects of long-term climate change are difficult to measure and separate from natural medium- and short-term variability. Declines in rainfall in Hawaii during the past century are attributed to climate change but may have been caused partially by volcanic emissions for the past few decades (Giambelluca et al. 2013). The Pacific Decadal Oscillation and the El Niño—Southern Oscillation (ENSO) variously affect sea level, storms, and drought, and Pacific islands are characterized by high natural variability as a result. “ENSO-related precipitation variability on regional scales will likely intensify with long-term global warming” (IPCC 2014).

Sea levels around the western Pacific have risen at rates double or more than double the global averages during La Niña-dominated conditions since 1993 (Keener et al. 2012). In 2014, conditions changed with the apparent onset of El Niño conditions. The National Oceanic and Atmospheric Administration observed that “the below average sea level in Micronesian waters is a huge shift from very high sea levels only a few months ago, and indeed, for most of the past decade” (NOAA 2014). Sea-level rise is expected ultimately to inundate Pacific Island coastal areas and atoll islands. The highest point on most atolls is typically 2 to 3 m (6 to 9 ft) above sea level. Within a generation, the freshwater lenses that underlie atolls and many coastal areas will shrink in volume and/or become increasingly saline as a result of the dynamic interplay between rising sea levels, drought, ocean water inundation events, and over-pumping wells. Increased groundwater salinity may reduce or eliminate the ability of low coral islands to support breadfruit and taro (Manner 2014). Storms will also deposit coralline material on land in a natural process of island-building (Lobban and Schefter 1997); however, even where the elevation of the land is thus increased and might seem to balance sea-level rise, it does not result in a steady state with respect to agriculture, because each disturbance event depositing gravel or saltwater requires a significant recovery period before agriculture again becomes productive.

Typhoons and tropical storms such as super typhoon Pongsona in Guam in 2002, Typhoon Sudal in Yap in 2004, Typhoon Bopha in Palau in 2012, and Hurricane Iselle in Hawaii in 2014 are particularly destructive to small islands. The Intergovernmental Panel on Climate Change (IPCC) (IPCC 2014) predicts that “extreme precipitation events… over wet tropical regions will very likely become more intense and more frequent.” Upland agroforestry systems will be damaged by high winds, and coastal systems may be highly degraded by storm surges. Although the forest cover provided by agroforestry protects against surface erosion, heavy rainfall can cause mass wasting events that devastate entire watersheds, as when Typhoon Chata’an caused several hundred landslides in Chuuk, including many that carried away the entire agroforest and soil horizon from some plots and inundated other plots with debris and mud (USGS 2002).

Droughts often occur in the Pacific under El Niño conditions and, under climate change, may increase in frequency and intensity, even though average rainfall is predicted to increase on most islands. Droughts may be particularly severe on coral atolls and the leeward sides of high islands such as Hawaii (Keener et al 2012). Guam and the Northern Marianas Islands already have seasonally dry climates (Mueller-Dombois and Fosberg 1998). The Northern Marshall Islands experienced a severe drought during 2013 and 2014, which resulted in the loss of much of the breadfruit crop. Tree-based agricultural systems, although resistant to moderate changes in climate, can be pushed past a breaking point when shifts in temperature and precipitation are so severe that the trees die, causing catastrophic losses. Droughts will also lead to increases in wildfires, which damage native forests and agroforests on the drier islands of the western Pacific, including Guam, Palau, and Yap.

Invasive plants, pests, and diseases brought to the Pacific Islands as a result of increased transportation and migration threaten the sustainability of agroforestry systems. Changing climates and the interaction with other disturbance may exacerbate the competition of nonnative species with native and traditionally cultivated species.

Finally, loss of traditional knowledge of cultivation techniques and cultivars is an important threat to Pacific Island agroforestry systems. Loss of knowledge is exacerbated by movement into towns and cities for jobs and migration from smaller islands to larger ones, including to Hawaii and Guam and also to the mainland United States. In part, migration is fueled by concerns of climate change.

## Conclusions

Pacific Islanders recognize the need to adapt to shifting weather and climatic conditions. The traditional agroforestry systems are not static and have evolved to take advantage of new plants, new markets, and new methods of cultivation since western contact. A major need is for cultivars that are more drought and salt tolerant and new methods of cultivation, because it is likely that drier and more saline conditions will prevail in the future (Friday 2011). Because these systems exist across the Pacific, farmers on wetter islands may be able to learn from those living on drier islands today. Recognizing the increased threat from sea-level rise and storm surges, islanders have expressed needs for plants for coastal stabilization and windbreaks and systems that are more resistant to damage by storms. Addressing these new threats is an appropriate job for Pacific Island universities and local agriculture and natural resource agencies. Often these efforts are facilitated through farmer-led research and training, especially farmer-to-farmer programs. On small islands, it is particularly evident how agriculture is linked to nutrition, employment, and economic activity. Establishing and nurturing traditional agroforestry systems to enhance their resiliency to climatic variability and food security will have benefits across society.

## Key Information Needs

- Documentation of traditional agroforestry systems and knowledge of indigenous Pacific Islanders regarding growth, phenology, and management of these systems.
- Better agroecological understanding of how to apply agroforestry at farm and landscape levels to address various climate change scenarios and establishment on degraded or abandoned lands within the Pacific Islands.
- Development of methodologies to identify and manage for invasive species that are increasingly affecting agroforestry and other plant systems in the Pacific Islands.
- Identification of current economic and cultural impediments to adoption and retention of island agroforestry practices and of practical interventions that can enhance agroforestry's appeal and use.
- Development of tools that can help assess differences in production and natural resource services in conventional monocropped systems and agroforestry systems under changing climatic conditions.

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# Northwest

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## Description of the Region

The Northwest is a region of dramatic physical and environmental contrasts, ranging from high alpine ecosystems to moist lowland rainforests and high deserts. Land uses and opportunities for agroforestry vary accordingly. Proximity to the Pacific Ocean and elevation are the major climatic influences. Rain shadows lie east of the Cascade, Olympic, and Coast Ranges and, west of the mountains, heavy rainfall and moderate temperatures prevail (Hardesty and Lyon 1994).

Agriculture is important to the Northwest's economy, environment, and culture. Agriculture contributes 3 percent of the Northwest's gross domestic product, crop and pasturelands comprise about one-fourth of Northwest land area, and farming and ranching have been a way of life for generations. Wheat, potatoes, tree fruits, hazelnuts, vineyards, and more than 300 minor crops and also livestock grazing and confined animal feeding operations, such as beef and dairy, depend on adequate water and particular temperature ranges (Dalton et al. 2013). During the past century, the average annual temperature increased by 1.5 °F, with increases in some areas up to 4 °F. Changes in snowpack, streamflows, and forest cover are already evident (USGCRP 2009). Future climate change will likely continue to influence agriculture. The average annual temperature in the region is projected to increase by 3 to 10 °F by the end of the century (USGCRP 2009). Winter precipitation is projected to increase, but summer precipitation is projected to decrease, though precipitation projections are less certain than those related to temperature (USGCRP 2009). Pressures related to the rapidly growing population in this region would compound future climate change impacts.

Higher temperatures, changing streamflows, and increases in pests and disease threaten forests, agriculture, and fish populations in the Northwest (USGCRP 2009). Decreasing supplies of water for irrigation, increasing incidents of pest and disease attacks, and growing competition from weeds threaten Northwest agriculture, particularly the production of tree fruits, such as apples and wine grapes (USGCRP 2009). Human activities already threaten Northwest salmon populations and climate change impacts would add stress. Lower summer streamflows and warmer stream and ocean temperatures are less favorable for salmon and other cold-water fish species.

Agroforestry practices that integrate animal husbandry, crop rotations, and fallow periods have long been part of the heritage of North American peoples (Bishaw 2013; Davies 1994). In the Willamette Valley, Oregon, the Kalapuya managed oak savannas, vast woody huckleberry shrubs, and forests while also managing crops, including camas and wapato (Goodness 2011). Prescribed burning was a tool most Pacific Northwest tribal communities used to maintain and enhance prairie edges and oak woodland savannas for vegetation and wildlife management for various food and cultural resource products throughout western Washington and Oregon (Anderson 2007). The Pacific Northwest tribal communities also managed soil fertility.[2] They gathered food, medicine, and other supplies in a rotational basis for sustained harvests. This management process, enforced by tribal leaders (Anderson 2007; Goodness 2011),[3] was conducted by "skilled and knowledgeable applied ecologists who actively managed the land" (Bainbridge 1995: 147). Some of these management practices, collectively referred to as traditional ecological knowledge (TEK), are ongoing today. This regionally specific body of knowledge has tremendous potential for supporting sustainable agroforestry development in the Northwest.

The most common agroforestry practices in the Northwest region include silvopasture, riparian buffers, forest farming, mixed-practice agroforests, alley cropping, and windbreaks. Silvopasture is used primarily for economic production. Riparian buffers are implemented to address water pollution, create fish habitat, and control erosion. Forest farming is often used for producing mushrooms, floral greenery, and juniper berries. Agroforests use woody crops as part of whole-farm crop and income diversification systems. Windbreaks are used to protect high-value crops and animals. Each of these practices sometimes integrates bioenergy crops. These practices increase income and biological diversity in the region and protect against water and wind erosion (Bishaw 2013). In 1990, researchers surveyed nonindustrial private forest landowners in

[2] Petrie, M. [N.d.]. The land management practices of Coos, Lower Umpqua, and Siuslaw Indians. Term paper for RNG 477 agroforestry course. Corvallis, OR: Oregon State University.

[3] Petrie, M. ([N.d.]).

Washington State and found that 57 percent practiced agroforestry (Lawrence et al. 1992). Although many landowners in this region may not identify themselves as agroforesters or as practicing agroforestry, they are often engaged in practices that may be considered agroforestry.

## Silvopasture

Silvopasture in the Northwest involves many forms, including grazing native understory vegetation in young commercial forests and woodlands, tree/livestock production in forested rangelands, and livestock/timber production in thinned, mid-rotation forests. Livestock grazing is the primary agricultural use of approximately 1 million hectares (2.5 million acres) of hill land in western Oregon (Sharrow 1993; Sharrow and Fletcher 1994). In Washington, a survey of nonindustrial private forest landowners found 39 percent of respondents practiced forest grazing; among respondents in eastern Washington, 47 percent practiced forest grazing (Lawrence et al. 1992). Although silvopasture differs from forest grazing commonly practiced in the Northwest (particularly on public lands), an opportunity exists for this agroforestry practice to expand. This change would require more intentional, intensive management of trees, forage, and livestock. Research specific to western Oregon has found that silvopastures may be more efficient at sequestering carbon than forest plantation or pasture monocultures (Sharrow and Ismail 2004).

Sheep grazing is a traditional use of temperate coniferous forests in the United States and Canada. Like any management tool, prescription sheep grazing can be misused. Properly applied sheep grazing often reduces competition between trees and other ground vegetation, thus increasing tree growth (Sharrow 1994). Conifers on grazed plantations in western Oregon had increased height and diameter growth, averaging 63 centimeters (cm) (25 inches [in]) taller and 0.7 cm (0.3 in) greater in diameter at breast height than the nongrazed plots after 12 years of plantation growth (Jaindl and Sharrow 1988). This long history of sheep grazing in forests in the Northwest also indicates opportunities for increased silvopasture applications.

## Riparian Buffers

Riparian forest buffers in crop and grazing lands have gained increasing attention in the Northwest because of popular demand and regulation to protect salmon and steelhead. In Oregon, this attention has also come through the Governor's Salmon and Watershed Restoration initiatives (Independent Multidisciplinary Science Team 1999; Nicolas 1997). The focus during the past 15 years of riparian land use in Oregon has been to achieve water quality and restore aquatic habitats (Riparian Management Work Group 2000; Bishaw et al. 2002). These efforts seeking to lower stream temperatures using shade and to enhance fish habitat through large woody debris are only more critical with climate change projections. These efforts have been ongoing in Washington also, with requirements for streamside buffers in forest lands through the Salmon Recovery Act of 1999 (Engrossed Substitute House Bill (ESHB) 2091 [1999]) and the resulting Forest Practices Habitat Conservation Plan passed in 2006 and also with voluntary buffer programs on agricultural lands (Washington State Department of Natural Resources 2015). In July 2014, the U.S. Environmental Protection Agency began requiring Washington State to include conditions in Federal pass-through grants that require projects to be consistent with National Marine Fisheries Service buffer guidance to help protect and recover Washington's salmon runs (Washington State Department of Ecology 2013).

Both State and Federal Governments currently offer incentive programs to encourage landowners to establish riparian forest buffers. In Oregon, between 1999 and 2012, Federal and State Governments spent $18 million USD to establish more than 40,300 acres of riparian buffers (Oregon Watershed Enhancement Board 2012). Other State and nonprofit organizations, particularly watershed councils, are also involved in establishing riparian forest buffers, both through regulatory and voluntary incentive programs (Cochran and Logue 2011; Lurie et al. 2013). Currently in development in Washington State, the Puget Sound Working Riparian Buffer Feasibility Study project is seeking to provide best available science on agroforestry strategies specific to enhancing ecosystem service function within Puget Sound watersheds. The project goal is to work with local tribes, regulatory agencies, and the agricultural community to provide a policy and implementation framework for allowing for the management of native and nonnative species within the riparian buffer corridors as opposed to the "no-touch" buffer framework that is currently enforced. Throughout the Northwest region, riparian forest buffers, if properly practiced and managed, have great potential to improve water quality and create favorable fish habitat in the region, promoting adaptation to the impacts of field runoff created by extreme precipitation events and unfavorable temperatures.

## Forest Farming

Forest farming, also called multistory cropping, is a practice in which existing forest stands are intentionally and intensively managed to create an appropriate environment for growing understory crops. The chanterelle mushroom harvest from Pacific Northwest forests is a multimillion-dollar industry, yet managers, harvesters, and scientists lack a current synthesis of information about chanterelles. Because chanterelles grow symbiotically with the roots of forest trees, managing the fungi for sustainable harvests also means managing forest habitats (Pilz et al. 2003). Research on the biology, ecology, and management of truffle fungi in the Northwest has increased interest in forest farming and forest gardening systems that combine trees and truffles (Trappe et al. 2009). Along with a variety of other mushrooms, other nontimber forest products harvested in the Northwest include fruits (such as huckleberries), decorative woody florals, and medicinal plants (such as Oregon grape and elderberries). Many of these are harvested from naturally occurring stands.

Forest farming provides a significant opportunity to increase the harvest of these nontimber forest products while ensuring their sustainability. Some researchers have studied the design of agroforestry systems that integrate high-quality timber and matsutake mushroom production in the Cascade Range of southern Oregon. These systems could also produce ornamental conifer boughs, pine cones, and Christmas trees (Weigand 1998). Forest farming, however, has not been widely implemented. Forest farming enterprises could prove profitable for family forest owners in the Northwest.

The projected shifts in temperatures and precipitation that threaten forests are likely to also affect forest-farming systems. These projected impacts include greater fire risk, decreasing tree growth, and increasing insect attacks (USGCRP 2009). Climate change impacts on nontimber forest products cultivated through forest farming systems, however, are not well understood.

## Agroforests

Agroforests include the management of forests on farmlands. Agroforests are a complex mix of trees and shrubs, often incorporating multiple agroforestry practices on one parcel. This system has high levels of biodiversity and achieves the ecological dynamics of a forest ecosystem (Michon and de Foresta 1999). Farm diversification requires a holistic landscape approach. Diversifying a farm with woody crops involves intentionally integrating trees into the farming system. Practices are designed for the conditions and needs of specific parcels of land, to integrate and create interaction between crops and trees, and to use the management skills of the landowner. Such plantings meet landscape integration criteria for agroforestry. These woody perennials enhance biodiversity, diversify producer income, minimize risk, generate alternative profits, and create a more integrated and visually appealing land use system that may be more environmentally, economically, and socially sustainable than the original farm (Angima 2009). For example, converting 40 acres of marginal agricultural land to incorporate hybrid poplar, hazelnut, or Christmas trees through alley cropping, windbreaks, or other practices introduces trees and shrubs into the whole farm system. Research evaluating the level of resources and habitats for important beneficial insects has benefited some agroforestry systems (Russell 2013). Agroforestry practices also can increase beneficial insect habitat and resources. This diversified agroforestry approach may be particularly suitable to the smaller scale farms in the region. Diversified operations may be more resilient to weather variability caused by climate change.

## Alley Cropping

Alley cropping is an agroforestry practice in which agricultural or horticultural crops are grown in the alleyways between widely spaced rows of woody plants. Alley cropping can diversify farm income, increase crop production, improve landscape aesthetics, enhance wildlife habitat, and provide protection and conservation benefits to crops. By combining annual and perennial crops that yield multiple products and profits at different times, a landowner can use available space, time, and resources more effectively. Although alley cropping can increase soil organic carbon, yield decreases to the primary crop grown between the rows can be significant, constraining the appeal of alley cropping (Seiter et al. 1999). Some hazelnut growers in the Northwest plant snap beans or other crops between newly planted trees (Hazelnut Marketing Board 2013). Apple growers in Hood River and the Willamette Valley historically planted strawberries between apple rows (Fortier 1940).

The Northwest's orchards and vineyards may provide some innovative opportunities for alley cropping systems, if growers are interested in adding crops for soil retention, pollination, or income production reasons. In particular, the extensive hazelnut orchards in the Northwest may allow for opportunities for alley cropping additional crops between the rows of existing or new orchards. Relatively few studies clearly show how alley cropping or agroforestry systems contribute to managing the risks from climatic variability, which include the potential to reduce available winter chilling days and crop yields. Luedeling et al. (2011) projected climate change effects on winter chill, an agroclimatic factor that affects agroforestry systems that include temperate fruit trees. These models project sufficient winter chill in the Northwest, which may shift more fruit growing to this region from regions that will not have sufficient winter chill. Concerns remain, however, about early bud break followed by a freeze that could potentially kill the developing buds or flowers. These concerns call for more research on fruit and nut trees' adaptations to climate change and also on the potential development of new or existing cultivars more resilient to these stressors.

## Windbreaks

In some parts of the Northwest, particularly the Columbia River Gorge and coastal areas, windbreaks play an important role in protecting agricultural enterprises from harsh winds. This protection is particularly important for high-value crops grown in the region, such as fruit, wine grapes, and vegetables. Livestock are also affected by wind. Hedgerows are also common in western Oregon, particularly among those landowners interested in sustainable farming methods. Oregon State University Cooperative Extension has released publications that suggest hedgerows can enhance the beauty, productivity, and biodiversity of farms in the region (Hobbs and McGrath 1998). Washington State University's Tree Fruit Research and Extension Center reported bees are more numerous in orchards having windbreak protection (Hanley and Kuhn 2003). Windbreaks are also used in the region as living snow fences to protect roads, communities, and livestock (Hanley and Kuhn 2003). With effective planting and management practices, it is possible to establish windbreaks and hedgerows to provide ecological and economic benefits to landowners and to address climate change in the Northwest.

## Special Uses

Agroforestry practices can be designed to produce certain specialty products. Short-rotation biomass species are one specialty product that can be incorporated into agroforestry design. Advanced Hardwood Biofuels Northwest (AHB) grows hybrid poplar trees to demonstrate the latest biofuel development in the region. AHB is a "consortium of university and industry partners led by the University of Washington. AHB is working to prepare Washington, Oregon, Northern California, and Northern Idaho for a sustainable hardwood bioproducts and biofuels industry" (AHB 2014). The longer term goal is to develop poplar-based biofuels, including jet fuel, diesel, and gasoline that can supplement existing fossil fuels (AHB 2014). These species could be integrated into existing or new agroforestry systems.

Northwestern tribal communities are active in conserving and managing their natural resource base. This management is carried out in part through tribal natural resources agencies. Some of the agroforestry practices discussed in the region may overlap with TEK and management strategies. These practices may help preserve and maintain this TEK and can also provide substantial economic development and food sovereignty potential for tribal communities (Anderson 2007).

## Problems and Limitations

Agroforestry is widely underexploited for both the production of goods and environmental services in the Northwest. Priorities include developing regional and site-specific practices and demonstrations of the ecological and economic performance of various agroforestry practices. The benefits of riparian buffers and effective planting strategies need to be developed and verified. Evaluation of options and impacts of the following should be assessed: (1) forest grazing compared with establishing silvopasture systems and (2) wild harvesting of nontimber forest products compared with forest farming.

Interest in agroforestry in the Northwest is expected to grow as increasing emphasis is placed on land stewardship and environmental protection in agroecosytems in the region. The potential of agroforestry to simultaneously provide economic, environmental, conservation, and social benefits is rapidly being recognized by Federal and State agencies, universities, and conservation organizations. Despite its potential, however, numerous barriers have impeded the development and application of agroforestry in the Northwest. The challenges surrounding agroforestry are that it is unconventional, lacks recognition, and cuts across agencies and disciplines. In addition, the large equipment used by producers in large-scale crop production may not be compatible with what is needed to install and maintain agroforestry practices. Agroforestry may also have higher labor requirements than existing large-scale crop-production systems. Current agroforestry research and development and related extension activities are limited, disconnected, and minimally funded in relation to the need and interest.

Agroforestry can address many important natural resource concerns in the region. Water-quality problems can be addressed with agroforestry practices such as riparian forest buffers that increase stream protection to reduce erosion, capture agricultural chemical pollutants, provide shade to cool stream temperatures, provide thermal protection for wildlife, and improve drinking water. Agroforestry practices used as climate-change adaptation and mitigation tools should be explored at the watershed and landscape levels to optimize integrated land-use systems and provide landowners with products and ecosystem services. Riparian buffers and hedgerows can provide habitat to improve the health of bees and other pollinators in the region. These pollinators are very important for food crop production, which is heavily centered on pollinator-dependent fruits and vegetables in some parts of the region. New markets can create opportunities for agroforestry products. For example, vineyards could have salmon-safe certification for their value-added products and edible fruits, and nontimber forest products could be grown in riparian areas. Agroforestry can also help with diversifying income sources for rural communities and make farmers more economically and ecologically resilient while coping with climate variability and change.

The Northwest faces some limitations specific to the region. The region is very diverse ecologically and agriculturally, which may limit the abilities of landowners from across this region to learn from one another. What practices and species work in one part of the region may not work in another part. This diversity may make the development of interest groups related to agroforestry more difficult. In addition, significant portions of these States are publically owned. These forested areas largely cannot be managed using agroforestry practices, though recent interest in landscape-scale conservation may increase the appeal of agroforestry for its ability to work across landownerships.

Although riparian forest buffers are strongly encouraged because of salmon and other fish species concerns, some of these riparian buffers are "no touch" and do not allow for any harvesting. This policy may make their implementation more challenging and limit the integration of nontimber forest products into these buffers. The region also has a shortage of trained professionals in agroforestry to disseminate the many economic benefits and ecological services of agroforestry to landowners. Strengthening partnerships and cooperation among agencies and forming alliances among Federal, State, university, and private sectors will help develop, disseminate, and apply agroforestry. The establishment of the Pacific Northwest Agroforestry Working Group brings together agroforestry professionals to conduct joint research and training and will help remove the barriers between agencies and universities and create cooperation among scientists, natural resources professionals, and landowners.

