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Supporting U.S. Agricultural Landscapes Under Changing Conditions With Agroforestry

An Annotated Bibliography



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Cover Photos (left to right): A shelterbelt around a Great Plains farm, a silvopasture system in Georgia, blueberries growing in an agroforestry practice, alley cropping with soybeans and walnuts, and a riparian forest buffer in Iowa; (background): shiitake mushrooms grown on logs under a forest canopy. Shelterbelt photo courtesy of the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service; all other photos courtesy of the USDA National Agroforestry Center.

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Gary Bentrup, Ina Cernusca, and Michael Gold

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Abstract

Agroforestry can reduce risks and promote sustainable agricultural production under shifting climate and weather extremes by (1) reducing threats and enhancing agricultural landscape resiliency, (2) facilitating species movement to more favorable conditions, (3) sequestering carbon, and (4) reducing greenhouse gas emissions. Although agroforestry practices can provide these positive adaptation and mitigation services, they in turn can be vulnerable to the same forces. The design and management of agroforestry systems must therefore take into account how these systems can incorporate resiliency into agriculture in ways that the systems are more resilient to these changing conditions. As a key step in this process, the authors conducted a search of the scientific literature on agroforestry's role in adaptation and mitigation under climatic variability and change, as well as on the effects of these stressors on agroforestry. The temporal scope of the literature search focused on the period of 1992 to 2017, and the geographical scope concentrated on temperate agricultural regions. This publication is available at http://www.treesearch.fs.fed.us/ as a printable and searchable document. The references and annotations are also available from an online Zotero™ database that will be periodically updated as new literature becomes available. The public database is accessible at https://www.zotero.org/groups/1738910/agroforestry__climate_change.

Keywords: climate variability, climate change, mitigation, adaptation, carbon sequestration, greenhouse gas emissions, resiliency

Introduction

U.S. agricultural operations and landscapes are already impacted by changes in climate patterns and weather variability, with impacts expected to increase throughout the 21st century. Future growing conditions across the temperate zone of the United States are predicted to include longer growing seasons that could potentially increase crop yields but also increase heat waves, floods, droughts, and insect and weed issues deleterious to production (Walthall et al. 2012). Other ecosystem services that we, as a society, derive from farms and ranches—such as clean water, soil and air quality, and wildlife habitat—can also be negatively impacted (Melillo et al. 2014). Enhancing food security and preserving other vital ecosystem services from U.S. agricultural lands under current and future shifting weather and climate conditions will require a transition to production systems that are more productive, use inputs more efficiently, have greater stability, and are more resilient to risks, shocks, and long-term climate variability (Scherr et al. 2012). Approaches will need to be based on agroecological principles and the availability of many practices in order to attain and capitalize on greater multifunctionality within the agricultural system (Beddington et al. 2012, Tomich et al. 2011, Wall and Smit 2005).

Agroforestry—the intentional integration of trees and shrubs into crop and animal production systems to create productive, healthy, and resilient agricultural operations and lands—is one of these potential practices (Jose et al. 2012, Schoeneberger et al. 2012, Smith et al. 2013). As defined within the United States, agroforestry 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). Brief overviews of agroforestry practices used in the United States are presented in fig. 1 and table 1.

Agroforestry and Climate Variability and Change

Agroforestry is a suite of tree-based management practices that farmers and ranchers can use to enhance the capacity of their agricultural operations and lands to adapt to climatic variability and change. These practices blend trees and shrubs into agricultural settings to modify landscape structure in specific ways to produce desired ecosystem services and human benefits (fig. 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 benefits 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.

Based on available evidence, agroforestry has the potential capacity to contribute to climate change mitigation and adaptation by (1) reducing threats and enhancing agricultural landscape resiliency, (2) facilitating species movement to more favorable conditions, (3) sequestering carbon, and (4) reducing greenhouse gas emissions (table 2; Matocha et al. 2012, Schoeneberger et al. 2012). One of the strengths of agroforestry is the opportunity it affords to provide these services in an integrated and synergistic manner (Duguma et al. 2014). Often, an enhanced outcome results when the components interact with each other, increasing effectiveness, minimizing costs, and ensuring continuity of production and service provision by minimizing risks (Duguma et al. 2014).

The use of agroforestry to address extreme weather events on agricultural lands in the United States is not a new idea. To mitigate one of the largest North American wind-erosion events in history—the 1930s Dust Bowl—the Prairie States Forestry Program planted windbreaks

Figure 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 the U.S. Department of Agriculture, National Agroforestry Center (A, B, D, F), Ben Fertig, Integration and Application Network, University of Maryland, Center for Environmental Science (ian.umces.edu/imagelibrary/) (C), and Catherine Bukowski, Virginia Tech (E).

across the length of the Great Plains (fig. 3). Nearly 220 million seedlings were planted, creating 18,600 miles of windbreaks occupying 240,000 acres on 30,000 farms (Williams 2005).

Although agroforestry practices can help address the negative impacts of climatic variability, they in turn can be vulnerable to the same forces. Agroforestry systems are complex assemblages of ecosystem components, each responding to changes in weather and climate. Some potential impacts include tree mortality or reduced production due to increasing droughts and floods, pests and diseases, or lack of chilling requirements. Whereas impacts on monoculture crops or simple livestock production systems can be reasonably predicted with process-based models, robust models for agroforestry systems are not yet available (Luedeling et al. 2014). This lack is a serious concern given the long planning horizons required for implementing and managing tree-based practices.

Table 1. Categories of agroforestry practices used 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, 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. • 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.	• Control wind erosion. • Protect wind-sensitive crops. • Enhance crop yields. • Reduce animal stress and mortality. • Serve as barriers to dust, odor, and pesticide drift. • Conserve energy. • Manage snow dispersal to keep roads open or harvest moisture.
Riparian forest buffers[c]	Areas of trees, shrubs, and herbaceous vegetation established and managed adjacent to streams, lakes, ponds, and wetlands.	• 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.	• 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 and/or shrubs that are managed as an overstory, with an understory of plants grown for a variety of products.	• 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.	• Treat municipal and agricultural wastes. • Manage stormwater. • Produce biofeedstock.

C = carbon.

[a] Descriptions follow USDA Natural Resources Conservation Service Practice Standards.

[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 buffers refers to the planted practice. This category does not include naturally established riparian forests.

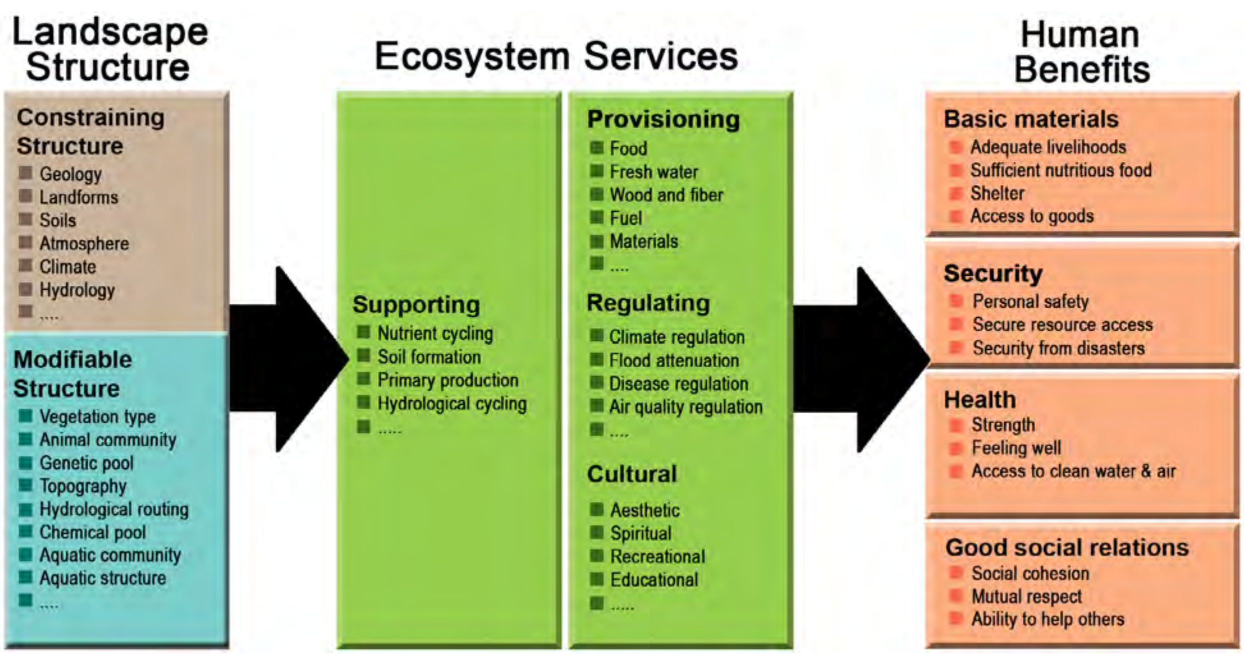

Figure 2. Agroforestry reduces climate-related threats to agriculture by modifying the structure of agricultural landscapes. Through landscape structure, agroforestry practices modify microclimate, stabilize soil, protect water and air quality, and provide for biological diversity, including the diversity of agricultural crops. Each general type of agroforestry practice (table 1) represents a different structural template for emphasizing certain benefits over others. Figure from Dosskey et al. (2012) as modified from MEA (2005).

Table 2. Agroforestry functions that support climate change adaptation and mitigation

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. • Alter microclimate to maintain quality and quantity of forage production. • Alter microclimate to reduce livestock stress. • Provide greater habitat diversity to support organisms (e.g., native pollinators, beneficial insects). • Provide greater structural and functional diversity to maintain and protect natural resource services. • Create diversified production opportunities to reduce risk under fluctuating climate.
	Facilitate species movement to more favorable conditions.	• Assist in plant species movement through planting decisions. • 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. • Accumulate C in soil.
	Reduce GHG emissions.	• Reduce fossil fuel consumption: ◊ With reduced equipment runs in areas with trees. ◊ With reduced farmstead heating and cooling. • Reduce N_2O emissions: ◊ By greater nutrient uptake through plant diversity. ◊ By reduced N fertilizer application in tree component. • Enhance forage quality, thereby reducing CH_4.

C = carbon. CH_4 = methane. GHG = greenhouse gas. N = nitrogen. $N_2$0 = nitrous oxide.

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

Figure 3. (A) A giant dust storm rolls across eastern Colorado during the 1930s. (B) Landowners tending to their windbreak planted with the Prairie States Forestry Project. Photos by the U.S. Department of Agriculture, Natural Resources Conservation Service (A) and Forest Service (B).

The Bibliography

Purpose

A pressing need exists to design and manage agroforestry systems that offer resiliency under climatic variability and change that are themselves resilient. A better understanding of the scientific basis for these services, identification of knowledge gaps, and translation of the knowledge into planning and design tools are needed. As a critical step in this process, we—as authors of this document—conducted a search of the scientific literature on agroforestry's role in climate change adaptation and mitigation, as well as the potential impacts of climatic variability and change and associated stressors on agroforestry. This annotated bibliography is intended primarily as a reference for researchers, planners, and managers. The temporal scope of the literature search is the period from 1992 to 2017. Although useful literature exists prior to this time period, we concentrated on recent material that was framed within a climatic variability and change context. References and information prior to the surveyed time period are found in other publications (e.g., Brandle et al. 1988, Buck et al. 1998, Garrett 2009, Gordon and Newman 1997, Nair 1993, Smith 1950, Young 1989). The geographical scope of this bibliography was primarily temperate agricultural regions, although we included some studies involving tropical regions if they were relevant to U.S. agricultural production and food security concerns (i.e., Hawaii and other U.S.-affiliated tropical islands). Each study listed in the bibliography is followed by a concise summary of its methods and primary results. At the time of publication, this bibliography contains 206 publications.

Using This Bibliography

This annotated bibliography is available as a downloadable and printable document at http://www.treesearch.fs.fed.us/. The bibliography is published as a searchable document, allowing for users to define keywords of interest. To conduct a word search, use the *Find* function in a pdf reader. Stable digital object identifier, or DOI, links are provided for most publications. See the appendix tables for descriptions of units of measurement, names and abbreviations of chemical elements and compounds, and the definitions of abbreviations and acronyms contained within the annotations. The references and annotations are also available in an online Zotero[1] database that will be periodically updated as new literature becomes available. This database is searchable based on keywords, authors, dates, and titles. Access the public database at https://www.zotero.org/groups/1738910/agroforestry__climate_change.

A companion report, entitled *Agroforestry: Enhancing Resiliency in U.S. Agricultural Landscapes Under Changing Conditions*, provides a synthesis of the most current science regarding how these tree-based practices can impact agricultural production and resiliency and what will be needed to successfully capitalize on agroforestry's benefits under uncertain climate. The assessment report is available at https://doi.org/10.2737/WO-GTR-96.

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Garrett, H.E., ed. 2009. North American agroforestry: an integrated science and practice. Madison, WI: American Society of Agronomy. 400 p.

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Jose, S.; Gold, M.A.; Garrett, H.E. 2012. The future of temperate agroforestry in the United States. In: Nair, P.K.; Garrity, D., eds. Agroforestry—The future of global land use. Advances in Agroforestry, Vol. 9. Dordecht, Netherlands: Springer: 217–245.

Luedeling, E.; Kindt, R.; Huth, N.I. [et al.]. 2014. Agroforestry systems in a changing climate—challenges in projecting future performance. Current Opinion in Environmental Sustainability. 6: 1–7.

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[1] Mention of product or trade names does not constitute endorsement by the Forest Service.

Melillo, J.M.; Richmond, T.C.; Yohe, G.W. eds. 2014. Climate change impacts in the United States: the Third National Climate Assessment. Washington, DC: U.S. Global Change Research Program. 841 p.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and human well-being: current state and trends assessment. Washington, DC: Island Press. 948 p.

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1992

Winjum, J.K.; Dixon, R.K.; Schroeder, P.E. 1992. Estimating the global potential of forest and agroforest management practices to sequester carbon. Water, Air, and Soil Pollution. 64(1): 213–227. http://doi.org/10.1007/BF00477103.

This study compiles a global database of 94 forested nations that represent boreal, temperate, and tropical latitudes to quantitatively assess the potential of forest practices to sequester C. Reforestation practices in temperate and tropical latitudes, afforestation in temperate regions, and agroforestry and natural reforestation in the tropics were predicted to be the most effective and widely employed practices to increase C sequestration potential based on current literature. Mean C storage values were lowest for silviculture practices in all three latitudinal zones. Medians of the mean C storage values for boreal (n=46), temperate (n=401), and tropical (n=170) latitudes respectively are 16 t C ha^{-1}, 71 t C ha^{-1}, and 66 t C ha^{-1}. Based on preliminary projections, if the suggested practices were implemented on 0.6 to 1.2x109 ha of available land during 50 years, approximately 50 to 100 Gt C could be sequestered, which is considered a significant contribution to global C sequestration given the increasing rate of C emissions from human activities.

1993

Kürsten, E.; Burschel, P. 1993. CO_2-mitigation by agroforestry. Water, Air, and Soil Pollution. 70(1–4): 533–544. http://doi.org/10.1007/BF01105020.

The authors' analyzed results of biomass studies conducted in Central American agroforestry plantations compared with prior estimates to better understand C sequestration by trees within various tropical agroforestry systems, additional CO_2-mitigating effects of agroforestry practices, and the economic and social variants that affect possibility for agroforestry applications. Two groups of effects of the C-ecological role of trees emerged: (1) accumulation, as well as conservation of C stores in trees, soils, and wood products; and (2) reduction of C emissions resulting from energy and material substitution. The first is difficult to quantify and is restricted by site conditions and the type of system and management, although the second can be perpetually produced with each harvest. A relatively dense tree crop in agroforestry plantations of Central America could permanently store 3 to 25 t C ha^{-1}. Additional CO_2-mitigating effects may achieve more than 20 times this quantity. Such effects are derived from protection of existing forests, conservation of soil productivity, reduction of fossil energy consumption by use of timber instead of more energy intensive raw materials, and substitution of fossil fuel with wood as an energy source.

Schroeder, P. 1993. Agroforestry systems: integrated land use to store and conserve carbon. Climate Research. 3: 53–60. http://www.int-res.com/articles/cr/3/c003p053.pdf.

This literature review paper presents an evaluation of C dynamics of agroforestry practices and assesses their potential to store C based on tree growth and wood production data. The median C storage value for agroforestry practices was 9 t C ha^{-1} in humid and 63 t C ha^{-1} in temperate ecoregions. With the recognition that net effects of C storage from implementing agroforestry practices depends on the C content of the land uses they replace, the author suggests that short fallows of less than 5 years represent the most substantial C storage pool. Results of the conversion of these lands, in addition to currently degraded and nonproductive land and lands in more or less permanent pasture, agroforestry may result in reduced clearing of mature forest to create new agricultural land, extended regrowth of fallows that no longer need to be recleared on short cycles, and potential increased productivity due to facilitation of intercropping.

1994

Dixon, R.K.; Winjum, J.K.; Andrasko, K.J. [et al.]. 1994. Integrated land-use systems: assessment of promising agroforest and alternative land use practices to enhance carbon conservation and sequestration. Climatic Change. 27(1): 71–92. http://doi.org/10.1007/BF01098474.

Degraded or substandard soils and marginal lands occupy a significant proportion of boreal, temperate, and tropical biomes. Management of these lands with a wide range of existing, site-specific, integrated, agroforest systems represents a significant global opportunity to reduce the accumulation of GHG in the atmosphere. Authors conducted a global analysis of biologic and economic data from 94 nations illustrating diverse climatic and edaphic conditions under which integrated land use systems could be used to establish and manage vegetation on marginal or degraded lands. These land use systems and practices that conserve and temporarily store C include agroforestry systems, fuel wood and fiber plantations, bio-reserves, intercropping systems, and shelterbelts and windbreaks. Social conditions (demographic factors, land tenure issues, market conditions, lack of infrastructure), economic obstacles (difficulty of demonstrating benefits of alternative systems, capital requirements, lack of financial incentives) and ecologic considerations are among constraints to wide-spread implementation of agroforestry systems.

Schroeder, P. 1994. Carbon storage benefits of agroforestry systems. Agroforestry Systems. 27(1): 89–97. http://doi.org/10.1007/BF00704837.

This assessment of the C storage potential of agroforestry systems uses an extensive literature survey on C dynamics of agroforestry practices. Based on the growing body of literature addressing agroforestry production, tree growth and wood production were converted to estimates of C storage. Agroforestry practices estimated median C storage at 9 t C/ha in semiarid, 21 t C ha^{-1} in subhumid, 50 t C ha^{-1} in humid, and 63 t C ha^{-1} in temperate ecozones, not including belowground C accumulation. Temperate zone C storage was higher than humid zone, despite the higher growth rates in humid tropical zones, because the average cutting cycle was six times longer in the temperate zones (30 versus 5 years). The author asserts that agroforestry may provide both local and global effects toward the reduction of land degradation and the increased capacity for C storage, especially when applied to degraded or nonproductive land, permanent agriculture and pasture lands, or lands under short fallow agriculture.

1995

Dix, M.E.; Johnson, R.J.; Harrell, M.O. [et al.]. 1995. Influences of trees on abundance of natural enemies of insect pests: a review. Agroforestry Systems. 29(3): 303–311. http://doi.org/10.1007/BF00704876.

The authors review the role of trees in supporting endemic natural enemies in controlling insect pests in agricultural systems. Although information is currently limited, available evidence suggests that woody vegetation, both natural or planted agroforestry practices, can offer structural and functional diversity to support natural enemies, including providing overwintering habitat. Conservation and enhancement of natural enemies might include manipulation of plant species and plant arrangement, particularly at field edges, and consideration of optimum field sizes, number of edges, and management practices in and near edges. For example, narrow windbreaks might be adequate to support carabids and staphylinids, and wider windbreaks will probably be necessary for insectivorous birds.

Dixon, R.K. 1995. Agroforestry systems: sources of sinks of greenhouse gases? Agroforestry Systems. 31(2): 99–116. http://doi.org/10.1007/BF00711719.

This paper evaluates the C dynamics of agroforestry practices and assesses their potential contribution to slowing the increase of atmospheric CO_2. The evaluation is based on several criteria: (1) levels of direct C storage; (2) levels of C conservation resulting from reduced land clearing; (3) crop production; and (4) profitability. The author conducted an extensive literature survey to evaluate the C dynamics of agroforestry practices. The focus of the analysis is primarily on tropical agroforestry practices, and where available, included information for practices in the temperate zones for comparison. A very rough approximation of the potential range for total C storage is attempted. Accurate estimates of agroforestry benefits in C storage are very difficult because of uncertainties in land availability for conversion to agroforestry. More research is needed to quantify the impact of introducing agroforestry practices and reducing deforestation on the global C cycle.

1996

Brown, S.; Sathaye, J.; Cannell, M.; Kauppi, P.E. 1996. Mitigation of carbon emissions to the atmosphere by forest management. Commonwealth Forestry Review. 75(1): 80–91. http://www.jstor.org/stable/42607279.

The authors review the potential for managing forests to mitigate CO_2 emissions. The paper presents three categories of promising forestry practices that promote sound management of forests and at the same time conserve sequester C, agroforestry being one of them. The paper quantifies the cumulative amounts of C that could potentially be conserved and sequestered during the 1995 to 2050 period and the cumulative costs to conserve and sequester the C. Under a changed climate, atmospheric composition and land use, the C conservation and sequestration by new forests in temperate and boreal regions might by offset by transient decline and loss of C from existing forests in response to climate change.

