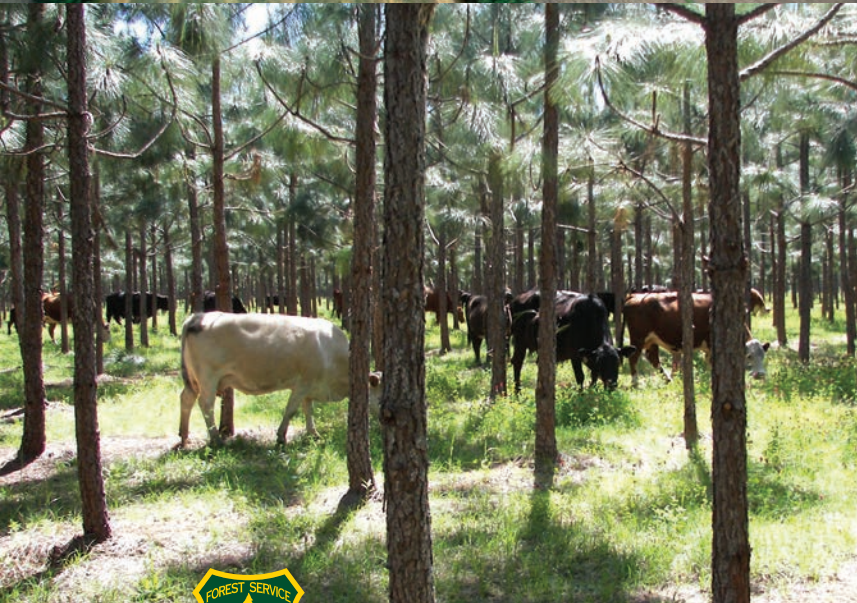




United States Department of Agriculture

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

Executive Summary



Forest Service

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Executive Summary

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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 Conservation 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



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.

landowner.

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



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.

as partnering with others, to create more resilient agricultural landscapes that include agroforestry practices.

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.



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.

- 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.

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.

Literature Cited

- Peterson, D.L.; Vose, J.M.; Patel-Weynand, T., eds. 2014. Climate change and United States forests. *Advances in Global Change Research*. Vol. 57. Dordrecht, Netherlands: Springer. 261 p.
- Vose, J.M.; Clark, J.S.; Luce, C.; Patel-Weynand, T. eds. 2016. Effects of drought on forests and rangelands in the United States: a comprehensive science synthesis. Gen. Tech. Rep. WO-93b. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 289 p.
- Walthall, C.J.; Hatfield, J.; Backlund, P. [et al.]. 2012. Climate change and agriculture in the United States: effects and adaptation. *Tech. Bull.* 1935. Washington, DC: U.S. Department of Agriculture. 186 p.

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.	<ul style="list-style-type: none"> • Produce annual and higher value but longer term crops. • Enhance microclimate conditions to improve crop or forage quality and quantity. • Reduce surface water runoff and erosion. • Improve soil quality by increasing utilization and cycling of nutrients. • Enhance habitat for wildlife and beneficial insects. • 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.	<ul style="list-style-type: none"> • Control wind erosion. • Protect wind-sensitive crops. • Enhance crop yields. • Reduce animal stress and mortality. • Serve as a barrier to dust, odor, and pesticide drift. • Conserve energy. • 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.	<ul style="list-style-type: none"> • Reduce nonpoint source pollution from adjacent land uses. • Stabilize streambanks. • Enhance aquatic and terrestrial habitats. • Increase C storage in plant biomass and soils. • Diversify income either through added plant production or recreational fees.
Silvopasture	Trees combined with pasture and livestock production.	<ul style="list-style-type: none"> • Produce diversification of livestock and plant products in time and space. • Produce annual and higher value but longer term products. • 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.	<ul style="list-style-type: none"> • Improve crop diversity by growing mixed but compatible crops having different heights on the same area. • Improve soil quality by increasing utilization and cycling of nutrients. • 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.	<ul style="list-style-type: none"> • Treat municipal and agricultural wastes. • Manage stormwater. • 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.

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]).