## Key Information Needs

- Ecological and economic performance of various agroforestry practices, as determined by site-specific research and demonstration.
- Site-specific adaptation of agroforestry practices by landowners that reflects the tremendous diversity of sites and conditions in the Northwest and limited technical resources.
- Benefits of riparian buffers and effective planting strategies among landowners.
- Long-term impacts of silvopasture and harvesting of nontimber forest products.
- Cultural practices for the sustainable production of nontimber forest products.
- Potential of alley cropping systems with existing and new growers.

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# Southwest

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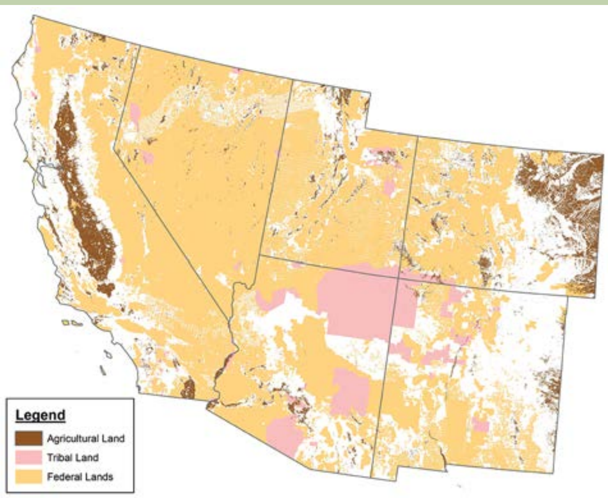
## Description of the Region

The Southwest is a region defined by water scarcity. Composed of Arizona, California, Colorado,[4] Nevada, New Mexico, and Utah, this region has some of the greatest landscape and climate diversity in North America (Neary and Ffolliott 2005, Warshall 1995). Federal and tribal lands dominate the Southwest, with croplands comprising only 8 percent of the region and with the majority being located in California and eastern Colorado (fig. A.4) (USDA NRCS 2013). Agriculture is mainly confined to intermontane valleys, the broad plateaus, and plains with adequate groundwater resources or along alluvial river systems fed by mountain snowmelt. Major river systems like the Colorado, Rio Grande, and Sacramento-Feather-San Joaquin supply water to many areas with irrigated agriculture.

**Figure A.4.** Federal and tribal lands comprise much of the region, with cropland and pastureland limited to areas with available water resources. Rangeland grazing occurs on Federal and tribal lands and also on private rangeland (on some of the areas shown in white). Agricultural land data from Homer et al. (2015) and Federal and tribal land data from USDOI USGS (2003).




Much of the cropland in the region, outside of California, is dedicated to growing alfalfa hay. Other crops include cotton, lemons, lettuce, onions, peanuts, peppers, potatoes, tangerines, and wheat (USDA NASS 2014). Together with hay production, agriculture accounts for 79 percent of the water consumption (Garfin et al. 2014). This usage, however, is changing as urbanized areas such as Phoenix expand by securing the rights to agriculture water. The Phoenix metropolitan area has transitioned from being agricultural in the 1960s to being predominantly urban in the 21st century.

California is different from the rest of the Southwest because it ranks first in the United States for agricultural production, with a value in excess of $42.6 billion or 10.8 percent of the Nation's total agricultural sales (USDA NASS 2014). This amount is about 2.6 times the economic production of the rest of the region combined. Approximately 28 percent of California's agricultural sales is from livestock products, and the remainder is from traditional crops such as vegetables, fruit, grapes, nut crops, lettuce, and berries (USDA NASS 2014).

Rangelands comprise the largest portion of Federal and non-Federal land area in the Southwestern United States (USDA NRCS 2013), generating agricultural revenue through dairy and livestock production (USDA NASS 2014). Rangelands in the region are diverse and encompass different ecotypes from oak savanna, sagebrush steppe, and scrubland to arid grasslands (Shiflet 1994).

Forests of the region occur on rugged peaks and low ranges, over broad plateaus and isolated mesas, and along minor and major river systems (table A.3). These systems provide many ecosystem services crucial to water resource availability. Simultaneous production of wood for fiber or other tree-based benefits, forage for livestock, and traditional agricultural products has been a historical land management objective in the Southwestern United States. Livestock grazing occurs on many forest types in the region; however, these production systems may not necessarily be considered silvopasture systems by definition and practice. (See box A.1.)

[4] Eastern Colorado is best described by the conditions and considerations discussed in the Great Plains regional summary in this appendix.

**Table A.3.** Forests of the Southwest Region.

| Forest type | Extent | Forest management as It pertains to agroforestry |
|---|---|---|
| Southern Rocky Mountain forests | 10.1 million ha (24.9 million ac) of mountainous terrain in Colorado, New Mexico, Arizona, Utah, and parts of Nevada. | Forage increases as forest density decreases and vice versa, making timber management a forage management tool (Clary and Ffolliott 1966). Prescribed fire is also a tool being used more recently to eliminate undesirable plants. Utilization of 30 to 40 percent of the forage growth provides a sustained level of forage resources for livestock on rangelands in good condition. Continuous yearlong grazing is practiced on lower-elevations in the southern part of the region. Fencing, strategic placement of stock tanks and salt licks, and constructing driveways to move livestock from one allotment to another are used to improve livestock distribution, attain specified stocking levels, and obtain more uniform utilization of forage resources. |
| Sierra coniferous forests | 6.9 million ha (16.9 million ac) of mountain landscapes in California with minor occurrences in Nevada. | Forage production increases rapidly, slowly giving way to shrub species, and then to tree regeneration following harvesting of timber. Forage is almost nonexistent beneath old-growth forests but increases once overstory canopies open. Prescribed fire has also been applied to increase forage production. Utilization of 40 percent of the forage growth provides a sustained level of livestock production on rangelands in good condition. Forage on high elevation rangelands is grazed from June through late October with continuous yearlong livestock grazing on lower elevations. |
| Oak woodlands | Throughout California and scattered in western Colorado, Utah, and southwestern New Mexico and southeastern Arizona. | Inherently low levels of growth, irregular stem forms, and a lack of markets constrain the intensive management of oak trees for wood production, although trees are cut locally for fuelwood, and small poles and posts. Many of the rangelands are fair to poor in condition. Therefore, managers often prescribe a utilization level of forage plants that is less than 40 percent to sustained production. Selected seeding of preferred species has improved forage production on some rangelands. |
| Pinyon-juniper woodlands | Eastern slopes of the Sierra Nevada Mountains, eastward throughout the Great Basin, through the Rocky Mountains of Colorado, southward into New Mexico and Arizona. | A past management activity has been to control the invasion of Pinyon-Juniper Woodlands onto lower elevation grasslands to reduce competition and improve forage production. Cattle and native ungulate forage production declines rapidly as the woodlands increase in density due to low precipitation and pinyon-juniper competition. Many rangelands are only fair or poor in their condition. As a consequence, managers consider utilization of forage plants in excess of 40 percent to be detrimental to sustained forage production (Gottfried 1999). |
| Mesquite-dominated ecosystems | Scattered throughout the semidesert rangelands of the region, along the southern boundaries of Arizona, New Mexico, and western Texas. | Mesquite as an agroforestry resource is a source of fuelwood, poles and posts, and feed for ruminants. It also makes excellent charcoal. Small wood-producing (cottage) industries largely dependent on mesquite as the raw material have evolved into a number of profitable enterprises in the southwestern United States. Knowledge of effective silvicultural practices is limited, however, jeopardizing achieving sustainability of the wood resource (Ffolliott 1999). |

ac = acre. ha = hectare.

## **Box A.1.** But is it agroforestry?

Silvopastoral activities and food gathering within forests have been long-standing activities in the Southwest, especially on Federal lands (Bainbridge 1995). The question arises, however, regarding whether all silvopastoral and food-gathering activities are agroforestry. By definition, agroforestry must be *intentional*, *intensive*, *deliberate*, and *integrated* (Gold et al. 2000). Although it is easy to see how practices involving the introduction of trees into agricultural operations may meet this definition, it is less clear for those activities occurring on nonagriculturally managed lands. Silvopastoral systems have been described in the literature as "a form of structural agroforestry in which tree, forage, and animal components all share the same hectare of land at the same time" (Sharrow 1999: 113). Some of these systems, though, lack intentional design and/or management for the production of trees, tree products, forage, and livestock components (USDA NAC 2014). Examples of such systems would be livestock grazing that occurs on forest land where adequate forage already exists or on rangeland where trees are encroaching, which would probably reflect most of the grazing operations that occur on Federal lands. Likewise, harvesting of foods and other nontimber forest products from forested land in the Southwest and elsewhere, especially from Federal lands, is another gray area in terms of whether these activities are actually agroforestry. The question in this case becomes—Is the practice wild harvesting or is it forest farming (agroforestry)? Again, to be considered forest farming (agroforestry), deliberate management of the forested (treed) area to enhance the production of these products needs to exist. On Federal lands, agencies such as the U.S. Department of Agriculture, Forest Service are working to develop forest plans that take into account climate change impacts and the sustained production of these nontimber forest products, especially those that many Native American tribes rely on as indigenous foods (see chapter 5).

*continued on next page*

**Box A.1.** But is it agroforestry? (continued)

The distinction of whether a practice is agroforestry is not an absolute one. Rather, it is one of discerning where on the continuum of design and management the practice lies and then deciding whether that is enough to qualify it as an agroforestry practice.

To complicate the discussion further, situations exist, especially on Federal lands, in which management decisions are made for a primary purpose(s) other than agricultural production, but which can then secondarily provide agricultural benefit. In the Southwest, primary goals for thinning forest stands are for watershed health services that include improvement of timber and tree health, water resource management, and/or fuel load reduction. Regardless of intent, it also generally results in forage production improvement. So the question then becomes—Was this benefit to forage growth deliberately considered and recognized in the planning process? Further, what if the intent is twofold—to increase water resources available to downstream agricultural production and to increase forage production for grazing?

With our understanding of these practices in the Southwest, we do not have the information needed to explicitly state the extent of current agroforestry activities nor that of the potential of agroforestry in the Southwest. Opportunities are emerging that suggest agroforestry may be able to play a larger role in the Southwest as other technologies come on line (more efficient and/or recycled water irrigation systems) and as the Southwest faces more pressing climate conditions.

*California oak woodland management as agroforestry, where goals can include enhanced soil quality and carbon sequestration, generation of annual and longer term incomes from timber products, grazing, and potentially other operations such as mushroom production (Dahlgren et al. 2003, Frost et al. 1991). (Photo courtesy of the USDA Natural Resources Conservation Service).*

Management of the region's watersheds to ensure sustainable flows of high-quality water to downstream agricultural and municipal users in this drought-prone part of the country is integral to the sustainability of this region. Climate projections of increasing and prolonged drought make this service an important consideration when determining management strategies and actions for this region.

## Threats and Challenges to Agricultural Production, Forestry, and Community Sustainability

The Southwest has heated up in recent decades, and the period since 1950 has been hotter than any comparably long period in at least 600 years (Melillo et al. 2014). The 2001-to-2010 decade was the warmest in the 110-year instrumental record, with temperatures nearly 1.1 °C higher than historic averages, fewer cold air outbreaks, and more heat waves (Kunkel et al. 2013). Regional annual average temperatures are projected to rise by 1.4 to 3.1 °C by the 2041-to-2070 period (Garfin et al. 2014). Extreme daytime and nighttime temperatures have been shown to accelerate crop ripening and maturity; reduce yields from vegetables, fruit trees, and vineyards; cause livestock stress; and increase agriculture water consumption (Walthall et al. 2012). The freeze-free period throughout the Southwest is estimated to increase on average by about a month by 2055, with the largest increases (greater than 35 days) occurring in the interior of California (Kunkel et al. 2013). It is projected that required winter chill periods will fall below the number of hours necessary for many of the nut- and fruit-bearing trees of California and that yields will decline as a result (Luedeling et al. 2011). Under warmer winter temperatures, some existing agricultural pests can persist year round, while new pests may become established (Garfin et al. 2014). Pollination services by managed honey bee colonies are expected to decline under predicted climate change scenarios (Reddy et al. 2013), impacting the numerous pollinator-dependent crops in the region.

Long-term and extensive drought is the greatest threat to agricultural production and forestry in the Southwest (Garfin et al. 2014). To compound this threat, the region is projected to transition to a more arid climate (Seager et al. 2007). Drought, as expressed in Colorado River flow, is projected to become more frequent, more intense, and longer lasting, resulting in water deficits heretofore not seen in the instrumental record (Garfin et al. 2014). The current drought in California may foreshadow what is coming (fig. A.5).

The drought in California is posing community sustainability challenges. Current projections are for an unemployment rate of 50 percent in farm towns (Marois 2014). This trend threatens the viability of small farming communities that are spread throughout the agricultural region of the State. It also impacts State and national budgets, which are required to deal with unemployment. Larger cities can be affected by influxes of unemployed people from farming communities.

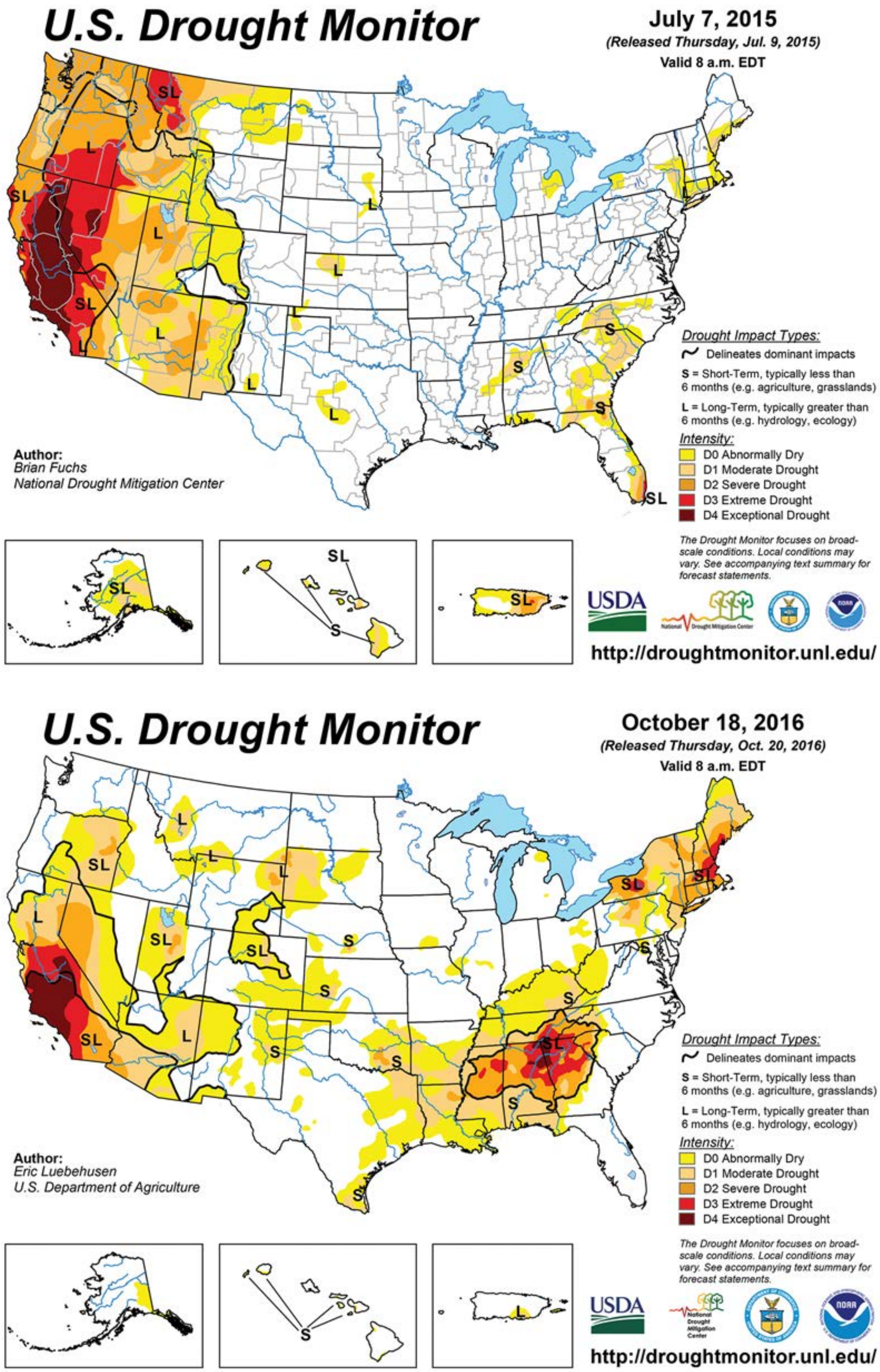
Numerous threatened and endangered (T&E) species reside in the region and likely will experience increasing pressure under climate change (Staudinger et al. 2012). Rangeland grazing historically has contributed to impacts on T&E species (Flather and Joyce 1994). Negative impacts to 22 percent of federally listed T&E species have been attributed to livestock grazing in Southwest forests (Wilcove et al. 1998). Because of T&E species concerns and other environmental issues, public land grazing is a contentious issue that will likely escalate under climate change, and strategies to reduce impacts will need to be implemented (Brown and McDonald 1995).

## Agroforestry as an Opportunity To Build Resilience

Bainbridge (1995) describes a variety of opportunities for agroforestry practices in the Southwest. In this summary, we highlight a few. Numerous adaptation strategies exist for managing grazing lands under climate change (Joyce et al. 2013), and managing forested rangeland grazing as silvopastoral agroforestry systems can offer another option for enhancing stability and resilience in the agriculture and forestry economies (Bainbridge 1995). The greater diversity of enterprises that can be incorporated with the livestock grazing, beginning with timber products but extending to nontimber products (e.g., mushroom production) (Harper et al. N.d.) and hunting and recreational operations (Standiford and Howitt 1991), can reduce risk under variable climate. In addition, this type of operation may also provide other ecosystem services and goods, such as improved soil health, carbon sequestration, and long-term productivity (Dahlgren et al. 2003, Frost et al. 1991).

During the next several decades, many Southwest forests will be going through restoration treatments to reduce fuels and to manage stands at an appropriate density to withstand frequent, low-severity fires. Overstocked forests have led to large, high-severity, landscape-level wildfires. The Four Forest Restoration Initiative is an example of the type of programs that need to be initiated to restore ponderosa pine ecosystems to properly functioning conditions (Covington et al. 1997). After the restoration thinning treatments, higher densities of grasses and forbs will provide significantly greater forage resources to support silvopastoral agroforestry. Judicious management of animal-stocking levels should be able to provide adequate livestock forage, and, in combination with prescribed fire, ensure ecological goals (Laughlin et al. 2006, Moore et al. 2006). Because forest harvesting will be episodic after the restoration treatments are complete, silvopastoral agroforestry has the potential to provide economic resilience for both Federal land managers and grazing permittees (Sharrow et al. 2009).

**Figure A.5.** The State of California recently experienced exceptional drought of prolonged duration, the third most severe on record (Howitt et al. 2014). Stream and irrigation flows to the Central Valley were reduced by 30 percent, and California's water reservoirs statewide were at 28 percent of total capacity and 49 percent of normal (Howitt et al. 2014). Snowpack levels in the Sierra Nevada's forests were estimated at a 500-year low in 2015 (Belmecheri et al. 2016). Reductions in snowpack and rainfall mirrored in depleted water reservoirs impacted the productivity of oak woodlands that sustain silvopastoral agroforestry in California (Asner et al. 2016). Surface water losses in California have been offset by unsustainable groundwater pumping at an additional cost of $0.5 billion to the State's agricultural sector (Howitt et al. 2014). (From USDA Drought Monitor, http://droughtmonitor.unl.edu/).



The Southwest also affords several other potential agroforestry endeavors tied to nut production. Such endeavors could be the deliberate establishment of nut trees, such as pecan, into operations or the deliberate management of lands, such as the pinyon-juniper rangelands, for pine-nut production, along with ongoing grazing activities (Sharashkin and Gold 2004). Tribes in the Southwest, as elsewhere, have long depended on foods they could harvest from the forests (Bainbridge 1995). Given the potential impacts of climate change, such as fire and species shifts, using an agroforestry approach for these nontimber forest products, even on Federal lands, may need to occur to sustain and/or replace production. (See chapter 5 and box A.1.)

Woody species generally used in Southwest agroforestry may also be well suited to producing biofeedstock for heat and power generation (Kirmse and Fisher 1989). Agroforestry could serve as the means for building a viable feedstock supply by augmenting the biofeedstock generated from forest operations (i.e., fuel load reductions). Use of agroforestry for this purpose has some potential in the Southwest, as evidenced in California, where short rotation biomass efforts are already in progress (Standiford 2014).

Agroforestry also can reduce climate change impacts on agricultural production by supporting biological pest control and pollination services for high-value crops in the region, while creating critical habitat for a diversity of wildlife species. (See chapter 2 and box A.2.)

## **Box A.2.** California: buffers, bees, biocontrol, and bucks

One-third of California's agricultural returns come from pollinator-dependent crops (e.g., sunflower, almonds, melons, and many other vegetable crops) making pollinators key players in California's agricultural economy. Pollinator services needed for this crop production are by managed honey bees and also by native bees (Chaplin-Kramer et al. 2011). Given the continuing dilemma of colony collapse, dependence on the honey bee, which is a single species, represents a significant vulnerability in the agricultural sector. In addition, abundance and numbers of native bee species continue to decline as agricultural operations intensify. Shifting climate is expected to impact the quality, quantity, and timing of habitat components critical to the survival and functioning of pollinators.

Hedgerows, windbreaks, and other agroforestry buffer practices that are established to provide nonpollinator services, such as air-, soil-, and water-quality protection, can be used to increase the diversity and abundance of habitat features native bees and honey bees need for survival. These plantings have also been found to enhance beneficial (biocontrol) insects that can help control levels of insect damage to some of these crops in California (Long and Anderson 2010, Morandin et al. 2014).

With appropriate planning and management, these plantings can enhance habitat for both pollinators and biocontrol insects by producing the strategic diversity (i.e., a variety of flowering plants with overlapping blooming times, a diversity of protected and suitable nesting and overwintering sites) that will be needed to create resilience under the unpredictable impacts of changing climate (see chapter 2).

*Blue blooms of native California lilac and other native shrubs and perennials form part of a 1-mile-long hedgerow in Yolo County, CA. Hedgerows have been shown to increase pollination activity from native bees and provide crop protection by harboring beneficial native insects over crop pests by a margin of three to one (Morandin et al. 2011). (Photo courtesy of Jessa Cruz, the Xerces Society for Invertebrate Conservation).*

## Challenges to Agroforestry Adoption

Although agroforestry is often viewed as a potential mitigation measure for climate change in both the agricultural and forestry sectors (Nair 2012), the practice is also threatened by climate change (Pachauri 2012). The big threat that will challenge both agroforestry and conventional agriculture in the Southwest far beyond any other is drought.

One challenge to silvopastoral agroforestry adoption in the Southwest will be T&E species interactions and controversy over grazing impacts on the environment. Federal lands that make up the bulk of Southwest forests are much more prone to this challenge than are private lands. Care will be needed to balance stock numbers with productivity potential. Fluctuating aridity can cause large changes in forage vegetation productivity. The key to success will be preventing irreversible damage to vegetation and site productivity. Because of increasing arid conditions, attention will have to be paid to providing adequate watering resources for livestock.