Ceulemans, R.; Shao, B.Y.; Jiang, X.N.; Kalina, J. 1996. First- and second-year aboveground growth and productivity of two *Populus* hybrids grown at ambient and elevated CO_2. Tree Physiology. 16(1–2): 61–68. http://web.b.ebscohost.com/ehost/pdfviewer/pdfviewer?sid=8bd7f759-0cae-4cef-b99b-07a1d13512d6%40sessionmgr103&vid=1&hid=129.

This paper reports on the investigation of the long-term effects of an increase in atmospheric CO_2 concentration on two *Populus* clones (fast-growing Beaupré and slow-growing Robusta). The clones were exposed to ambient or elevated CO_2 in open-top chambers for one or two growing seasons. Both clones responded positively to elevated CO_2 with an increase in stem volume. The CO_2-induced responses of the fast-growing clone included increased investment in branch and leaf biomass that resulted in a significantly increased leaf area index. The CO_2-induced responses of the slow-growing clone included an increase in height growth and increased investment in branch biomass and total leaf N content. Tree responses to increasing atmospheric CO_2 concentrations appear to be species and genotype specific.

Lee, J.J.; Phillips, D.L.; Dodson, R.F. 1996. Sensitivity of the U.S. corn belt to climate change and elevated CO_2: II. Soil erosion and organic carbon. Agricultural Systems. 52(4): 503–521. http://doi.org/10.1016/S0308-521X(96)00015-7.

This study used the Erosion Productivity Impact Calculator model to examine the sensitivity of soil erosion (from wind and water) and SOC at 15 cm and 1 m depths in the U.S. Corn Belt to 2 °C increases in temperature, 10 and 20 percent increases and decreases in precipitation and wind speed, and increases in atmospheric CO_2 concentration in 100 year simulations. Under increased CO_2 (from 350 to 625 ppmv), with all other variables constant, wind erosion decreased 4 to 11 percent, and water erosion was not impacted due to increased vegetation cover, although wind erosion was very sensitive to changes in wind speed and temperature. One-half of the simulated SOC loss to 1 m depth (from 18.1 Mg C ha^{-1} to 4.8 Mg C ha^{-1} total) was attributed to soil erosion transport off site.

1997

Alig, R.; Adams, D.; McCarl, B. [et al.]. 1997. Assessing effects of mitigation strategies for global climate change with an intertemporal model of the U.S. forest and agriculture sectors. Environmental and Resource Economics. 9(3): 259–274. http://doi.org/10.1007/BF02441399.

U.S. policymakers are considering two options, increasing forest area and enhancing productivity of existing forests, to mitigate global climate change through sequestration of C in forests and forest products. The paper uses a model of product and land markets to examine the consequences of market forms on forest C storage, C fluxes, and costs. The study applies a linked model of the U.S. forest and agriculture sectors and treats both land use and forest management decisions as endogenous. The results demonstrate the importance of using a dynamic two-sector model to capture landowner responses to program-induced price changes and the impacts on net C sequestration.

Easterling, W.E.; Hays, C.J.; Easterling, M.M.; Brandle, J.R. 1997. Modelling the effect of shelterbelts on maize productivity under climate change: an application of the EPIC model. Agriculture, Ecosystems & Environment. 61(2–3): 163–176. http://doi.org/10.1016/S0167-8809(96)01098-5.

The authors investigated the potential of shelterbelts to reduce climate change induced crop stress. They used the Erosion-Productivity Impact Calculator (EPIC) crop model to simulate the response of dryland maize to shelter in eastern Nebraska. Two EPIC versions were subjected to prescribed increments to temperature, and increments or decrements to precipitation, and wind speed to examine differences in crop productivity. Based on the results, shelter equals or increases modeled dryland maize yields compared with corresponding open field yields for all levels of climate change. The modeling results suggest three climate change-related benefits of shelter relative to open field conditions: (1) night-time cooling of the crop that offsets the shelter-induced increase in daytime temperatures and lengthens the period leading to maturation, allowing greater grain fill and higher yields; (2) lower night-time temperatures that reduce respiration, and thus, increases net productivity; and (3) a reduction in evapotranspiration rates and the number of days of water stress. The positive effect of shelter on dryland maize is greatest for the most severe precipitation deficiency coupled with the greatest increase in wind speed—in short, the most severe climate changes. However, full compensation at the highest temperature increase is only possible when accompanied by precipitation increases and decreased wind speed for the upper range of shelter. Shelter is unable to overcome yield decreases relative to the baseline at any temperature (0 to +5 °C) when precipitation is at maximum deficiency (-30 percent). The prime advantage of shelter was from lengthening the period from emergence to maturation relative to open field conditions, thus allowing the crop to achieve greater grain fill than in the open. Despite methodological limitations, the findings suggest that shelterbelts may provide important protection from climate warming.

Rhoades, C.C.; Nissen, T.M.; Kettler, J.S. 1997. Soil nitrogen dynamics in alley cropping and no-till systems on ultisols of the Georgia Piedmont, USA. Agroforestry Systems. 39(1): 31–44. http://doi.org/10.1023/A:1005995201216.

This study demonstrates the short-term impacts of the addition of leguminous *Albizia julibrissin* mulch on plant available N on highly weathered Ultisols of the State of Georgia piedmont. Three years after the establishment of *Albizia* hedgerows and no-till trials, inorganic soil N and net N mineralization were measured during this 4-month study to compare alley cropping and no-till effects on nutrient availability and soil restoration. Soil NO_3–N increased four-fold within 2 weeks of adding *Albizia* leaf mulch. Averaged during the duration of the study, soil NO_3 and NH_4 were 2.8 and 1.4 times higher in the alley-cropped plots than in the treeless no-till plots. The tree mulch additions also enhanced crop biomass production and N uptake 2 to 3.5 times under both high and low soil moisture conditions. Although the degree of soil improvement in Georgia Piedmont may be limited by the capacity of the kaolinitic clays to sequester soil C, a combination of no-till agriculture and alley cropping with *Albizia* hedges is suggested for Piedmont farmers as an option for reducing reliance on chemical N fertilizer while improving SOM levels.

Stamps, W.T.; Linit, M.J. 1997. Plant diversity and arthropod communities: implications for temperate agroforestry. Agroforestry Systems. 39(1): 73–89. http://doi.org/10.1023/A:1005972025089.

The authors review theories of arthropod diversity in relationship to traditional agricultural and forestry systems and discuss their implications for agroforestry systems with particular emphasis on alley cropping in temperate regions. Experimental evidence suggests that herbivore damage is lower in complex plant systems than in single-species systems. The deliberate association of trees with agronomic crops likely will result in insect management benefits due to the structural complexity and permanence of trees and to their modification of microclimates within the production area. Many parasitoids require nectar or pollen as adults, and the combination of trees and crops may provide a constant nutritional source for them, because the resource availability through time is increased. Trees can serve as alternate hosts for parasitoids and can provide overwintering sites and shelter. Trees offer shade and other microclimate effects, which may reduce pest density in intercrops. Agroforestry practices may disrupt visual cues used by herbivores and may alter chemical cues, because trees can present different chemical signals than annual herbaceous plants intercropped in the system, both potentially contributing to pest control. Although the potential pest management benefits of agroforestry are many, potential problems could exist and likely will be dependent on the specific context and agroforestry system.

Thevathasan, N.V.; Gordon, A.M. 1997. Poplar leaf biomass distribution and nitrogen dynamics in a poplar-barley intercropped system in southern Ontario, Canada. Agroforestry Systems. 37(1): 79–90. http://doi.org/10.1023/A:1005853811781.

Poplar leaf biomass, nitrification rates, and soil C were measured in this study of intercropped hybrid poplar (*Populus* spp. clone DN 177) and barley (*Hordeum vulgare* cv. OAC Kippen), and hybrid poplar-corn (*Zea mays* cv. Pioneer 3917) in Guelph, Ontario, Canada from 1993 to 1995. Soil nitrification rates, soil C content, and plant N uptake adjacent to the poplar tree rows (4 to 11 m from tree rows) were positively influenced by the presence of poplar leaf biomass input from the preceding year in both trials. These differences also likely contributed to increased aboveground crop biomass and grain N concentration adjacent to the tree row. The area of beneficial effect is expected to expand as the tree canopy develops. When possible, the authors suggest possible enhancement with the combination of poplar with more valuable hardwood species or trees with N-fixing characteristics, although poplar alone is fast growing, tolerant of a wide range of site and climatic conditions in the temperate zone, and is seen here to provide benefits similar to leguminous species.

1998

Iverson, L.R.; Prasad, A.M. 1998. Predicting abundance of 80 tree species following climate change in the Eastern United States. Ecological Monographs. 68(4): 465–485. http://doi.org/10.1890/0012-9615(1998)068[0465:PAOTSF]2.0.CO;2.

To evaluate the effects of climate warming on tree species distribution in the Eastern United States, the authors developed models based on weighted environmental factors associated with current ranges of tree species using geographic information system, or GIS, in conjunction with regression tree analysis and Forest Inventory Analysis data from more than 100,000 forested plots to measure potential shifts for 80 tree species. Data on climate, soils, land use, elevation, and species assemblages in more than 2,100 counties east of the 100th meridian were used to extend the method for greater understanding of the potential for species to survive or migrate under changing climate conditions. Predictions for two climate change scenarios with twofold increases in the level of atmospheric CO_2 reveal that 27 to 36 species could expand their range or weighted importance by at least 10 percent, although an additional 30 to 34 species could decrease by at least 10 percent, and 4 to 9 species could move north of the United States following equilibrium after a change in climate. Nearly one-half of the 80 species assessed showed potential for ecological optima to shift at least 100 km north, 7 of which could move more than 250 km, although currently fragmented habitat is likely to slow predicted rates of migration. Potential ranges presented from these models do not represent forecasts but rather an indication of the potential impact on species distributions.

Kort, J.; Turnock, R. 1998. Carbon reservoir and biomass in Canadian prairie shelterbelts. Agroforestry Systems. 44(2–3): 175–186. http://doi.org/10.1023/A:1006226006785.

This paper describes a study conducted to determine the amount of biomass and C held in prairie shelterbelts (on sites ranging from 17 to 90 years since establishment) in Saskatchewan and Manitoba, where shelterbelts have been planted since 1903 to protect soils, crops, and farmyards. Common shelterbelt species were sampled for impact of soil type and tree species on biomass and C content. Species that were sampled in all three soil zones generally had a lower biomass in the driest soils (62 percent biomass of those in the higher moisture soil). Improved, fast-growing hybrid poplars were documented as having the greatest biomass at maturity (544.3 kg/tree and 105 t/km stored C), although green ash (*Fraxinus pennsylvanica*) and caragana (*Caragana arborescens*) are the main field shelterbelt species used, holding 32 and 26 t/km of C respectively. The amount of C held in shelterbelts was significantly related to soil zone, soil texture, shelterbelt age, location, topography, and shelterbelt condition. Based on measurable tree or shrub parameters (DBH, shelterbelt volume, aboveground-to-belowground biomass ratio), the authors developed models to calculate the C content of prairie shelterbelts that may be used to support appropriate shelterbelt management for C offset goals.

Lin, C.H.; McGraw, M.L.; George, M.F.; Garrett, H.E. 1998. Shade effects on forage crops with potential in temperate agroforestry practices. Agroforestry Systems. 44(2–3): 109–119. http://doi.org/10.1023/A:1006205116354.

This study compared the MDW of 30 forages under full sun, 50 percent shade, and 80 percent shade during spring-early summer and summer-fall during 2 years. Although absolute yields of the native warm-season grasses under shade treatments were generally higher than yields of cool-season species, warm-season grasses consistently displayed significant reductions in MDW under shade regardless of season. Cool-season forages grown during spring-early summer also showed a decrease in MDW under shade, although some showed no significant decrease in MDW under 50 percent shade (“Benchmark” and “Justus” orchardgrasses, “KY 31” tall fescue, *Desmodium canescens* and *D. paniculatum*). In general, cool-season grasses showed more shade tolerance when grown during the summer-fall than during spring-early summer. In fact, smooth bromegrass and Justus orchardgrass MDW increased under shade conditions. Similarly, the MDW of some legumes harvested in the fall increased significantly under 50 and 80 percent shade (*Desmodium* species and hog peanut), although other legumes showed no significant MDW reductions. Of the forages studies, 15 species and cultivars were identified as suitable for use as companion crops in silvopastoral systems, with indicated groupings based on establishment phases.

Marquez, C.O.; Cambardella, C.A.; Isenhart, T.M.; Schultz, R.C. 1998. Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA. Agroforestry Systems. 44(2–3): 133–140. http://doi.org/10.1023/A:1006261519080.

This paper details trends in SOM C accrual and intraseasonal SOM C and POM C changes in each vegetation zone of a multispecies riparian buffer strip 7 years after establishment on previously cultivated or heavily grazed soil. After six growing seasons, total SOM C and POM C in soil under perennial vegetation (poplar, switchgrass, and cool season grasses) were significantly higher than under cropped soil; SOM C increased 8.5 percent under poplar with cool season grasses and 8.6 percent under switchgrass. Within the 4-month study period, POM C increased significantly, especially under poplar, whereas SOM C did not change. These findings suggest that changes in SOM C and POM C can occur in a relatively short time after establishment of perennial vegetation and may increase the ability of riparian buffer strips to process nonpoint source pollutants by providing a continuous supply of C used as an energy source for sustained NO_3^- - N removal.

Saxe, H.; Ellsworth, D.S.; Heath, J. 1998. Tree and forest functioning in an enriched CO_2 atmosphere. New Phytologist. 139(3): 395–436. http://doi.org/10.1046/j.1469-8137.1998.00221.x.

The authors of this paper provide an overview of tree and forest responses to an enriched CO_2 atmosphere, the experimental approaches used to determine these effects, and future research needs and unresolved questions related to this subject area. More than 300 studies of trees and forests on five continents were reviewed. The systematic review evaluated the impact of elevated CO_2 on water relations, photosynthesis and respiration, foliar chemical composition, interactions with mineral nutrition, temperature, air pollution, and other biota, and effects at the forest ecosystem scale. The authors emphasize that numerous interactions exist between CO_2 and factors of the biotic and abiotic environment, many additive rather than synergistic or antagonistic. Additionally, many responses to elevated CO_2 and their interactions with stress show considerable variability among species and genotypes, all which suggests the need for comparative, long-term studies of a large variety of woody species and ecosystems under realistic conditions.

Tufekcioglu, A.; Raich, J.W.; Isenhart, T.M.; Schultz, R.C. 1998. Fine root dynamics, coarse root biomass, root distribution, and soil respiration in a multispecies riparian buffer in Central Iowa, USA. Agroforestry Systems. 44(2): 163–174. http://doi.org/10.1023/A:1006221921806.

This study compared root distributions and dynamics and total soil respiration among six sites comprising an agricultural buffer system—poplar, switchgrass, cool-season pasture grasses, corn, and soybean. During the sampling period, live fine-root biomass in the top 35 cm of soil averaged more than 6 Mg ha^{-1} for the cool-season grass, poplar, and switchgrass sites, although root biomass in the crop fields was less than 2.3 Mg ha^{-1} at its maximum. Roots of trees, cool-season grasses, and switchgrass extended to more than 1.5 m in depth, with switchgrass roots being more widely distributed in deeper horizons. Root density was significantly greater under switchgrass and cool-season grasses than under corn or soybean. Soil respiration rates, which ranged from 1.4 to 7.2 g C m^{-2} day^{-1}, were up to twice as high under the poplar, switchgrass, and cool-season grasses as in the cropped fields. Abundant fine roots, deep rooting depths, and high soil respiration rates in the multispecies riparian buffer zones suggest that these buffer systems added more organic matter to the soil profile, and therefore, provided better conditions for nutrient sequestration within the riparian buffers.

1999

Borken, W.; Xu, Y.-J.; Brumme, R.; Lamersdorf, N. 1999. A climate change scenario for carbon dioxide and dissolved organic carbon fluxes from a temperate forest soil. Soil Science Society of America Journal. 63(6): 1848–1855. http://doi.org/10.2136/sssaj1999.6361848x.

Little is known about the effect of soil drought and rewetting on CO_2 emission and DOC leaching under field conditions in temperate forest soils. The authors conducted the study in situ in a mature Norway spruce plantation in Solling, Germany. Soil moisture was simulated under two scenarios—summer drought of 172 days followed by a rewetting period of 19 days and summer drought of 108 days followed by a rewetting period of 33 days. Soil CO_2 emission, DOC, soil matric potential, and soil temperature were measured. The droughts tended to reduce soil respiration, although numbers were not significantly different from controls. Rewetting increased CO_2 emissions in the first 30 days by 48 percent ($P < 0.08$) in 1993 and 144 percent ($P < 0.01$) in 1994. The CO_2 flush during rewetting was highest at high soil temperatures and strongly affected the annual soil respiration rate. The drought and rewetting treatments did not affect the annual emission rate from the drought plot in 1993 (2981 kg C ha^{-1} yr^{-1}), but the rate increased by 51 percent ($P < 0.05$) to 4813 kg C ha^{-1} yr^{-1} in 1994. Results suggest that reduction of rainfall or changes in rainfall distribution due to climate change will affect soil CO_2 emissions and possibly C storage in temperate forest ecosystems.

Nadelhoffer, K.J.; Emmett, B.A.; Gundersen, P. [et al.]. 1999. Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests. Nature. 398(6723): 145–148. http://doi.org/10.1038/18205.

In this paper, the authors use evidence from N-tracer studies in nine forests to show that elevated N deposition is unlikely to be a major contributor to the putative CO_2

sink in forested northern temperate regions. Estimates of the effects of N deposition on forest C sequestration vary from 0.1 to 2.3 Pg C yr^{-1}, with most CO_2 uptake occurring in northern mid-latitudes, although estimates produced in this study indicate that N deposition currently accounts for less than 20 percent of the annual 1.5-to-1.9 Pg CO_2-C uptake attributed to forest growth. Soil, rather than tree biomass showed to be the primary sink for NO_3 and NH^4 inputs to temperate forests in this study. According to this review, long-term redistribution of nutrients from soils to trees from reforestation or climate warming is more strongly associated with the putative carbon sink in the northern mid-latitude forest.

Norby, R.J.; Wullschleger, S.D.; Gunderson, C.A. [et al.]. 1999. Tree responses to rising CO_2 in field experiments: implications for the future forest. Plant, Cell and Environment. 22(6): 683–714. http://doi.org/10.1046/j.1365-3040.1999.00391.x.

This paper reviews the results of prior experiments that had tested whether the short-term responses of tree seedlings in controlled environments would be sustained during several growing seasons in forest conditions. The authors' analysis confirmed evidence of continued and consistent stimulation of photosynthesis of about 60 percent for a 300 ppm increase in CO_2, although little evidence exists to support the long-term loss of sensitivity to CO_2 suggested by earlier potted tree seedling experiments. The effect of CO_2 on aboveground dry mass was more highly variable and greater than described by seedling studies. Leaf litter C:N ratio increases predicted were also not supported in field experiments. Wood mass per unit leaf area appears to be a more robust and informative measure of tree growth in these experiments for analysis of forest responses. Although inconsistencies exist between controlled and field results, the authors suggest that these experiments remain valuable for guiding ecosystem model development and revealing critical questions that must be addressed as experiments move to a more realistic scale.

2000

Ayres, M.P.; Lombardero, M.J. 2000. Assessing the consequences of global change for forest disturbance from herbivores and pathogens. Science of the Total Environment. 262(3): 263–286. http://doi.org/10.1016/S0048-9697(00)00528-3.

This paper examines potential impacts of climate change on forest disturbances by herbivores and pathogens. An extensive body of scientific literature suggests many scenarios and mechanisms by which climate change could significantly alter patterns of disturbance from forest herbivores and pathogens. The review of literature suggests that some types of disturbances will increase, some will decrease, and others will shift in their geographic occurrence. In all these cases, potentially important ecological and socioeconomic consequences exist. The assessment of impacts was limited to forests in North America and may not necessarily reflect impacts on trees in agroforestry systems. The greatest challenge at present is to assess the full spectrum of scenarios, identify the biological systems and geographic regions that face the greatest risks, and evaluate how specific forest management practices can mitigate the risks.

Groffman, P.M.; Gold, A.J.; Addy, K. 2000. Nitrous oxide production in riparian zones and its importance to national emission inventories. Chemosphere-Global Change Science. 2(3–4): 291–299. http://doi.org/10.1016/S1465-9972(00)00018-0.

In response to the lack of accounting for N_2O emission inventories from riparian buffers that intercept and process nitrogen from runoff, this review of the data on N_2O hot spots in the riparian zones reveals that, although current data are inadequate to propose a quantitative emission factor for riparian N_2O emissions, these emissions are likely to be significant in many regions. Large-scale riparian restoration efforts to achieve agricultural water quality objectives could cause significant changes in regional atmospheric N_2O budgets. The authors propose that detailed data on riparian N_2O emissions in relation to watershed mass balance be collected to allow for evaluation of IPCC methodology and for greater understanding of constraints on the magnitude of N_2O and $N_2O:N_2$ fluxes in riparian buffers. By exploring the potential for manipulation of this ratio in varying environments to reduce indirect N_2O emissions, an opportunity may exist to develop strategies for watershed restoration alongside N_2O yield reductions.

Post, W.M.; Kwon, K.C. 2000. Soil carbon sequestration and land-use change: processes and potential. Global Change Biology. 6(3): 317–327. http://doi.org/10.1046/j.1365-2486.2000.00308.x.

