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

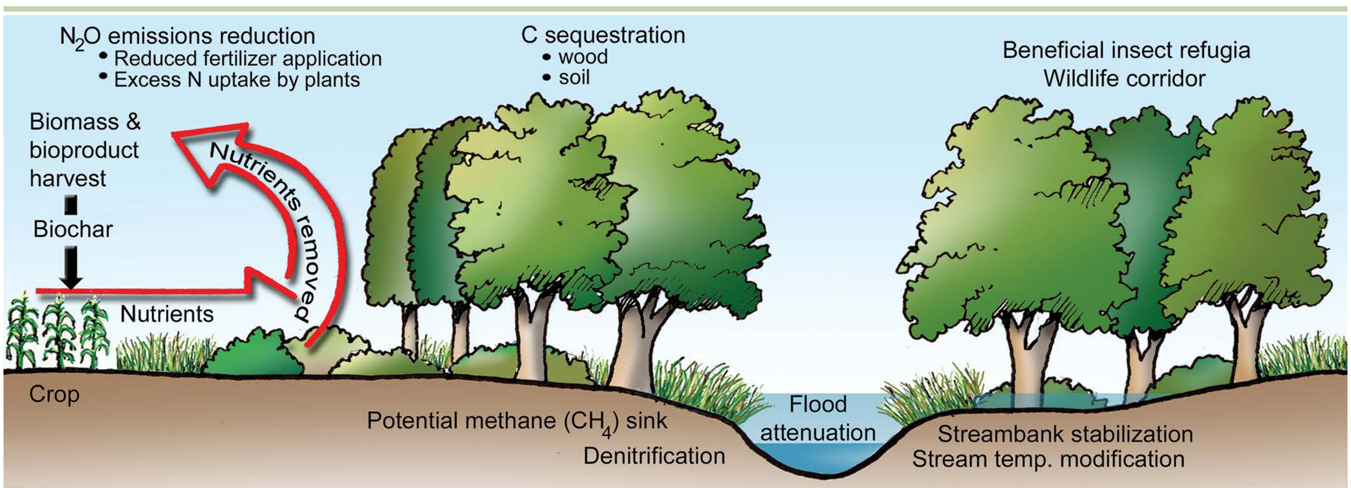
Demands on U.S. agricultural lands continue to grow for food, feed, and fiber and for other ecosystem services such as flood control, water quality protection, GHG mitigation, and wildlife habitat. With the additional demand to produce bioenergy from these lands, the sustainability and health of U.S. 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).

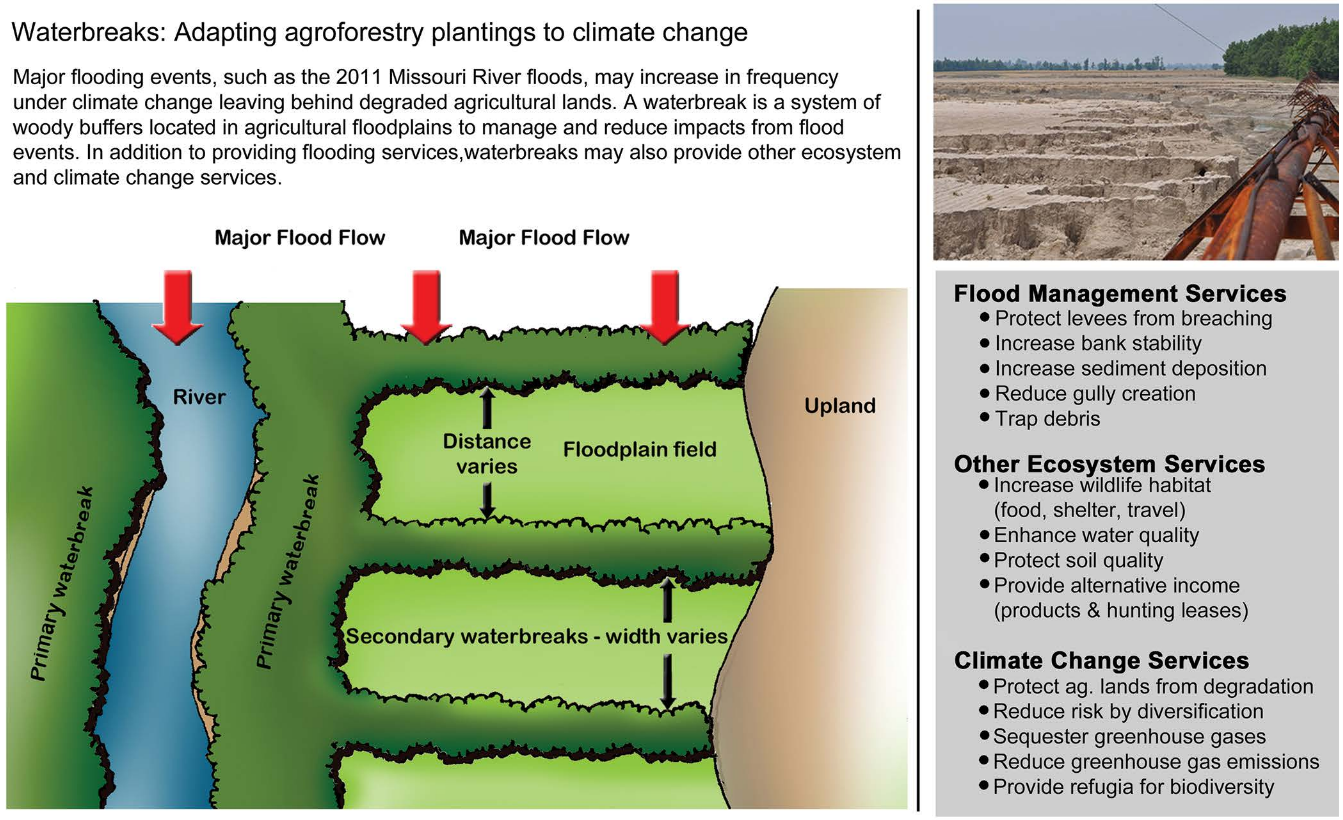
Productive Floodplain Management

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.