The adoption of conventional agroforestry practices on private agricultural lands will have the challenge of convincing landowners and managers that the economic and ecosystem services provided by agroforestry in a drying environment are worth the efforts and risk. Because irrigation is an important component of agriculture in the Southwest, the issue of increased water consumption by tree crops in an environment where water is becoming increasingly scarce will remain a stumbling block to agroforestry expansion (see chapter 2). On the other hand, greater harvesting of recycled water, including greywater, may provide an opportunity for use in more innovative agroforestry operations, such as plantation pinyon pine nut production, in this region.

## Key Information Needs

- Create an understanding of tree/forage/grazing interactions to develop silvopasture management options that reliably provide sustained and profitable operations in the various situations in which they can be placed in the Southwest.
- Identify climate change impacts on the dynamics and composition of woody and herbaceous plants to determine how sustainable agroforestry production systems will be in the Southwest under projected conditions.
- Identify pollinator populations and habitat requirements for these species in this region to provide planning and design criteria to establish the most effective agroforestry plantings for pollinators.
- Initiate markets and program support for agroforestry endeavors to develop sustainable levels of operations for producers.

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# Great Plains

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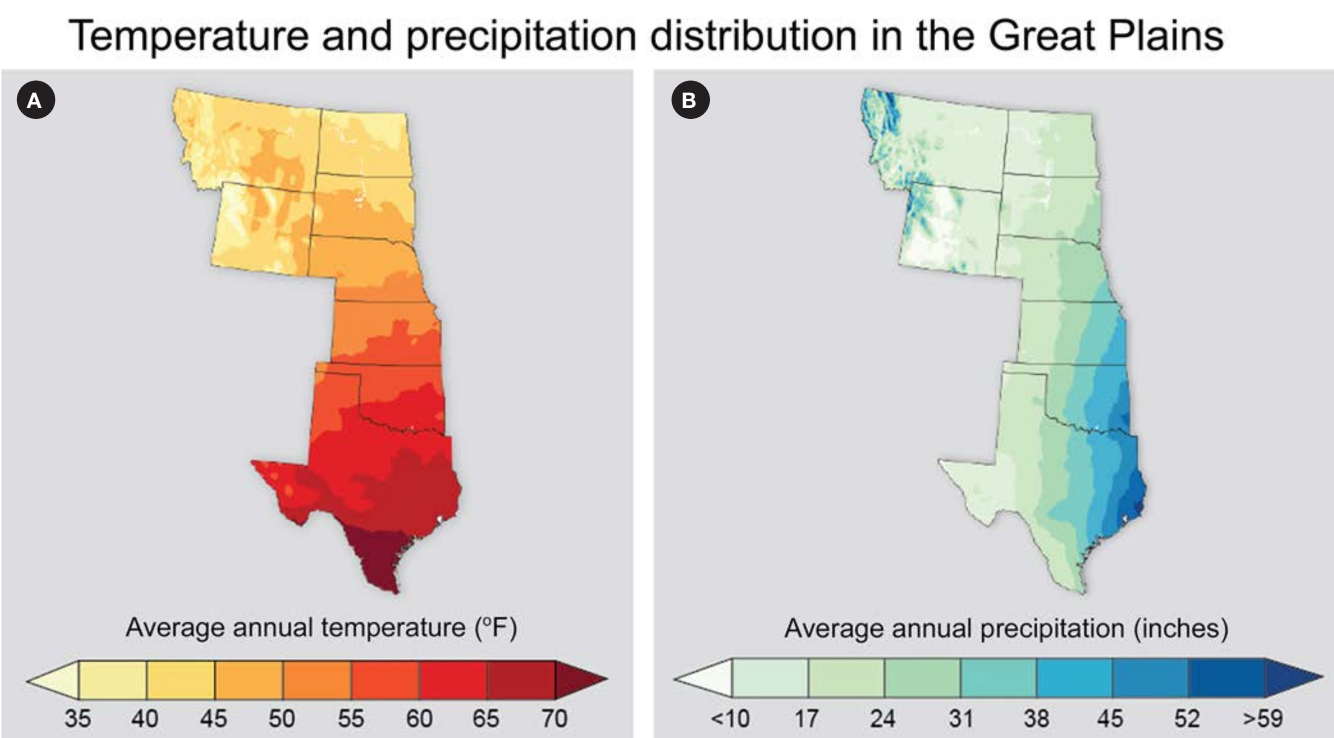
## Description of the Region

Extending from Mexico to Canada, the Great Plains Region covers the central midsection of the United States and is divided into the northern Plains (Montana, Nebraska, North Dakota, South Dakota and Wyoming) and the southern Plains (Kansas, Oklahoma, and Texas). This large latitudinal range leads to some of the coldest and hottest average temperatures in the conterminous United States and also to a sharp precipitation gradient from east to west (fig. A.6). The region also experiences multiple climate and weather hazards, including floods, droughts, severe thunderstorms, rapid temperature fluctuations, tornadoes, winter storms, and even hurricanes in the far southeast section (Karl et al. 2009).

Agriculture is the dominant land use in the Great Plains, with more than 80 percent of the region dedicated to cropland, pastureland, and rangeland (Shafer et al. 2014). This sector generates a total market value of about $92 billion, approximately equally split between crop and livestock production (USDA ERS 2012). Agricultural activities range in the northern Plains from crop production, dominated by alfalfa, barley, corn, hay, soybeans, and wheat to livestock production centered on beef cattle along with some dairy cows, hogs, and sheep. In the southern Plains, crop production is centered predominantly on wheat along with corn and cotton, and extensive livestock production is centered on pastureland or rangelands and intensive production in feedlots. Crop production is a mixture of 82 percent dryland and 18 percent irrigated cropland, with 34 and 31 percent of total irrigated cropland in the region occurring in Nebraska and Texas, respectively (USDA NRCS 2013). In the most arid portions, where irrigation is not available and land is not suitable for cultivation, livestock grazing is the predominant operation (Collins et al. 2012).

**Figure A.6.** The Great Plains Region has a distinct north-south gradient in average temperature patterns (A), with a hotter south and colder north. For precipitation (B), the regional gradient runs east-west, with a wetter east and a much drier west. Averages shown here for the period 1981 to 2010. (Kunkel et al. 2013).



Life in the Great Plains has always been played out against the backdrop of a challenging climate, the massive and extensive drought of the 1930s being a poignant example. Increasing frequency and intensity of extreme weather events, however, is starting to have a greater impact on agriculture and communities within the region. Since 2011, the region has suffered from severe droughts with swings to significant flooding in both the southern and northern Plains, resulting in agricultural losses in the billions of dollars (NOAA 2014). Changes in the overall climate are also ushering in new conditions that will require Great Plains agriculture to adapt. For instance, the average temperature in the Great Plains has already increased roughly 0.83 °C relative to a 1960s and 1970s baseline (Karl et al. 2009). Creating more diverse and resilient farming systems will help mitigate these challenges.

Both positive and negative impacts are predicted for the Great Plains as a result of climate change (Melillo et al. 2014). Although a longer growing season and increased levels of carbon dioxide ($CO_2$) in the atmosphere may benefit some types of crop production, unusual heat waves, extreme droughts, and floods may offset those benefits (Walthall et al. 2012). Farm diversification and intensification through agroforestry may help offset some of the negative effects of climate change. Before discussing the agroforestry practices that are relevant for the Great Plains, we describe a few of the key threats and challenges that Great Plains agriculture faces as a result of climate change.

## Threats and Challenges to Agricultural Production and Community Well-Being

Heat events and droughts are expected to increase in frequency, along with higher temperatures (Kunkel et al. 2013). These conditions can lead to soil erosion by wind, which is a significant threat to both production and human well-being in the region (fig. A.7).

**Figure A.7.** Dust storm event in southern Lubbock County, TX, on June 18, 2009. (Photo by Scott Van Pelt, USDA Agricultural Research Service).

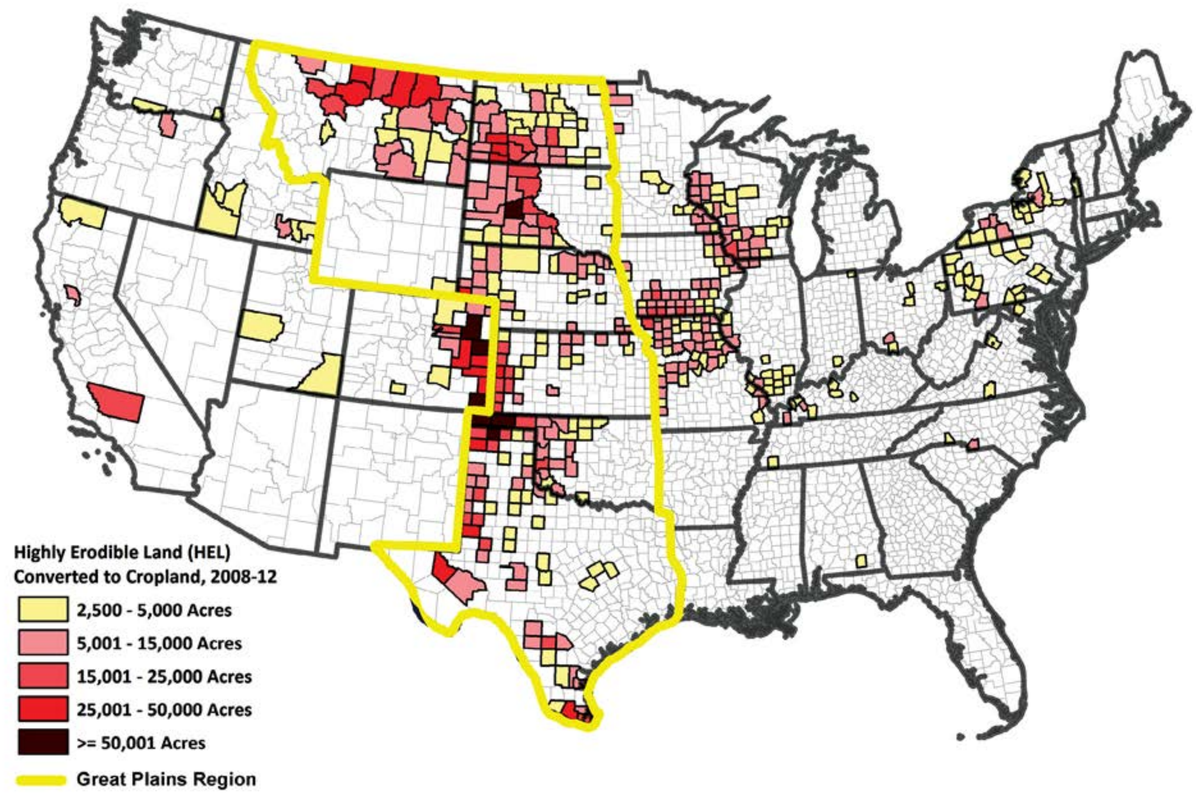
Some of the largest areas of highly erodible soils occur within this region (USDA NRCS 2013), with an increasing portion of these soils being converted to crops (fig. A.8) (Cox and Rundquist 2013). Although best management practices have reduced wind erosion during the past several decades, many areas are still above the tolerable rate for soil loss, and these rates are rising again due to extreme weather events (USDA NRCS 2013). In addition to the loss of soil productivity with wind erosion, human health and safety are also issues. The droughts of 2011 through 2014 have increased blowing dust events throughout the Plains, reducing air quality and contributing to road-related accidents and fatalities (Lincoln Journal Star 2014) and also to asthma and other lung diseases (see the Air Quality section in chapter 2).

The duration of droughts and heat waves is expected to increase in the southern Plains (Kunkel et al. 2013). These changes will impact crop productivity and livestock operations in terms of animal heat stress and obtaining affordable feed (Ojima et al. 2012). Indications are the northern Plains will have higher precipitation and warmer temperatures, creating longer growing seasons (Kunkel et al. 2013) that will continue to facilitate the northward migration of corn and soybean production (Barton and Clark 2014). The northern Plains will remain vulnerable to periodic droughts, however, because much of the projected increase in precipitation is expected to occur in the cooler months, and increasing temperatures will result in higher evapotranspiration during the growing season (Kunkel et al. 2013). In addition, these same conditions are expected to result in a northward spread of insects and weeds (Walthall et al. 2012). Increasing heavy precipitation events in the northern Plains are expected to worsen flooding and runoff events, impacting soil erosion, water quality, and downstream communities (Groisman et al. 2004, Kunkel et al. 2013).

Climate projections indicate that competition for the region's declining water resources will continue to intensify, especially in areas of irrigated corn production in the Great Plains (Barton and Clark 2014). Johnson et al. (1983) predicted this area would need to eventually return to a dryland production system within 15 to 50 years due to water scarcity. With the continued water drawdown occurring in the High Plains aquifer, the long-term outlook for irrigated operations remains uncertain (Brambila 2014, Sophocleous 2010). Given the future climate projections for this area, the need to begin making a transition, at least in part, to production systems less dependent on water seems inevitable.

Because communities in the Great Plains depend highly on farms and ranches, any reductions in agricultural output and income from climate change pose a significant threat to rural economies and vitality. Rural and tribal communities in the region already face challenges because of their remote locations, sparse development, and limited local services, which

**Figure A.8.** Between 2008 and 2012, 5.3 million acres of previously uncultivated, highly erodible land were planted with row crops. Fully 73 percent of that conversion occurred in 425 hotspot counties identified in this map, with most of the counties being within the Great Plains. (From Cox and Rundquist 2013. Copyright Environmental Working Group, http://www.ewg.org. Reprinted with permission).




only will be exacerbated by climate extremes (Shafer et al. 2014). Working-age people are moving to urban areas, leaving behind a growing percentage of elderly people and diminished economic capacity in rural communities (Ojima et al. 2012). Approximately 80 percent of Great Plains counties have a higher percentage of older residents than the U.S. average (Wilson 2009). Reducing risks to agriculture production will be an important step in maintaining economically viable communities, which underlies community well-being.

## Agroforestry as an Opportunity To Build Resilience

Agroforestry first came into widespread use to deal with extreme weather events in the Great Plains during the 1930s. To combat one of the largest wind erosion events in the United States, the 1930s Dust Bowl, more than 200 million trees and shrubs were planted in windbreaks from North Dakota to Texas through the Prairie States Forestry Project (Droze 1977) (see box 2.1). This region continues to be the largest user of this practice because of the preponderance of wind in the region (figs. A.9 and A.10). The protective services of windbreaks to

**Figure A.9.** Most windbreaks established each year are in the Great Plains Region based on linear feet of windbreak. Data from 2010 are presented because the proportions remained similar across all 4 years. No windbreaks were established in Alaska based on these data. (Data [2008 to 2010] derived from USDA Natural Resources Conservation Service National Practice Summary information).

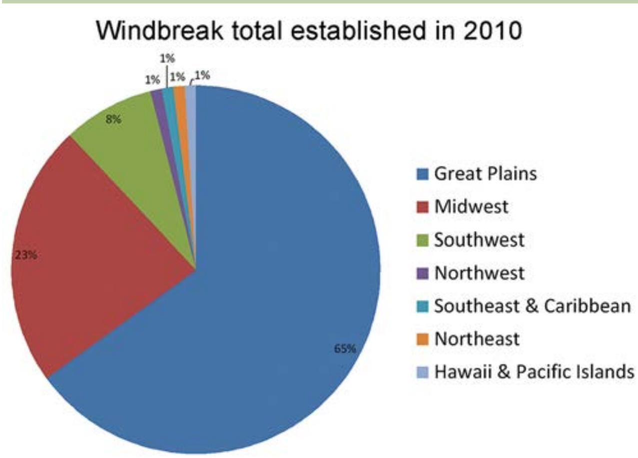
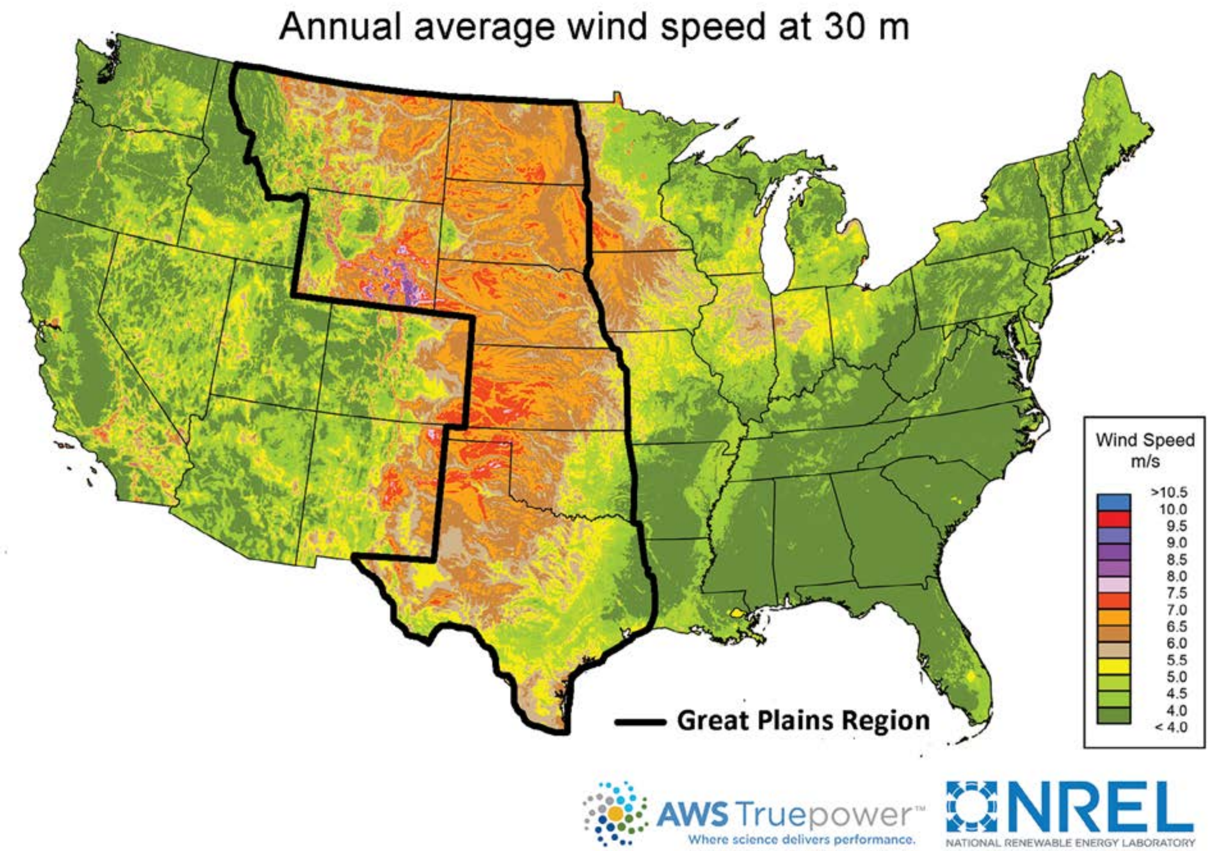


**Figure A.10.** Wind is a dominant feature in the Great Plains Region, as illustrated by this map, which shows the predicted mean annual wind speeds at a 30-meter height based on model-derived estimates. (Wind resource estimates developed by AWS Truepower, LLC. Map developed by the National Renewable Energy Laboratory).




favorably modify microclimate for crops, livestock, farmsteads, and wildlife remain the primary reason for use in the region (Anderson 1995, Schaefer and Ball 1995) (see also chapter 2). As awareness of water-quality and streambank-stability issues in the Great Plains has emerged, interest in the protective services of riparian forest buffers has also increased. Table A.4 summarizes the agroforestry practices that are most relevant to the Great Plains Region.

**Table A.4.** Agroforestry practices that have current or potential importance in the Great Plains Region.

| Practice | Relevance to Great Plains subregions |
|---|---|
| Field windbreaks | NGP, SGP |
| Livestock windbreaks | NGP, SGP |
| Farmstead windbreaks | NGP |
| Living snowfences | NGP |
| Riparian forest buffers | NGP, SGP |
| Silvopasture | SGP |
| Incorporating wildlife into agroforestry practice design | NGP, SGP |

NGP = northern Great Plains. SGP = southern Great Plains.

Source: Adapted from Anderson (1995) and Schaefer and Ball (1995).

Windbreaks remain a logical choice for building greater resiliency in Great Plains agriculture. Field windbreaks in the Great Plains have the potential to increase irrigation/water use efficiency and, therefore, crop production in this region with a high evapotranspiration demand (Dickey 1988). This function of windbreaks could also be instrumental for making the transition from irrigated to dryland operations where necessary. Modeling efforts using several climate change models for Nebraska indicate that windbreaks may aid production during key points in the growing cycle for nonirrigated corn operations (Easterling et al. 1997). For nearly all levels of climate change, dryland corn yields were greater under sheltered than non-sheltered conditions, with the greatest benefit of shelter under conditions having the maximum precipitation deficiencies and windspeed increases. Modeling results suggested the following three climate change-related benefits of windbreaks on crop yield compared with open fields: (1) night-time cooling of the crop that would counteract daytime temperatures in sheltered fields, thereby lengthening the period to maturation and allowing for greater grain fill and yields; (2) reduction in respiration and increase in net primary productivity due to lower night-time temperatures; and/or (3) reduction in the number of days plants experience water stress due to reduced levels of evapotranspiration.

In the southern Plains, the role of windbreaks may be limited, depending on how severe growing conditions become and with the resultant shifts in profitability. Early windbreak work documented enhanced plant and boll biomass in cotton in Texas under sheltered conditions (Barker et al. 1985). Although windbreaks have also been demonstrated to benefit wheat production and protect soils (Brandle et al. 1984), current use is limited. Additional research and technology transfer efforts are needed to demonstrate windbreaks' biophysical and economic utility to combat current and projected climate impacts on the sustained production of this crop.

In the northern Plains, where snow and winter winds are more prevalent, windbreaks can be used to distribute snow across a field to replenish crucial soil moisture and to insulate fall crops against desiccation by cold, dry winter winds (Scholten 1988). Livestock in the Great Plains experience a high level of thermal stress at both extremes, impacting overall survival, production, and profitability. Windbreaks in the Great Plains can provide critical livestock protection during extreme cold/snow events and also during heat waves (see the Livestock Protection section in chapter 2).

Regarding community well-being, agroforestry plantings in the Great Plains—again, predominantly windbreaks and riparian forest buffers—may offer valuable services. Projected increases in winter and spring precipitation events in the northern Plains and the extreme events being predicted throughout the Plains can result in increased urban flooding, as evidenced in the Red River Valley (ND Forest Service 2010). Waterbreaks, a concept similar to windbreaks but with the primary purpose of modifying flooding impacts, could aid in reducing flood damage (Wallace et al. 2000). In addition, this practice could provide other ecological and economic returns from high-risk floodplain agriculture (Schoeneberger et al. 2012). Woody riparian vegetation can be effective in providing streambank protection during large flood events, such as documented in Kansas during the 1993 floods (Geyer et al. 2000). Properly located windbreaks can reduce home heating and cooling costs by as much as 10 to 40 percent (DeWalle and Heisler 1988). In the northern Plains, windbreaks can be used as cost-effective living snowfences to keep roads cleared and reduce snow removal costs and to also provide greenhouse gas emission mitigation and carbon (C) sequestration (Shaw 1988).