This review paper summarizes changes in SOC after changes in land use that favor C accumulation. The data summary provides a guide to approximate rates of SOC sequestration that are possible with management and indicates some of the major factors that influence the rates of organic C sequestration in soil. These factors include (1) increasing the input rates of organic matter, (2) changing the decomposability of organic matter inputs that increase light fraction organic C in particular, (3) placing organic matter deeper in the soil either directly by increasing belowground inputs or indirectly by enhancing surface mixing by soil organisms, and (4) enhancing physical protection through either intra-aggregate or organomineral complexes. Conditions favoring these processes generally occur when soils are converted from cultivated use to permanent perennial vegetation such as agroforestry. Variation exists in the rates of SOC change due to the differences in the influences of these various factors. To obtain a higher precision predictive capability of detecting changes in SOC, additional empirical studies are needed, combined with a better understanding of the biological and physical processes involved.

2001

Hunter, M.D. 2001. Effects of elevated atmospheric carbon dioxide on insect-plant interactions. Agricultural and Forest Entomology. 3(3): 153–159. http://doi.org/10.1046/j.1461-9555.2001.00108.x.

This review paper focuses on changes in plant quality under elevated CO_2 and alterations of changing food quality on the performance and abundance of insects on plants. Complex interactions among temperature, plant quality, and insect performance and range expansion make predictions of pest problems extremely difficult under elevated CO_2 conditions. For example, the reduced rates of insect growth observed under elevated CO_2 may disappear as temperature increases in response to rising levels of atmospheric CO_2. Despite this complexity, some generalizations may apply. Lower levels of N and higher C:N ratios in plants under elevated CO_2 generally have been associated with compensatory feeding and subsequent increases in levels of damage or defoliation. No differences were found between CO_2-mediated herbivore responses on woody and herbaceous plant species. Leaf-chewing insects generally increased their consumption of foliage under elevated CO_2 to compensate for reduced nutritional quality and suffered no adverse effects on pupal weights. Leaf-mining insects could compensate only partially by increased consumption, and their pupal weights declined. Phloem-feeding and whole-cell-feeding insects responded positively to elevated CO_2, with increases in population size and decreases in development time. Of course, exceptions will exist to these general patterns, but they provide a benchmark from which to develop hypotheses for future studies.

Lin, C.H.; McGraw, M.L.; George, M.F.; Garrett, H.E. 2001. Nutritive quality and morphological development under partial shade of some forage species with agroforestry potential. Agroforestry Systems. 53(3): 269–281. http://doi.org/10.1023/A:1013323409839.

This study examined the quality of 30 forage cultivars, both cool and warm season legumes (15) and grasses (15), grown under full sun and 50 percent and 80 percent shade to better understand the impact of shade in agroforestry systems. With few exceptions (‘Kobe’ lespedeza, Desmodium paniculatum, D. canescens), acid detergent fiber was either not affected or was slightly increased by shade, although neutral detergent fiber of shade tolerant forages slightly increased or was not affected for all but ‘Kobe’ lespedeza and ‘Martin’ tall fescue. Total mass of crude protein per pot increased or was not affected for all species except ‘Kobe’ lespedeza under 50 percent shade. Hog peanut, D. paniculatum and D. canescens showed higher crude protein in both 50 and 80 percent shade than in full sun. For select species, intermodal length and leaf area increased, although specific leaf dry weight decreased for plants grown in shade compared with those in full sun. Although increased cell wall content in some species under shade reduces forage digestibility, change in both acid detergent fiber and neutral detergent fiber was small (1 to 4 percent). Overall, these data reflect potential enhancement of forage quality for select species (smooth bromegrass, D. paniculatrum, D. canescens, ryegrass, KY 31 tall fescue and hog peanut) in shaded agroforestry environments.

Saxe, H.; Cannell, M.G.R.; Johnsen, Ø. [et al.]. 2001. Tree and forest functioning in response to global warming. New Phytologist. 149(3): 369–399. http://doi.org/10.1046/j.1469-8137.2001.00057.x.

Few experiments have isolated the effects of increased temperature due to climate change on trees and forests. This review offers a new synthesis by singling out the effects of temperature, which are arguably the most important of the environmental responses of ecosystems. This review focuses on tree and forest responses at boreal and temperate latitudes, ranging from the cellular to the ecosystem level. Adaptation to varying temperatures revolves around the trade-off between utilizing the full growing season and minimizing frost damage through proper timing of hardening in autumn and dehardening in spring. The evolutionary change in these traits must be sufficiently rapid, however, to compensate for the temperature changes. Management is critical for a positive response of forest growth to a warmer climate, and selection of the best species for the new conditions will be of vital importance.

Tufekcioglu, A.; Raich, J.W.; Isenhart, T.M.; Schultz, R.C. 2001. Soil respiration within riparian buffers and adjacent crop fields. Plant and Soil. 229(1): 117–124. http://doi.org/10.1023/A:1004818422908.

The study evaluated variability in soil respiration in riparian cool-season grass buffers, in reestablished multispecies (switchgrass and poplar) riparian buffers and in adjacent crop (maize and soybean) fields. Mean daily soil respiration across all treatments ranged from 0.14 to 8.3 g C m^{-2} d^{-1}. No significant differences existed between cool-season grass buffers and reestablished forest buffers, but respiration rates beneath switchgrass were significantly lower than those beneath cool-season grass. Soil respiration was significantly greater in both buffer systems than in the cropped fields. Seasonal changes in soil respiration were strongly related to temperature changes. Across all sites, soil temperature and soil moisture together accounted for 69 percent of the seasonal variability in soil respiration. Annual soil respiration rates correlated strongly with SOC ($R = 0.75$, $P < 0.001$) and fine root (less than 2 mm) biomass ($R = 0.85$, $P < 0.001$). Annual soil respiration rates averaged 1,140 g C m^{-2} for poplar, 1,185 g C m^{-2} for cool-season grass, 1,020 g C m^{-2} for switchgrass, 750 g C m^{-2} for soybean, and 740 g C m^{-2} for corn. Overall, vegetated buffers had significantly higher soil respiration rates than did adjacent crop fields, indicating greater soil biological activity within the buffers.

2002

Bale, J.S.; Masters, G.J.; Hodkinson, I.D. [et al.]. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology. 8(1): 1–16. http://doi.org/10.1046/j.1365-2486.2002.00451.x.

This review paper examines the direct effects of climate change on insect herbivores phenology, life cycles, and distribution. Temperature directly affects herbivore insects (e.g., winter survival, longer time for growth and reproduction). Individuals may develop faster at higher temperature and survival may be enhanced, but these insects may consequently have lower adult weight and fecundity. Insect responses to climate change may be specific to site, species, and host plant. Flexible, polyphagous species occupy different habitat types across a range of latitudes and altitudes and show that climate change is less likely to adversely affect high phenotypic and genotypic plasticity than those species that occupy narrow niches. The increase in likelihood of extreme events (e.g., storms, late frosts, and droughts) may outweigh small overall increases in mean temperature. Additionally, direct effects are difficult to disentangle from indirect ones, particularly in the interpretation of phenological responses and for effects along altitudinal versus latitudinal gradients. Adaptation to climate change by dispersal has been neglected and relatively little is known about the dispersal abilities of many insect herbivores. The review focused on natural ecosystems rather than agricultural systems.

Feldhake, C.M. 2002. Forage frost protection potential of conifer silvopastures. Agricultural and Forest Meteorology. 112(2): 123–130. http://doi.org/10.1016/S0168-1923(02)00058-8.

The author of this paper quantified the effect of thermal radiation from conifer tree canopies on forage canopy temperature at either end of the growing season (autumn and spring) in a 35-year-old mixed conifer silvopasture with variable tree density and orchard grass forage. A radiation frost potential sensor was designed to collect data at multiple sites simultaneously. On clear sky nights that induce high radiation frost prevalence, temperature from the designed long-wave radiation-sensitive sensor indicated that under 77 percent tree cover, temperature remained within one-half a degree of air temperature (similar for all silvopasture tree densities between 55 percent and 77 percent); under 7 percent cover (the open control field), forage temperature averaged 10.4 °C below air temperature during radiation frost events. Where radiation frosts are prevalent, conifer silvopasture may substantially extend both ends of the grazing season.

Hannah, L.; Midgley, G.F.; Millar, D. 2002. Climate change-integrated conservation strategies. Global Ecology and Biogeography. 11(6): 485–495. http://doi.org/10.1046/j.1466-822X.2002.00306.x.

This review paper provides a basic framework for integrating biogeography, conservation biology, and on-the-ground conservation management to produce CCS. It presents five elements of CCS: regional modeling; expanding protected areas; management of the matrix; regional coordination; and transfer of resources. Agroforestry may play an important role in CCS, particularly in regards to management of the matrix. The matrix of land uses surrounding protected areas provides a biophysical framework that both impacts core reserves and maintains biodiversity in transition. The authors suggest that biodiversity-friendly land uses such as agroforestry may provide habitat for many species, increasing the chance for persistence when climate change affects populations in reserves. Options that do not break the soil are especially important, as they improve the possibility of future use of the land for biodiversity management. No-till agriculture, forestry, forest plantations, agroforestry, and even low-density housing may be options.

Olson, B.E.; Wallander, R.T. 2002. Influence of winter weather and shelter on activity patterns of beef cows. Canadian Journal of Animal Science. 82(4): 491–501. http://doi.org/10.4141/A01-070.

This study aimed to determine if access to windbreaks altered diurnal activity patterns of beef cattle grazing a windy, foothill range site during winter, and if diurnal activity patterns could be related to weather. Cattle grazed behind windbreaks from 0 to 30 percent of the two winters observed. The animals used similar behaviors in both cases to minimize energy expended and to maximize energy gain. Time spent grazing and standing varied widely on a day-to-day basis, reflecting either an immediate response to that day's weather or a compensatory response to the previous day's weather, especially following cold, windy days. High wind velocity, associated with relatively warm days, did not affect grazing time. Likewise, grazing times of nonwindbreak and windbreak cattle were not related to temperature. During the first winter observed, nonwindbreak cattle spent slightly less time grazing and slightly more time lying down than windbreak cattle. The magnitude of the effect of the windbreak was slight and may have been a reflection of rigorous culling of cattle for performance in Montana winters and differences in body condition entering each winter.

Stamps, W.T.; Woods, T.W.; Linit, M.J.; Garrett, H.E. 2002. Arthropod diversity in alley cropped black walnut (*Juglans nigra* L.) stands in eastern Missouri, USA. Agroforestry Systems. 56(2): 167–175. http://doi.org/10.1023/A:1021319628004.

This study investigated the effects of two forages on the growth, nut production, and arthropod communities of alley cropped eastern black walnut (*Juglans nigra*). Plots of eastern black walnut, intercropped with alfalfa (*Medicago sativa*), smooth bromegrass, (*Bromis inermis*), and a no-vegetation control were sampled prior to each forage cutting. Tree growth measurements, nut yield, and other nut quality measurements were taken at the end of each growing season. No differences existed in tree growth among alleyway treatments. The first season's nut yield was greater from trees with vegetation-free alleyways; otherwise, nut production did not differ among the treatments. Arthropods were more numerous and diverse in alley cropped alfalfa than in alley cropped bromegrass or in the vegetation-free controls. Alfalfa intercropped with walnut supported twice as many predators and parasitic hymenoptera and one-half as many herbivores than alfalfa alone. These findings suggest monocropped alfalfa would be a more likely target of pest problems than alley cropped alfalfa. Alley cropped bromegrass supported a more diverse population of arthropods than did the vegetation-free control. Arthropod diversity in the tree canopies did not differ among treatments. Alley cropped forages supported a more diverse and even arthropod fauna than did adjacent monocropped forages. Overall, alley cropped forages had a relatively minor impact on the growth and nut yield of walnut trees.

Wullschleger, S.D.; Tschaplinski, T.J.; Norby, R.J. 2002. Plant water relations at elevated CO_2—implications for water-limited environments. Plant, Cell & Environment. 25(2): 319–331. http://doi.org/10.1046/j.1365-3040.2002.00796.x.

This paper explores existing literature related to four critical areas of research on the response of plants to elevated CO_2 and drought. The premise that increased root growth of plants in elevated CO_2 will increase water uptake, improve water balance, or help to avoid water deficits has not been well-supported with experimental data. It is also difficult to separate CO_2-induced effects on photosynthesis and growth from those on leaf transpiration and whole-plant water, although small changes in soil water content can be important to the survival of young plants where periodic droughts are frequent. As a result, CO_2-enrichment studies that link plant and soil-based processes are needed. Research on reductions in stomatal conductance and impacts on leaf water potential, and solute accumulation, osmotic adjustment, and dehydration tolerance are also included in this analysis. Ultimately, the implications of elevated CO_2 for water-use efficiency, water use, and whole-plant water relations are difficult to quantify and interpret because actual data often do not support common inferences regarding these effects. A framework with which to guide this research, identify new measurements, and evaluate relationships among multiple processes will be needed to understand the impact of elevated CO_2 and drought, through effects on water relations, on plant growth and development.

2003

Giese, L.A.B.; Aust, W.M.; Kolka, R.K.; Trettin, C.C. 2003. Biomass and carbon pools of disturbed riparian forests. Forest Ecology and Management. 180(1–3): 493–508. http://doi.org/10.1016/S0378-1127(02)00644-8.

In this study, riparian forest biomass and C pools were quantified for four riparian forests representing different seral stages in the South Carolina Upper Coastal Plain.

Three of the riparian forests were recovering from disturbance (thermal pollution), whereas the fourth represents a mature, relatively undisturbed riparian forest. The mature riparian forest stored approximately four times more C than the younger stands. As stands grew older fine root biomass increased, but an inverse relationship existed between percentages of fine root biomass to total biomass. The root C pool increased with forest age and development due to a combination of greater fine root biomass and higher root percent C. Aboveground NPP in young riparian forests rapidly approached and exceeded NPP of the more mature riparian forest. As a woody overstory became established (after about 8 to 10 years), annual litterfall rate as a function of NPP was independent of forest age, and litterfall amount in the young riparian forests was comparable with mature riparian forests. Biomass in the riparian forest floor and C pool declined with increasing riparian forest development. Woody debris in these riparian forests comprised a relatively small C pool.

Graham, P.J. 2003. Potential for climate change mitigation through afforestation: an economic analysis of fossil fuel substitution and carbon sequestration benefits. Agroforestry Systems. 59(1): 85–95. http://doi.org/10.1023/A:1026145321640.

This paper assesses the economic viability of using biomass from afforested lands and industrial wood waste as a feedstock for ethanol production to substitute for fossil fuels in the transportation sector and as a C sink. Using mathematical models accounting for costs, planning decisions, revenue, and an emission reduction discount rate, a hypothetical case study of an ethanol production facility in Alberta identified that production of 122 million liters of ethanol per year could have a net present value of CDN$245 million during 36 years, could supply up to 960 oven-dry tons of wood-biomass per day, and would reduce annual GHG emissions by ~349,000 tons of CO_2. The author identifies land rental and transportation as the most significant costs limiting afforestation potential. Although more analysis of scales of production is needed, based on this analysis, biomass for ethanol production is economically viable and stable, reduces GHG levels, and reduces reliance on fossil fuels.

Hefting, M.M.; Bobbink, R.; de Caluwe, H. 2003. Nitrous oxide emission and denitrification in chronically nitrate-loaded riparian buffer zones. Journal of Environment Quality. 32(4): 1194–1203. http://doi.org/10.2134/jeq2003.1194.

Denitrification and N retention in riparian buffer zones reduce diffuse N pollution from agricultural runoff. The denitrification process also emits the GHG N_2O. The researchers measured denitrification, nitrification, and N_2O emissions seasonally in grassland and forested buffer zones, along first-order streams in the Netherlands. Lateral nitrate loading rates were high, up to 470 g N m^{-2} yr^{-1}. Nitrous oxide emissions were significantly higher in the forested buffer zone (20 kg N ha^{-1} yr^{-1}) compared with the grassland buffer zone (2 to 4 kg N ha^{-1} yr^{-1}), whereas denitrification rates were not significantly different. Higher rates of N_2O emissions in the forested buffer zone were associated with higher nitrate concentrations in the ground water and higher soil moisture. The relatively high emissions found in the forested zone confirm the risk of riparian zones in nitrate-loaded agricultural landscapes as a significant source of GHG emissions. Based on the N_2O fluxes measured, the authors recommend that IPCC methodologies for quantifying indirect N_2O emissions distinguish between agricultural uplands and riparian buffer zones in landscapes receiving large N inputs.

Masera, O.R.; Garza-Caligaris, J.F.; Kanninen, M. [et al.]. 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO_2FIX V.2 approach. Ecological Modelling. 164(2–3): 177–199. http://doi.org/10.1016/S0304-3800(02)00419-2.

This paper presents testing and validation of the CO_2FIX V.2 model, developed as part of the Carbon Sequestration in Afforestation and Sustainable Forest Management (CASFOR) project. CO_2FIX Version 2 is a multicohort ecosystem-level model based on C accounting of forest stands, including forest biomass, soils, and products. This user-friendly tool for dynamically estimating the C sequestration potential of forest management, agroforestry, and afforestation projects estimates C stores in living biomass with a model that allows for competition, natural mortality, logging, and mortality from logging damage. Litter and humus stock pools model soil C, and short-, medium-, and long-lived wood product C storage dynamics are simulated with inclusion of processing efficiency, reuse of by-products, recycling, and disposal forms. Total C balance estimates for alternative management regimes in even and uneven-aged forests provide both temperate and tropical applications for the model using a full C accounting approach. The current version of the model can be downloaded at http://dataservices.efi.int/casfor/models.htm

Pallardy, S.G.; Gibbins, D.E.; Rhoads, J.L. 2003. Biomass production by two-year-old poplar clones on floodplain sites in the Lower Midwest, USA. Agroforestry Systems. 59(1): 21–26. http://doi.org/10.1023/A:1026176702075.

The objective of this research was to test different *Populus* genotypes in short-rotation plantations for biomass production and C sequestration capacity on floodplain sites under climatic conditions of the lower Midwest. Through two growing seasons on a Missouri River floodplain in central Missouri, *Populus* (three eastern cottonwood -*P. deltoids*- and one hybrid clone -*Populus deltoides x P. nigra*) planted at 1 × 1 m spacing were monitored for dimensional growth, leaf area development, and estimated biomass. Total biomass (aboveground and belowground) in the first year ranged from 3.9 Mg ha^{-1} (hybrid clone) to 1.9 Mg ha^{-1} (*P. deltoides*). Biomass in the second year was substantially higher, ranging from 13.9 Mg ha^{-1} (hybrid clone) to 7.4 Mg ha^{-1} (*P. deltoides*). Second year leaf area index values for the hybrid *Populus deltoides x P. nigra* clone indicated near complete canopy closure (4) in contrast to significantly lower leaf area index for *P. deltoides* (less than 2.4). Some evidence existed for differential allocation to roots and shoots among *Populus* clones, with 26C6R51 showing relatively more allocation to root biomass than other clones. Early results suggest that *Populus* in the lower Midwest appears feasible and competitive with other regions with respect to productivity, where belowground biomass patterns of *P. deltoides* may be exploited and where higher root-shoot ratio is desirable for drought-prone sites.

Tufekcioglu, A.; Raich, J.W.; Isenhart, T.M.; Schultz, R.C. 2003. Biomass, carbon and nitrogen dynamics of multi-species riparian buffers within an agricultural watershed in Iowa, USA. Agroforestry Systems. 57(3): 187–198. http://doi.org/10.1023/A:1024898615284.

This study evaluated biomass dynamics, C sequestration and plant N immobilization in multispecies riparian buffers, cool-season grass buffers and adjacent crop fields in central Iowa. The 7-year-old multispecies buffers were composed of poplar and switchgrass. Nonnative forage grasses dominated the cool-season grass buffers. Crop fields were under an annual corn-soybean rotation. Poplar had the greatest aboveground live biomass and N and C pools, whereas switchgrass had the highest mean aboveground dead biomass and C and N pools. During the 2-year sampling period, live fine root biomass and root C and N in the riparian buffers were significantly greater than in crop fields. Growing-season mean biomass and C and N pools were greater in the multispecies buffer than in either of the crop fields or cool-season grass buffers. Rates of C accumulation in plant and litter biomass in the planted poplar and switchgrass stands averaged 2,960 and 820 kg C ha^{-1} yr^{-1}1, respectively. Nitrogen immobilization rates in the poplar stands and switchgrass sites averaged 37 and 16 kg N ha^{-1} yr^{-1}, respectively. Planted riparian buffers containing native perennial species have potential to sequester C from the atmosphere and to immobilize N in biomass.

2004

Allen, S.C.; Jose, S.; Nair, P.K.R. [et al.]. 2004. Safety-net role of tree roots: evidence from a pecan (*Carya illinoensis* K. Koch)–cotton (*Gossypium hirsutum* L.) alley cropping system in the Southern United States. Forest Ecology and Management. 192(2–3): 395–407. http://doi.org/10.1016/j.foreco.2004.02.009.

This study of a pecan (*Carya illinoensis*)–cotton (*Gossypium hirsutum*) alley cropping system in northwestern Florida measured the potential for pecan tree roots to reduce NO_3 leaching into surface and subsurface ground water from N fertilizer agricultural use. A belowground polyethylene root barrier isolated tree roots from cotton alleys in one-half the number of test plots in order to provide two treatments—barrier and nonbarrier. Lysimeter samples from root depths of 30 cm and 90 cm revealed that in both treatments, the 90 cm-depth NO_3 levels were significantly lower, and NO_3 levels were significantly lower in the nonbarrier than the barrier treatment. Greater tree water uptake from the nonbarrier treatment compared with the barrier treatment may also have reduced water drainage and leaching rates. Total NH_4 leached was also measured and found to be higher in the barrier treatment than nonbarrier (P=0.0197), although NH_4 leaching levels in the barrier treatment decreased significantly in both depths after the first growing season. Overall, this study demonstrates that the competitive presence of tree roots in temperate alley cropping systems serve as a safety net for capturing excess fertilizer that leaches below the root zone of annual crops.