Valuation of services from windbreaks and other agroforestry practices in the Great Plains regarding on-farm and off-farm benefits is limited due to the lack of agroforestry inventory in the Great Plains and elsewhere (Perry et al. 2005). The Great Plains Initiative (GPI) is developing an approach to inventorying nonforest trees, including agroforestry, with future use of the method to extend beyond the Plains (Lister et al. 2012). Using 2009 GPI data, dollar values estimated for the various windbreak services in Nebraska were $9 million in annual gross income from field windbreaks based on improved crop yields, $24 million from energy savings due to farmstead windbreaks and $27 million in energy savings for acreages (Josiah 2016). The value of these services under changing climate would vary, depending on location in the region. These estimates do not include offsite benefits from these systems, such as reducing the cost of dealing with windblown soil removal and increasing C sequestration, two aspects being projected as having great significance under projected climate changes in the Plains. Adaptation strategies in the northern Plains can include using the beneficial microclimate effects of windbreaks on crop growth; on the winter protection of livestock, roads, and farmsteads; and on wildlife, as identified in chapter 2. The findings from Brandle et al. (1992) indicate a targeted windbreak planting program in the Great Plains could potentially provide considerable C contributions through C sequestration in the woody biomass and through indirect C benefits via avoided emissions and fuel savings realized through reduced home heating requirements and equipment usage in the tree-planted area.

Given the flexibility in designing agroforestry systems, options to contribute to production, mitigation, and adaptive services are many. For instance, the incorporation of suitable plant materials within windbreaks or riparian forest buffers could serve as an additional source of biofeedstock for onsite or school/community heating systems. In addition, harvesting biofeedstock from riparian forest buffers can enhance the nutrient-absorbing capacity of the plants, maintaining water-quality functions (Schoeneberger et al. 2012). Center pivot irrigation corners may provide areas for additional tree plantings that can provide wildlife habitat and C sequestration opportunities. The potential to store C in the woody biomass in pivot corners in Nebraska was estimated between 13 to 60 teragrams during a 40-year period from establishment (NE DNR 2001). These materials over time could also be used as biofeedstock for local heat or power generation if markets and infrastructure are available.

## Challenges to Agroforestry Adoption

Although the value of agroforestry in the Great Plains has been demonstrated since the 1930s, its adoption in the Great Plains has been limited (Anderson 1995, Schaefer and Ball 1995). A lack of public understanding, institutional infrastructure, and quantitative information is identified as the main obstacle (Anderson 1995, Schaefer and Ball 1995). Reasons for lack of adoption in this region include—

- High cost of establishment and renovations.
- Difficulties/complexities of Farm Bill cost/share assistance programs.
- Lack of compatibility with farm machinery now used in larger scale operations.
- Perceptions that plantings are costing rather than benefiting operations; these costs includes real and perceived competition for water resources (Rasmussen and Shapiro 1990).
- Reluctance by producers to take on the longer management timeframes within a predominantly annual system.
- Limited need to adopt risk-reduction strategies for extreme weather events due to multiple-peril crop insurance (Wright 2014).
- Desire by producers to maximize production when crop prices are high.

Future climate variability and uncertainty will likely necessitate a shift in Great Plains production from maximization of yields per acre to one that can better use renewable resources and sustain production, incomes, natural resources, and communities. Agroforestry in the Great Plains has the potential to contribute to this end (Brandle et al. 1992, Schoeneberger et al. 2012). To increase the adoption of agroforestry in the Great Plains, both on-farm and off-farm valuations of services afforded by these plantings are needed. A study conducted in the northern Plains of Canada indicated windbreaks provided significant returns that extended beyond the individual practice and farm boundaries (Kulshreshtha and Kort 2009). Additional studies like this one will be valuable in providing a broader base of considerations in management decisionmaking.

Despite the benefits of windbreaks in the Great Plains, a big challenge is to keep these practices in place. The declining condition of windbreaks in the region has been identified as a significant issue, and many of these degraded windbreaks are being removed and not replaced because of recent high crop prices (Marttilo-Losure 2013). A nursery responsible for supplying many of the windbreak seedlings in the northern Great Plains has seen a 70-percent decrease in sales from 2002 to 2013 (Knutson 2014). Interest in the practice still exists, however, and two major windbreak workshops—the Great Plains Windbreak Renovation and Innovation Conference and the Southern Plains Windbreak Renovation Workshop—were held in 2012 and 2013. Continued opportunities for exchange of windbreak expertise will be required to modify the design and management of windbreaks and other agroforestry practices to address future conditions. One such effort is an ongoing Great Plains-wide effort to reevaluate the impact of windbreaks on crop yields, given current growing conditions, cultivars, and management practices.

Another challenge facing agroforestry use in the Great Plains is the availability of suitable plant material. Tree and other woody plant species will need to be resilient to the same future weather and climate shifts. Trees in the Great Plains historically have been exposed to numerous pests, diseases, and environmental conditions that hinder planting success, reduce their effectiveness, and limit their long-term survival. Damage in trees planted in the Prairie States Forestry Program was observed most commonly in trees previously stressed by drought (Read 1958). Modeling efforts by Guo et al. (2004) indicate that tree growth in agroforestry-like plantings may be impaired in the region under several climate change scenarios, likely affecting the services desired from these plantings. Findings from Wyckoff and Bowers (2010) suggest shifts in climate along with elevated levels of $CO_2$ may prompt the expansion of species from the eastern forests into the Plains, potentially increasing new options for suitable plant material.

The number of tree species historically used for agroforestry plantings in the Great Plains is few. Two primary species used in agroforestry plantings throughout the region, Scots pine (*Pinus sylvestris*) and green ash (*Fraxinus pennsylvanica*), are no longer recommended because of diseases and pests, with the recommendation for black walnut (*Juglans nigra*) also becoming questionable with the emergence of thousand cankers disease. Because stress events are expected to increase in the Great Plains, a greater diversity of plant materials and management strategies for creating resilient agroforestry plantings will be required. Although agroforestry alone might not create sufficient pressure for the innovation and production of suitable plant materials, the need for appropriate materials for community forestry, green infrastructure, restoration, and agroforestry should collectively create ample demand.

## Key Information Needs

- Develop climate-smart design, planning, and management guidelines for agroforestry systems to better meet the needs and conditions of the Great Plains region.
- Conduct an economic assessment of internal and external benefits, from production to natural recourse conservation, derived over time from agroforestry practices in the Great Plains.
- Identify and produce on a large scale a variety of stress-/pest-/climate-resilient/resistant plant materials for use in the different Great Plains growing zones.

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# Midwest

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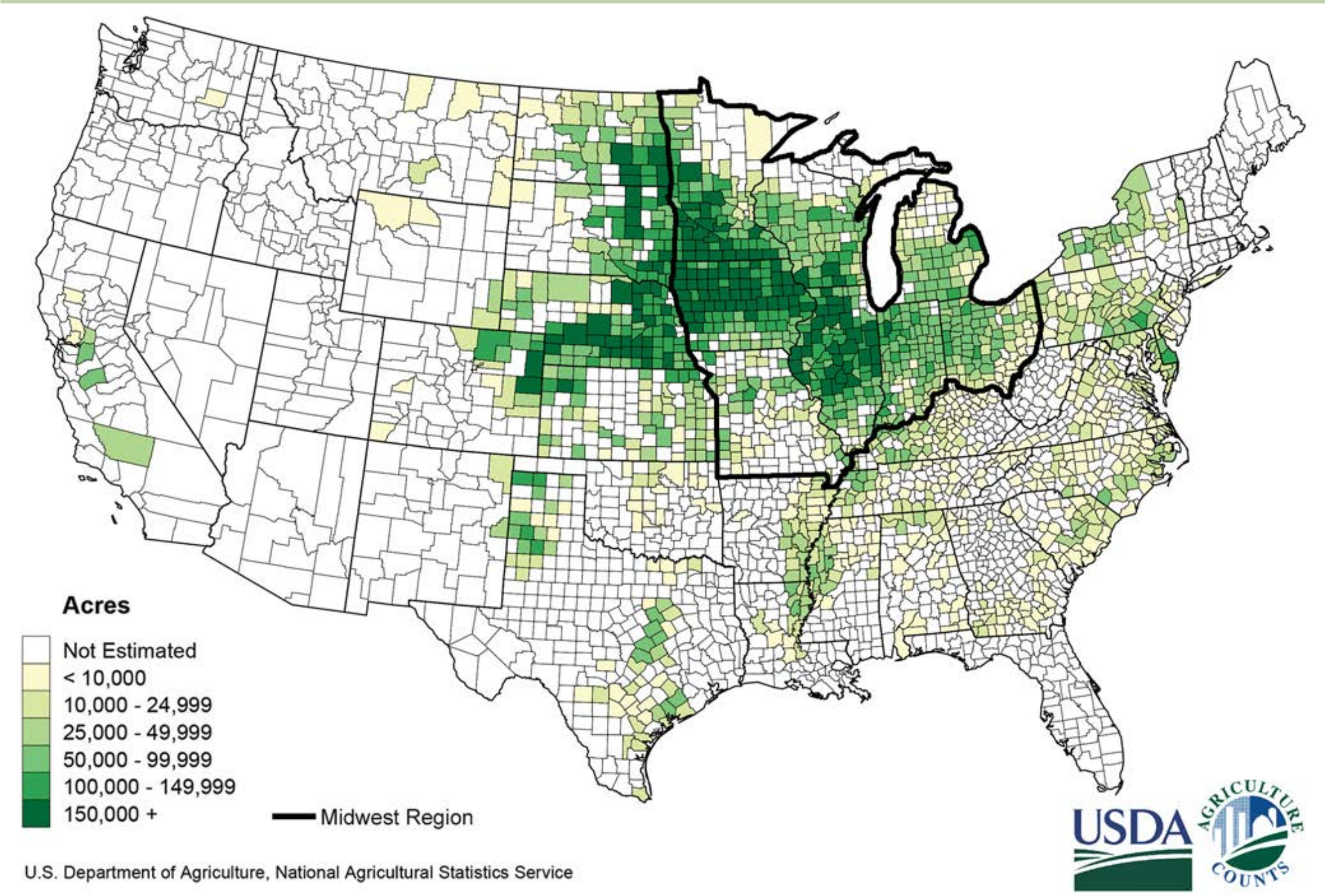
## Description of the Region

The Midwest Region encompasses the States of Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin and includes about 20 percent of the U.S. population (61 million), which primarily lives within its cities. Agriculture is the dominant land use in the Midwest, with more than two-thirds of the land designated as farmland, and plays a major role in the regional and national economy (fig. A.11). Midwestern States traditionally are considered to be the Corn Belt, because corn (*Zea mays*) and soybean (*Glycine max*) constitute 85 percent of the crop receipts. Agricultural exports from the Midwest accounted for more than $86 billion in 2009, which amounted to nearly 87 percent of the national agricultural export. A diversity of production systems, however, ranges from corn, oats, soybean, and wheat to fruits, nuts, vegetables, and livestock. The Midwest is also home to some of the most valuable timber species in the United States that include the central hardwood, northern hardwood, and Lake States coniferous regions.

The Midwest Region enjoys a continental climate, with warm summers and cold winters. The frequency and intensity of extreme weather events, such as droughts and floods, have increased during the past few decades, threatening agriculture in the region (Andresen et al. 2012). The rate of warming has also accelerated, resulting in warmer nights and milder winters. For example, the average Midwest air temperature increased 0.11 °F per decade between 1900 and 2010. The average temperature increased twice as rapidly (0.22 °F per decade)

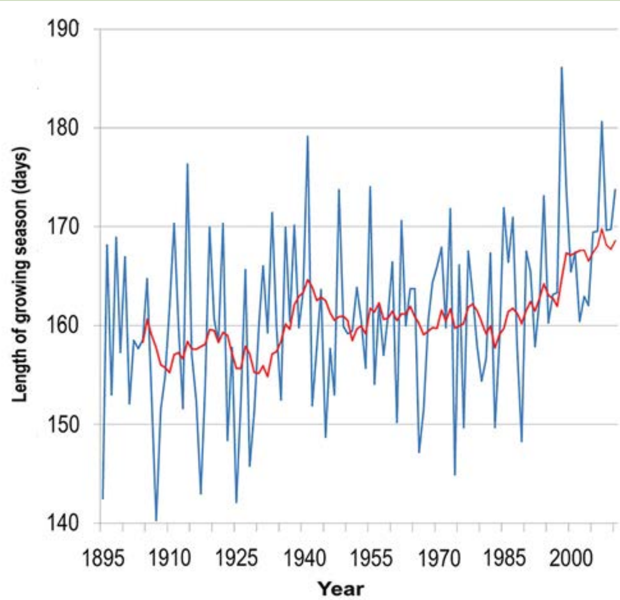
**Figure A.11.** Corn acres planted for all purposes, by county, 2015. (Map by USDA National Agricultural Statistics Service).



during the past 60 years and four times as rapidly (0.47 °F per decade) during the past 30 years compared with the increase from 1900 to 2010 (Kunkel et al. 2013). The Midwest has also experienced a lengthening of the growing season by 1 to 2 weeks since 1950 (Robeson 2002, Skaggs and Baker 1985). Fig. A.12 shows that the growing season averaged about 155 days before the 1930s and has been approaching 170 days in recent years (Andresen et al. 2012).

Positive and negative impacts are predicted for the Midwest as a result of climate change. Although a longer growing season and increased levels of carbon dioxide ($CO_2$) in the atmosphere may benefit agriculture, those benefits may be offset by the impacts of unusual heat waves, spring freezes, extreme droughts, and floods of greater intensity. Farm diversification and intensification through agroforestry may help offset some of the negative effects of climate change. The following sections describe some of the threats and challenges that Midwest agriculture faces as a result of climate change and identify potential mitigating effects that agroforestry practices provide.

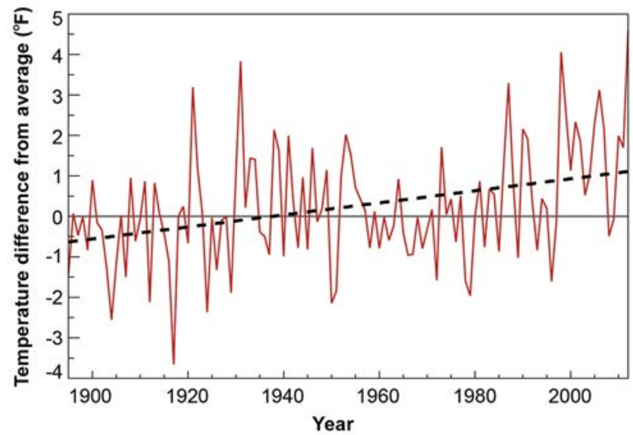
**Figure A.12.** Length of growing season in the Midwest. The red line is a 10-year moving average. (Andresen et al. 2012).




## Threats and Challenges to Agricultural Production and Other Ecosystem Services

The Midwest is projected to experience a continuing rise in average annual temperature (fig. A.13). This rise will lead to increased heat stress and associated yield decline in many crops, despite the $CO_2$ fertilization effect. Trees modify site microclimate in terms of temperature, water vapor content or partial pressure, and wind speed, among other factors. Trees can also improve water recharge in the soil and reduce

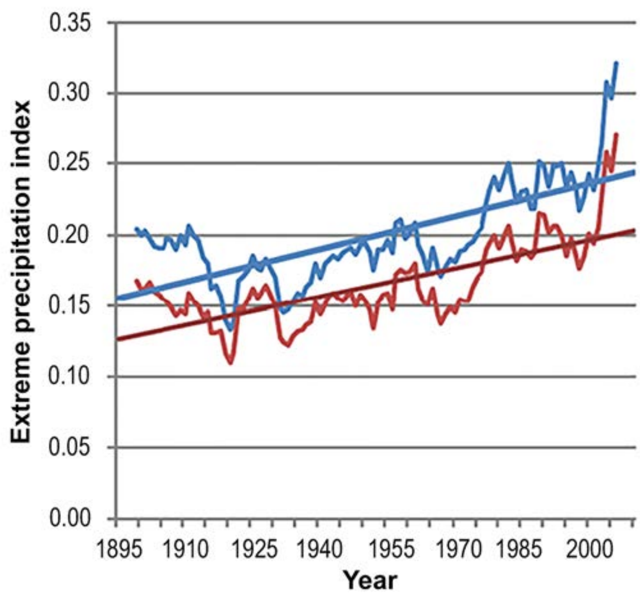
**Figure A.13.** Average annual temperature (red line) across the Midwest shows a trend toward increasing temperature. The trend (heavy dashed black line), calculated during the period 1895 to 2012, is equal to an increase of 1.5 °F. (http://nca2014.globalchange.gov/report/regions/midwest).




evaporative water loss from exposed soil surfaces. For example, windbreaks slow the movement of air and thus, in general, reduce evaporative stress. Windbreaks are known to improve soil moisture availability, improve the distribution and utilization of irrigation water, reduce evapotranspiration, and improve crop water use efficiency (Davis and Norman 1988). Temperature reductions from tree shade can help reduce heat stress of crops and animals in agroforestry systems. A study in Nebraska showed earlier germination, accelerated growth, and increased yields of tomatoes (*Lycopersicon esculentum*) and snap beans (*Phaseolus vulgaris*) under simulated narrow alleys compared with wider alleys (Bagley 1964).

Extreme rainfall events result in more frequent flooding, more erosion, declining water quality, and difficulty in crop establishment in the spring. The frequency of heavy precipitation events has been increasing in the Midwest in recent decades (Changnon and Kunkel 2006). Andresen et al. (2012) showed that the number of 24-hour, once-in-5-years storms increased about 4 percent per decade since the beginning of the 20th century (fig. A.14). This trend of increasing frequency of heavy rainfall has exacerbated the intensity and frequency of flooding events in the region. Frequent flooding and the resulting loss of agricultural production have caused large-scale economic loss and hardship in the Midwest in recent years. The introduction of trees into agricultural fields as riparian forest buffers or alley cropping along the contour as an upland buffer has been shown to take up large quantities of water and lower the water table, particularly when there is excess water (Anderson et al. 2009). Planting fast-growing trees such as poplar (*Populus* spp.), sycamore (*Platanus occidentalis*), and willow (*Salix* spp.) in combination with shrubs and warm-season grasses in multispecies riparian forest buffers or in alley cropping configurations can help lower the water table in marginal land that experiences

**Figure A.14.** Temporal pattern of extreme precipitation index for occurrence of 24-hour, once in 5-year extreme precipitation events in the Midwest. The annual time series and linear trend (straight line) are shown in blue. A time series and linear trend for the months of May through September are shown in red. (Andresen et al. 2012).




frequent flooding or wet conditions (Zaimes et al. 2004, 2008). Research also shows that having a 500-foot buffer of trees situated between major rivers and levees can protect levees from failure, thus protecting crop fields in floodplains (Allen et al. 2003). It is well known that properly designed riparian forest buffers can reduce surface runoff and sediment loss by as much as 90 percent (Udawatta et al. 2005). The same buffers can also act as filters to trap, store, and transform agricultural chemicals, including pesticides and fertilizers, thereby improving water quality in streams and rivers (Lin et al. 2007, Lin et al. 2011).

Stress on the region's agriculture will likely include larger populations of harmful insects. Insect populations are likely to increase as a result of warmer winters, increasing their winter survival, and higher summer temperatures, increasing reproductive rates and favoring multiple generations each year. Diversification by introducing trees into monocultured croplands will increase the number and abundance of birds and beneficial insects that feed on harmful insects. Alley cropping is a potentially useful technology for reducing pest problems because tree-crop combinations provide greater niche diversity and complexity than do annual crops alone (Stamps and Linit 1998). Studies with pecan (*Carya illinoensis*), for example, have looked at the influence of ground covers on arthropod densities in tree-crop systems. Bugg et al. (1991) observed that annual legumes and grasses cover crops sustained lady beetles (Coleoptera: Coccinellidae) and other arthropods that may be useful in the biological control of pests in pecan. Willow show promise for supporting biological control of insect pests in agricultural systems (Dalin et al. 2011). Stamps and Linit (1998) and Stamps et al. (2009) observed similar results in a black walnut (*Juglans nigra*)-based alley cropping system in Missouri. In an alley cropping trial with peas (*Pisum sativum*) and four tree species (*Juglans*, *Platanus*, *Fraxinus*, and *Prunus* spp.). Peng et al. (1993) found an increase in insect diversity and improved natural-enemy abundance compared with monocultured peas. Agroforestry systems also have a greater diversity of birds compared with monoculture agronomic systems and are also likely to provide additional pest reduction to adjacent crops (Berges et al. 2010, Gillespie et al. 1995).

Higher summer temperatures will stress livestock, increasing costs as livestock productivity decreases and ventilation and cooling costs increase. Heat stress has been identified as a major constraint to cattle production. At high temperatures, evaporative cooling is the principal mechanism for heat dissipation in cattle. It is influenced by humidity and wind speed and by physiological factors such as respiration rate and density and activity of sweat glands. Failure to maintain homeostasis at high temperatures may lead to reduced productivity or even death. Providing shade, however, can reduce the energy expended for thermoregulation, which, in turn, can lead to higher feed conversion and weight gain. For example, in a study in Missouri, cattle in a silvopastoral practice gained more weight than in open pasture, translating to nearly $50 more per cow-calf pair (Kallenbach 2009).

Climate change may threaten forests in the Midwest with more frequent droughts and wildfires and larger populations of harmful insects. Forest farming and silvopastoral practices reduce unwanted understory growth, provide added protection from fire, reduce crowding and stress on remaining trees, and improve overall forest health. Moser et al. (2008) estimated that farmers owned nearly one-half of the 11 million acres of all woodlands in three of the Midwestern States (Illinois, Indiana, and Iowa). They showed that active management of those woodlands increased productivity and biodiversity. Actively managing the woodlands using agroforestry can further enhance the value of the forests. For example, periodic thinning is essential in maintaining a woodlot under a forest farming or silvopastoral practice. Thinning also helps to produce valuable sawlogs, and reduce wildfire risks while reducing understory invasives and outbreaks of harmful pests.

Degraded air quality due to human-induced emissions and increased pollen season duration are projected to be amplified with higher temperatures. More than 20 million people in the Midwest experience air quality that fails to meet national ambient air-quality standards. Traditional farming systems are often impacted negatively by high winds. Windbreak systems can easily be integrated into existing farm, horticulture, and animal production systems to minimize impacts of adverse weather caused by climate change. These windbreaks can also reduce dust pollution, thereby enhancing air quality.

Specially designed windbreaks and shelterbelts, known as vegetative environmental buffers, can improve air quality around confined animal feeding operations. Most odor-causing chemicals and compounds are carried as volatile organic compounds (VOCs) (particulates). These buffers can filter airstreams of particulates by removing dust, gas, and microbial constituents (Tyndall and Colletti 2007).