Green, C.; Byrne, K.A. 2004. Biomass: impact on carbon cycle and greenhouse gas emissions. In: Cleveland, C.J., ed. Encyclopedia of energy. New York: Elsevier: 223–236. http://www.sciencedirect.com/science/article/pii/B012176480X004186.

This paper explores the various applications of biomass for its potential influence on stabilizing GHG emissions. The authors review the biological, political-social, and economic factors influencing the role of biomass around the world, including forest conservation, afforestation and reforestation activities, efficiency of conversion technologies and choice of crops for biomass production, national agreements for GHG emission reductions, applications in developed and less developed countries, the role of subsidies, and major impact areas of uses (house heating, construction, fossil fuels). They identify land availability and competition for food production as the largest limiting factor to maximizing the potential of biomass production. They recommend a detailed assessment of biomass in the C cycle at a global, regional, and local scale with a life-cycle approach to determine whether biomass is better utilized as a sink, as fuel, or as long-lived timber products. Policy and economic incentives to stimulate reductions in GHG emissions will strongly influence the success of sustainable biomass production.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science. 304(5677): 1623–1627. http://doi.org/10.1126/science.1097396.

This article examines the potential for soil C sequestration to beneficially impact food security through soil quality improvement, with additional climate change mitigation impacts. Based on a review of the current soil C sequestration rates (50 to 66 percent of the historic C loss of 42 to 78 gigatons of C), the author suggests that adoption of recommended management practices that may enhance crop yields globally, including no-till farming, cover crops, improved grazing, water conservation, diverse cropping systems, agroforestry and others, is an inevitable necessity in lieu of extractive farming practices, with emphasis in the tropics. According to this report, soil C sequestration improves and sustains biomass-agronomic productivity, although potentially offsetting fossil-fuel emissions by 0.4 to 1.2 Gt C yr^{-1}, or 5 to 15 percent of global emissions.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma. 123(1–2): 1–22. http://doi.org/10.1016/j.geoderma.2004.01.032.

This review of global C emissions in relation to SOC depletion and restoration depicts the role of recommended management practices for reducing short-term atmospheric CO_2 emissions and identifies research and development priorities toward achieving these practices. Conversion of marginal lands to restorative uses, adoption of conservation tillage, nutrient cycling, and other soil and water conservation measures described in this paper have the capacity to sequester 50 to 1,000 kg ha^{-1} yr^{-1} of C (one-fourth to one-third of the annual increase in atmospheric CO_2 estimated at 3.3 Pg C yr^{-1}); however, soil C sequestration has a limited capacity and is but one strategy toward mitigation of anthropogenic enrichment of atmospheric CO_2. Still, the implementation of these recommended management practices are considered a win-win strategy given the multifold outcomes of SOC restoration, including augmentation of biomass production and crop yields, purification of surface and ground waters, offsets of fossil fuel emissions, and restored soil health.

Montagnini, F.; Nair, P.K.R. 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforestry Systems. 61–62(1–3): 281–295. http://doi.org/10.1023/B:AGFO.0000029005.92691.79.

This paper reviews the C storage potential for agroforestry systems in tropical and temperate regions. Average C storage by agroforestry practices are estimated as 9, 21, 50, and 63 Mg C ha^{-1} in semiarid, subhumid, humid, and temperate regions. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C ha^{-1} yr^{-1}. Agroforestry can have an indirect effect on C sequestration when it helps decrease pressure on natural forests, which are the largest sink of terrestrial C. Another indirect avenue of C sequestration is through the use of agroforestry technologies for soil conservation, which could enhance C storage in trees and soils. The area under existing and potential agroforestry practices is not known, and the *in situ* and *ex situ* C storage and dynamics in different agroforestry practices has not been determined yet. Proper design and management of agroforestry practices can make them effective C sinks.

Nearing, M.A.; Pruski, F.F.; O'Neal, M.R. 2004. Expected climate change impacts on soil erosion rates: a review. Journal of Soil and Water Conservation. 59(1): 43–50. http://www.jswconline.org/content/59/1/43.short.

This paper reviews recent studies conducted by the authors that address the potential effects of climate change on soil erosion rates. It uses Output from two atmosphere-ocean GCMs: the Hadley Centre and the Canadian Centre models. Rainfall erosivity levels likely will rise with projected climate change across much of the United States, although results vary from region to region. A general increase in rainfall erosivity is predicted for large parts of the Eastern United States, as well as an increase across the Northern States of the United States and Southern Canada. Results were more variable for other regions depending on the models. Simulation studies suggest where rainfall amounts increase, erosion and runoff will increase at an even greater rate. Erosion will increase approximately 1.7 percent for each 1 percent change in annual rainfall, and runoff will increase by 2 percent. Even in cases where annual rainfall would decrease, system feedbacks related to decreased biomass production could lead to greater susceptibility of the soil to erode. The change in erosion rates as a function of biomass, however, is complex, and the overall effect is difficult to predict.

Sharrow, S.H.; Ismail, S. 2004. Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agroforestry Systems. 60(2): 123–130. http://doi.org/10.1023/B:AGFO.0000013267.87896.41.

This study examines the hypothesis that silvopasture systems, which combine C and N storage capacity of aboveground woody plant tissue and fibrous litter with belowground grassland nutrient cycling patterns, may accrue more C and N than either pastures or timber plantations. Measurements of C and N on three 11-year-old Douglas fir (*Pseudotsuga menziesii*), perennial ryegrass (*Lolium perenne*), and subclover (*Trifolium subterraneum*) agroforests were compared with ryegrass-subclover pastures and Douglas fir timber plantations near Corvallis, OR. Agroforests accumulated 740 kg ha^{-1} yr^{-1} more C than forests and 520 kg ha^{-1} yr^{-1} more C than pastures. N in agroforests and pastures were 530 kg ha^{-1} and 1,200 kg ha^{-1} greater than plantations respectively. The subclover present in both agroforests and pasture is attributed to the significant source of N fixed and stored in these land use systems.

Thevathasan, N.V.; Gordon, A.M. 2004. Ecology of tree intercropping systems in the North temperate region: experiences from southern Ontario, Canada. Agroforestry Systems. 61–62(1–3): 257–268. http://doi.org/10.1023/B:AGFO.0000029003.00933.6d.

This paper summarizes ecological information generated from 15 years of tree- crop intercropping research at the University of Guelph and in other parts of Canada. Ten tree species were planted and annually intercropped with corn, soybean, and winter wheat or barley. Tree rows were spaced at 12.5 or 15 m apart with within-row spacing of 3 or 6 m. Crops were planted between the tree rows every year according to local standard cultural practices. Yields of C3 crops—those that fix and reduce inorganic CO_2 into organic compounds using only the C3 pathway in photosynthesis—intercropped with trees, as well as growth of trees, did not differ from those in corresponding sole-stand (conventional) systems of crops and trees. SOC content, soil health, and bird and insect diversity increased in the intercropped area. The C sequestration potential in fast-growing tree (hybrid poplar)-based intercropping systems was four times more than that reported for conventional agricultural fields in the region. Because of reduced fertilizer use and more efficient N-cycling, the tree-intercropping systems could also lead to the reduction of N_2O emissions from agricultural fields by about 0.7 kg ha^{-1} yr^{-1}. Based on results of this research, tree-crop intercropping shows great potential for this region, and this land-management option can be placed above conventional agriculture in terms of long-term productivity and sustainability.

Thevathasan, N.V.; Gordon, A.M.; Simpson, J.A. [et al.]. 2004. Biophysical and ecological interactions in a temperate tree-based intercropping system. Journal of Crop Improvement. 12(1–2): 339–363. http://doi.org/10.1300/J411v12n01_04.

This long-term study aimed to quantify the numerous biophysical interactions that occur at the tree-crop interface in order to improve the ecological understanding of TBI systems. A variety of spacing, crop compatibility, tree growth, and survival experiments in Guelph, Ontario, Canada employed 10 tree species within genera *Picea*, *Thuja*, *Pinus*, *Juglans*, *Quercus*, *Fraxinus*, *Acer*, and *Populus*. N transfer from fall-shed leaves to adjacent crops consistently enhanced soil nitrification. SOC adjacent to tree rows increased more than 1 percent, and NO_3 loading in adjacent waterways reduced by 50 percent. Bird diversity, small mammal populations, and earthworm abundance also increased due to the presence of trees. Sequestration of C was five times higher in TBI systems compared with conventional agriculture as well. These results support the viability of TBI in southern Ontario, Canada, based on the beneficial effects of trees in relation to soil fertility, productivity and nutrient cycling, and microclimate, resulting in higher economic returns when paired with an appropriate crop.

2005

Hazlett, P.W.; Gordon, A.M.; Sibley, P.K.; Buttle, J.M. 2005. Stand carbon stocks and soil carbon and nitrogen storage for riparian and upland forests of boreal lakes in northeastern Ontario. Forest Ecology and Management. 219(1): 56–68. http://doi.org/10.1016/j.foreco.2005.08.044.

This paper examines the potential C removal impact of harvesting wood from riparian forests with that of upland boreal forests. Forest C and soil C and N storage were measured in 21 lake shorelines and upland forests in northeastern Ontario, Canada. Despite significant differences in stocking density and species composition between riparian and upland sites, the total aboveground C storage did not differ, although a greater proportion of total site C in riparian areas was stored in the overstory tree layer (more than 5 cm DBH) compared with upslope areas. Riparian forest organic soil horizons stored greater C and N compared with upslope stands, whereas upslope forest mineral soil horizons stored greater C and N than those within the riparian forests. The authors identify that full-tree harvesting in upslope stands result in removal of approximately 76 percent of total aboveground C compared with 98 percent loss of total aboveground C in riparian forests from the same harvest. The magnified impact of harvesting in riparian zones suggests that selective or modified harvesting may decrease C removal levels equal to full-tree harvests in upslope forests.

Lal, R. 2005. Forest soils and carbon sequestration. Forest Ecology and Management. 220(1–3): 242–258. http://doi.org/10.1016/j.foreco.2005.08.015.

This paper offers a synthesis relating to forest SOC stock and factors affecting its dynamics, in addition to an assessment of the role of forest management on SOC sequestration, sampling and analytical procedures and modeling options, and challenges of achieving forest SOC stock potential. The rate of SOC sequestration and the magnitude and quality of soil C stock depend on the complex interaction between climate, soils, tree species and management, and chemical composition of litter. Maximized forest SOC stock requires site preparation, fire management, afforestation, species management, and use of fertilizers and soil amendments. Projected climate changes may also affect soil C stock through increased availability of N caused by mineralization, CO_2 fertilization effect, and reduction in soil C from increase in soil temperature and the attendant oxidation. Global potential of C sequestration by forest soils is estimated at 0.4 Pg C yr^{-1} (1 to 3 Pg C yr^{-1} total in forest biomes).

Maracchi, G.; Sirotenko, O.; Bindi, M. 2005. Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. Climatic Change. 70(1–2): 117–135. http://doi.org/10.1007/s10584-005-5939-7.

This paper reviews the impact of climate variability and climate change on European agriculture and forestry. Based on the review, the effects of global change on Europe are likely to increase productivity of agricultural and forestry systems, because increasing CO_2 concentration will directly increase resource use efficiencies of plants and warming will give more favorable conditions for plant production in Northern Europe. In southern areas, however, the benefits of the projected climate change will be limited, although the disadvantages will predominate. The increased water use efficiency caused by increasing CO_2 will compensate only partially for the negative effects of increasing water limitation. In the southern areas, the increase in water shortage and extreme weather events (e.g., heat waves, wind speed, etc.) may also cause higher yield variability and an increase in abiotic and biotic damages (i.e., wind, fire, pest disease damages). These negative impacts could be addressed in supporting the development and introduction of specific agricultural and forestry adaptive management measures (e.g., agronomic and water conservation practices, modification of microclimate, regular forest management, shorter rotations, etc.).

Suwanwaree, P.; Robertson, G.P. 2005. Methane oxidation in forest, successional, and no-till agricultural ecosystems. Soil Science Society of America Journal. 69(6): 1722–1729. http://doi.org/10.2136/sssaj2004.0223.

This study examines the effects of soil disturbance and N-fertilizer additions on CH_4 oxidation in mature forests, mid-successional, and no-till maize ecosystems in southwest Michigan. Soil tillage alone did not show any significant effect on soil CH_4 uptake at these sites, although the depth of the simulated tillage was about one-half of normal tillage depth, where more than one-half of CH_4 oxidation takes place. Forest sites showed the highest oxidation rates, with successional and no-till sites at 75 percent and 12 percent of the forest oxidation rates, respectively. The high forest CH_4 oxidation is attributed to soil temperature, total C, N, and ammonium differences, in addition to the lower soil bulk density in the forest implying more gas diffusion, thus more soil CH_4 uptake by methanotrophs. The successional field rates of CH_4 oxidation suggest a recovery period of more than 50 years for CH_4 uptake following cessation of agricultural activities. The authors conclude that the impact of agriculture on CH_4 oxidation is likely due primarily to greater N availability via N-fertilization, and that recovery of CH_4 suppression following cessation of elevated N inputs is related to slow-changing soil properties such as SOM and microbial community structure.

2006

Asshoff, R.; Zotz, G.; Körner, C. 2006. Growth and phenology of mature temperate forest trees in elevated CO_2. Global Change Biology. 12(5): 848–861. http://doi.org/10.1111/j.1365-2486.2006.01133.x.

This study investigated how mature trees will react to future CO_2 concentrations. The experiment consisted in exposing ca. 100-year-old temperate forest trees at the Swiss Canopy Crane site near Basel, Switzerland to a ca.

540 ppm CO_2 atmosphere using web-FACE technology and reporting growth responses to elevated CO_2. The web-FACE method of CO_2-enrichment made it possible for the first time to study growth responses to elevated CO_2 in tall trees growing in a near-natural forest. The first 4 years of treatment provide little evidence for any changes in tree growth and phenology in elevated CO_2. Several more years are needed to ascertain longer term trends.

Desprez-Loustau, M.-L.; Marçais, B.; Nageleisen, L.-M. [et al.]. 2006. Interactive effects of drought and pathogens in forest trees. Annals of Forest Science. 63(6): 597–612. http://doi.org/10.1051/forest:2006040.

This review synthesizes the available knowledge on drought-disease interactions in forest trees with a focus on (1) evidence and patterns of drought-disease interactions, (2) current understanding of processes and mechanisms, and (3) three well-documented cases studies. The study reviewed about 100 studies dealing with specific cases of drought-disease interaction. Most of the studies referred to a positive association between drought and disease, i.e., disease favored by drought or drought and disease acting synergistically on tree health status, with a predominance of canker or dieback diseases. The type of disease-related variables (incidence versus severity) and the intensity and timing of water stress proved to be significant factors affecting the drought- infection interaction. Direct effects of drought on pathogens are generally negative, although most fungal pathogens exhibit an important plasticity and can grow at water potentials well below the minimum for growth of their host plants.

Hemery, G.E.; Russell, K. 2006. Advances in walnut breeding and culture in the United Kingdom. Acta Horticulturae. 705: 95–101. http://dx.doi.org/10.17660/ActaHortic.2005.705.9.

This paper reports on walnut breeding programs in the United Kingdom (UK). Recent research activities in the UK stimulated renewed interest in various walnut species and hybrids as providers of timber and fruit crop. In addition, these walnut species are likely to be more suitable than many native tree species to the climatic conditions predicted for the UK within a single generation. A substantial collection of walnut germplasm was established through complimentary research programs at the Northmoor Trust and East Malling Research. The genetic resource within these combined programs provides an unrivalled resource for breeding and genetic improvement both for timber and fruit production and for genetic diversity and adaptive trait studies. Jointly, the two programs initiated a black walnut timber improvement program, comprising seedling progeny from seven European countries and 13 U.S. States.

Kallenbach, R.L.; Kerley, M.S.; Bishop-Hurley, G.J. 2006. Cumulative forage production, forage quality and livestock performance from an annual ryegrass and cereal rye mixture in a pine walnut silvopasture. Agroforestry Systems. 66(1): 43–53. http://doi.org/10.1007/s10457-005-6640-6.

To complement research in silvopasture using winter annual forages, this paper researches forage and livestock production from annual ryegrass or cereal rye in a silvopasture mixture of pitch pine (*Pinus rigida*) x loblolly pine (*Pinus taeda*) hybrids and black walnut (*Juglans nigra*) versus an open (nonforested) pasture. The study was conducted near New Franklin, MO. Cumulative forage production in the silvopasture treatment was reduced by approximately 20 percent compared with the open pasture, but the forage was of superior quality. Moreover, beef heifer average daily gain and gain per hectare were equal for both treatments. By adopting silvopasture practices, beef producers in the lower Midwest could improve long-term farm income by obtaining substantial future income from the forest products without sacrificing livestock production.

Matyssek, R.; Le Thiec, D.; Löw, M. [et al.]. 2006. Interactions between drought and O_3 stress in forest trees. Plant Biology. 8(1): 11–17. http://doi.org/10.1055/s-2005-873025.

This review highlights tropospheric ozone (O_3)-drought interactions in biochemical and ecophysiological responses of trees, as these interactions pertain to temperature increases and altered precipitation with increased O_3 and CO_2 levels, in this case, in relation to the 2003 drought in Central Europe. Tree responses vary depending on genotype and factorial regimes relative to stress event timing. If O_3 alters stomatal regulation, tolerance to both drought and persisting O_3 exposure may be weakened, although drought preceding O_3 stress may also build a tolerance for O_3 changes due to stomatal closure that prevents O_3 uptake and injury. Tree *tuning* between O_3 uptake and defense capacity is critical for stress tolerance. Limited C fixation may also result from the trade-off with O_3 exclusion on stomatal closure. Reduction in stem growth is more closely associated with drought than with annual ozone changes. Ultimately, both ozone and drought can have destabilizing effects on tree stress resistance.

Oelbermann, M.; Voroney, R.P.; Thevathasan, N.V. [et al.]. 2006. Soil carbon dynamics and residue stabilization in a Costa Rican and southern Canadian alley cropping system. Agroforestry Systems. 68(1): 27–36. http://doi.org/10.1007/s10457-005-5963-7.

This study quantifies C input, changes in the SOC pool, residue decomposition rate, residue stabilization efficiency, and annual rate of SOC accumulation in a 13-year-old hybrid poplar alley cropping system in Southern Canada and a 19-year-old tropical (*Erythrina poeppigiana*) alley cropping system in Costa Rica. Tree prunings contributed 401 g C m^{-2} yr^{-1} in Costa Rica compared with C input of 117 g C m^{-2} y^{-1} from litterfall at the Canadian site. Although crop residue C input from maize, soybeans, and wheat grown in alley cropping systems were not significantly different from the sole crop in Canada, Costa Rican crop residue C inputs were significantly greater in the alley crop compared with the sole crop. The SOC pool mirrored this difference to a 20 cm depth in the Costa Rican alley cropping system. Residue stabilization (the efficiency of the stabilization of added residue added to the soil C pool) to a 20 cm depth was more efficient in alley cropping systems of Southern Canada (31 percent) compared with Costa Rica (40 percent) due to a lower organic matter decomposition rate in Southern Canada, although average annual accumulation rate of SOC is greater in Costa Rica due to the greater input of organic material derived from prunings. Given variability in the amount of C input from prunings and litterfall based on tree age, density, and site-specific factors including edaphic and climatic conditions, results from this study are consistent with similar analyses.

Peichl, M.; Thevathasan, N.V.; Gordon, A.M. [et al.]. 2006. Carbon sequestration potentials in temperate tree-based intercropping systems, southern Ontario, Canada. Agroforestry Systems. 66(3): 243–257. http://doi.org/10.1007/s10457-005-0361-8.

This study investigated the C sequestration potential in two TBI systems, poplar-barley and Norwegian spruce-barley, and one monoculture system—barley. The study was conducted in southern Ontario, Canada. Aboveground and belowground C in trees, soil C, soil respiration, and C leaching were determined *in situ* for each system. The data were coupled with complementary data from the literature and C cycle models, C pools and fluxes were constructed for each system. Total C pools (including an assumed barley C pool of 3.4 and 2.9 t C ha^{-1} within the sole cropping and the intercropping systems respectively) were 96.5, 75.3, and 68.5 t C ha^{-1} within poplar, spruce intercropping, and in barley sole cropping systems, respectively. The results suggest that intercropping systems have a greater potential in reducing the atmospheric CO_2 concentration compared with sole cropping systems. Intercropping systems could contribute to a substantial GHG mitigation strategy globally. Further research is needed to quantify the aboveground and belowground C contents of mature intercropped trees at the end of their rotation period.

Rennenberg, H.; Loreto, F.; Polle, A. [et al.]. 2006. Physiological responses of forest trees to heat and drought. Plant Biology. 8(5): 556–571. http://doi.org/10.1055/s-2006-924084.

This article reviews current knowledge on the effects of heat and drought on key metabolic processes for growth and productivity of forest trees, based on data collected from the 2003 Central Europe summer drought. General consequences of photosynthesis and respiration at the cellular and community levels reveal that the photosynthetic apparatus was probably negatively affected by the heat wave. Findings related to nutrient uptake, partitioning, and competition for nutrients are also summarized. Additionally, this article discusses the interaction of heat and drought with stress compensation mechanisms and emission of biogenic VOCs for their connection to C metabolism and atmospheric pollution contributing to ozone formation. It also discusses species-specific findings in detail and suggests the complexity and lack of information to fully understand the impacts of repeated heat and drought events on forest ecosystems.