## Agroforestry Uses—Opportunities and Challenges

Early settlers in the Midwest historically practiced slash-and-burn agriculture and tended multilayer home gardens. Grazing by livestock such as bison, combined with the intentional use of fire by Native Americans, was a form of management in the oak savanna ecosystem in the region. During the past 30 years, Federal cost-share programs (e.g., Conservation Reserve Program [CRP], Environmental Quality Incentives Program [EQIP]) administered by the USDA Natural Resources Conservation Service have resulted in major increases in riparian forest buffer establishment in the Midwest Region. A recent national assessment revealed that most of the USDA funds spent on agroforestry in fiscal years 2011 and 2012, about $316 million, enabled landowners across the country to install riparian buffers and windbreaks on their land through CRP and other USDA conservation programs (USDA 2013).

Research in the Midwest Region has also concentrated on selecting plants better adapted to the expected climate change. Within in the transition zone from cool-season to warm-season forages, preliminary estimates are available for selecting new forages with tolerance to moderate or heavy shade that can be integrated into alley cropping, silvopastoral, and riparian buffer practices (Van Sambeek et al. 2007). Likewise, if crop options need to change under a changing climate, decision tools exist for selecting new crops with more favorable tree-crop interactions (Van Sambeek and Garrett 2004). Other studies have concentrated on what cultivars are currently adopted and where, to make better decisions as to what cultivars can be moved. For example, Casler et al. (2007) examined the latitudinal and longitudinal adaption of switchgrass populations. Likewise, understanding genetic variation among nut tree cultivars adapted to growing in open conditions rather than closed forest conditions will aid in selecting more productive mast species for use in alley cropping and silvopastoral practices. Results from flood-tolerance screening trials and use of large container-grown planting stock will aid in decisions regarding what hardwood planting stock to include in bottomland restorations in a region dominated by river systems (Dey et al. 2004, Kabrick et al. 2005).

Additional opportunities for agroforestry adoption in the Midwest are presented by new, small landowners willing to use incentive programs and their own funds to try alternative land uses that do not provide immediate financial returns. According to the 2012 USDA Census of Agriculture, the number of small- (1-9 acres) to medium-sized farms that exist in the Midwest represent opportunity for a wide range of agroforestry practices (USDA NASS 2014). Hundreds of thousands of acres in the Midwest are also under orchard and timber production suitable for integrating agronomic and horticultural crops to enhance production and utilization of these lands. Alley cropping can be used to optimize productivity of the land. The growing demand for "nutraceuticals" (supplements designed to optimize nutrient benefits) and specialty crops, such as ethnic vegetables, herbs, fruits, and nuts, may provide candidate crops for production in tree crop alleys. Alley cropping, which is a good option for sustainable farming in hilly lands, reduces soil erosion and helps diversify regional horticulture production. The emerging biobased economy is providing additional opportunities to grow fast-growing, short-rotation woody crops and herbaceous biomass crops (annuals and perennials) in agroforestry configurations in the Midwest. Establishing such mixed-species systems in strategic locations in the Mississippi River watershed will help improve water quality and alleviate the hypoxia issue in the Gulf of Mexico.

Episodic periods of high commodity row crop prices (e.g., corn and soybeans) encourage continued production by farmers, sometimes without adequately considering environmental implications. During times of high commodity prices, lands enrolled under the CRP may be converted back to intensively managed row-crop systems when CRP contracts expire. This conversion is likely to reestablish the environmental degradation (e.g., loss of soil quality, accelerated erosion causing nonpoint source pollution) evident before enrolling. More than 7.3 million acres of land enrolled in CRP are expiring within the next 5 years (USDA-FSA 2012). Of those acres, more than one-half are located in the Midwest. Alternative and holistic approaches to maintaining these areas in continuous living cover systems that support sustainable production and economic opportunities to farmers and that provide conservation benefits must be developed using agroforestry (NWF 2012, USDA 2013).

With more than 85 percent of the agricultural landscapes under corn/soybean rotational systems, riparian and upland forest buffers or strips (Tyndall et al. 2013) can be used to minimize the environmental impacts of intensive row crops. The use of riparian buffers can also meet an expanding set of landowners' and societal objectives. Government cost-share programs help to promote the establishment and maintenance of buffers through EQIP. State programs, such as the Minnesota Agricultural Water Quality Certification Program, enable farmers and agricultural landowners the opportunity to take the lead in implementing conservation practices that protect our water. Landowners who implement and maintain approved farm management practices will be certified and, in turn, obtain regulatory certainty for a period of 10 years (Minnesota Department of Agriculture 2014).

The Midwest is home to lush hardwood ecosystems, but their long-term productivity is threatened due to unsustainable woodland grazing (Loeffler et al. 2000). The grazed woodlots are often unmanaged for timber, resulting in both low yield of forage and reduced timber production. Even though the conversion of pastures to planned agroforestry systems could have long-term economic benefits for producers, many landowners think that it is economically difficult for them to make the change. Agroforestry practices can provide landowners with needed income from their land during the 10 to 60 years or more necessary to sell marketable forest products. As an integrated management system, silvopasture can offer better woodland management both for economic production and environmental benefits and can address these concerns.

The relevance of small-scale farm and forest landowners in the Midwest continues to increase as consumer demand for food that is locally produced and marketed is gaining popularity throughout the United States. Local food markets typically involve small-scale farmers and woodland owners who sell directly to consumers. A recent study showed that in two regions in Missouri (the Old Trails Region near Kansas City and the Ozarks Region in the south), local foods created approximately 40 to 45 percent more indirect economic activity than conventional food sales (Johnson et al. 2014). A growing number of smaller acreage landowners practice agroforestry, including growing nontimber forest products, such as ginseng (*Panax* sp.), log-grown mushrooms, black cohosh (*Actaea racemosa*), and other cultivated plants under shade. The history of wildcrafting and the use of medicinals, especially within specific cultural groups, provide additional opportunities for development of forest farming in the region (Gold et al. 2004). Likewise, the introduction of nut trees, including walnut, pecan, and chestnut, into agroforestry practices will not only diversity the farmscape but also will enhance the economic viability of the farming enterprise.

Agroforestry adoption among landowners remains a challenge in the Midwest because of the cost to establish these systems, the incompatibility of existing farm equipment, and the long lag time before the benefits of these systems can be realized. The complexity of the practices, lack of information and demonstration sites, and limited extension/outreach personnel are also identified as limitations to large-scale adoption of agroforestry in the Midwestern landscape.

## Key Information Needs

- Interactive maps identifying landowners practicing agroforestry and growing specialty crops.
- Trained professionals with agroforestry certification credentials.
- Improved financial information on emerging specialty crops coupled with widely tested improved specialty crop cultivars available to farmers to reduce risks and ensure profitability.

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# Northeast

Sally Claggett, Tracey Coulter, Katrina Krause, and Julie Mawhorter

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## Description of the Region

The Northeast Region is composed of 12 States (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia) and includes 9 of the 10 most densely populated States in the country. The Interstate 95 corridor from Washington, DC to Boston is a heavily urbanized landscape that is mostly at sea level and close to the coast. The Northeast climate is diverse—frequent winter storms bring bitter cold and frozen precipitation, especially to the north in the New England States. Summers are warm and humid, especially to the south in the Mid-Atlantic States surrounding the Chesapeake Bay. The Northeast has been affected by extreme events such as ice storms, floods, droughts, heat waves, hurricanes, and major storms in the Atlantic Ocean off the Northeast coast.

The Northeast is naturally forested, but agriculture is vital in the region. About 21 percent of land in the 12 States of the Northeastern United States is farmland (6 percent of the national total) and 62 percent of the land in the region is classified as timberland. The Northeastern United States is home to about 175,000 farms that collectively produce agricultural commodities worth more than $21 billion per year (USDA NASS 2009). The most prevalent commodities in the Northeast are dairy products and poultry, split about equally between chicken and eggs. About one-half of the field crops grown in the Northeast, including pasture, go to animal feed. Horticulture is a relatively large portion of total plant production in the Northeast, which includes perennial fruits such as apples, pears, blueberries, and cranberries.

Farms in the Northeast, on average, are smaller than farms in many other parts of the country. Organic production is more common in this region than in other regions. Locally grown initiatives, such as farmers markets and farm-to-table restaurants, are important to Northeast urban communities.

Urban areas disrupt much of the natural landscape in the region, which also is an area of high natural biodiversity—second only to the Southeast—and, with the various mountain ranges and physiographic provinces, microclimatic variation is extreme. The combination of urban areas and natural biodiversity in the region indicates a greater importance of the role of agroforestry to expand and link natural habitats to support biodiversity and adaptation. Farmed lands are a necessary part of landscape planning for future climate scenarios. Agroforestry practices in the Northeast can also help protect the many communities here from flood and fire. Hurricanes Irene, Lee, and Sandy provided "teachable moments" by demonstrating the region's vulnerability to extreme weather events and wide-scale flooding.

## Threats and Challenges to Agricultural Production and Community Well-Being

Although some uncertainty exists about the impact of temperature rises on rainfall and storm events, increasing temperatures will at least increase the use of water and cause shifts in the timing and nature of plant growth and changes in plant species, ecosystem composition, pests, and disease dynamics. Between 1895 and 2011, temperatures in the Northeast increased by nearly 2 ˚F (NCA 2014). Projections in the Mid-Atlantic States indicate more summer days of extreme heat. More than any other region in the United States, the Northeast Region has seen a greater increase in extreme precipitation. Between 1958 and 2010, precipitation during heavy rain events increased by more than 70 percent. Due to a rise in sea level, coastal flooding has increased approximately 1 foot since 1900. This rate of sea-level rise exceeds the global average of approximately 8 inches due primarily to land subsidence (NCA 2014).

The following agricultural vulnerabilities are of known concern in the Northeast (NCA 2014, USDA Forest Service 2015)—

- Livestock operations could face increased intensity and frequency of summer heat stress, which could decrease production of dairy and poultry and increase the impact of pathogens and parasites. These conditions would likely affect livestock health and increase mortality.
- In addition to direct crop damage, increasingly intense precipitation events can result in wetter fields that may delay planting or harvesting. Field crops are likely to experience heat and ozone stress; drought conditions; impacts of water inundation on fields; and invasive weed, pest, and pathogen outbreaks.

- Warmer winters could impact apple crops due to earlier bloom, causing frost damage; increased summer heat could impact fruit set and result in greater susceptibility to fungal infections.
- Many varieties of berries require substantial winter chilling and may become less viable as warmer winter temperatures become more frequent. This trend may cause increased freeze damage after plants de-harden or if early bloom occurs. Warmer temperatures also likely will intensify pest infestations by pests such as the grape berry moth or blueberry gall midge.
- Increased summer drought frequency will likely challenge Northeast crop producers. Excessive rainfall in the other seasons could lead to flooding, delay springtime planting, and result in lower crop yields. A longer, hotter growing season may benefit some vegetable crops but could also intensify weed and pest pressures by pests such as the Colorado potato beetle, tomato and potato blight, Stewart's Wilt, kudzu, and Palmer amaranth.
- Milder winters have affected and can further affect maple syrup production. With earlier starts in the sugaring season currently experienced in central New England and with the potential decline in sugar maple trees as a result of shifts in forest species composition, producers may experience shorter tapping seasons, lower grade syrup, and reduced maple syrup production (Rustad et al. 2012, Skinner et al. 2010).

Impacts to community well-being are as follows—

- Sea level rise, saltwater intrusion, and flooding will compromise infrastructure and will increased the need for emergency response actions.
- Erosion from heavy rains and, conversely, erosion from drier conditions can adversely affect commercially important aquatic fish and shellfish habitat, as can agricultural pollutants. With additional precipitation, fertilizer applications could increasingly end up in waterways, greatly exacerbating dead zones in our bays and estuaries. Additional sediment in runoff can also be devastating because it greatly alters underwater habitat and can block primary production and sunlight energy.
- Many weeds, pests, and fungi thrive under warmer temperatures, wetter climates, and increased carbon dioxide ($CO_2$) levels. Many weeds and vines respond better than desirable vegetation to increasing $CO_2$ concentrations.
- Because each species has a unique biological response to climate change, disruptions of important species interactions—especially with plants and pollinators—can be expected. This shift in range and plant lifecycle can have negative effects culturally on traditional forest food gathering by Native American communities—such as the Wabanaki society's use of berries in the Northeast (NCA 2014).

## Agroforestry as an Opportunity To Build Resilience

Agroforestry, as a professional term and suite of practices, has been gaining attention among partners in the Northeast Region during the past 5 or more years, though some agroforestry-related practices have been in use for decades. The ingenuity and flexibility of agroforestry practices and the potential for the long term would be a welcome addition to many farms in the region. On a larger landscape scale, agroforestry could play an important community role by protecting communities, reducing pollutants, storing carbon (C), adding green jobs, and providing linkages and corridors for ecosystem functions.

In summary, agroforestry can help manage the uncertainties and complexities of climate change on multiple fronts by—

- Reducing the impacts of extreme and shifting weather patterns on agricultural production.
- Expanding and linking natural habitats to support biodiversity adaptation.
- Protecting communities from flood and fire.
- Trapping sediments and nutrients before they wash into sensitive aquatic habitats.
- Reducing C impacts through the production of lower emitting biofuel energy and building materials (wood) that store C.
- Providing economic benefits and incentivizing conservation practices by making them more affordable, or providing cost-effective alternatives to traditional approaches.

As part of the development of the Chesapeake Forest Restoration Strategy (USDA Forest Service 2012), a regional Chesapeake Agroforestry Team was formed in 2011, with representatives from the U.S. Department of Agriculture (USDA) (Natural Resources Conservation Service [NRCS] and Forest Service), State forestry agencies, and universities. An expanded version of this team held a 2-day meeting in May 2014 to identify common agroforestry priorities across the partners, and the group is now developing a plan and structure for ongoing collaboration and network building. Additional examples of agroforestry collaborations are woven into the summary of specific agroforestry practices in the following sections.

## Riparian Forest Buffers

Riparian forest buffers have been the primary agroforestry practice implemented in the Northeast Region to improve water quality, wildlife habitat, and farm sustainability. For example, since 1996, States in the Chesapeake Bay watershed have set policy targets for restoring riparian forest buffers on farmland and have made great strides in implementing these goals through landowner cost-share programs, such as the USDA Conservation Reserve Enhancement Program. More than 7,400 miles of riparian forest buffers have been restored in the watershed since the late 1990s (USDA Forest Service 2012). Despite this progress, implementation of riparian forest buffers has dropped significantly during the past 5 years, prompting renewed partnership efforts to promote the practice. As part of the Chesapeake Bay Executive Order strategy, USDA supported a 2014 leadership summit and State task force process to address key barriers and identify new strategies for accelerating riparian forest buffer restoration in the future.

With climate change impacts, riparian forest buffers and other types of green infrastructure will be needed more than ever to help moderate the effects of intensified storms, flooding, and related hydrologic regime changes. Farmers benefit from the practice by putting a relatively small area of vulnerable, marginally productive land into a natural buffer that absorbs flooding impacts and reduces polluted runoff, while focusing resources on productive farmland outside the floodplain/riparian zone.

Riparian forest buffers—also a key tool in headwater streams of the Northeast—help protect sensitive cold-water aquatic species from increases in water temperatures resulting from climate change. For example, partners in the Eastern Brook Trout Joint Venture conducted sophisticated climate/habitat analyses and identified riparian forest buffer restoration as a key strategy to retain and restore brook trout populations (Trumbo et al. 2010).

Riparian forest buffers restore to trees those areas that may have been in row crop agriculture, pastureland, or other land uses with limited ability to store C. Tree cover increases C storage in both long-lived woody biomass and stable, high-C forest soils. Increased C storage may eventually reverse the effects of climate change.

## Forest Farming

Forest farming—or more broadly, the sustainable management of nontimber forest products—is another important agroforestry practice in the Northeast Region where most of the land is forested. A key challenge facing many forest landowners is having the economic resources to keep the forest land base sustainably managed and intact amidst development pressures. Forest farming can provide supplemental income to support forest landowners, including farmers who own woodlots. Sustainable management of nontimber forest products, such as maple syrup, mushrooms, and medicinal plants, can provide diversified income streams to buffer losses due to erratic weather patterns, new disease and insect infestations, and other anticipated effects of a changing climate.

Most maple syrup production in the United States (87 percent) takes place in seven Northeast States—Connecticut, Maine, Massachusetts, New Hampshire, New York, Pennsylvania, and Vermont—with Vermont comprising 41 percent of the annual U.S. production (USDA NASS 2015). Researchers at Cornell University who examined the potential impact of climate change on the maple syrup industry found that the number of sap flow days may not change in the Northeast, but the timing of peak production will shift earlier (Skinner et al. 2010). The findings suggest that, by adapting to an earlier tapping season, maple syrup producers in Vermont and other Northern States may be able to sustain their livelihoods for the next 100 years, but in States farther south, such as Pennsylvania, overall production may be reduced sooner.

Edible mushrooms are another forest farming product of interest in the region. Recent work by Cornell, the University of Vermont, and Chatham University in the Northeast Region resulted in the Temperate Forest Mushroom Growers Network, which provides growers with resources for the successful cultivation and marketing of log- and forest-grown mushrooms, including shiitake, oyster, lion's mane, and stropharia. In 2012, the three institutions initiated an on-farm research trial in which 25 growers inoculated 100 shiitake logs and kept data on costs, revenue, labor, and other factors. Researchers found that growers were able to begin making a profit in year 2 and projected that a small 500-log operation could gross $9,000 during a 5-year period (Cornell University 2015).

Although some edible and medicinal plants such as American ginseng, ramps (wild leeks), goldenseal, and fiddleheads are native and occur naturally in some woodlands, these plants are threatened by market pressures that can fuel overharvesting and depletion of wild populations. Forest farming can help mitigate pressure on wild populations of these species. A third-party forest-grown verification program was recently launched in Pennsylvania to verify woods-grown species are sustainably grown or managed. This program, managed by Pennsylvania Certified Organic and developed in partnership with Pennsylvania State University researchers and the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry, addresses market demand for ethically and sustainably harvested native edible and medicinal plants.

Additional information and resources regarding forest farming are available at the following Web sites developed by partners in the region.

- The How, When, and Why of Forest Farming Resource Center (Cornell University): http://hwwff.cce.cornell.edu.
- eXtension Forest Farming (Virginia Polytechnic Institute and State University and partners): http://articles.extension.org/forest_farming.

### Silvopasture

Silvopasture is an agroforestry practice that, although relatively new to the Northeast Region, is gaining in interest among natural resource professionals and landowners. Integration of trees into existing pasture provides shelter and shade to protect animals from temperature extremes and winter storms that may intensify with climate change. Carbon is sequestered in long-lived tree biomass. Practitioners are also experimenting with using intensively managed, short-rotation, fenced grazing systems in existing forests through a combination of prescribed thinning and enhancing understory forage. These systems must be carefully planned and managed to ensure that forest health will be improved through the silvopasture system by managing invasive understory plants and establishing diverse understory vegetation to improve soil health and reduce erosion. Ample training and technical assistance for practitioners are needed to clarify the silvopasture practice and ensure proper techniques are in place to benefit both the grazing animals and the condition of the forest.

A regional Web site and networking forum for silvopasture has been created by Cornell University: http://silvopasture.ning.com/. Additional webinars, videos, and other documents relevant to silvopasture in the Northeast have been archived at http://www.forestconnect.info.

### Windbreaks

Windbreaks are a practice that has been used historically in the Northeast Region, although less frequently than in other regions, such as the Midwest. A modified application of windbreaks that has been growing in interest in the Chesapeake Bay region is the use of tree windbreaks—or "vegetative environmental buffers"—around animal operations such as poultry houses. These buffers filter air pollutants and odors that are emitted through the fans of these animal facilities, while also providing a visual screen for the facility, protecting it from wind and temperature extremes and sequestering C. In areas with heavy snow accumulations, living snow fence windbreaks can keep snow off roadways and can save energy by reducing snow removal needs.

Other agroforestry applications such as alley cropping have not been widely used in the Northeast but are included in agroforestry trainings and may find increased interest in the years ahead.

## Challenges to Agroforestry Adoption

Agroforestry is still relatively a new term in the Northeast Region. Many practitioners cite lack of awareness of the practices and limited access to technical assistance as a key challenge to adoption. In the course of history, not much integration has occurred among the agricultural and forestry professionals who serve landowners. Furthermore, as noted, there are more, smaller farms in the Northeast so more landowners to reach.

The region offers niche agroforestry opportunities that may be unique from farm to farm requiring even more knowledge, research, and technical assistance to demonstrate the tangible benefits of adoption. As is often needed for adoption of new practices and technologies, real life examples (e.g., demonstration sites) and peer-to-peer networks are important for spreading the awareness and use of agroforestry practices. The Chesapeake Agroforestry Team, referenced above, identified a number of recommended actions to help overcome barriers and promote expanded use of agroforestry in the region.

## Chesapeake Forest Restoration Strategy: Recommended Actions for Agroforestry

- Work with NRCS State Technical Committees in the Chesapeake Bay watershed to promote agroforestry practices through Farm Bill programs.
- Deliver train-the-trainer workshops that target resource professionals in the watershed as a first step toward reaching watershed landowners. Subsequent workshops can introduce agroforestry practices to landowners.
- Establish agroforestry demonstration areas by finding early adopters with working farms and forests so that others can see the conservation and economic benefits of agroforestry practices. Pursue USDA Conservation Innovation Grants and other funding sources to establish these sites.
- Work with staffs of the NRCS Ecological Sciences Division in the Chesapeake Bay watershed to get the five main agroforestry practices included in the Field Office Technical Guide and Farm Bill programs.
- Explore a bay branding campaign for agroforestry products similar to Edible Chesapeake but focused specifically on foods and products developed from businesses committed to sustaining working forests within the Chesapeake Bay watershed.
- Design and implement agroforestry research projects to ensure stakeholders have access to cutting-edge and regionally relevant science.
- Expand application of agroforestry practices and innovations to small-scale landscapes, including urban settings.

## Key Information Needs

- Conduct additional field research to better quantify the environmental, social, and economic benefits of agroforestry practices in mitigating specific climate change impacts in the Northeast.
- Increase the limited data that are available on the geographic extent of agroforestry practice implementation in the region to assist current and potential agroforestry practitioners with appropriate climate change adaptation strategies.
- Conduct further analysis of climate-related changes in vegetation and wildlife species composition/ranges affecting the Northeast to inform agroforestry practice guidance in the region.