Thuiller, W.; Lavorel, S.; Sykes, M.T.; Araújo, M.B. 2006. Using niche-based modelling to assess the impact of climate change on tree functional diversity in Europe. Diversity and Distributions. 12(1): 49–60. http://doi.org/10.1111/j.1366-9516.2006.00216.x.

The authors of this paper use niche-based models to analyze the impact of climate change on 122 tree species distributions and bioregional functional diversity in Europe. Using present climate data, a 2080 climate scenario considered two dispersal assumptions—no dispersal and limited dispersal. Temperate areas were projected to lose both species richness and functional diversity due to the migration of broadleaved deciduous species to boreal forests, coinciding with an increase in boreal species richness and functional diversity. A loss of broadleaved functional types, but overall maintenance of the functional group is predicted for Atlantic areas under an intermediate climate scenario. Although the current niche-based models cannot take into account the migration process of species as they coincide with environmental change, the predicted and observed replacement of deciduous by evergreen broadleaved trees in temperate climates could have significant functional impacts such as shifting fire regimes and productivity patterns.

2007

Davies, Z.G.; Pullin, A.S. 2007. Are hedgerows effective corridors between fragments of woodland habitat? An evidence-based approach. Landscape Ecology. 22(3): 333–351. http://doi.org/10.1007/s10980-006-9064-4.

The authors conducted a systematic review to evaluate the effectiveness of hedgerow corridors in promoting population viability of faunal species and biodiversity within remnant woodland habitat patches. Systematic searching yielded 26 studies that satisfied the review inclusion criteria. The empirical evidence currently available is insufficient to evaluate the effectiveness of hedgerow corridors as a conservation tool to promote the population viability of woodland fauna. Little can be inferred from the available empirical evidence with regard to the breadth and type of species (e.g., habitat specialists or type of autoecology) that would benefit from hedgerow corridors. However, the studies did provide anecdotal evidence of positive local population effects and indicated that some species use hedgerows as movement conduits. The research suggests that hedgerows with greater diversity of vegetation and structural complexity are favorable for movement over hedgerows of a more basic composition.

Desprez-Loustau, M.-L.; Robin, C.; Reynaud, G. [et al.]. 2007. Simulating the effects of a climate-change scenario on the geographical range and activity of forest-pathogenic fungi. Canadian Journal of Plant Pathology. 29(2): 101–120. http://www.tandfonline.com/doi/abs/10.1080/07060660709507447.

This study explored the possible effects of climate change on the geographic range or local impact of several forest-pathogenic fungi within France. Specific statistical models and the generic model CLIMEX were used to make simulations under a future climatic scenario. The authors studied a range of pathogens commonly reported in Europe. The predicted warming would be favorable to most of the studied species, especially those for which winter survival is a limiting factor. For some species, the favorable effect of warming would be counterbalanced by the negative effect of a decrease in summer rainfall, leading to a stable or decreased impact of these pathogens by the end of the century. Conversely, other species that water stress favors should have an increased impact. Although the results were specific to France, they likely indicate general pathogen responses that could affect agroforestry systems.

Geßler, A.; Keitel, C.; Kreuzwieser, J. [et al.]. 2007. Potential risks for European beech (*Fagus sylvatica* L.) in a changing climate. Trees: Structure and Function. 21(1): 1–11. http://doi.org/10.1007/s00468-006-0107-x.

This review provides an assessment of risk for European beech (*Fagus sylvatica*) under climate change with particular focus on increased CO_2 concentrations, higher air temperatures, and intensified drought or waterlogging conditions. Climate models predict an increase in temperature of about 1 °C on global scale and up to 2 °C for the southern part of Central Europe within the next 40 years. Together with the increase in precipitation during spring and a higher frequency of intensive drought periods in summer, forest trees will have to withstand drastic changes in environmental conditions. Beech may suffer from drought during periods of low precipitation on shallow soils with low water storage capacity and from waterlogging in floodplains, as well as on soils with low drainage capacity in the future. On particular sites, beech may lose its dominance and growing potential compared with drought or flooding-tolerant species. This finding may affect agroforestry practices utilizing European beech.

Howden, S.M.; Soussana, J.-F.; Tubiello, F.N. [et al.]. 2007. Adapting agriculture to climate change. Proceedings of the National Academy of Sciences. 104(50): 19691–19696. http://doi.org/10.1073/pnas.0701890104.

The objectives of this paper are first to outline options for cropping and livestock systems, forestry, and fisheries using the literature on crop yields as an example to assess the benefits of adaptation; and second, to suggest some general pathways that can help move from technical assessment of adaptation options to more practical action. Listed farm-level practices and technologies exist that suit low-end adaptation purposes for cropping systems, livestock systems, forestry, and fisheries. In addition, at an upper level, measures are suggested to facilitate a broader range of responses. The implementation of adaptation options is likely to have substantial benefits under moderate climate change for some cropping systems. However, likely limits to their effectiveness exist under more severe climate changes. The article recommends more systemic changes in resource allocation such as targeted diversification of production systems, including agroforestry practices. Increased adaptation action will require integration of climate change risk with a more inclusive risk management framework, taking into account climate variability, market dynamics, and specific policy domains.

Kirby, K.R.; Potvin, C. 2007. Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. Forest Ecology and Management. 246(2–3): 208–221. http://doi.org/10.1016/j.foreco.2007.03.072.

This study examined aboveground and belowground C stocks in three land use types (managed forests, agroforests, and pasture) in the tierra colectiva of eastern Panama in order to collect evidence for a functional relationship between tree-species diversity and C storage in each land use type and to explore the effects of the use of particular tree species on C storage. Average stored C including all vegetation-based C stocks and soil C to 40 cm depth averaged 335 Mg C ha^{-1} in managed forest sites, 145 Mg C ha^{-1} in traditional agroforests, and 46 Mg C ha^{-1} in pastures. A relationship between C storage and diversity was not detected, although relative contributions of species to C storage per ha in forests and agroforests were highly skewed and often not proportional to the species' relative abundances. Given that several of the tree species selected for timber production in managed forests were the greatest contributors to C storage, species-level management requires selective logging in these forests if C-impoverishment is to be avoided. The authors suggest that protecting forests from conversion to pasture, reducing monoculture teak plantation land use, and expanding agroforests into areas currently in pasture would have the greatest positive impact on C stocks and also contributing to biodiversity and livelihood benefits.

Marcos, G.M.; Obrador, J.J.; García, E. [et al.]. 2007. Driving competitive and facilitative interactions in oak dehesas through management practices. Agroforestry Systems. 70(1): 25–40. http://doi.org/10.1007/s10457-007-9036-y.

This analysis of the spatial distribution and temporal dynamics of both aboveground and belowground resources in dehesa agroforestry systems in Central-Western Spain indicates that trees could have a positive impact on understory crops or forage and mutually benefit tree health. Spatial variability of resources (light, soil moisture, and fertility), microclimate, fine roots of both herbaceous plants, trees, and forage yields were measured to compare nutritional and physiological status, growth and acorn production of oaks in cropped (fodder crop), grazed (native grasses), and encroached (woody understory) dehesa plots. Although light interception from tree cover was limited to the direct vicinity of the trees, soil fertility was positively affected to a broader spatial extent, irrespective of soil management. Soil moisture varied very little and foliar nutrient content of oaks did not increase significantly with crop fertilization, indicating minimal competition for nutrients and soil water between trees and crops. In fact, crop production was higher beneath trees than beyond the trees in unfertilized plots, and trees also benefited from crop or pasture management. Trees in dehesas, compared with those in encroached or forest plots, showed significantly improved nutritional and physiological status, faster growth, and higher fruit productivity.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forests of the future. Ecological Applications. 17(8): 2145–2151. http://doi.org/10.1890/06-1715.1.

In this review paper, the authors offer a conceptual framework for developing forest management strategies in a context of climate change. A framework of options is presented that includes adaptation strategies, mitigation strategies, and integrative approaches. The approaches should be flexible, in steps, and with capacity to modify direction as situation change. Adaptive strategies include resistance options (forestall impacts and protect highly valued resources), resilience options (improve the capacity of ecosystems to return to desired conditions after disturbance), and response options (facilitate transition of ecosystems from current to new conditions). Mitigation strategies include options to sequester C and reduce overall GHG emissions. Management practices such as assisting species migrations, creating porous landscapes, or increasing diversity in genetic and species planting mixes may be appropriate. Essential to managing for uncertainty is the imperative to learn as you go.

Povellato, A.; Bosello, F.; Giupponi, C. 2007. Cost-effectiveness of greenhouse gases mitigation measures in the European agro-forestry sector: a literature survey. Environmental Science & Policy. 10(5): 474–490. http://doi.org/10.1016/j.envsci.2007.02.005.

The authors review literature assessing that cost effectiveness and efficiency of GHG mitigation strategies targeted to the agricultural and forestry sectors. Different policy instruments and their estimated costs and effectiveness are evaluated with a focus mainly on European countries. All the studies indicate that the agricultural and forestry sector can potentially provide GHG abatement at competitive costs. Mitigating CH_4 emissions seems to be cheaper than for N_2O. C sequestration is more cost effective with appropriate forest management measures. Afforestation, cropland management, and bioenergy are less economically viable due to competition with other land use. Regional variability is one of the main drawbacks to fully assessing the cost-effectiveness of different measures. Mitigation policies should be carefully designed either to balance costs with expected benefits in terms of social welfare.

Sauer, T.J.; Cambardella, C.A.; Brandle, J.R. 2007. Soil carbon and tree litter dynamics in a red cedar–scotch pine shelterbelt. Agroforestry Systems. 71(3): 163–174. http://doi.org/10.1007/s10457-007-9072-7.

This study quantifies C stores in surface soil layers and tree litter within and adjacent to a 35-year-old two-row shelterbelt, composed of red cedar (*Juniperus virginiana*) and scotch pine (*Pinus sylvestris*) on Tomek silt loam in eastern Nebraska. Total, organic, and inorganic C, total N, texture, pH, and nutrient content were measured in soil samples at 0-to-7.5 and 7.5-to-15 cm depth increments under the shelterbelt and in cultivated fields. SOC in the 0-to-15 cm layer within the shelterbelt was significantly greater than in the cultivated fields (55 percent greater in the 0-to-7.5 cm layer), representing an annual accrual of 10.6 g m^{-2} yr^{-1}. Total N concentration and mass were also significantly greater under the shelterbelt. Total litter mass between ~1,000 g m^{-2} and 8,000 g m^{-2} was greatest east of the tree row and least near the shelterbelt margins. Tree litter contained an additional ~1,300 g C m^{-2} and is attributed to contributing increased organic inputs with wind-blown sediment under the shelterbelt. These results indicate that tree litter provides contributions to the overall C sequestration potential of the shelterbelt and should be included in a full accounting of this system's C sequestration potential.

Verchot, L.V.; Noordwijk, M.V.; Kandji, S. [et al.]. 2007. Climate change: linking adaptation and mitigation through agroforestry. Mitigation and Adaptation Strategies for Global Change. 12(5): 901–918. http://doi.org/10.1007/s11027-007-9105-6.

The authors examine the scientific evidence on the mitigation and adaptation potential of agroforestry in the humid and subhumid tropics, particularly to reduce the vulnerability of smallholder farmers to increased interannual variability in rainfall and temperature. Tree-based systems have some advantages for maintaining production during wetter and drier years. First, their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during droughts. Second, increased soil porosity, reduced runoff, and increased soil cover lead to increased water infiltration and retention in the soil profile, which can reduce moisture stress during low rainfall years. Third, tree-based systems have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems. Finally, tree-based production systems often produce crops of higher value than row crops. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with climatic variability. Based on the review, agroforestry also offers potential to reduce GHG emissions in the tropics, particularly C sequestration. The authors conclude with research questions that should be addressed concerning the role of agroforestry in both mitigation and adaptation to climate change.

Zhou, X.; Brandle, J.R.; Schoeneberger, M.M.; Awada, T. 2007. Developing above-ground woody biomass equations for open-grown, multiple-stemmed tree species: shelterbelt-grown Russian-olive. Ecological Modelling. 202(3–4): 311–323. http://doi.org/10.1016/j.ecolmodel.2006.10.024.

This paper presents a procedure of selecting predictors, formulating models, and determining equations for biomass estimation of open-grown multiple-stemmed tree species, using shelterbelt-grown Russian olive (*Elaeagnus angustifolia*) as a case study. Because trunk biomass comprises only 32 percent of the total aboveground woody biomass of these trees, as compared with branch biomass (68 percent), models for single-stemmed trees using trunk DBH or height do not adequately represent aboveground biomass of multiple-stemmed trees. Two sets of equations that include both branch and trunk measures were developed—one that has a cost-saving-preferred element is less precise but requires only measures of trunk and stem DBH, and a second that includes a precision-preferred element (reduced relative error by 0.8 to 1.2 percent) and requires additional measures of height and diameter at branch bark ridge. Ultimately, the extra cost associated with the precision-preferred equations may not be justified based on the difference in relative error.

2008

Aitken, S.N.; Yeaman, S.; Holliday, J.A. [et al.]. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications. 1(1): 95–111. http://doi.org/10.1111/j.1752-4571.2007.00013.x.

This review examines the theoretical and empirical literature pertaining to predicting the capacity of forest tree population to adapt in a rapidly changing climate. Authors focused on species distribution models to predict migration and quantitative genetic models to address constraints to adaptation. They summarized available data on local adaptation of forest trees from seedling common garden experiments, provenance trials, hybridization, and genomics that inform these predictions. Further, they identified areas for research, forest management, and operational conservation that might improve predictions of responses to climate change, increase the probability of maintaining sufficient populations of forest trees in protected areas, improve seed-sources election for reforestation, facilitate adaptive responses of natural populations, or accelerate range shifts through facilitated migration. The authors conclude that the extent to which populations will adapt will depend on phenotypic variation, strength of selection, fecundity, interspecies competition, and biotic interactions.

Haile, S.G.; Nair, P.K.R.; Nair, V.D. 2008. Carbon storage of different soil-size fractions in Florida silvopastoral systems. Journal of Environment Quality. 37(5): 1789–1797. http://doi.org/10.2134/jeq2007.0509.

In this study of soil C sequestration in a silvopastoral agroforestry system in Florida that included slash pine (*Pinus elliottii*) and bahiagrass (*Paspalum notatum*) in Spodosols and Ultisols, the authors tested total soil C content at six soil depths between 0 and 125 cm and in 3 fractionated size-classes in both the silvopasture areas and in adjacent open pastures with bahiagrass. Averaged across all sites and depths, compared with the open pasture total SOC, the silvopasture total SOC was 33 percent higher near trees and 28 percent higher in alleys between tree rows. The largest soil fraction showed the highest SOC increase (39 percent in alleys and 20 percent near trees), although the highest SOC increase (up to 45 kg m-2 SOC) in the soil profile was in the 75-to-125 cm depth at Spodosol sites. Higher SOC accumulation was also observed in the surface soils of silvopasture alleys, with variation based on prior land use patterns. Supporting the hypothesis that silvopasture systems contain more C in deeper soil layers compared with open pastures under similar ecological settings, the authors attribute this increased SOC to the SOM contributions of long-term biomass stock from the decomposition of dead tree roots and the higher rates of NPP in tree-based land use relative to open pasture.

Iverson, L.R.; Prasad, A.M.; Matthews, S.N.; Peters, M. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management. 254(3): 390–406. http://doi.org/10.1016/j.foreco.2007.07.023.

This study modeled the habitat responses of 134 eastern U.S. tree species individually for two emission scenarios under an "average" future climate (high emissions on current trajectory and reasonable conservation of energy implemented) and three of the most current high-resolution climate models—Parallel Climate Model, Hadley CM3 model, and Geophysical Fluid Dynamics Laboratory model. Using data from more than 100,000 Forest Inventory and Analysis plots, the authors found that under a high emissions trajectory, climate change could cause 66 species to gain and 54 species to lose at least 10 percent of their suitable habitat. Lower emission scenarios have a slightly more moderate effect on habitat moving generally northeast, whereas the highest emissions scenario may move habitat up to 800 km northeast. Spruce-fir zones were shown to retreat, although southern oaks and pines advance. The primary single driving predictor for tree species response is growing season precipitation, followed closely by slope, annual precipitation, and potential soil productivity.

Kim, D.-G. 2008. Nitrous oxide and methane fluxes in riparian buffers and adjacent crop fields. Ames, IA: Iowa State University. 124 p. Ph.D. dissertation. http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=16704&context=rtd.

This study measured N inputs, weather conditions, N_2O and CH_4 fluxes from soils in forested riparian buffers, warm-season and cool-season grass filters, and an adjacent crop field in central Iowa to determine sources of N_2O, the ratio of N_2O to N_2, and the production and consumption of CH_4 *in vitro* for a greater understanding of atmospheric deterioration potential from denitrification-related GHG production in riparian buffer systems. N_2O emissions from soils in all riparian buffers (1.8-4.5 kg N_2O ha^{-1}) were significantly less than those in the crop fields (7.2-16.8 kg N_2O ha^{-1}), but no differences among different kinds of riparian buffers were observed. Results indicate that the emission factor (ratio of N_2O emission to N inputs) of soils in riparian buffers was smaller than the crop fields. Although N_2O peak emissions followed by rewetting dry soils and thawing frozen soils significantly contributed to annual N_2O emissions from soils in the crop fields, soils in the riparian buffers were less sensitive to such events. The ratio of N_2O to N_2 in riparian buffer soil (0.88 to 6.80) was less than that found in crop field soil (16.5). These results suggest that N_2O emissions from soils in all riparian buffers were significantly less than those in the crop field. In both a multispecies riparian buffer and a cool-season grass filter, NO_3 concentrations in groundwater significantly decreased in comparison with those in the crop field, by 48 to 59 percent. However, dissolved N_2O concentrations in groundwater did not differ among locations (6 to 14 μg L-1). These results indicate that the riparian buffers decreased NO_3 concentrations in near-surface groundwater without increasing N_2O losses. CH_4 fluxes in crop field soil were not significantly different from those in the forest buffer and grass filter soils, and no significant difference in CH_4 flux was found between the forest buffer and grass filter soils. Annual CH_4 flux was -0.80 kg C ha^{-1} yr^{-1}, -0.46 kg C ha^{-1} yr^{-1}, and 0.04 kg C ha^{-1} yr^{-1} in the crop field, forest buffers and grass filters, respectively. These results suggest that (1) N_2O emissions from soils in all riparian buffers were significantly less than those in the crop field, (2) the riparian buffers decreased NO_3 concentrations in near-surface groundwater without increasing N_2O losses, and (3) CH_4 flux in the crop field, forest buffers and grass filters were not different, and CH_4 flux was not changed in the forest buffers and grass filters soils, despite significant changes in soil properties due to planting forest buffers and grass filters.

Kramer, K.; Vreugdenhil, S.J.; van der Werf, D.C. 2008. Effects of flooding on the recruitment, damage and mortality of riparian tree species: a field and simulation study on the Rhine floodplain. Forest Ecology and Management. 255(11): 3893–3903. http://doi.org/10.1016/j.foreco.2008.03.044.

This study of tree mortality data collected following extensive flooding on the Rhine River in May 1999 offers valuable insight into the potential impact of climate change on the zonation of tree species along rivers in Northwest Europe. Analysis of the extensive dataset of the damage and mortality suffered by groups of adult trees as a consequence of this flood revealed that flooding duration, flooding depth, and flooding velocity explained 19, 11, and 8 percent, respectively, of the variation in damage and mortality of trees. Individual tree species were identified as more or less prone to mortality in each scenario, with no mortality identified for either Salix spp. or Populus spp. in either flooded or unflooded areas. In conjunction with results from a prior study, an individual-tree, process-based simulation model resulted in a realistic zonation of tree species along the river where an extreme event shifted zonation upward. The model may prove useful in assessment and planning studies of the impacts of climate change on tree species composition in river floodplains.

Roy, V.; de Blois, S. 2008. Evaluating hedgerow corridors for the conservation of native forest herb diversity. Biological Conservation. 141(1): 298–307. http://doi.org/10.1016/j.biocon.2007.10.003.

This field study investigated the potential of hedgerow corridors in conserving native forest herbs in Quebec, Canada, a potential adaptation strategy under climate change. Objectives were to identify the characteristics of hedgerows at landscape and local scales that could help predict their potential at maximizing native forest herb richness, abundance, and diversity. Landscape variables could be used to target hedgerows with the best potential for conservation, although local variables could provide onsite qualitative management guidelines. Based on the study, important landscape variables included adjacent forest area and hedgerow age, which were both positively related to species richness, abundance, and diversity. Species richness also increased with the number of connections to other hedgerows, and species abundance decreased with increasing land use intensity, although these relationships were less important. A direct link to a forest patch does not appear to influence forest herbs in this system, but it may affect which species will be able to colonize. The local model indicated that abundance, richness, and diversity increased with hedgerow width, canopy cover, and available ground space. Shrub cover and ruderal herb cover were negatively related, especially with herb abundance. The authors conclude that hedgerows can extend forest conditions into the agricultural matrix, possibly mitigating some of the impacts of habitat loss and fragmentation on dispersing forest herbs with minimal effect on crop yield.