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# Southeast and Caribbean

Sarah Workman, Becky Barlow, and John Fike

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## Description of the Region

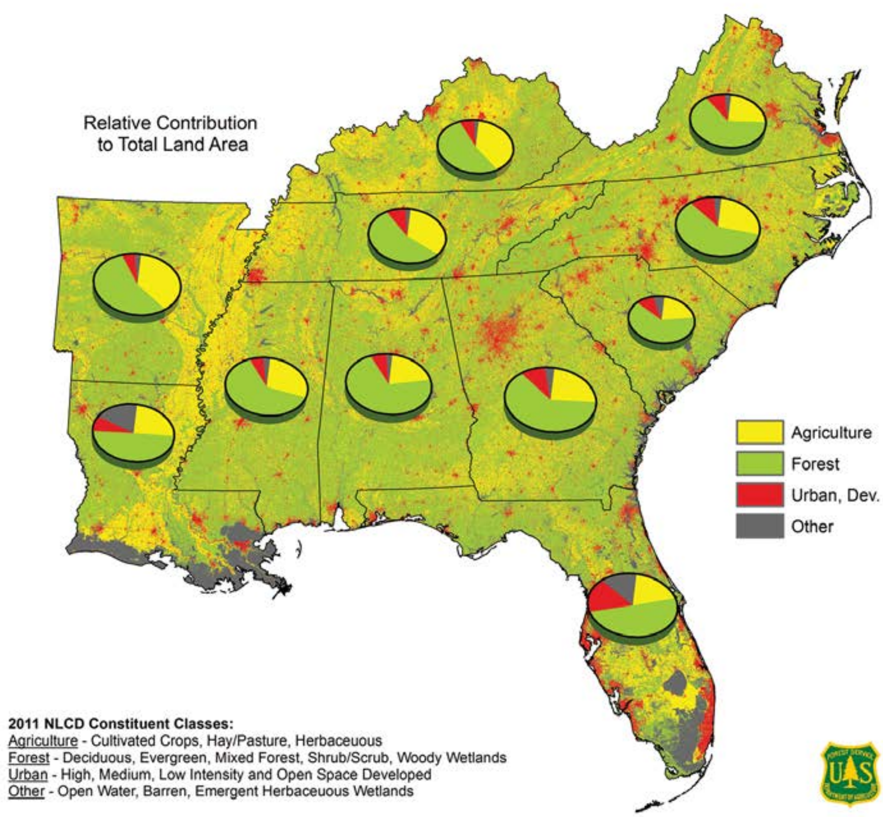
Cropland and pastureland occupy significant portions of land area in the Southeastern United States. Forests occupy from 50 to 69 percent of the land within each State in the region (fig. A.15). All of these land uses provide significant productivity and income. The Southeast encompasses physiographic provinces, or ecoregions (Wear and Greis 2012), that have unique climate, fire history, and composition of vegetation. From the physiographic province of the Appalachian Mountains

**Figure A.15.** Acres of land-use categories of the 11 Southeastern States. (Map and table prepared by William M. Christie, Eastern Forest Environmental Threat Assessment Center, USDA Forest Service, Southern Research Station, Asheville, NC).

**Percent Agriculture and Forest for 11 Southeastern States**

*Source: 2011 National Land Cover Database*

| State | Agriculture | % of Total | Forest | % of Total | Urban, Dev. | % of Total | Other | % of Total | *State Total* |
|---|---|---|---|---|---|---|---|---|---|
| Alabama | 6,821,453 | 21% | 22,580,332 | 69% | 2,388,761 | 7% | 931,798 | 3% | 32,722,344 |
| Arkansas | 11,988,555 | 36% | 18,727,329 | 56% | 2,019,953 | 6% | 934,239 | 3% | 33,670,075 |
| Florida | 7,127,234 | 20% | 18,066,765 | 50% | 5,232,627 | 15% | 5,458,966 | 15% | 35,885,593 |
| Georgia | 8,850,379 | 24% | 23,103,176 | 62% | 3,740,669 | 10% | 1,565,959 | 4% | 37,260,183 |
| Kentucky | 9,451,253 | 37% | 13,555,903 | 53% | 1,910,059 | 7% | 652,578 | 3% | 25,569,793 |
| Louisiana | 7,136,092 | 24% | 14,680,875 | 50% | 2,071,030 | 7% | 5,713,188 | 19% | 29,601,185 |
| Mississippi | 8,343,911 | 28% | 18,886,290 | 63% | 1,941,509 | 6% | 1,022,707 | 3% | 30,194,417 |
| North Carolina | 8,160,063 | 26% | 18,516,853 | 59% | 3,414,561 | 11% | 1,158,195 | 4% | 31,249,672 |
| South Carolina | 4,208,803 | 21% | 12,175,005 | 62% | 1,883,596 | 10% | 1,334,596 | 7% | 19,602,000 |
| Tennessee | 8,601,207 | 32% | 14,805,674 | 55% | 2,586,309 | 10% | 684,328 | 3% | 26,677,518 |
| Virginia | 5,980,234 | 23% | 16,214,224 | 63% | 2,499,889 | 10% | 876,702 | 3% | 25,571,049 |
| *SE Total* | 86,669,185 | 26% | 191,312,424 | 58% | 29,688,962 | 9% | 20,333,255 | 6% | 328,003,826 |




Source: Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G. 2013. A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sensing of Environment, 132: 159 – 175.

to the alluvial plains of the Mississippi River Basin, within deciduous forests of Kentucky and Tennessee and the Interior Highlands of the Ozarks, to the Piedmont, Flatwoods, and Coastal Plains, a large portion of the land area is appropriate for implementing several types of agroforestry, integrating either crops or livestock, or both, with trees and woody crops. All these Southeastern ecoregions have land area capable of supporting agroforestry as a tool for climate-smart agriculture to meet priority elements of the U.S. Department of Agriculture (USDA) Climate Change Science Plan (USDA 2010a). Diversified landscapes using agroforestry practices in the Southeast can help enhance rural prosperity; restore and conserve the Nation's forests, farms, ranches, and grasslands; and help protect and enhance America's water resource—all elements of strategic goals stated in the plan.

As part of the Lesser Antillean archipelago, the U.S. Caribbean islands consist primarily of Puerto Rico and the U.S. Virgin Islands, along with disputed Navassa Island, Bajo Nuevo Bank, and Serranilla Bank. Puerto Rico is the largest island of a group of cays and islands that includes Mona, Monito, and Desecheo to the west and Culebra and Vieques to the east. Of the island of Puerto Rico, 53 percent is mountainous (three ranges), with nearly 12 percent of the landscape in ridges, 25 percent in plains, and 20 percent in hills. Dry climatic conditions prevail on nearly 30 percent of the island and, of the 57 landscape units of the islands of Puerto Rico, the most abundant landforms are moist and wet slopes, primarily on volcanic soils (Gould et al. 2008, Martinuzzi et al. 2007, PR DNER 2009). Six subtropical Holdridge life zones are on the island (Ewel and Witmore 1973). The island also has diverse terrestrial, wetland, coastal, and marine ecosystems and also agroforest and urban systems (Miller and Lugo 2009).

The U.S. Virgin Islands has three large islands—St. Croix, St. John, and St. Thomas—and includes nearby Water Island along with 68 smaller islands and cays. The topography is characterized by central mountain ranges and small coastal plains. The uplands are rocky, rugged slopes; e.g., 50 percent of St. Croix's land area contains slopes of 25 to 35 percent. Natural influences such as landslides, hurricanes and tropical storms, and fire are key to shaping the environment and the marine and terrestrial communities of the islands (Chakroff 2010).

From the viewpoint of suitability, the Caribbean islands provide a diversity of tropical species and a variety of options for agroforestry-based land management. Puerto Rico consists of 49 percent forest, 33 percent agriculture/pasture, and 14 percent developed land. Forest cover is approximately 90 percent on St. John (two-thirds national park), 70 percent on St. Thomas, and 55 percent on St. Croix (fig. A.16). Loss of forested landscapes to development is perhaps the greatest land-use pressure for Puerto Rico; this places critical stress on watersheds and results in a fragmented and increasingly urbanized landscape. Also, land use outside developed zones is perhaps best viewed in terms of the nature of woody plant cover and whether animals are excluded or allowed access. Both Puerto Rico and the U.S. Virgin Islands are experiencing a trend toward an increase in woody cover with the loss of agricultural land and pastureland (Brandeis and Turner 2013a, 2013b; Brandeis et al. 2009). With informed management, this cover could be suitable for return to production or conservation use and less prone to the establishment of invasive plants.

Agroforestry practices are viable for both larger acreages and for small land holdings for mitigation and adaptation to climate change and resilience under climate variability in the Southeast United States-Caribbean. The economics of risk and value of diversified systems bode well for production in the region. Riparian forest buffers and conservation buffers with trees are the most widely used practices across the Southeast (Lowrance and Sheridan 2005, Trozzo et al. 2014b, Twilley et al. 2001). Buffers may be more popular, because they typically can meet objectives of the landowner and help maintain environmental health and ecosystem services without active management. More interactive and intensified practices, such as energy, food, fiber, floral, or medicinal crop production, could be implemented in many of these buffer zones, increasing their overall utility and productivity.

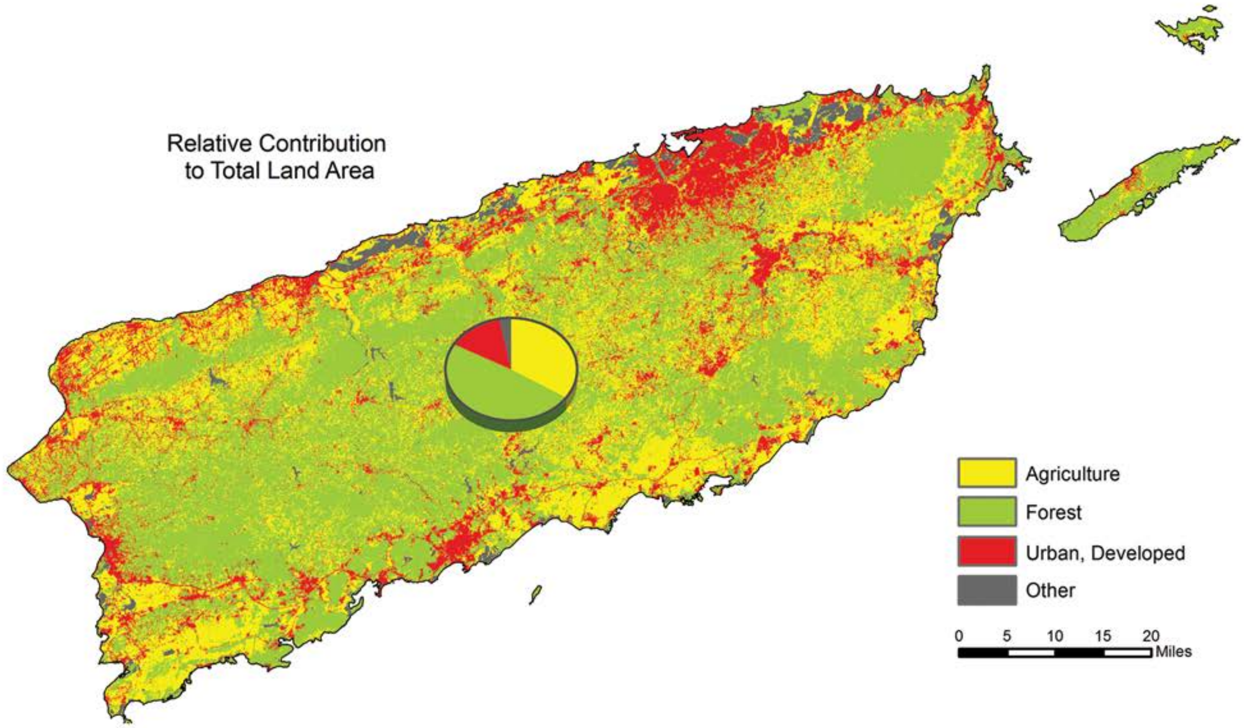
The diversity of farms and forest tracts in the region offer many opportunities to integrate trees with crop or pasture systems. Such systems would benefit many of these lands beyond their value for addressing climate change. Sloping lands of the Interior Highlands, the Blue Ridge Plateau, and the Caribbean, for example, are good candidates for integrating contoured swale practices with silvopasture or alley cropping, using nut, fruit, fodder, or timber trees to better harvest water and reduce erosion (fig. A.17) (Hill 2010, Smith 1929).

In a similar way, forest farming is possible on extensive areas of forest and woodland, and people of the southern mountains have a long tradition of harvesting and, more recently, of cultivating nontimber forest products (NTFPs) (Chamberlain et al. 2009, Persons and Davis 2007). Two-strata or multistrata land management options—whether with crop and timber trees or NTFPs—can offset seasonal risks associated with monocultural production systems and buffer the suite of effects driven by a shifting climate. That tree crops provide protective functions (e.g., soil and water conservation) especially on marginal lands or steeper slopes, is becoming more widely recognized (Delgado et al. 2011). These diversified agroforestry systems can offer reduced risk and greater economic stability under climate variability with both short- and long-term income sources (CIER 2008, Cubbage et al. 2012). Recent census data confirm producers are identifying and using these practices, although current adoption rates are low (table A.5).

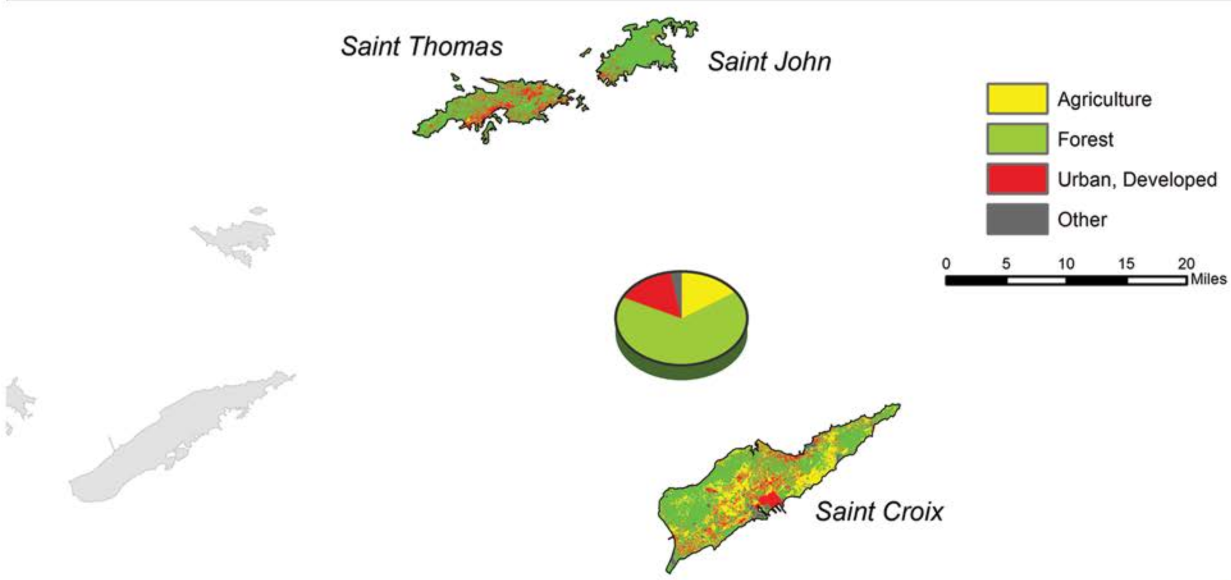
**Figure A.16.** Acres of land-use categories of the Caribbean islands—U.S. territories. (Map and table prepared by William M. Christie, Eastern Forest Environmental Threat Assessment Center, USDA Forest Service, Southern Research Station, Asheville, NC).

## Percent Agriculture and Forest for Puerto Rico and the U.S. Virgin Islands

| Territory | Agriculture (ac) | % of Total | Forest (ac) | % of Total | Urban, Dev. (ac) | % of Total | Other (ac) | % of Total | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| Puerto Rico | 725,911 | 33% | 1,079,709 | 49% | 320,806 | 15% | 77,568 | 4% | 2,203,994 |
| US Virgin Islands | 14,382 | 17% | 54,259 | 64% | 13,246 | 16% | 2,836 | 3% | 84,724 |




Source: The National Map, 2013 (data 2007). USGS Small-scale Dataset: 100-Meter Resolution Land Cover of Puerto Rico and the U.S. Virgin Islands 201301.




Source: Kennaway, T., E. H. Helmer, M. A. Lefsky, T. A. Brandeis and K. R. Sherrill. 2008. Mapping land cover and estimating forest structure using satellite imagery and coarse resolution lidar in the Virgin Islands. Journal of Applied Remote Sensing 2:023551, DOI:10.1117/1.3063939. The Department of Forestry Rangeland and Watershed Stewardship, College of Natural Resources at Colorado State University in cooperation with the USDA Forest Service International Institute of Tropical Forestry.

Table A.5. Selected agroforestry practices, 2012 Census of Agriculture—State Data.

| State | Farms practicing alley cropping or silvopasture (farms in State) | Percent of farms practicing agroforestry |
|---|---|---|
| Alabama | 119 (43,233) | 0.28 |
| Arkansas | 47 (45,071) | 0.10 |
| Florida | 137 (47,740) | 0.29 |
| Georgia | 99 (42,257) | 0.23 |
| Kentucky | 96 (77,064) | 0.13 |
| Louisiana | 37 (28,093) | 0.13 |
| Mississippi | 65 (38,076) | 0.17 |
| North Carolina | 119 (50,218) | 0.24 |
| South Carolina | 51 (25,266) | 0.20 |
| Tennessee | 51 (68,050) | 0.08 |
| Virginia | 74 (46,030) | 0.16 |
| **Total farms** | **895 (511,098)** | **0.18** |

Nationwide, 2,725 farms report using agroforestry practices. Thus, one-third of the reporting farms nationwide which use these practices are in the Southeast United States.

Source: Adapted from Table 43; USDA National Agricultural Statistics Service.

Along with agroforestry's potential in agricultural and forested systems, incorporating agroforestry practices may provide many benefits on lands that could be classified as mixed land cover (after Riitters et al. 2000). These benefits would be at the interfaces of agricultural lands with forests or with either of these cover types with urbanized areas. At these interfaces, agroforestry practices hold the potential to help buffer against the effects of forest fragmentation, to provide or mimic natural corridors for species movement (wildlife) or maintenance (biodiversity), and to increase options for provision of ecosystem services in these dynamic land-use landscapes (e.g., Douglas and Jennings 2014, Morgan and Zimmerman 2014).

## Threats and Challenges to Agricultural Production and Other Ecosystem Services

Land-use change (e.g., due to urbanization and market forces), climate change, and environmental policies affecting land-use choices are the largest potential challenges or uncertainties facing agricultural and forested landscapes in the Southeast (e.g., Keyser et al. 2014). Under current climate change scenarios, the Southeast faces increasing temperatures and frequency of extreme weather events, reduced precipitation, and land area losses due to rising sea levels. Increased disturbances such as drought (Pederson et al. 2012, Seager et al. 2009, Sun et al. 2013), insect infestations (Brandle et al. 2004, Doblas-Miranda et al. 2014, Poch and Simonetti 2013), hurricanes (Mitchum 2011, Philpott et al. 2008), and fire (Liu et al. 2014, Mitchell et al. 2014, Stanturf and Goodrick 2012) may also occur as a consequence of climate change (Vose et al. 2012). These responses are likely to be magnified by the changes in land use and cover, which are occurring at some of the most rapid rates nationwide.

The main threats to the production and supply of ecosystem services in Puerto Rico include lack of resource management, lack of incentives, lack of valuation of forested land, threats from invasive species and nonnative grasses, wildfire, and climate change. In the U.S. Virgin Islands, primary threats include lack of effective forest management strategies, lax enforcement of existing statutes, and too few technical professionals with adaptation/mitigation knowledge. The Caribbean archipelago is a global biodiversity hotspot, and species manipulation and unregulated species introductions are threats to local ecological systems (vegetation, wildlife, and hydrological

Figure A.17. Swale system on a hillslope, St. Croix, U.S. Virgin Islands, before (A) and after (B) installation of contour tree rows and horticultural crop. The hedgerows are planted with fruit trees and fodder trees that are periodically coppiced for leaf material to serve as animal feed. The crop fields are rotated seasonally and annually to diversify and manage production. Soil and water conservation are a valued ecosystem service on these slopes. (Photos by Nate Olive, Ridge to Reef Farm).


processes). Despite these challenges, climate is the overarching influence on forest species composition when recovering from deforestation; all other factors are secondary to the influence of climate (Brandeis and Turner 2013a, 2013b). Based on the 2014 National Climate Assessment for the U.S. Southeast and the Caribbean (Carter et al. 2014), the region is exceptionally vulnerable to sea level rise, hurricanes, extreme heat events, and decreased water availability. Freshwater availability is already an issue in the region (CCCCC 2009).

On Caribbean islands, businesses, ports, and homes ring the coast and are extremely vulnerable to small rises in sea level. With 56 percent of the population living in coastal municipalities, Puerto Rico has one of the highest population densities in the world. As a result of current sea-level rise, the coastline of Puerto Rico around Rincón is being eroded at a rate of 3.3 feet per year (Carter et al. 2014). Temperatures for Puerto Rico under climate change with global warming are projected to increase 2 °F to 5 °F by the end of the century (Carter et al. 2014). The trend exhibited in the Caribbean since the 1950s is of increasing numbers of very warm days and nights, with daytime maximum temperatures rising above 90 °F and nighttime temperatures remaining above 75 °F. Increasing temperatures contribute to increased fire frequency, intensity, and size.

Also, since the early 1980s, the number of Category 4 and 5 hurricanes in the Atlantic basin has distinctly increased (Carter et al. 2014). Ocean warming could support species shifts, growth rate, migrations, and invasive species. Droughts are one of the most frequent climate hazards in the Caribbean, resulting in economic losses. Precipitation trends in the region are unclear, with some higher and some lower average rainfall areas noted. Most models show future decreases in precipitation are likely, with a few areas showing increases. Caribbean islands already have a high human and livestock health burden from climate-sensitive disease. In addition, either because of cyclical changes or climate change, more Saharan dust is being carried into the region by prevailing winds from Africa.

Agroforestry practices can play a key role in mitigating these threats by improving diversity, modifying microclimate to maintain production, and enhancing resilience. Although recognizing and monetizing the value of ecosystem services can be a key challenge, doing so has potential as a mechanism for furthering agroforestry implementation, because the value of these services may be worth more than the agricultural and forest products derived from agroforestry systems (e.g., Alam et al. 2014). Most managers perceive their cropland or forested land as most valuable when managed with traditional production practices. For this audience, greater government investments via cost-share payments may be needed to drive the adoption of agroforestry practices to levels that meet desired environmental outcomes under current market conditions (Martinuzzi et al. 2014, Stainback et al. 2004). Such support may be less important, however, for newer landowners and beginning farmers who have goals beyond production outcomes, and these systems may foster greater cross-generational ties if they provide ways to support intergenerational transfer. Although agroforestry practices offer opportunities to meet the challenges of growing global demand for natural resources, adaptation measures must go beyond technical solutions around single components; they must address human-institutional dimensions and the social and economic consequences of climate change (Seppälä et al. 2009), especially in support of poor and forest-dependent communities.

Policies to mitigate climate change likely will have both direct and indirect impacts on production systems of the region. For example, the Southeast is predicted to supply about one-half the biomass for U.S. bioenergy systems in the future (USDA 2010b). In this scenario, agroforestry practices could help meet demands for fuel and fiber, but policies driven strictly to bioenergy feedstock production may run counter to more integrated, agroforestry system development. Many private landowners do not actively manage their lands, and only some understand the connections between their lands and land use and the broader ecosystem. Thus, reaching new audiences of landowners with effective outreach (e.g., through trusted contacts) and partnering with diverse stakeholder groups for education and incentive programs will be critical components in meeting the demands for products and ecosystem services from these lands.

## Agroforestry as an Opportunity To Build Resilience

In the Caribbean, agricultural lands were being abandoned by the mid-1800s due to the crash of the sugar market, emancipation and the loss of slave labor, and the difficulty of farming steep slopes. Agroforestry practices are part of the region's tradition and have commercial benefits that include development of NTFPs, such as medicinal plants, arts and crafts materials, food, animal forage, resins, and oils (Morgan and Zimmerman 2014). Landowners may grow row or orchard crops with windbreaks, or they may combine animal production within orchards. Forest farming of plants used for the floral industry, food/culinary uses, or health supplements is well documented (Chamberlain et al. 2009, Robinson et al. 2014, Vaughan et al. 2011).

On Puerto Rico, some local artisans are using native and other locally grown wood to produce musical instruments and crafts. Shaded coffee production is most developed in western Puerto Rico and silvopasture in the southern landscape on more level land and alluvial plains, where greater livestock and cropping exist. More so than in the Southeastern States, the implementation of practices in the islands is frequently based more on cultural identity and inherited knowledge than on technical assistance. Exceptions may be beekeeping and honey production or growing high-value crops such as mushrooms. Planting traditional varieties of fruits (e.g., indigenous fruits like guavaberry [*Myrciaria floribunda*] or West Indian avocado [*Persea americana* var. *americana*]) or mixtures of culinary crops under tree shade are practices with cultural roots that support a pride in the sense of place.

In the U.S. islands, patio or dooryard gardens—a form of multistrata agroforestry used in both urban and rural settings—vary in their potential for ecosystem service provisioning and buffering climate change. Zones of management and cultivation often ring rural family dwellings, from a zone near the home patio, with materials for both aesthetic and food sources along with fruit trees to the next zone, with less intensive management but similar species and some soil enrichment practices. Living fences and field border plantings are sometimes incorporated.

Farther away, fields with less or little shade are used for open grazing or market crops and usually have fewer inputs. Areas with higher rainfall have some bananas and plantain agroforestry. Some places use trees to isolate chicken farms and mitigate odor. In the islands, riparian buffers could be managed to increase cover by adding woody components to what now is a "grass only" practice (USDA Natural Resources Conservation Service [NRCS] standard). Some discussion was begun in 2012 regarding planting fruit tree crops, such as mamey (*Mammea americana*), açaí (*Euterpe oleracea*), and cacao (*Theobroma cacao*), in riparian zones (USDA Forest Service 2016) around El Yunque National Forest.

In the Southeast, frequent natural and sometimes human-caused fire created open presettlement woods and savannahs with grassy understories, where bison and elk once roamed. The Scotch-Irish who settled this region brought a tradition of grazing domestic stock, often with low stocking rates (5 to 10 acres per head) and limited management. This history is noted in Wahlenberg's 1946 book: "In accordance with age-old custom, southern landowners usually tolerate grazing on their forest lands by the livestock of numerous small famers. The typical forest range is open, no permits are required, no fees are charged, and usually no attempt is made to control fires set by stock owners" (Wahlenberg 1946: 309).

In a similar way, settlers to the Ozarks were grazing cattle on bluestem forage in the shortleaf-hardwood and hardwood forest as early as 1800. Graeber (1939) documented the effects of cattle, sheep, and pig "free range" woodland grazing on forest soils in North Carolina in the early 1930s in and around what is now the Great Smoky Mountains National Park (Lindsay and Bratton 2014). J. Russell Smith (1929), a formative advocate for soil and water conservation, outlined how to put trees to work as perennial crops to counter erosion, flooding, and "climatic peculiarities" to extend agriculture on hill slopes and marginal lands and also on level lands to create two-story agriculture (trees above and annual crops below). Raking pine straw for profit was also popular during this time (Mattoon 1930). In 1930, W.R. Mattoon noted that a landowner in North Carolina "…makes regular income selling pine straw (leaves or needles) from his 10-acre patch of pines. He sells the straw on the ground at a rate of 25 cents per cartload. As an acre produces three to five loads, his net income is from 75 cents to $1.25 per acre yearly" (Mattoon 1930: 12). Fencing laws enacted in the 1930s eventually precluded livestock from freely wandering open forests, thus the practices of woodland grazing and burning largely disappeared from the landscape.

Modern agroforestry techniques take us beyond free-ranging cattle to science-based land management. In the Southeastern United States, agroforestry practices can help address threats posed by global climate change. In this region, riparian buffers are used extensively as a best management practice for water quality, however, most land managers and landowners do not often view their use as an agroforestry practice (Trozzo et al. 2014a). Forest farming and silvopasture are other agroforestry practices that seem to have the most promise in the region (fig. A.18–A.22). Forest farming for medicinals or decorative and floral items provides additional income to landowners, thus improving livelihoods. North Carolina, Florida, and Georgia are considered to be pine-straw industry leaders (Mills and Robertson 1991). Estimates for market value range from a 1996 pine-straw value of $50 million in North Carolina (Rowland 2003) to a $79 million value for Florida in 2003 (Hodges et al. 2005). The State with the most detailed records regarding pine-straw production is Georgia, where data for pine straw is actually collected as a separate commodity. In 2012, pine straw

**Figure A.18.** Pine-based silvopasture managed with cattle is perhaps the most common type of silvopasture in the Southeast. Cattle benefit both in summer and winter from the buffered environment created by the tree canopy cover. (Photo by USDA National Agroforestry Center).

**Figure A.19.** Small ruminants may be an important means of managing silvopastures. Goats and sheep can be instrumental in removing invasive weeds and stump sprouts that often develop in thinned tree stands. Goat silvopasture, Dallas County, AL; McIntire Stennis Forestry Research Program. (Photo by Nar Gurung, Tuskegee University).

**Figure A.20.** While it is most often used as a landscape mulch, pine straw is a nontimber forest product that is highly sought after in floral, craft and decorative markets (A). Pine straw and nontimber forest products crafts; Alabama-Coushatta Tribe longleaf pine needle baskets (B). (Photo by Beverly Moseley, USDA Natural Resources Conservation Service).


**Figure A.21.** In the Southeastern United States, pine straw is usually harvested from the forest floor of longleaf, slash, or loblolly stands, and may be compatible with many land uses including silvopasture. The open understory of a silvopasture allows for pine straw to be bailed by machine (A) or hand (B), and can provide an additional source of income for landowners. (Photos by Becky Barlow, School of Forestry and Wildlife Sciences, Auburn University).

**Figure A.22.** Plants valued for traditional use and/or with high value in the supplements market are utilized in multistrata agroforestry systems. Cultivated in forest shade environments, these herbs provide an income stream and play a role in conservation of wild populations by reducing collection pressure. In this figure, goldenseal (*Hydrastis canadensis*) roots are ready for planting in Catawba, VA (A) and goldenseal cover under canopy (B). (Photos by Forest Farming Community of Practice).


accounted for 9.6 percent of Georgia's forest products market, at \$58.7 million. Successful silvopasture management requires good grazing management practices, which improve cattle waste management and forage production, and it also limits the amount of commercial feed used. Integrated crop-livestock agriculture, including tree crop systems, all contribute to carbon dioxide ($CO_2$) sequestration and enhance soil fertility, water quality, and biodiversity (Sulc and Franzluebbers 2014). In the islands, these practices hold promise for the transition of abandoned pasture, shade coffee, or agricultural lands (Brandeis et al. 2009).

In Alabama, Florida, Georgia, Louisiana, and Mississippi, forest farming and silvopasture are common agroforestry practices. Of these 5 States, 4 were in the top 10 reported as participating in alley cropping or silvopasture in 2012 (table A.5). Harvesting pine straw is common and may actually motivate landowners to restore imperiled longleaf pine (*Pinus palustris*) ecosystems in the southern part of the Southeast. This restoration would accrue additional benefits, because longleaf pine forests are likely to be among the most resilient against the effects of expected future climatic changes, given their tolerance to wind, drought, fire, insects, and disease (Johnsen et al. 2009, Kush et al. 2004, Remucal et al. 2013).

Silvopasture is well suited to most southern pines and could benefit longleaf and shortleaf pine (*P. echinata*) restoration efforts across the region. With that restoration comes the opportunity to restore the understories of these systems, which were typically low and grassy, providing excellent habitat for native pollinators. Climate change, in turn, may benefit loblolly (*P. taeda*) and longleaf pine growth, which may respond positively to increases in atmospheric $CO_2$ and temperatures (Boyer 2001, Wertin et al. 2012, Whelan et al. 2013).

Opportunities and benefits for longleaf and shortleaf pine restoration on agroforestry sites west of the Mississippi River in States such as Arkansas are similar to those of other Southern States. Shortleaf and loblolly pine silvopastures may have the added benefit of mitigating the effects of ice storms (Burner and Ares 2003) in these States of the "Glaze Belt," which experienced a catastrophic ice storm event every 2 years in the period between 2000 and 2009 (Kovacik et al. 2010). For example, some Arkansas landowners are planting windbreaks along the edges of their pastures to provide shade and reduce the heat stress load for their stock and also to buffer other weather effects.

In the Upper Coastal Plain and Appalachian Highlands of Kentucky, North Carolina, South Carolina, Tennessee, and Virginia, all the agroforestry practices show promise for climate change mitigation and adaptation. Although the benefits of silvopasture and riparian buffers for soil stabilization, diffusion of animal waste, pollination, and plant diversity are similar to the benefits in other regions, the production of NTFPs and woodland medicinals is a customary focus (Vaughan et al. 2013). Silvopasture has the potential to benefit lands making the transition from the conservation programs (e.g., USDA's Conservation Reserve Program) to provide both annual and periodic income to landowners and to motivate them to actively manage their forests rather than converting them to pastureland or commercial/residential development.

## Potential of and Limitations to Agroforestry

The ability to provide ecosystem services and mitigate the effects of climate change through agroforestry practices is great in the Southeast and Caribbean Region—provided adoption of agroforestry practices can be increased. The Southeast has among the highest potential for carbon (C) storage and sequestration, and adding trees to mixed cropping and integrated crop-livestock systems offers several options to help maximize this potential (Franzluebbers et al. 2014; Schoeneberger et al. 2012). Along with their potential use in cropland systems, agroforestry practices can be deployed on rugged or sloping grounds as a means for addressing climate change challenges and meeting ecosystem services needs (Dosskey et al. 2012a, Smith et al. 2013).

In addition to increasing C storage (Haile et al. 2010), agroforestry practices can conserve soil and water by reducing runoff (Smith et al. 2013) and buffering streams (Dosskey et al. 2012b) while improving site conditions for wildlife habitat (Bowling et al. 2014; Rittenhouse and Rissman 2012) and providing safety-net goods (e.g., NTFP and firewood). The improved delivery of ecosystem services may simultaneously be accompanied by increased diversity and productivity of agricultural systems in the Southeast and Caribbean. Such improvements also may enhance cashflows to farm families and provide good return for the labor invested. Inroads have been made in promoting agroforestry with small land holders, beginning farmers, and minority farmers in the Southeast that could serve as models for advancing agroforestry adoption in other regions of the country. Increasing interest from these groups and the potential for them to apply agroforestry are notable through products and activities of the 1890s Agroforestry Consortium (Idassi 2012). Compared with traditional plantation forestry or agricultural systems, agroforestry techniques provide opportunities to diversify incomes, expand production, and enhance nonmarket benefits such as soil and water conservation and wildlife habitat. Systems with perennial components with their influence on microclimate and potential reduction of inputs and costs, while diversifying outputs and conservation, hold promise. Thus, agroforestry practices are viable options to enhance farm livelihoods and increase resilience of food systems while providing C storage and other conservation benefits (Fike et al. 2004, Russelle et al. 2007, Steiner and Franzluebbers 2009, Workman et al. 2004).

Constraints to adopting agroforestry practices include lack of technical knowledge and management skills and high establishment or annual management costs for some practices. Incompatibility between multiple components, potential for weedy species and pest interactions, and potential negative impacts of livestock on tree seedlings and soil productivity can be obstacles. The more important constraint is the long-term investment required, coupled with limited economic analysis, which remains a liability in promoting the systems.

Economic data and planning assistance (for intensity and timing of inputs and outputs), along with institutional and policy support (including finances and incentives), are needed to drive early-stage implementation of agroforestry systems. Market development for agroforestry products has increased in the past decade, with landowner information and public education. The value of nonmarket benefits is evident to many practitioners and motivates many to design and implement practices (Bentrup 2008, Fraisse et al. 2009, Workman et al. 2005); however, it is often a constraint at higher levels of institutional and social policy (Lin et al. 2013, Merwin 1997). For example, at present no active market exists for carbon, though some industries may, in the future, be required to cap their emissions. Technology transfer needs for all agroforestry practices call for region- and situation-specific information to support design decisions based on research. Efforts to increase planting stock and improve genetic materials for tree resilience will help. More demonstration sites, training workshops, economic analysis, production budgets, marketing opportunities, and production effectiveness models are needed (fig. A.23). Technical designs must balance input availability and input quality and timing with production outputs and processing for various components and services.

Agroforestry practices have application potential over a range of land area sizes, from garden plots to total periphery of large park areas, from buffering and restoration of degraded sites to partitioning municipal landholdings, and, as envisioned for the Mississippi River and Chesapeake Bay watersheds, to serve as riparian buffer zones to guard against nonpoint source pollution and sedimentation. These integrated land-use practices can help bridge the gaps in the mosaic of land uses across a region and

**Figure A.23.** Site tour and hands-on activities at the Trainer's Training on Sustainable Agroforestry Practices in the Southeast Region, Atkins Agroforestry Research and Demonstration Site, Tuskegee University, Tuskegee, AL, conducted by the 1890s Agroforestry Consortium and funded by Southern Sustainable Agriculture Research and Education program. (Photo by Dr. Uma Karki, Tuskegee University).

serve as tools to strengthen the sustainable supply of goods and environmental services that society needs. Given that farming and plantation forestry have been rural economic mainstays compared with other development options in the region, ways that improve their value as a land use will continue to support rural communities and offer greater future land-use flexibility.

Agroforestry systems hold great potential in the Southeast and Caribbean Region and could likely be practiced in some form on more than 50 percent of the land area in most States and territories, with consideration of management intent, protected status, and limitations of soils and slope. Under good management, these systems can help provide increased resiliency and mitigation under changing moisture patterns and temperature extremes (Schoeneberger et al. 2012, Sulc and Franzluebbers 2014). The economic value of these systems, particularly in the event of climate change, has not been well defined, however. Realizing their potential likely will require more active management than commonly practiced. Greater understanding and capacity of service providers to promote agroforestry as an integrated approach, coupled with focused research and landowner innovation, is needed to push these systems forward in practical ways that will meet economic and environmental goals in the face of climate change foreseen for the region (Franzluebbers et al. 2014, Howden et al. 2007, Ingram et al. 2013, Kunkel et al. 2013, Vose et al. 2012).

Greater use of available scientific tools is needed for better decisionmaking, considering the complexity of agroforestry with its diversity of species, field conditions, and management options in use. Some policy and programmatic review (e.g., buffer practice sheets, forest health monitoring, resource inventory) would support decision tools and benefit the region. Landowners have to perceive the practices as valuable, whether in terms of income and livelihood, in terms of aesthetics and land ethics, or with belief in stewardship and resilience for the future. The U.S. Department of the Interior Southeast Climate Science Center (CSC) is one of eight regional CSCs and works with the USDA Caribbean Climate Sub Hub and Southeast Regional Climate Hub. These centers, along with their partners concerned with landscape conservation (e.g., http://lccnetwork.org/OurWork/DecisionTools) or social vulnerability (e.g., Oxfam), have tools to contribute to decisionmaking efforts. Development of models (such as Carbon Management Evaluation Tool for Voluntary Reporting [COMET-VR] from USDA NRCS), measurement protocols (such as GRACEnet from USDA ARS), and monitoring/reporting tools (such as the Forest Change Assessment Viewer [ForWarn] and Template for Assessing Climate Change Impacts and Management Options [TACCIMO] from USDA Forest Service) reflect the expertise and opportunity for climate mitigation and adaptation using agroforestry in the Southeast and Caribbean Region.

## Key Information Needs

- Development of strategies to help transition lands coming out of Conservation Reserve Program contracts into sustainable agroforestry systems.
- Identification of appropriate forage species and their management in silvopasture systems over the range of tree species and densities that might be utilized in the diverse ecosystems of the Southeast.
- Better understanding of how to incentivize and integrate the development of silvopasture systems within a whole-farm (or whole-plantation) context in order to increase ecosystem services, sequester carbon, and other conservation goals.
- Development of tools to assist with nonmarket valuation and marketing of nontimber forest products sustainably harvested from agroforestry systems.
- Identification of strategies to spur innovation and adoption of alley cropping systems in the region.

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# Appendix B
# Risk-Based Framework and Assessments of Agroforestry as a Climate Change Adaptation and Mitigation Strategy

## Risk-Based Framework for Evaluating Adaptation and Mitigation Strategies

Michael G. Dosskey, W. Keith Moser, Gary Bentrup, and Thomas B. Treiman

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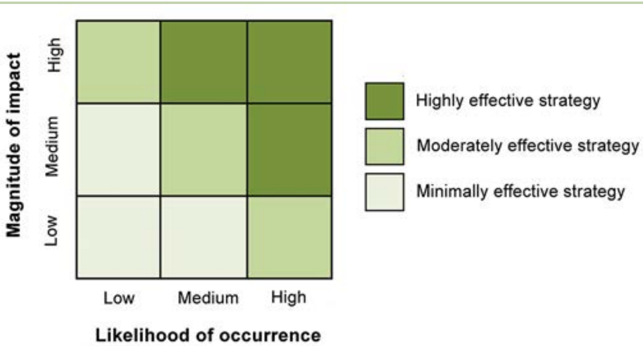
The effectiveness of an agroforestry strategy for adapting agriculture to climate change or for mitigating it can be evaluated within a risk-based framework. Such a framework has been used to evaluate hazards from climate change (Iverson et al. 2012, Yohe 2010). The same approach can be used to evaluate adaptation and mitigation strategies. The framework describes both the likelihood that a strategy will have a positive impact and the magnitude of that impact (fig. B.1). A highly effective strategy has a high probability or likelihood of occurring or being implemented and also has a high magnitude of positive impact. A strategy that has a high magnitude of impact is less effective if it has a low probability of occurring. Strategies that are minimally effective have a low magnitude of impact and a low probability of occurring. This framework can be applied to evaluate and compare potential adaptation strategies by organizing thoughts along two dimensions—likelihood and consequence. The results will help managers and decisionmakers prioritize management options.

**Figure B.1.** A matrix illustrating the framework for identifying better strategies for adapting to or mitigating climate changes. (Adapted from Iverson et al. 2012, Yohe and Leichenko 2010). A highly effective strategy (dark green) has a high likelihood of occurring (or being implemented) and a high level of positive impact. Strategies that would have minimal effectiveness (light brown) have a low probability of occurring and a low magnitude of impact.




In a qualitative definition of impact—

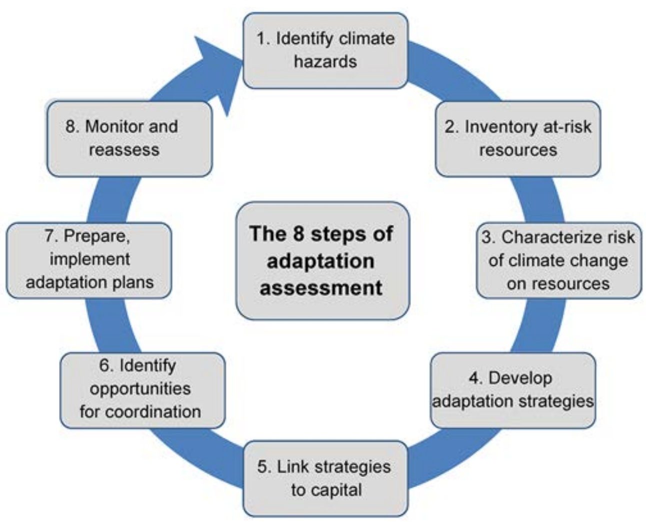
- Low = the strategy will have an insignificant impact.
- Medium = the strategy will have a measurable and potentially significantly positive impact.
- High = the strategy will produce a large positive impact of critical importance.

In a qualitative definition of likelihood—

- Low = an impact of the strategy is deemed to be unlikely to occur.
- Medium = an impact of the strategy is deemed to be likely to occur.
- High = an impact of the strategy is deemed to be very likely to occur.

The process of developing strategies begins with an assessment of risk, starting with identification of current and future climate hazards (step 1 in fig. B.2) and followed by an inventory of at-risk assets (step 2 in fig. B.2). A future hazard can be a particular or aggregate threat of climate change on a particular resource or service. The risk framework can be used to evaluate the level of climate change risk to various resources and services (step 3 in fig. B.2). The risks that climate change poses for U.S. agriculture have been recently evaluated by the USDA (Walthall et al. 2012); their pervasive scope is one of the fundamental insights of the National Climate Assessment (Melillo et al. 2014). That assessment covers both effects on agricultural production (e.g., reduced crop yield) and on environmental resources (e.g., soil erosion).

**Figure B.2.** Flowchart of an adaptation/mitigation planning process. Risk management begins with the development of strategies for adaptation and mitigation (step 4) that reduce risks to agricultural resources and services identified in step 3. (Adapted from Carnesale et al. 2010, Yohe 2010).




Adaptation strategies, such as agroforestry practices, can also be evaluated by using the risk framework (step 4 in fig. B.2). The effectiveness of an agroforestry strategy is determined by comparing the level of risk (calibrated in terms of likelihood and impact) without adaptation with the risk level if a given agroforestry strategy were implemented. Because risks can also be influenced by changes in various agronomic practices (e.g., crop types, cultivation practices) not related to agroforestry, a key challenge for managers is to determine an appropriate balance of agronomic and agroforestry practices for providing desirable outcomes. Assessing agroforestry options by themselves (that is, by assuming that other agronomic practices remain unchanged) will provide a clear baseline condition from which to make these determinations.

The risk-based framework and underlying concepts are used in the following case studies. These case studies are intended as examples of different ways to convey risk and to evaluate benefits and tradeoffs. Scientists and managers can use the framework and concepts for assessing adaptation strategies for a wide range of impacts on threatened agricultural resources. As readers consider these case studies, they may wish to keep in mind that different decisionmakers may have different perceptions about the likelihood of occurrence and magnitude of impact.

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# Evaluation of Agroforestry for Reducing Soil Erosion

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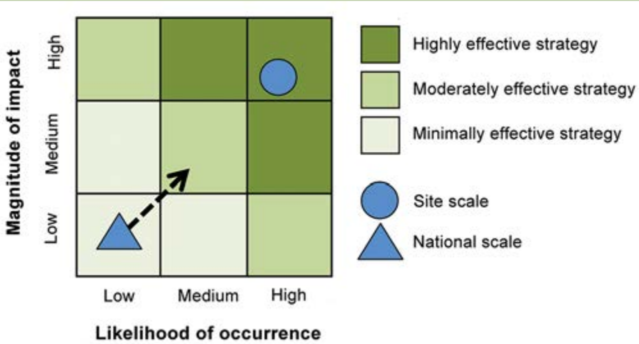
Implementation of agroforestry on U.S. farmlands can offset predicted increases in soil erosion due to climate change (Walthall et al. 2012). Agricultural tillage exposes soil to erosion by excessive rainfall. Agroforestry practices stabilize and protect soil from erosion. The reduction of erosion will be very large where agroforestry is implemented, but reluctance by many landowners to implement it could severely limit the magnitude of impact at a national scale (fig. B.3).