Trabucco, A.; Zomer, R.J.; Bossio, D.A. [et al.]. 2008. Climate change mitigation through afforestation/reforestation: a global analysis of hydrologic impacts with four case studies. Agriculture, Ecosystems & Environment. 126(1–2): 81–97. http://doi.org/10.1016/j.agee.2008.01.015.

This paper examines the hydrologic dimensions of international efforts to mitigate climate change, particularly the potential impacts of the Clean Development Mechanism-Afforestation/Reforestation (CDM-AR) provisions of the Kyoto Protocol. An investigation of the probability of increased actual evapotranspiration or decreased runoff from afforestation based on hydrologic models with four case studies of proposed CDM-AR projects revealed that nearly 20 percent of land suitable for this change showed little or no impact on runoff and another 28 percent showed moderate impact. Twenty-seven percent exhibited an 80- to 100-percent decrease in runoff, most prevalent in drier areas, the semi-arid tropics, and in grassland conversions from subsistence agriculture. The current limit on C offset projects would keep hydrologic cycle impacts restricted to local scales. Nonclimate factors were also shown to be important in evaluation of offsite impacts, where each variable is highly site specific. The authors urge that the selection of CDM-AR sites take into consideration the specific hydrologic and socio-ecological aspects of the project in order to provide a comprehensive evaluation that minimizes potential negative aspects and capitalizes on net benefits.

2009

Hlásny, T.; Turčáni, M. 2009. Insect pests as climate change driven disturbances in forest ecosystems. In: Střelcová, K.; Mátyás, C.; Kleidon, A. [et al.], eds. Bioclimatology and natural hazards. Amsterdam: Springer: 165–177. http://doi.org/10.1007/978-1-4020-8876-6_15.

This study investigated the impact of increasing temperatures on the development of two key pests in spruce, i.e., eight-toothed bark beetle (*Ips typographus*) and oak-beech, i.e., gypsy moth (*Lymantria dispar*) ecosystems in Slovakia. These pest species are sensitive to temperature, thus changes in their distributional ranges and population dynamics can be expected. The study analyzed alterations of climate change on insect pest-related forest disturbances and provides the fundamental data for the development of short-term, medium-term, and long-term adaptation and mitigation strategies. Results indicate the area providing climatic conditions suitable for additional generations of bark beetle will expand. Gypsy moth outbreak areas are expected to enlarge significantly in the near future as well. Also, strong indications exist that pests may feed on beech as an alternative host.

Jose, S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems. 76(1): 1–10. http://doi.org/10.1007/s10457-009-9229-7.

This review paper examines four major ecosystem services and environmental benefits of agroforestry: (1) C sequestration; (2) biodiversity conservation; (3) soil enrichment; and (4) air and water quality. Evidence suggests that the potential to sequester soil C increases with species richness and tree density. In regards to conserving biodiversity, agroforestry plays five major roles: providing habitat for species that can tolerate a certain level of disturbance; helping preserve germplasm of sensitive species; helping reduce the rates of conversion of natural habitat by providing a more productive, sustainable alternative to traditional agricultural systems that may involve clearing natural habitats; providing connectivity by creating corridors between habitat remnants, which may support the integrity of these remnants and the conservation of area-sensitive floral and faunal species; and helping to conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat. Agroforestry is a proven strategy for enhancing water and air quality through processes including filtration, uptake, infiltration, and others.

Jose, S.; Holzmueller, E.J.; Gillespie, A.R. 2009. Tree–crop interactions in temperate agroforestry. In: Garrett, H.E., ed. North American agroforestry: an integrated science and practice. Madison, WI: American Society of Agronomy: 57–74. https://dl.sciencesocieties.org/publications/books/abstracts/acsesspublicati/northamericanag/57.

In this review paper, the authors describe the theory and practice of ecological interactions in agroforestry systems. Agroforestry, the intentional incorporation of trees, agricultural crops, or animals into a single land use system, requires appropriate management intervention for yield advantage where multiple species coexist. Aboveground and belowground competition in species compositions typical in agroforestry systems are described in terms of light, water, and nutrient distribution, in addition to allelopathic interactions. Facilitative interactions are also reviewed for these systems, including benefits of microclimate modification, enhanced beneficial insect populations, improved wildlife habitat, hydraulic lift of water and nutrients, nitrogen fixation, and the safety net role of perennial plant roots typical in riparian buffer systems. The authors foresee possible increase in overall biomass production, economic value from diversification, and improved environmental services, as the information gaps of interactive effects of multiple resources on system productivity within the landscape matrix are further investigated.

Nair, P.K.R.; Kumar, B.M.; Nair, V.D. 2009. Agroforestry as a strategy for carbon sequestration. Journal of Plant Nutrition and Soil Science. 172(1): 10–23. http://doi.org/10.1002/jpln.200800030.

This review of C sequestration in agroforestry outlines the context of the growing recognition of agroforestry as a GHG mitigation strategy and the methodological difficulties of estimating C sequestration potential for agroforestry given the biological, climatic, soil, and management factors unique to each site. As an integrated approach to sustainable land use, agroforestry is now recognized internationally as a climate change mitigation strategy under the Kyoto Protocol, bringing attention to the strategy for C sequestration resulting from the greater efficiency of multispecies systems to capture and utilize nutrients, light, and water. However, according to these authors, the low-cost environmental benefit of agroforestry will continue to be underappreciated and underexploited due to the rudimentary understanding of the potential for agroforestry based on land use, C sequestration potential, environmental efficiency, markets, and other site-specific factors.

Quinkenstein, A.; Wöllecke, J.; Böhm, C. [et al.]. 2009. Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environmental Science & Policy. 12(8): 1112–1121. http://doi.org/10.1016/j.envsci.2009.08.008.

This review paper summarizes the effects of alley cropping on ecosystem services with an emphasis on temperate conditions and Central Europe. Alley cropping is an agroforestry practice of increased interest in Central Europe for potentially providing renewable energy resources and adaptation to climate change. Based on the review, alley cropping systems contribute to improve microclimatic conditions, which can enhance the crop yield stability in sensitive regions of Central Europe. This beneficial effect is supported by a more efficient use of water resources and improved nutrient-use efficiency. With low input needs of fertilizers, pesticides, and manpower, alley cropping has the potential to improve the economic value of arable lands. Higher biodiversity is supported through increased structural heterogeneity and may augment the connection of meta-populations at a regional scale. Furthermore, the cultivation of perennial woody plants contributes significantly to C sequestration within the soil and supports the formation of soil humus. The produced biomass can be used to replace fossil energy resources, increasing the utility of alley cropping in mitigating the effects of climate change.

Schoeneberger, M.M. 2009. Agroforestry: working trees for sequestering carbon on agricultural lands. Agroforestry Systems. 75(1): 27–37. http://doi.org/10.1007/s10457-008-9123-8.

This paper offers a description of the multifaceted advantages of agroforestry practices for addressing issues such as economic diversification, biodiversity, and water quality, while sequestering significant amounts of C on agricultural lands. C storage values are compared with agroforestry practices and currently promoted agricultural management practices, revealing an untapped capacity for GHG mitigation programs through agroforestry. The author cites a limited information base and number of tools offered in agroforestry that contribute to its status as an underrecognized and underutilized GHG mitigation option for agriculture in the United States. A need for enhanced communication about agroforestry's C cobenefit and its inclusion in national natural resource programs, such as the U.S. Farm Bill, are suggested as important steps toward wider spread application of these practices.

Udawatta, R.P.; Kremer, R.J.; Garrett, H.E.; Anderson, S.H. 2009. Soil enzyme activities and physical properties in a watershed managed under agroforestry and row-crop systems. Agriculture, Ecosystems & Environment. 131(1–2): 98–104. http://doi.org/10.1016/j.agee.2008.06.001.

The study evaluated if permanent vegetative buffers increase the proportion of water-stable aggregates and contribute to increased soil enzyme activity. Soil samples from agroforestry, grass buffer, grass waterway, and crop areas were collected from summit, middle, and lower landscape positions at a paired watershed study site in Missouri. Soils under permanent vegetative buffers and grass waterways had significantly lower bulk density and more water stable aggregates than the crop areas. Soil C contents were highest in the grassed waterways and lowest in the crop treatments. Fluorescein diacetate hydrolase, β-glucosidase, and glucosaminadase enzyme activities were higher in agroforestry, grass buffer, and grass waterway soils than crop soils. Dehydrogenase activity differed between grass buffer or grass waterways and crop areas. The results of the study show that water stable aggregates, soil C, and functional diversity of enzyme activity increased due to establishment of buffers with trees and grass.

2010

Allen, C.D.; Macalady, A.K.; Chenchouni, H. [et al.]. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management. 259(4): 660–684. http://doi.org/10.1016/j.foreco.2009.09.001.

The paper presents the first global assessment of recent tree mortality attributed to drought and heat stress. Many recent examples of drought and heat-related tree mortality from around the world suggest that no forest type or climate zone is safe from anthropogenic climate change, even in environments not normally considered water limited. Current observations of forest mortality are insufficient to determine if worldwide trends are emerging in part due to the lack of a reliable, consistent, global monitoring system. Although the effects of climate change cannot be isolated in these studies and clearly episodic forest tree mortality occurs in the absence of climate change, the globally extensive studies identified here are consistent with projections of increased forest mortality and suggest that some forested ecosystems may already be shifting in response to climate. This overview illustrates the complex impacts of drought and heat stress on patterns of tree mortality and hints at the myriad ways in which changes in drought or heat severity, duration, and frequency may lead to gradually increasing background tree mortality rates and even rapid die-off events.

Bambrick, A.D.; Whalen, J.K.; Bradley, R.L. [et al.]. 2010. Spatial heterogeneity of soil organic carbon in tree-based intercropping systems in Quebec and Ontario, Canada. Agroforestry Systems. 79(3): 343–353. http://doi.org/10.1007/s10457-010-9305-z.

The authors studied TBI systems, where annual crops are grown between established tree rows at sites established with TBI for 4, 8, and 21 years in Quebec and Ontario. The study quantified spatial variability of SOC in TBI systems, compared the SOC content of TBI and nearby conventional agroecosystems, and assessed if SOC was related to soil fertility. Spatial variation in the SOC content of recently established TBI systems was observed in two of the three TBI systems with 4- to 8-year-old trees; wherein, SOC content was higher within the litterfall radius of the young trees, which became more uniform as the tree canopy expanded. In a TBI including Norway spruce (21-year-old site), SOC spatial variability was not detected until trees were 20+ years old. TBI systems more than 4 years old contained significantly more SOC than nearby conventional agroecosystems, and increased SOC at TBI sites was positively related to plant-available N concentrations. As trees in TBI systems age, more research will be needed to inform SOC content and soil fertility changes.

Beaudette, C.; Bradley, R.L.; Whalen, J.K. 2010. Tree-based intercropping does not compromise canola (*Brassica napus* L.) seed oil yield and reduces soil nitrous oxide emissions. Agriculture, Ecosystems & Environment. 139(1–2): 33–39. http://doi.org/10.1016/j.agee.2010.06.014.

The authors established field trials to compare canola seed oil yield and soil N_2O emissions in 4- to 5-year-old TBI and CM systems. The trials used four N fertilizer rates to investigate the net environmental impacts of N fertilizer use on biofuel crops, as well as canola cultivar and cropping system choice for minimal N_2O emissions. At an optimal N fertilization rate of 80 kg N ha^{-1}, seed oil concentrations were higher in the CM than in the TBI system, but seed oil yield did not differ significantly between the two systems. N_2O emissions were three times higher in the CM than in the TBI alley crop system due to oxygen depletion in soils. An unexpected effect of higher N_2O emissions from one canola cultivar (04C204), which also produced the best seed oil yield, may have been due to greater rates of rhizodeposition alleviating C limitation among heterotrophic denitrifying bacteria indicated by higher microbial biomass. It is expected that the result of equivalent canola seed oil yields in the model TBI system containing hybrid poplar and high-value hardwood species with 8 m-wide alleys may provide further incentive for landowners to adopt TBI systems given current and proposed cap-and-trade programs that reward production systems that limit GHG emissions.

Calfapietra, C.; Gielen, B.; Karnosky, D. [et al.]. 2010. Response and potential of agroforestry crops under global change. Environmental Pollution. 158(4): 1095–1104. http://doi.org/10.1016/j.envpol.2009.09.008.

In this review paper, the authors examine the use of short rotation forestry crops as a tool for reducing atmospheric CO_2 concentration through fossil fuel substitution. The authors reviewed findings from large-scale experiments where elevated CO_2, ozone pollution, and warming were simulated in open environments. It is challenging to design experiments that investigate the effects of multiple, interacting global changes, and as a result, many of the observed experimental responses are from experiments examining one main global change factor. Based on the review, elevated CO_2 likely will support higher biomass yields; however, ozone pollution may offset or negate the stimulation. Besides the potential benefits deriving from the establishment of millions of hectares of these plantations, a risk exists of increased release into the atmosphere of VOCs emitted in large amounts by most of the species commonly used. These hydrocarbons play a crucial role in tropospheric ozone formation, which might represent a negative feedback, especially in regions already characterized by elevated ozone level. Warming will affect other factors including drought and pest attacks that likely will impact short rotation forestry plantations.

Darbah, J.N.T.; Sharkey, T.D.; Calfapietra, C.; Karnosky, D.F. 2010. Differential response of aspen and birch trees to heat stress under elevated carbon dioxide. Environmental Pollution. 158(4): 1008–1014. http://doi.org/10.1016/j.envpol.2009.10.019.

This study measured the effect of high temperature on photosynthesis of isoprene-emitting (aspen) and nonisoprene emitting (birch) trees under elevated CO_2 and ambient conditions in an experimental site in northern Wisconsin. High temperatures induce the production of isoprene in isoprene-producing trees, and isoprene is thought to protect trees from heat stress by increasing their thermo tolerance. Results indicate the isoprene-emitting trees tolerated heat better than nonisoprene-emitting trees and elevated CO_2 protected photosynthesis of both species against moderate heat stress. Authors concluded that in the face of rising atmospheric CO_2 and temperature (global warming), trees will benefit from elevated CO_2 through increased thermo tolerance, although isoprene-emitting trees will have added protection from heat stress. The increased isoprene emission resulting from the higher temperatures and possible shifts in species composition toward isoprene-emitting plants could have negative consequences for atmospheric chemistry, as isoprene and isoprene nitrate have been found to be among the VOCs that play a key role in photochemical (tropospheric ozone) formation.

Eckard, R.J.; Grainger, C.; de Klein, C.A.M. 2010.
Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livestock Science. 130(1): 47–56. http://doi.org/10.1016/j.livsci.2010.02.010.

In this paper, the authors review options for reduction and abatement potential of GHGs CH_4 and N_20 from ruminant production systems. Globally, ruminant livestock produce ~33 percent of anthropogenic emissions of enteric CH_4, and ~90 percent of anthropogenic N_2O emissions. Improved strategies for breeding, feeding, animal management, soil and fertilizer management, and rumen manipulation consider whole-farm systems modeling and full life-cycle assessment to ensure that the strategy does not increase emissions elsewhere in the production chain. Improved forage quality (i.e., lower fiber and higher soluble carbohydrates, changing from C4 to C3 grasses, or grazing on less-mature pastures), breeding for genotype x nutrition performance, minimizing unproductive animal numbers, promoting condensed tannins and saponins in plant matter, and stimulating acetogenic microbes with dietary supplements all may significantly reduce CH_4 production. N_20 emissions may be reduced with nitrification inhibitors, restricted grazing on seasonally wet soils and irrigation in extended dry seasons, fertilizer, and effluent management. The authors conclude that although these options are likely to be cost-effective, they require further research before the strategies become commercially viable and available for farm use. Additionally, the options currently available are more suited to intensive animal production than extensive grazing systems.

Evers, A.K.; Bambrick, A.; Lacombe, S. [et al.]. 2010.
Potential greenhouse gas mitigation through temperate tree-based intercropping systems. The Open Agriculture Journal. 4(Spec. issue): 49–57. http://doi.org/10.2174/1874331501004010049.

This paper examines research on temperate TBI systems in southern Ontario and Quebec, Canada with an emphasis on limiting GHG emissions. Based on the review, TBI systems have the potential to lower N_2O emissions by 1.2 kg ha^{-1} yr^{-1} compared with a conventional agricultural field cropping system. Trees can assimilate residual NO_3 left from N fertilizer applications, thereby leaving less NO_3 available for denitrification and subsequently reducing N_2O losses. Management practices, such as incorporating tree prunings and leaf litter inputs, reduce the need for N fertilizers, which may also lower the potential for N_2O losses. C sequestration is also enhanced in TBI systems, as C is stored in both aboveground and belowground tree components. SOC is higher in systems incorporating trees, because tree litter decomposes slowly, therefore reducing CO_2 loss to the atmosphere. The C sequestration potential of TBI systems and the possibility to include fast-growing tree species for bioenergy production in TBI systems make it a valid solution to mitigate climate change in temperate regions. The extent of the C pools and fluxes can vary among tree species, tree planting density, cutting cycles, and crop combinations, as well as a result of tree height and crown diameter within species.

Fortier, J.; Gagnon, D.; Truax, B.; Lambert, F. 2010.
Nutrient accumulation and carbon sequestration in 6-year-old hybrid poplars in multiclonal agricultural riparian buffer strips. Agriculture, Ecosystems & Environment. 137(3–4): 276–287. http://doi.org/10.1016/j.agee.2010.02.013.

This study investigated nutrient accumulation and C sequestration potential of five different hybrid poplar clones across a range of riparian soil fertility conditions and comparison with natural herbaceous vegetation in southern Quebec, Canada. Results are based on measurements after 6 years of growth compared with unmanaged herbaceous buffer strips. Hybrid poplar riparian buffer systems can accumulate substantial amounts of C and nutrients, but their effectiveness depends on site fertility, particularly in terms of NO_3 supply rate. Important differences in C and nutrient sequestration exist between the clones. Compared with unmanaged herbaceous buffer, ecological services generated by multiclonal hybrid poplar buffers, in terms of C and nutrient sequestration, greatly increased as site fertility increased.

Haile, S.G.; Nair, V.D.; Nair, P.K.R. 2010. Contribution of trees to carbon storage in soils of silvopasture systems in Florida, USA. Global Change Biology. 16(1): 427–438. http://doi.org/10.1111/j.1365-2486.2009.01981.x.

In this study of the relative influences of C3 trees and C4 warm season grasses on SOC in a silvopastoral agroforestry system in Florida, the authors examined SOC content in whole (nonfractionated) and three soil fraction sizes in silvopasture alleys, tree rows, and in adjacent open pasture at six depths between 0 and 125 cm. The silvopasture sites included slash pine (*Pinus elliottii*) and bahiagrass (*Paspalum notatum*) in Spodosols and Ultisols. C3-derived SOC in the whole soil sample was significantly higher at silvopasture locations than in the open pasture system, especially in the comparison of surface soils (13 to 19 percent in open pasture compared with 30 to 76 percent in silvopasture). A reverse trend was observed for the SOC derived from C4 plants. Compared with the C4-derived SOC, the proportion of the C3-derived SOC generally increased with soil depth in both land use systems for all sites. Given that the main source of C input to the soil is root biomass, transformed to SOC by microorganisms, in open pasture C4 bahiagrass was the main primary source of SOC, whereas in silvopasture, C3 slash pine litter and roots contribute to a deeper, longer lasting C source.

Kim, D.-G., Isenhart, T.M.; Parkin, T.B. [et al.]. 2010. Methane flux in cropland and adjacent riparian buffers with different vegetation covers. Journal of Environment Quality. 39(1): 97–105. http://doi.org/10.2134/jeq2008.0408.

Given the riparian buffer conditions favorable to CH_4 production, this study evaluated CH_4 fluxes from soils of riparian buffer systems comprised of three vegetation types (forest buffers, warm-season grass filters, and cool-season grass filter) compared with an adjacent crop field in central Iowa. Soils within all riparian buffer vegetation types showed significantly lower bulk density and higher pH, NH_4, total C, and total N compared with crop field soils. These results were attributed to the decomposition of aboveground and belowground litter, root exudates, and microbial C accumulation. Higher soil moisture and lower soil temperature in forest buffer soils compared with crop fields were associated with shade from buffer vegetation and organic matter soil-moisture holding capacities. These reestablished riparian forest buffers and grass filter were not considered major sources of CH_4 due to their less frequent saturation and altered hydrology, although their CH_4 sink capacity is expected to increase beyond the 7- to 17-year maturity time since reestablishment.

Kumar, S.; Udawatta, R.P.; Anderson, S.H. 2010. Root length density and carbon content of agroforestry and grass buffers under grazed pasture systems in a Hapludalf. Agroforestry Systems. 80(1): 85–96. http://doi.org/10.1007/s10457-010-9312-0.

The authors evaluated differences in RLD and root and soil C content within grass buffer, agroforestry buffer, rotationally grazed pasture, and continuously grazed pasture treatments in Mid-Missouri. Buffer treatments (167 cm/100 cm^3) had 4.5 times higher RLD than pasture treatments (37.3 cm/100 cm^3). The agroforestry buffer treatment had the highest (173.5 cm/100 cm^3) RLD value, and continuously grazed pasture had the lowest (10.8 cm/100 cm^3) RLD value. Soil C was ~115 percent higher for the buffers compared with pasture treatments. Variation in RLD in comparison with former studies is attributed to age and species of trees, treatment and land management, and sampling depth. Given that the enhancement of root development improves soil physical properties, C sequestration, and water quality of streams, the results of this study suggest that agroforestry and grass buffers on grazed pasture watersheds can improve environmental quality.

Lindner, M.; Maroschek, M.; Netherer, S. [et al.]. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management. 259(4): 698–709. http://doi.org/10.1016/j.foreco.2009.09.023.