**Figure B.3.** Likelihood of occurrence and impact of agroforestry implementation on the predicted increase in soil erosion due to climate change. At the site scale, implementation of agroforestry can offset the predicted increase in soil erosion due to climate change (circle). At a national scale, however, the impact will be low, because most landowners are currently reluctant to implement agroforestry on their farms (triangle). National-scale effectiveness would be higher (arrow) if market conditions and program incentives, among other factors that affect landowner decisions, become more favorable for adoption of agroforestry and the aerial extent of implementation increases.




Soil loss is a major threat to long-term sustainability of agricultural production and other ecosystem services. Erosion by large, high-intensity rainfall events is a major cause of soil loss from cultivated fields (Larson et al. 1997; SWCS 2003, 2006). Climate change is predicted to increase the magnitude and intensity of rainfall events across most of the United States and, in the absence of protective measures, to increase rates of soil erosion (Garbrecht et al. 2014; SWCS 2003, 2006; Walthall et al. 2012).

Implementation of agroforestry practices can reduce soil erosion from cultivated fields and moderate the predicted increases in erosion rates that will come with climate change. The rate of erosion depends on many factors, including precipitation amount and intensity, soil characteristics, topography of the terrain, and land cover characteristics. Climate change is predicted to increase erosion mainly by increasing precipitation intensity. A change in land cover from a completely cultivated condition to an appropriate agroforestry practice can reduce the vulnerability of the soil to erosion and can offset the effects of increased precipitation intensity.

Contour buffers (also called contour stripcropping and buffer stripcropping) (Wischmeier and Smith 1978), in which the protective vegetation cover is placed in a strip configuration on topographic contours, are a recommended practice for reducing soil erosion. They function to reduce the erosive power of overland runoff during large rainfall events and stabilize soil against erosion. Agroforestry in the form of alley cropping can be configured into contour buffers and function like contour buffers.

The potential for erosion reduction by implementing agroforestry can be estimated using concepts and relationships from the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). In the USLE, soil loss is predicted for a given pattern of precipitation (local amounts, frequencies, and intensities determined from local weather data) on an agricultural field having a standard set of site conditions (soil, topographic, soil cover, and land cover). That soil loss value, called the Rainfall and Erosion Index (R), is adjusted to other site conditions by the amount that those site conditions differ from the standard set. Adjustments are expressed as a ratio of soil loss under actual site conditions compared with that under the standard set. Thus, a site condition that reduces an adjustment factor ratio by, say, 0.25, translates into a reduction of soil loss by 25 percent. Based on the USLE, properly designed contour buffers consisting of fall-planted small grains can reduce the ratio for an otherwise spring-cultivated corn field by about 0.50 (Wischmeier and Smith 1978) and, thus, the erosion rate by about 50 percent. In a field experiment, Udawatta et al. (2011) measured a 28- to 30-percent reduction in annual soil loss over a 5-year period from fields planted with agroforestry contour buffers consisting of perennial grasses and trees.

The impact that alley cropping in a contour buffer configuration can have on climate change-enhanced erosion rates can be estimated by comparing erosion reduction by implementing the agroforestry practice to the magnitude of erosion increase predicted by climate change. The average R (under standard site conditions) for the conterminous United States is estimated to increase between 16 and 58 percent during the 21st century (Nearing 2001, Nearing et al. 2004). Others (e.g., O'Neal et al. 2005, Segura et al. 2014) have predicted similarly large increases in erosion rates. Estimates of future increases in soil erosion are similar in magnitude to the amount by which implementation of alley cropping could reduce soil erosion from a field. On this basis, agroforestry may be capable of completely offsetting any increase in erosion that a future climate would cause (fig. B.3). If combined with additional protective measures, such as no-till, residue management, or cover crops, erosion rates could be reduced still further.

The total mass of eroded soil would be reduced by a greater amount if agroforestry were applied to fields in regions where the increase in soil erosion rate would be relatively greater. Segura et al. (2014) predicted greater increases in the threat of erosion in the Eastern and Northwestern United States and decreases in the Central Great Plains. On this basis, agroforestry for soil erosion control under climate change may provide greater benefit if focused on the northern tier and Eastern U.S. croplands. Uncertainty associated with a regional focus is high, however, because spatial distribution of predicted changes in erosion differs widely, depending on which climate change model is used (Nearing 2001, O'Neal et al. 2005, Segura et al. 2014).

At the national scale, the impact that agroforestry can have may be small—hindered by landowner resistance to adoption and limited extent of sites that are most suitable for alley cropping (fig. B.3). Landowners view agroforestry as more complex than they are willing to deal with. From that perspective, some land is taken out of the cropping system that they are familiar with and put into a system that they do not know as well. This change creates financial risk because they are less familiar with the new crop and it increases complexity because they have to manage for two crops instead of one. Management practices for their traditional crop are made more difficult by having to work around the trees. In combination, agroforestry makes more work for farmers and raises financial risk for the landowner. Incentive programs that offer financial and technical assistance have had very little success in achieving adoption of alley cropping. Furthermore, the magnitude of impact at the national scale will be limited by the aerial extent of implementation. For national-scale estimations of agroforestry impacts, Udawatta and Jose (2012) used a value of 10 percent of U.S. cropland. That would leave 90 percent of U.S. croplands requiring other protective measures to counter soil erosion due to climate change.

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# Evaluation of Agroforestry for Protecting Coldwater Fish Habitat

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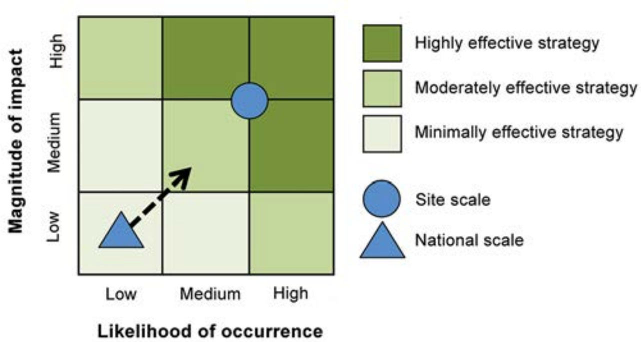
The implementation of agroforestry practices on U.S. agricultural lands can offset predicted increases in stream temperatures due to climate change, thereby protecting coldwater habitat for salmon, trout, and related fishes. Riparian forest buffers can moderate the rise in stream temperatures in watersheds where they are implemented, but the magnitude of impact on the aerial extent of favorable fish habitat, at both local and national levels, will be low if landowners are reluctant to implement agroforestry on their farms (fig. B.4).

**Figure B.4.** The likelihood of occurrence and impact of agroforestry implementation on stream temperatures in agricultural areas. The implementation of agroforestry practices can offset predicted increases in stream temperatures due to climate change, thereby protecting coldwater habitat for salmon, trout, and related fishes. Riparian forest buffers can moderate the rise in stream temperatures in watersheds where they are implemented thoroughly (circle). At a national scale, however, the impact will be low, because many landowners are currently reluctant to implement agroforestry on their farms (triangle). National-scale effectiveness would be higher (arrow) if market conditions and program incentives, among other factors that affect landowners' decisions, become more favorable for the adoption of agroforestry and the aerial extent of implementation increases.




Salmon, trout, char, grayling, and whitefish (collectively called salmonids) are a significant ecological, commercial, recreational, and cultural resource in the United States. A number of these species are listed under the Federal Endangered Species Act and face increasing pressures under climate change (Mantua et al. 2010). Water temperature is a key factor in determining habitat suitability for salmonids, and excessively high water temperature can act as a limiting factor for the distribution, migration, health, and performance of salmonids (McCullough 1999). As temperatures rise, salmon become more susceptible to disease, and prolonged exposure to stream temperatures across a threshold can be lethal for juveniles and adults (McCullough 1999). Climate change is predicted to increase air temperatures and the frequency and magnitude of droughts, all of which, in turn, lead to higher water temperatures in streams and rivers (Melillo et al. 2014, Mohseni et al. 1999). Water temperatures have been increasing in many streams and rivers throughout the United States during the past several decades (Kaushal et al. 2010).

Riparian forest buffers can reduce the effect of climate change on stream temperature and salmonids. Solar radiation received by a stream is one of the most influential factors affecting stream temperatures (Brown and Krygier 1970, Caissie 2006). Riparian forest buffers provide shade, reducing solar radiation received by a stream, leading to lower summer water temperatures and a reduction in stream temperature fluctuations (Barton et al. 1985, Bowler et al. 2012, Brown and Krygier 1970). The implementation of riparian forest buffers along salmonid-bearing streams that currently lack shade can help offset increases in stream temperatures due to climate change.

Preferred temperatures for salmonids vary by species and life history stage; however, temperatures above maximum weekly temperature thresholds indicate habitat loss and increased mortality. For most salmonids in the United States, the maximum weekly temperature thresholds range between 21 and 24 °C (Eaton et al. 1995).

Maximum weekly stream temperatures are projected to increase from 1 to 3 °C across the continental United States, based on a climate scenario in which the atmospheric concentration of carbon dioxide is doubled from 330 to 660 parts per million (ppm) (Mohseni et al. 1999). It is estimated that the 660 ppm level could be reached by the end of this century (Karl et al. 2009). In response, maximum weekly stream temperatures are predicted to be 18 to 24 °C in the Rocky Mountains and on the West Coast, 22 to 26 °C in the upper Mississippi River basin and on the East Coast, and 26 to 30 °C in the lower Mississippi

River basin and portions of the South (Mohseni et al. 1999). Under this climate scenario, the number of U.S. Geological Survey stream-gauging stations nationwide indicating suitable thermal habitat for coldwater fishes is projected to decrease 36 percent (Mohseni et al. 2003).

Riparian forest buffers can maintain lower maximum summer stream temperatures by 3.3 °C compared with streams without buffers and lower summer mean stream temperatures by 0.6 °C based on a meta-analysis of 10 studies (Bowler et al. 2012). On this basis, implementing riparian forest buffers may be capable of offsetting the projected increases in maximum summer stream temperatures and maintaining those temperatures below critical thresholds in most regions currently containing salmonids.

In one geographically specific case, Wisconsin is recognized for its abundance of coldwater streams, which include more than 10,000 miles of classified trout streams that provide fisheries for brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) (WDNR 2002). Three future climate scenarios for Wisconsin predict (1) a "best case" scenario in which summer air temperature increases by 1.0 °C and water temperature by 0.8 °C, (2) a "moderate case" in which summer air temperature increases by 3.0 °C and water temperature by 2.4 °C, and (3) a "worst case" in which summer air temperature increases by 5.0 °C and water temperature by 4.0 °C (Lyons et al. 2010). Under the worst-case climate scenario, fish habitat suitability models predict brook trout to be eliminated from all Wisconsin streams and brown trout habitat, based on stream length, to decrease by 88 percent (Lyons et al. 2010). Even under the moderate scenario, brook trout habitat is expected to decrease by 94 percent; the best case scenario predicts a 44-percent loss of habitat (Lyons et al. 2010).

Increasing riparian shade on Wisconsin streams can substantially reduce stream temperatures. Based on a heat-transfer model, Cross et al. (2013) predicted maximum weekly temperature would decrease by 4.8 °C as stream shading increased from 0 to 75 percent and Gaffield et al. (2005) predicted temperature would decrease by 4.5 °C as stream shading increased from 0 to 80 percent. These predictions indicate that the establishment of riparian forest buffers may be capable of offsetting the projected increases in water temperatures in Wisconsin streams due to future climate change. Agriculture occupies 43 percent of the land area in Wisconsin. Riparian areas are frequently embedded in watersheds where agriculture is the primary activity (Wang et al. 1997), suggesting a high potential exists for implementing riparian forest buffers to protect trout from rising stream temperatures.

If mean summer water temperatures are already at or above critical temperature thresholds before projected climate change, the implementation of riparian forest buffers may not be enough to bring these temperatures below critical thresholds under a future warmer climate. A useful implementation strategy will be one that targets areas identified as those where riparian forest buffers can have the most impact (Cross et al. 2013).

Stream thermal regimes are quite complex and are influenced by many factors, including stream discharge, streambed conduction, air temperature, wind speed, channel morphology, groundwater inputs, and surrounding land use, in addition to solar radiation (Caissie 2006). In some cases, riparian forest buffers may increase stream widening, leading to shallower flows and increased solar exposure on the water surface, which could potentially offset the temperature reductions from riparian shade (Allmendinger et al. 2005, McBride et al. 2008). This complexity raises the uncertainty of the overall impact of riparian forest buffers on stream temperatures.

The likelihood of impact will be greatly influenced by the likelihood that landowners will adopt riparian forest buffers. Farmers and ranchers generally dislike riparian forest buffers because they view them as taking land out of production (Gillespie et al. 2007, Luloff et al. 2012). Piecemeal implementation of riparian forest buffers may diminish the magnitude of impact at a national scale or even at watershed scales. Programs offering financial incentive and technical assistance have had some success in increasing the adoption of riparian forest buffers. Nontimber forest products (e.g., nuts, fruits, medicinal plants, decorative materials) can be produced from riparian forest buffers, generating income for landowners willing to harvest and sell the products. It is unclear, however, how many landowners might be interested in this enterprise option.

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# Evaluation of Agroforestry for Carbon Sequestration

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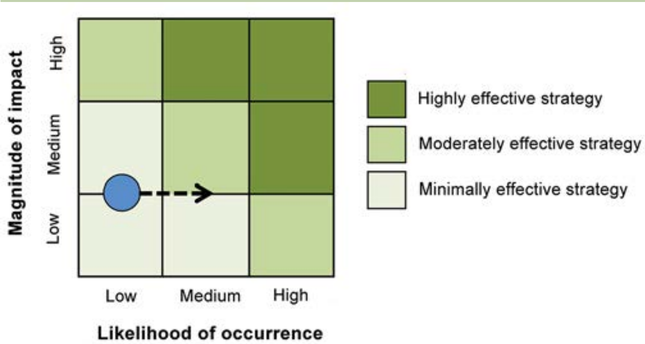
Implementation of agroforestry practices can help moderate effects of climate change through sequestration of carbon (C). Trees in agroforestry practices absorb and store larger quantities of atmospheric carbon dioxide ($CO_2$) than do the herbaceous annual crops they would replace. This case study assessment indicates that the potential impact of agroforestry implementation on concentration of $CO_2$ in the atmosphere is likely to be small but measurable if implemented extensively but that the likelihood of widespread adoption under current economic conditions is low (fig. B.5).

**Figure B.5.** Likelihood of occurrence and impact of agroforestry implementation on U.S. farmlands on global atmospheric $CO_2$ concentration. The impact will be low but measurable if implemented on 10 percent of U.S. farmland and along 5 percent of river miles, but the likelihood of achieving that level of implementation (circle) is low under current market conditions and program incentives, among other factors that affect adoption by landowners. The likelihood of occurrence would rise (arrow) if those factors become more favorable for adoption of agroforestry and the aerial extent of implementation increases.




Atmospheric concentrations of greenhouse gases, of which $CO_2$ is a major component, are rising and are considered to be largely responsible for a changing global climate. The absorption and sequestration of the C in $CO_2$ are viewed as strategies for limiting the increase of atmospheric $CO_2$, climate change, and the effects of a changing climate on Earth's systems and resources. Total global C emissions as $CO_2$ in 2012 were estimated to be 9,825 million metric tons (GCP 2014). That emission rate is raising the concentration of atmospheric $CO_2$ by approximately 2 parts per million (ppm) per year, which stood at 391 ppm in 2012 (NOAA ESRL 2014). Total U.S. C emissions as $CO_2$ in 2012 was estimated to be 1,460 million metric tons of C (U.S. EPA 2014), or about 15 percent of the global total.

Forests can be important contributors to C sequestration. Forest vegetation absorbs and converts atmospheric $CO_2$ into C compounds in plant biomass. The C is stored for long periods in wood and recalcitrant degradation products like soil organic matter. Afforestation (i.e., the conversion of herbaceous cover to forest cover) has the capability of increasing the total amount of C that can be stored on the land. Agroforestry implementation on agricultural land can be viewed as a form of afforestation. A risk-based framework can be used to assess the C sequestration potential of afforesting agricultural lands with agroforestry practices.

Agroforestry implementation can mitigate climate change to the extent that its rate of C sequestration is significant compared with total C (as $CO_2$) emissions. Potential C sequestration rates after adopting agroforestry practices in the United States (including silvopasture, alley cropping, windbreaks, and riparian forest buffers) on 10 percent of current U.S. cropland and pastureland and 5 percent of total river length (42 mega hectares, or an area about the size of the State of California) have been estimated to be 90 to 219 million metric tons of C per year (Nair and Nair 2003, Udawatta and Jose 2012). These estimates put the potential agroforestry sequestration rate at about 1 to 2 percent of the global $CO_2$ emission rate in 2012 and 6 to 15 percent of the U.S. $CO_2$ emission rate. At most, then, the rate of increase in global atmospheric $CO_2$ concentration would be slowed by about 2 percent of the 2012 rate or 0.045 ppm per year. Assuming that current agricultural systems have been in place long enough to have reached a steady state of C stocks (net C sequestration rate = 0), then these values fairly represent the potential effect of implementing agroforestry on agricultural lands in the United States.

A high C sequestration rate is unlikely to be sustainable in the long term without active management. Rates can be expected to fall as agroforests mature and approach a natural steady state of aboveground and belowground C stocks—possibly within 50 to 100 years of implementation. A high sequestration rate can be partially sustained for a longer term to the extent that the standing stock of plant biomass is harvested and preserved in the form of wood products like structural lumber.

Based on this analysis, the potential for agroforestry implementation in the United States to moderate global atmospheric $CO_2$ concentrations is probably small but still significant (fig. B.5). Agroforestry could contribute substantially toward reducing the U.S. footprint (by 6 to 15 percent) on the global increase of atmospheric $CO_2$. Furthermore, this rate could contribute substantively to a global effort that includes additional mitigation approaches. Its impact, however, will depend largely on how widely agroforestry is implemented. There are substantial technical and sociological headwinds for achieving the implementation rates that are assumed in this analysis.

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# Suitable Tree Species Under a Changing Climate

Michael G. Dosskey, Andrew C. Bell, and Gary Bentrup

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Successful agroforestry practices depend on the ability of the trees to survive and grow well enough to provide the benefits sought. Local climate is a major factor in determining which tree species could be effective in an agroforestry practice, and a great deal of variability in this regard exists among different species. As climate changes, local climate can shift beyond tolerable thresholds for some species and move to within tolerable thresholds for other species (table B.1). In a changing climate, agroforestry species must be able to survive and grow under both current and future climatic conditions. If species that are currently used cannot adapt to future climate, risk is high that the desired functional lifespan of the agroforestry practice will not be achieved.

Geographic ranges of naturally occurring forest tree species are predicted to shift in response to climate change (Iverson et al. 2008). Agroforestry, by contrast, avoids many vectors that affect natural reproduction and growth in natural forests. Agroforestry systems typically consist of planted trees that may be protected from environmental stresses, at least initially, through weed and insect control, fertilization, and irrigation. A list of tree species suitable for agroforestry in a given region consequently may look very different from that of naturally occurring forest.

The Chicago Botanic Garden conducted a study in which it evaluated effects of a changing climate on the region's urban trees. The study predicts that climate conditions for species now flourishing in the Chicago, IL, area will become less suitable after 2020. The predictions were made using the MaxEnt (Maximum Entropy Modeling) computer model (Merow et al. 2013, Phillips et al. 2006), which assesses suitability of species under future climate regimes based on bioclimatic parameters related to those listed in table B.1.

Climate change will not affect all species in the same way. The ranking of different species by their relative suitability in the Chicago area will change substantially by mid-century (table B.2). Some species will be able to tolerate future climates better than others. Among species that are well suited under current conditions—pecan, eastern redcedar, and silver maple—may continue to thrive under climate conditions expected in 2080; however, several other species, such as Norway spruce, American linden, and sugar maple, are likely to fare poorly in those conditions.

Based on these results, alley cropping-type agroforestry in the Chicago area should favor pecan over sugar maple. Both species could produce marketable products, but climate conditions within the lifespan of the tree crop may favor only pecan. Practices like windbreaks and riparian forest buffers should favor silver maple and eastern redcedar over other species for environmental benefits over the longer term.

**Table B.1.** Climate changes and their impact and consequences on tree species. In a changing climate, the success of agroforestry practices depends on planted trees being able to survive and grow under both current and future climate regimes. Changes in specific aspects of climate will have specific consequences, often negative, but not always, for tree growth and health. Suitable tree species will be able to tolerate such changes in climate over the designed lifespan of the agroforestry practice.

| Change in climate | Consequences for tree growth and health |
|---|---|
| Higher carbon dioxide concentrations; longer growing season | Increased growth rate of most species |
| Higher average winter temperature | Winter chilling requirements for flowering and seed germination might not be met |
| | Reduction in cold-associated mortality of insect pests |
| Higher temperature in early spring | Earlier budburst and potentially increased damages by late frosts |
| Increased frequency of drought | Reduced growth rate and increased mortality, especially for newly planted trees |
| Increased frequency of high or extreme temperature episodes | Increased susceptibility to damaging effects of pests |
| Increased frequency of floods | Waterlogging of soils; killing of tree roots<br>Physical erosion/removal of trees |

Source: Adapted from European Environmental Agency: http://www.eea.europa.eu/data-and-maps/figures/impacts-and-consequences-of-climate.

**Table B.2.** Ten tree species are ranked in order of suitability for planting in the Chicago, IL, area under current, 2050, and 2080 climate scenarios predicted by the Intergovernmental Panel on Climate Change in 2000. All species in the current column are suitable if current climate conditions do not change. By 2050, however, the climate will have changed, and some species will be favored and others disfavored by those conditions, so the rankings will change. By 2080, climate will have changed beyond the tolerance limits of several species (shaded). Agroforestry plantings in the Chicago area that are expected to function beyond 2080 accordingly should focus on the species that would still be suitable at that time, such as pecan, eastern redcedar, and silver maple.

| Current | 2050 | 2080 |
|---|---|---|
| Norway spruce (*Picea abies*) | Eastern redcedar | Pecan |
| Silver maple (*Acer saccharinum* L.) | Pecan | Eastern redcedar |
| Northern red oak (*Quercus rubra*) | Hackberry | Silver maple |
| Sugar maple (*A. saccharum* marshall) | White oak | Hackberry |
| Hackberry (*Celtis occidentalis*) | Silver maple | Sycamore |
| American basswood (*Tilia americana*) | Northern red oak | White oak |
| Eastern redcedar (*Juniperus virginiana*) | Sycamore | Northern red oak |
| White oak (*Q. alba*) | Sugar maple | Sugar maple |
| Sycamore (*Platanus occidentalis*) | Norway spruce | American basswood |
| Pecan (*Carya illinoinensus*) | American basswood | Norway spruce |

Source: Data from Bell (2014).

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