This study summarizes the existing knowledge about observed and projected direct and indirect impacts of climate change on forests in Europe. Climate change scenario projections for Europe suggest that by 2100, temperatures and atmospheric CO_2 concentration will increase. The study analyzed climate change impacts separately for different bioclimatic regions and forest types. The most important potential impacts of climate change on forest goods and services are summarized for the boreal, temperate oceanic, temperate continental, Mediterranean, and mountainous regions. Especially in Northern and Western Europe, the increasing atmospheric CO_2 content and warmer temperatures are expected to result in positive effects on forest growth and wood production, at least in the short to medium term. On the other hand, increasing drought and disturbance risks will cause adverse effects. These negative impacts are very likely to outweigh positive trends in Southern and Eastern Europe. From west to east, the drought risk increases. In the Mediterranean regions, productivity is expected to decline due to strongly increased droughts and fire risks. Understanding of adaptive capacity and regional vulnerability to climate change in European forests is still not well developed and requires more focused research efforts.

Morgan, J.A.; Follett, R.F.; Allen, L.H. [et al.]. 2010. Carbon sequestration in agricultural lands of the United States. Journal of Soil and Water Conservation. 65(1): 6A–13A. http://doi.org/10.2489/jswc.65.1.6A.

This paper analyses the role of agriculture in the United States to mitigate climate change through C sequestration. Various agricultural practices for sequestering C are presented, including agroforestry. Agroforestry represents a significant opportunity on agricultural lands. Because agroforestry is not explicitly inventoried, its potential contributions to C sequestration have been estimated based on assumptions of where these plantings would suitably occur for services other than C sequestration. Critical research needs in agroforestry include quantifying C dynamics in agroforestry systems, developing effective strategies for measuring and monitoring C sequestration in soil and woody components, and developing and implementing a national inventory of agroforestry.

Nair, P.K.R.; Nair, V.D.; Kumar, B.M.; Showalter, J.M. 2010. Carbon sequestration in agroforestry systems. In: Sparks, D.L., ed. Advances in agronomy. 108: 237–307. http://doi.org/10.1016/S0065-2113(10)08005-3.

This chapter provides an overview of agroforestry in the context of climate change. A history of agroforestry land use, definitions, and assumptions of agroforestry precedes a comprehensive review of agroforestry C sequestration findings. Although C sequestration estimates vary greatly across systems, ecological regions, and soil types, a general trend is identified of increasing soil C sequestration in order of forests> agroforests> tree plantations> arable crops. Estimates of C stored in agroforestry systems range from 0.29 to 15.21 Mg C ha^{-1} yr^{-1} aboveground and 30 to 300 Mg C ha^{-1} up to 1 m depth in the soil. Mechanisms and types of soil C sequestration are described in relation to the biophysical factors that affect it. Aboveground and belowground C sequestration measurement methods are described, in addition to the methodological difficulties that reduced universal applicability and comparability. The impact of agroforestry management decisions on C sequestration potential further emphasizes the variability of outcomes. More rigorous research results will be required for agroforestry to be included in global programs of C sequestration.

Oyebade, B.A.; Aiyeloja, A.A.; Ekeke, B.A. 2010. Sustainable agroforestry potentials and climate change mitigation. Advances in Environmental Biology. 4(1): 58–63. http://doi.org/10.1016/j.cosust.2013.09.002.

This paper provides a simplistic review of agroforestry's potential for climate change mitigation and adaptation and, in general, is very poorly documented with citations. The authors focus primarily on the benefits that agroforestry trees can provide to soils and soil process. Appropriate agroforestry systems have the potential to control erosion, maintain SOM and physical properties, augment N fixation, and promote efficient nutrient cycling. Many of these potentials are plausible climate change mitigating abilities of agroforestry systems. The cycling of bases in tree litter can help reduce soil acidity, thus helping with P uptake. Shade from trees can alter soil conditions to promote microbial activity and the rate of soil mineralization. This influence is important in agricultural areas where the soil N level is a limitation to crops or pasture growth.

Tamang, B.; Andreu, M.G.; Rockwood, D.L. 2010. Microclimate patterns on the leeside of single-row tree windbreaks during different weather conditions in Florida farms: implications for improved crop production. Agroforestry Systems. 79(1): 111–122. http://doi.org/10.1007/s10457-010-9280-4.

This study measured the modification of wind speed, temperature, and relative humidity on the leeside of single-row tree windbreaks of eastern red cedar (*Juniperus virginiana*) and cadaghi (*Corymbia torelliana*) in Florida where wind, freezing temperatures, hurricanes, and diseases can impact citrus and vegetable crop production. All windbreaks reduced wind speed about 5 percent, about 3 to 30 percent, and less than 50 percent of open wind speed at 2 H, 4 H, and 6 H distance from windbreak (H = windbreak height), respectively. Wind speed reduction was observed up to 31 H, and temperatures on the leeside of windbreaks were warmer during the day and cooler at night compared with open fields. Wind reduction varied with windbreak porosity and wind direction. Due to increased likelihood of freeze events near the leeside of the windbreak, the authors suggest allowing for some air to flow through the windbreak, based on the requirements of the landowner. A well-designed, single-row windbreak in this region is shown here to potentially reduce physical crop damage and lower canker infection in citrus.

Torres, A.B.; Marchant, R.; Lovett, J.C. [et al.]. 2010. Analysis of the carbon sequestration costs of afforestation and reforestation agroforestry practices and the use of cost curves to evaluate their potential for implementation of climate change mitigation. Ecological Economics. 69(3): 469–477. http://doi.org/10.1016/j.ecolecon.2009.09.007.

This study analyzed the C sequestration costs of agroforestry ARP. The costs of C sequestration activities need to be understood and analyzed within their socioeconomic context to generate appropriate policies and incentives to implement these activities extensively enough to cause significant reduction in GHG. This information is necessary to help identify the C prices required to motivate implementation of ARP. The methods used consist of a partial market equilibrium using average cost curves and economic break-even analysis to identify the supply costs. The results can help create incentive programs for widespread implementation of practices to remove GHG emissions and to mitigate climate change. Agroforestry practices, which do not require full land use conversion (e.g., living fences), can be particularly useful and should play a larger role in the efforts to mitigate climate change. Results also suggest that payments in the early years of the project and lower transaction costs favor the development of ARP in the voluntary market, especially in marginal rural areas with high discount rates.

2011

Bergeron, M.; Lacombe, S.; Bradley, R.L. [et al.]. 2011. Reduced soil nutrient leaching following the establishment of tree-based intercropping systems in eastern Canada. Agroforestry Systems. 83(3): 321–330. http://doi.org/10.1007/s10457-011-9402-7.

The study tested the hypothesis that the roots of 5- to 8-year-old hybrid poplars, growing in two TBI systems in southern Quebec, Canada, would play a safety-net role of capturing nutrients leaching below the rooting zone of alley crops. Deep tree roots extending beneath the main crop rooting zone may intercept leached nutrients and recycle them, thereby acting as a safety net and having a positive effect on GHG mitigation. The results indicate a safety-net role of poplar roots with respect to NO_3^-, DON, and sodium leaching in 5- to 8-year-old TBI systems of Eastern Canada. Although poplar roots reduced N leaching to a greater extent on clayey loam than on sandy soil, the role of soil texture in controlling N interception by poplar roots still needs to be confirmed with studies comprising replicate sites of similar textural class. Future research should also test the safety-net role of poplar roots at greater tree row spacing.

Delgado, J.A.; Groffman, P.M.; Nearing, M.A. [et al.]. 2011. Conservation practices to mitigate and adapt to climate change. Journal of Soil and Water Conservation. 66(4): 118A–129A. http://doi.org/10.2489/jswc.66.4.118A.

This review paper examines the science on conservation practices that could be used to mitigate and adapt to climate change, of which agroforestry is one of the practices evaluated. With so many concerns related to climate change, a need exists to develop a scientifically sound conservation system, a system that today could serve as a framework, not only for climate change mitigation, but also for climate change adaptation. The authors review the science of conservation and climate change and provide examples of mitigation strategies for agricultural production and examples of soil and water adaptation needs for climate change.

Hernandez-Ramirez, G.; Sauer, T.J.; Cambardella, C.A. [et al.]. 2011. Carbon sources and dynamics in afforested and cultivated Corn Belt soils. Soil Science Society of America Journal. 75(1): 216–225. http://doi.org/10.2136/sssaj2010.0114.

This paper assesses atmospheric C sequestration and dynamics on degraded cropland with a comparison of two 35-year-old coniferous afforestation sites: a forest plantation of eastern white pine (*Pinus strobus*) in northwest Iowa and a shelterbelt in eastern Nebraska with red cedar (*Juniperus virginiana*), Scots pine (*Pinus sylvestris*), cottonwood (*Populus deltoides*), and adjacent agricultural fields. The SOC, total N, and stable C isotope ratios were measured in both whole soil and fine POM fractions (53 to 500 µm) at each site. Researchers observed substantial increases in surface SOC storage in fine-textured soils in both the shelterbelt and forest plantation relative to the conventionally tilled cropping systems (57 percent or more; $P < 0.05$). Depleted C isotope ratios indicate a shift to greater tree-derived C sources. Tree-derived C contributed roughly one-half of the SOC found directly beneath trees, with SOC turnover rates of 0.018 to 0.022 per year with mean residence times from 55 to 45 years. Fine POM were identified as a significant sink for recently sequestered SOC in these systems based on the large proportion (21 percent) of the existing SOC in POM at the afforested sites, with 79 percent of this organic matter derived from tree inputs. This study supports the direct benefits of tree planting for SOC sequestration on degraded croplands.

Howlett, D.S.; Mosquera-Losada, M.R.; Nair, P.K.R. [et al.]. 2011. Soil carbon storage in silvopastoral systems and a treeless pasture in northwestern Spain. Journal of Environmental Quality. 40(3): 825–832. http://doi.org/10.2134/jeq2010.0145.

This study quantified the amounts of soil C stored at various depths to 100 cm under silvopastoral plots of radiata pine (*Pinus radiata*) and birch (*Betula pendula*) compared with treeless pasture in Galicia, Spain. Stored and nonfractionated C in three soil size classes was determined for each site. Up to 1 m depth in silvopasture sites, 78 percent of C (C stocks from 80.9 to 176.9 Mg ha^{-1}) was found in the 0-to-25 cm soil depth. From 0 to 25 cm, soils under birch showed the highest C in the 250-to-2000 μm size class, whereas the treeless pasture contained more C than radiata pine silvopasture in the smaller soil fractions (less than 53 and from 53 to 250 μm). At the 75-to-100 cm depths, significantly more C was stored in the 250-to-2000 μm fraction in both birch and pine silvopasture sites compared with treeless pasture. Although birch was the preferred species compared with pine for improving SOC storage due to the understory environment of broadleaf species that increase C and N inputs to the soil over time and promote understory vegetation growth, the 2 × 2 m spacing showed similar SOC storage for both tree species. Overall, these findings suggest that higher soil C storage in larger fraction size at lower depths in silvopasture result from the planting of trees and the conversion of agricultural landscapes to include trees will promote longer term storage of soil C.

Kumar, B.M.; Nair, P.K.R., eds. 2011. Carbon sequestration potential of agroforestry systems. 8 vol. Dordrecht, Netherlands: Springer. 310 p. http://link.springer.com/10.1007/978-94-007-1630-8.

Volume 8 of the Advances in Agroforestry book-series, a collection of publications, offers synthesis of research results and evaluations relating to opportunities and challenges of C sequestration potential in agroforestry systems. Three broad sections of the book organize themes of measurement and estimation, agrobiodiversity and tree management, and policy and socioeconomic aspects. Both temperate and tropical contexts are discussed, including research articles, case studies, and regional overviews regarding current trends in C sequestration research.

Lal, R.; Delgado, J.A.; Groffman, P.M. [et al.]. 2011. Management to mitigate and adapt to climate change. Journal of Soil and Water Conservation. 66(4): 276–285. http://doi.org/10.2489/jswc.66.4.27.

This paper reviews the scientific literature on how agricultural management decisions influence mitigation and adaptation to climate change. The authors focus on C management, N management, manure management, management in low-input systems (sustainable agriculture), and grazing land management. Management decisions that reduce soil erosion, increase C sequestration to improve soil functions, soil quality, and soil health, and contribute to the resilience of soils and cropping systems will be needed to respond to climate change and related challenges such as food security. Although the paper does not specifically address agroforestry, the mitigation and adaptation services provided by agroforestry are similar to the services covered in this review.

Luedeling, E.; Girvetz, E.H.; Semenov, M.A.; Brown, P.H. 2011. Climate change affects winter chill for temperate fruit and nut trees. PLoS ONE. 6(5): e20155. http://doi.org/10.1371/journal.pone.0020155.

This study quantified winter chill for the entire terrestrial globe using climate scenarios in the past and weather projections for the future. Warm regions are likely to experience severe reductions in available winter chill, potentially threatening production. In contrast, SWC in most temperate growing regions is likely to remain relatively unchanged, and cold regions may even see an increase in SWC. Climate change impacts on SWC differed quantitatively among GCMs and GHG scenarios. The extent of projected changes in winter chill in many major growing regions of fruits and nuts indicates that growers likely will experience problems in the future. To better prepare for likely impacts of climate change, efforts should be undertaken to breed tree cultivars for lower chilling requirements, to develop tools to cope with insufficient winter chill, and to better understand the temperature responses of tree crops.

Luedeling, E.; Steinmann, K.P.; Zhang, M. [et al.]. 2011. Climate change effects on walnut pests in California. Global Change Biology. 17(1): 228–238. http://doi.org/10.1111/j.1365-2486.2010.02227.x.

This study modeled the effects of projected climate change on the mean generation numbers of four walnut pests in California. Pests analyzed included the codling moth (*Cydia pomonella*), navel orangeworm (*Amyelois transitella*), two-spotted spider mite (*Tetranychus urticae*), and European red mite (*Panonychus ulmi*). The number of codling moth generations rose from 2 to 4 in 1950 to 3 to 5 among all future climate change scenarios. Generation numbers increased from 10 to 18 to 14 to 24 for two-spotted spider mite, from 9 to 14 to 14 to 20 for European red mite, and from 2 to 4 to up to 5 for navel orangeworm. Overall pest pressure can thus be expected to increase substantially under a warming climate. The study did not include the possibility of higher winter survival rates, leading to higher initial pest counts in spring or of extended pest development times in the summer, factors that are likely to exacerbate future pest pressure. On the other hand, initiation of diapause may prevent an extension of the season length for arthropods and higher incidence of heat death in summer may constrain pest population sizes.

Nair, P.K.R. 2011. Carbon sequestration studies in agroforestry systems: a reality-check. Agroforestry Systems. 86(2): 243–253. http://doi.org/10.1007/s10457-011-9434-z.

This paper identifies problems and erroneous assumptions of C sequestration estimation methods in agroforestry systems research. Although agroforestry holds tremendous potential to address climate change internationally, methods and procedures for collecting and estimating aboveground and belowground C sequestration in agroforestry systems are inconsistent, and therefore inconclusive and incomparable under various management practices, soils, environments, and social conditions. The author outlines several erroneous assumptions and operations that lead to inadequate computations and inaccurate estimations. Due to the integrated nature of agroforestry systems and its relative newness and slow growth rate of research on the subject, these methodological problems are of a higher order of magnitude compared with agricultural systems. The author recommends addressing these challenges with research reporting that includes detailed methodological explanation and extrapolation of estimations to a scale of Mg ha^{-1} to ensure that agroforestry holds a place in the progression of scientific understanding and quantification of agroforestry's underexploited ecosystem services.

Nair, P.K.R. 2011. Methodological challenges in estimating carbon sequestration potential of agroforestry systems. In: Kumar, B.M.; Nair, P.K.R., eds. Carbon sequestration potential of agroforestry systems. Dordrecht, Netherlands: Springer: 3–16. http://doi.org/10.1007/978-94-007-1630-8_1.

The chapter defines C sequestration and summarizes methods of C sequestration in agroforestry systems (aboveground and belowground, modeling, and global estimates). It also presents the methodological challenges that arise from erroneous assumptions, operational inadequacies and inaccuracies, and calculation and reporting of results. The author provides suggestions for improving estimates of C sequestration in agroforestry systems, recommending that researchers should describe accurately the collection, analysis, and management of data. This suggested method includes explaining unambiguously how the samples were drawn, estimations were made, and computations were calculated for extrapolation to broader scale such as Mg ha^{-1}. Such a clear presentation of the results will make it possible for others to understand and decide whether, how, and to what extent to incorporate the reported results into larger databases.

Plieninger, T. 2011. Capitalizing on the carbon sequestration potential of agroforestry in Germany's agricultural landscapes: realigning the climate change mitigation and landscape conservation agendas. Landscape Research. 36(4): 435–454. http://doi.org/10.1080/01426397.2011.582943.

This paper offers an analysis of agroforests in the Upper Lusatia area in eastern Germany as a means to participate in C markets while delivering other important ecosystem services in Central European agricultural landscapes. Hedgerows, isolated trees, riparian woodlands, scattered fruit trees, tree rows, and woodlots are defined as classes of agroforestry practices. The analysis revealed that agroforests cover relatively large areas of land and demonstrate remarkable continuity during 45 years in the study area, despite being in intensive agricultural setting. Vegetation structures of each class indicate highest C-sequestration potential for woodlots, riparian buffers, and scattered fruit trees where highest tree diameter and density are combined with low soil disturbance. Riparian woodlands represent the largest total area and mean patch size, with the largest current C sequestration potential of the classes studied. Together, these agroforestry classes integrate multiple ecosystem services and strengthen the multifunctionality and value of cultural landscapes. Although additional work needs to be done, the author suggests that including climate issues into efforts for protecting, managing, and planning diverse and high-quality landscapes may guide Europe toward a more comprehensive sustainability of cultural landscapes.

Powlson, D.S.; Gregory, P.J.; Whalley, W.R. [et al.]. 2011. Soil management in relation to sustainable agriculture and ecosystem services. Food Policy. 36: S72–S87. http://doi.org/10.1016/j.foodpol.2010.11.025.

This paper reviews research, practices, and policies affecting soil management in relation to global food security. SOC is identified as a central component of ecosystem functioning and crop growth, ensuring sustainability of all soil functions. Although soil is a major store of C in the biosphere, policies and international action have yet to encourage changes that are urgently required for soil C storage. Management options for soil C sequestration are often misunderstood. Some options that may be beneficial for soil C cause an increase in N_2O emissions that negates the beneficial effects. Root functions in soil are also seen as a focal point for soil health, with benefits including biocontrol of soil-borne pests and diseases, inhibition of the nitrification process, and possible improved N use efficiency with decreased N_2O emission. Research of soil microorganisms and their interaction with roots using molecular methods is a quickly progressing area of science that provides the basis for novel practical applications. Appropriate nutrient management and availability for smallholder farmers globally will require facilitating policies and practical strategies that take account of local economic and social conditions, which vary widely. Payment for ecosystem services may also assist the financial barrier for farmers to implement practices that are urgently required for successful nutrient management and reduction of soil erosion.

Zhou, X.; Brandle, J.R.; Awada, T.N. [et al.]. 2011. The use of forest-derived specific gravity for the conversion of volume to biomass for open-grown trees on agricultural land. Biomass and Bioenergy. 35(5): 1721–1731. http://doi.org/10.1016/j.biombioe.2011.01.019.

In response to the rarity and expense of developing biomass equations for C sequestration and cellulosic feedstock production estimates, this paper offers an evaluation of the use of forest-derived specific gravity for conversion of volume and biomass for three morphologically distinct open-grown species: green ash, ponderosa pine, and eastern red cedar in Nebraska and Montana. Trunk biomass was consistently underestimated from 6.3 to 16.6 percent depending on species, indicating open-grown trees have greater trunk specific gravity than forest-grown counterparts within the same geographic region. Branch specific gravity was not consistently different between open- and forest-grown trees. The use of forest-based equations for these open-grown species resulted in underestimation from greater trunk specific gravity and overestimation from larger crowns. A need remains for this information to be applied to forest-based equation modifications to account for open-grown tree differences.

2012

Anderson, E.K.; Zerriffi, H. 2012. Seeing the trees for the carbon: agroforestry for development and carbon mitigation. Climatic Change. 115(3–4): 741–757. http://doi.org/10.1007/s10584-012-0456-y.

Although land use, land use change, and forestry activities associated with agroforestry have the potential to deliver climate benefits and rural development benefits simultaneously, early projects suggest that co-benefits are difficult to achieve. This review on agroforestry, participatory rural development, tree-based C projects, and co-benefit C projects assesses how project characteristics produce tension, alignment, or synergy of multiple types of benefits. This analysis revealed limitations for achieving co-benefits based on differences in primary orientation and scale of impact for a development-focused project compared with a C-focused project. Some possibilities exist for improving participation in development projects while keeping costs down for C-focused projects. However, due to the inherent tension in designing co-benefit smallholder agroforestry projects, the authors suggest that designing projects to achieve ancillary benefits rather than co-benefits reduces co-maximization of goals and may enhance synergy of benefits.

Bogdanski, A. 2012. Integrated food–energy systems for climate-smart agriculture. Agriculture & Food Security. 1: 1–10. http://doi.org/10.1186/2048-7010-1-9.

This paper presents an overview of different options that allow for the joint production of food and energy in a climate-smart way, and the contribution of such integrated food–energy systems to improved food security, energy access, and adaptive capacity to climate change. The article reviews a collection of studies in tropical regions that prove adaptation and mitigation potential of integrated food-energy systems. These diversified land use systems appear to be more resilient and capable to adapt to climate change and contribute to climate change mitigation by increasing C stock. The agricultural residues can be used for energy extraction, and the byproducts resulted can replace chemical fertilizer, which ultimately contributes to GHG emissions reduction. Challenges in adopting these systems include the cost of initial investment, poor institutional support, capacity building, and technical support. The case studies presented are from tropical regions, but the conclusions may be applicable to temperate region also.

Bowler, D.E.; Mant, R.; Orr, H. [et al.]. 2012. What are the effects of wooded riparian zones on stream temperature? Environmental Evidence. 1(1): 3. http://doi.org/10.1186/2047-2382-1-3.

Predicted increases in stream temperature due to climate change will have a number of direct and indirect impacts on stream biota. A potential intervention for mitigating stream temperature rise is the use of wooded riparian buffers to increase shade and reduce direct warming through solar radiation. To assess the effectiveness of this intervention, the authors conducted a systematic review of the available evidence for the effects of wooded riparian zones on stream temperature. Included studies were sorted into three groups based on the scale of the intervention and design of the study. Two groups were taken forward for synthesis. Temperature data were extracted and quantitative synthesis performed using a random effects meta-analysis on the differences in mean and maximum temperature. Group 1 included 10 studies comparing Tw in streams with and without buffer strips or riparian cover. The overall mean difference in mean temperature of streams with and without a buffer strip was 0.39 °C. The effect size is larger for maximum temperature than mean temperatures. Maximum temperature was 3.16 °C lower in the presence of buffer strips. Group 2 included 10 studies comparing streams temperatures in open and forested landscapes. The overall mean difference in mean temperature of open-landscape and forested streams is 1.48 °C. Maximum temperature was 4.94 °C, lower in the presence of forest. Considerable uncertainty lies in the environmental variables that may modify the cooling effect of wooded riparian zones, and therefore, it is not possible to identify when the use of this intervention for cooling would be most valuable.

Holzmueller, E.J.; Jose, S. 2012. Biomass production for biofuels using agroforestry: potential for the north central region of the United States. Agroforestry Systems. 85(2): 305–314. http://doi.org/10.1007/s10457-012-9502-z.

This paper examines agroforestry practices with the greatest potential for biomass production (i.e., shelterbelts, riparian buffer strips, and alley cropping) that would satisfy energy demands without sacrificing food production in the north central region of the United States. Riparian marginal land is recommended as an ideal candidate for biomass production in an agroforestry system in this region. In addition to producing biomass, these systems could also potentially increase water quality, sequester C, improve aesthetics, and provide critical wildlife habitat. However, market values for perennial biomass need to increase to motivate large-scale adoption by landowners.

Jose, S.; Bardhan, S. 2012. Agroforestry for biomass production and carbon sequestration: an overview. Agroforestry Systems. 86(2): 105–111. http://doi.org/10.1007/s10457-012-9573-x.

The paper compiles several original research articles from North America, South America, and Africa that investigate C sequestration (aboveground and belowground C and the role of decomposition and nutrient cycling in determining the size of soil C pool) and the potential of producing biomass in specific agroforestry practices. The articles examined suggest that agroforestry could play a substantial role in reducing atmospheric concentration of CO_2 by storing C in aboveground and belowground biomass and in soil and by growing biomass for biopower and biofuels, thereby replacing fossil fuel. Agroforestry offers significant potential because of the large extent of area (630 × 106 ha) available worldwide for agroforestry adoption. Agroforestry could also protect existing C stocks by providing alternatives to forest wood, thereby reducing the rate of deforestation.

Luedeling, E. 2012. Climate change impacts on winter chill for temperate fruit and nut production: a review. Scientia Horticulturae. 144: 218–229. http://doi.org/10.1016/j.scienta.2012.07.011.

This article reviews approaches to estimate winter chill, the performance of these different approaches, and analyses of historic and projected future changes in winter chill. Although several approaches exist for estimating winter chill requirements, the Dynamic Model currently seems to be the best model for all growing regions. Based on this model, a reduction in the number of chilling hours is expected for California, Australia, South Africa, and most warm growing regions. Cold growing regions, in contrast, may experience little change or even increase in winter chill, as increasing numbers of days become frost free. Finding suitable tree species and cultivars will be necessary to adapt and climate analogues may be a strategy for adaptation planning. For example, the climate projected for a particular target-growing region for 2050 (according to a given climate model and GHG emissions scenario) can currently be found at a different location. Tree cultivars that are grown successfully at the analogue location may be candidates for planting in the target region today, and new cultivars slated for introduction into the target region should possibly be tested at the analogue site rather than the target site to ensure that they are viable in a warmer climate.

Matocha, J.; Schroth, G.; Hills, T.; Hole, D. 2012. Integrating climate change adaptation and mitigation through agroforestry and ecosystem conservation. In: Nair, P.K.R.; Garrity, D., eds. Agroforestry—The future of global land use. Dordrecht, Netherlands: Springer: 105–126. http://doi.org/10.1007/978-94-007-4676-3_9.

The paper reviews the literature on combining climate change mitigation and adaptation strategies together with a particular focus on tropical agroforestry approaches. Synergies between adaptation and mitigation actions are likely in projects involving income diversification with tree and forest products, reduction of the susceptibility of land use systems to extreme weather events, improvement of soil fertility, fire management, wind breaks, and the conservation and restoration of forest and riparian corridors, wetlands, and mangroves. Potential trade-offs between adaptation and mitigation are possible when fast-growing tree monocultures for mitigation conflict with local tree and forest uses, making livelihoods more vulnerable; when trees are planted in water-scarce areas conflicting with local water uses; and, in some cases, when *climate-smart* agroforestry practices conflict with the need for agricultural intensification to produce increasing amounts of food for a growing population. Such conflicts need to be avoided through careful, site-specific, and participatory project development.

Nair, P.K.R. 2012. Climate change mitigation: a low-hanging fruit of agroforestry. In: Nair, P.K.R.; Garrity, D., eds. Agroforestry—the future of global land use. Dordrecht, Netherlands: Springer: 31–67. http://doi.org/10.1007/978-94-007-4676-3_7.

This review provides a comparative analysis of agroforestry systems' (tree intercropping, multistrata, protective, silvopasture, and tree woodlots) operations that influence the role of climate change mitigation and adaptation. Although various reports on C sequestration potential of agroforestry systems have been reported, the site-specific nature and lack of uniformity in estimation methods make it difficult to compare results. Tillage, crop residue management, and plant diversity are reported as the major management operations that influence the role of land use systems in climate change mitigation. The extent of influence of these operations varies considerably in various agroforestry subgroups; representative values are reported for each. Based on this evaluation, the strengths, weaknesses, opportunities, and threats, or SWOT, of the role of agroforestry in climate change are presented as a SWOT analysis. On a global scale, although existing multistrata and tree-intercropping systems will continue to provide substantial climate change mitigation benefits, large-scale initiatives in grazing land management, working trees in drylands, and establishment of riparian buffers and tree woodlots are promising agroforestry pathways for climate change mitigation and adaptation.

Neufeldt, H.; Dawson, I.K.; Luedeling, E. [et al.]. 2012. Climate change vulnerability of agroforestry. Working Paper No. 143. Nairobi, Kenya: World Agroforestry Centre. 31 p. http://www.worldagroforestry.org/downloads/Publications/PDFS/WP12013.pdf.

This review paper focused on the potential impacts of climate change on agroforestry systems, particularly with an African agriculture perspective. A number of challenges make assessing this vulnerability difficult to predict. Spatial dimensions, time to reach maturity, and the complexities of aboveground and belowground interactions between often diverse assemblages of crop and tree species make experimental trials of agroforestry systems very difficult to implement and maintain in the field. Although field crops can be grown relatively easily under controlled-climate conditions, this controlled environment is much more difficult to obtain with trees. Due to scarcity of information on how trees and agroforestry systems respond to climate, no agroforestry models exist that can reliably be used for projecting the impacts of climate change. Ecological niche modeling offers an alternative, but caution should also be applied when interpreting results from this procedure. The techniques of tree-ring measurement and stable isotope analyses have been widely used to understand the long-term impacts of climate variations at the species, community, and landscape levels, particularly in temperate regions. In tropical regions, however, the technique was only recently introduced. Uncovering past responses to climate change could help in understanding the impacts of climate variability and the way society and ecosystems respond to them, and it provides a huge potential to make informed climate projections. Scientists can also use information from genetic trials and studies in natural populations in climate change adaptation planning. In regions where strong geographical gradients in rainfall exist, one would expect significant genetic and phenotypic variation in tree growth, wood properties, and other variables correlated with tree growth along the rainfall gradients. This information can be used to plan diversification of agroforestry parklands for future climatic conditions.

Nyakatawa, E.Z.; Mays, D.A.; Naka, K.; Bukenya, J.O. 2012. Carbon, nitrogen, and phosphorus dynamics in a loblolly pine-goat silvopasture system in the Southeast USA. Agroforestry Systems. 86(2): 129–140. http://doi.org/10.1007/s10457-011-9431-2.

These authors investigated the effect of grazing and forage enhancement on total soil C (TSC), soil N, and P dynamics in a goat—loblolly pine (*Pinus taeda*) silvopasture system in Alabama from 2006 to 2010. During the study period, grazing increased N and P levels, although TSC decreased slightly in the enhanced forage plots (trees thinned for managed grazing) compared with other treatments due to soil disturbance for liming, fertilizer incorporation, and forage planting. Still, temporary increases in TSC in the 0-to-15 cm soil depth were obtained in the high stocking rate and control treatments in 2008 and 2009. Soil pH in the enhanced forage plots in which understory brush had been cleared was 0.15 to 0.44 units higher than that in other plots after 1 year and remained at this level throughout the study period. The authors indicate that potential exists to improve soil C sequestration while enhancing soil nutrient composition in silvopasture systems by implementing improved soil and plant management strategies for enhanced forage production, thereby making the goat-loblolly silvopasture system both environmentally and economically viable.

Schoeneberger, M.; Bentrup, G.; de Gooijer, H. [et al.]. 2012. Branching out: agroforestry as a climate change mitigation and adaptation tool for agriculture. Journal of Soil and Water Conservation. 67(5): 128A–136A. http://doi.org/10.2489/jswc.67.5.128A.

This review paper provides a synthesis of agroforestry functions that support climate change mitigation and adaptation. Agroforestry practices can increase C sequestration in soils and woody biomass, which can be substantial despite the small area of land typically required by agroforestry. Agroforestry practices can reduce GHG emissions by reducing fossil fuel consumption through fewer equipment runs in areas with trees and lower farmstead heating and cooling requirements. Agroforestry can also reduce N_2O emissions by greater nutrient uptake through plant diversity and lower N fertilizer application in the tree component. In forage-based agroforestry applications, forage quality can be enhanced, which may reduce methane production from livestock. In regards to adaptation, agroforestry practices augment landscape diversity, thereby increasing the capacity for supporting ecosystems services that enhance resiliency to climate change and extreme weather events. Some of these adaptation services include altering microclimates to support crop and forage production and reduce livestock stress, providing habitat diversity to support organisms (e.g., native pollinators, beneficial insects), creating greater structural and functional diversity to protect soil and water resources, and providing diversified production opportunities to reduce risk under fluctuating climate. Agroforestry practices may also provide travel corridors, facilitating species migration to more favorable climates. Despite the positive climate change services that agroforestry can provide, climate change likely will negatively impact these systems. A need exists for a better understanding of the effects on agroforestry systems, as well as a need to develop agroforestry plant materials adapted to future climatic conditions.

Thaler, S.; Eitzinger, J.; Trnka, M.; Dubrovsky, M. 2012. Impacts of climate change and alternative adaptation options on winter wheat yield and water productivity in a dry climate in Central Europe. The Journal of Agricultural Science. 150(05): 537–555. http://doi.org/10.1017/S0021859612000093.

This crop simulation study aimed to determine the yield, water, and N balance impacts of climate change scenarios on regional management measures for winter wheat production in a dry area in northeast Austria. Based on the CERES-Wheat crop-growth simulation model associated with global circulation models, the authors identified outcomes from minimum tillage and hedgerow additions that may contribute to reducing an increased water demand. A baseline predicted 2 °C warming would shorten the growing season by up to 20 days, increase water demands by 6 to 37 mm per growing season, and decrease yields on all sites. Light-textured soils may benefit most from minimum tillage, which may increase these winter wheat yields by up to 8 percent through improved water storage capacity. Medium and moderately fine-textured soils could increase yields most effectively with the additional implementation of hedgerows, which reduced transpiration losses from wind and added water storage through snow retention.

Tsonkova, P.; Böhm, C.; Quinkenstein, A.; Freese, D. 2012. Ecological benefits provided by alley cropping systems for production of woody biomass in the temperate region: a review. Agroforestry Systems. 85(1): 133–152. http://doi.org/10.1007/s10457-012-9494-8.

This paper summarizes the ecological benefits of alley cropping systems based on the available scientific literature. The literature indicates that compared with conventional agriculture, alley cropping systems have the potential to increase C sequestration, improve soil fertility, and generally optimize the utilization of resources. As a direct benefit from integration of managed trees in cropping systems, more efficient nutrient cycling is achieved and the need for fertilization is reduced, especially if N-fixing trees such as black locust are used. Because of the rather low amount of nutrients lost from such systems with surface runoff and leaching, water quality is improved. Due to their structural flexibility, these systems may help to enhance biodiversity and increase overall productivity. Several studies suggest that the alley cropping productivity as estimated by the land equivalent ratio is enhanced compared with conventional agriculture.

Udawatta, R.P.; Jose, S. 2012. Agroforestry strategies to sequester carbon in temperate North America. Agroforestry Systems. 86(2): 225–242. http://link.springer.com/article/10.1007%2Fs10457-012-9561-1.

This paper estimates the C sequestration potential of silvopasture, alley cropping, windbreaks, and riparian buffers in the United States. A coarse approximation was made with limited data by multiplying the C sequestration in each system by the land area. A 4.7 Tg C yr^{-1} C sequestration potential for riparian buffers was based on a 30 m wide buffer along both sides of 5 percent of total river length that would occupy 1.69 million ha. The estimated area was multiplied by 2.6 Mg C ha^{-1} yr^{-1} accrual rate. For alley cropping, the authors estimated the potential conversion of 10 percent of the cropland with a sequestration value of 3.4 Mg C ha^{-1} yr^{-1} to potentially sequester 52.4 Tg C yr^{-1} through alley cropping. Using a sequestration potential of 6.1 Mg C ha^{-1} yr^{-1} and conversion of 10 percent of pasture land (25 million ha) and 51 million ha of forests to silvopastural practices, the total C sequestration potential for silvopasture in the United States could be as high as 464 Tg C yr^{-1}. Establishment of windbreaks that protect cropland, farmstead, and roads could sequester an additional 8.6 Tg C yr^{-1}. The total potential C sequestration by agroforestry in the United States is therefore 530 Tg yr^{-1}. This amount could offset the current U.S. CO_2 emissions (1,600 Tg C yr^{-1} from burning fossil fuel such as coal, oil, and gas) by 33 percent.

2013

Aertsens, J.; De Nocker, L.; Gobin, A. 2013. Valuing the carbon sequestration potential for European agriculture. Land Use Policy. 31: 584–594. http://doi.org/10.1016/j.landusepol.2012.09.003.

The authors examined the potential of agricultural measures in sequestering C as an option for climate change mitigation. The following practices for the European agricultural sector are discussed: (a) agroforestry, (b) introduction of hedges along agricultural plots, (c) introducing cover crops in the rotation system, and (d) practices of low or no tillage. The potential and value of these practices are estimated. All of the practices have potential to increase C sequestration. The introduction of agroforestry is the measure with the highest potential, i.e., 90 percent of the total potential of the four agri-environmental measures studied. In a European context, agroforestry has a net sequestration potential between 1.5 and 4 tonnes C ha^{-1} yr^{-1}. Results only indicate the order of magnitude of the agricultural practices discussed. The range in the sequestration potential by agroforestry varies greatly and the estimates of the social value of C are uncertain.

Clark, K.H.; Nicholas, K.A. 2013. Introducing urban food forestry: a multifunctional approach to increase food security and provide ecosystem services. Landscape Ecology. 28(9): 1649–1669. http://doi.org/10.1007/s10980-013-9903-z.

This study investigates a multifunctional approach called UFF as a means to improve urban food security under climate change. The authors used four approaches to gauge the potential of UFF. First, they analyzed 37 current initiatives based around urban food trees. Second, they analyzed 30 urban forestry master plans. Third, they used Burlington, VT, as a case study to quantify the potential fruit yield of publicly accessible open space if planted with the common apple (*Malus pumila*) under nine different planting and yield scenarios. They determined that most scenarios could contribute to the daily recommended minimum intake of fruit for the entire city's population. Finally, they developed a climate–food–species matrix of potential food trees appropriate for temperate urban environments as a decisionmaking tool. They conclude that substantial untapped potential exists for UFF to contribute to urban sustainability via increased food security and landscape multifunctionality.

Cross, B.K.; Bozek, M.A.; Mitro, M.G. 2013. Influences of riparian vegetation on trout stream temperatures in Central Wisconsin. North American Journal of Fisheries Management. 33(4): 682–692. http://doi.org/10.1080/02755947.2013.785989.

The goal of this study was to investigate the potential for riparian vegetation shading to increase the length of stream that is thermally suitable for Brook Trout (*Salvelinus fontinalis*). Twelve streams throughout central Wisconsin were evaluated. Riparian tree-vegetated segments had a significantly lower mean change in stream temperature per kilometer of stream compared with grass-vegetated segments during the periods of maximum daily and weekly average temperatures. Riparian grass-vegetated segments increased on average 1.19 °C/km during the maximum daily average temperature period and 0.93 °C/km during the maximum weekly average temperature period, whereas tree-vegetated segments decreased 0.48 °C/km and 0.30 °C/km during those respective time periods. Maximum weekly average temperatures were also modeled with different shading levels using a heat budget temperature model. Modeled stream temperatures in equilibrium with their environmental conditions ranging from 23.2 to 28.3 °C at 0 percent shading were reduced to 18.8 to 23.5 °C with 75 percent shading.

Dhillon, R.S.; von Wuehlisch, G. 2013. Mitigation of global warming through renewable biomass. Biomass and Bioenergy. 48: 75–89. http://doi.org/10.1016/j.biombioe.2012.11.005.

In this paper, the authors review causes and consequences of global climate change, with a particular focus on renewable biomass substitutions for fossil fuels. Terrestrial systems with renewable biomass including forests, agroforestry systems that include perennial crops, shrubs, and trees constitute a major C sink, which are not currently used to their highest potential. Studies indicate agroforestry is a particularly promising option for sequestering C on agricultural lands, because it can sequester significant amounts of C although leaving the bulk of the land for agricultural production. Agroforestry has such a high potential, not only because it is the land use practice with the highest C density, but also, because such a large area is suitable for the land use change. The area suitable for agroforestry is estimated to be 585 to 1215 Mha with a mitigation potential of 1.1 to 2.2 Pg C in terrestrial ecosystems during the next 50 years. Agroforestry can also help to decrease pressure on natural forests, promote soil conservation, and provide ecological services to livestock.

Fortier, J.; Truax, B.; Gagnon, D.; Lambert, F. 2013. Root biomass and soil carbon distribution in hybrid poplar riparian buffers, herbaceous riparian buffers and natural riparian woodlots on farmland. SpringerPlus. 2(1): 539. http://doi.org/10.1186/2193-1801-2-539.

This study investigated root and fine root biomass, as well as distribution of soil C stocks in three types of riparian land uses across four sites in farmlands of southern Quebec, Canada. These sites included (1) hybrid poplar riparian buffers (9th growing season), (2) herbaceous riparian buffers, and (3) natural riparian woodlots (varying in tree species and age). This study suggests that the greatest benefits of establishing hybrid poplar buffer in in a riparian zone previously dominated by herbaceous vegetation are important increases in coarse and fine root biomass at greater depth in the soil profile. By comparison with native woodlot species, poplar root systems have the ability to colonize deeper soil horizons. On the other hand, lower or similar soil C stocks were found in poplar buffers compared with adjacent herbaceous buffers, especially near the soil surface, probably because poplars caused a reduction in fine root biomass in surface soil. Another result was that, on average, natural woodlot soils (never disturbed or undisturbed for several decades) tend to have greater soil C stocks than buffer soils, which were still agricultural soils less than 10 years ago.

Priano, M.E.; Fusé, V.S.; Gere, J.I. [et al.]. 2013. Tree plantations on a grassland region: effects on methane uptake by soils. Agroforestry Systems. 88(1): 187–191. http://doi.org/10.1007/s10457-013-9661-6.

This study assessed the rates of CH_4 uptake by soils in tree plantations (pines, mixed deciduous species, and eucalyptus in a natural grassland in Argentinean Pampa) and a naturalized pasture as a control. CH_4 fluxes were weak in the control pasture with both negative (uptake) and positive (emission) values observed. In tree plantations, fluxes were always negative, with statistically significant intersite differences. Although CH_4 flux values in plantations were lower than those reported for pristine forests, the highest uptakes were observed in the mixed deciduous plantation (~10 ng m^{-2} s^{-1}), followed by pines and eucalyptus plantations. Intersite differences were attributed to soil spatial variation. Additionally, a significant inverse correlation between CH_4 uptake and soil water content was found in both the pine and the deciduous plantations, suggesting that high soil water content reduces CH_4 oxidation rates.

Rivest, D.; Lorente, M.; Olivier, A.; Messier, C. 2013. Soil biochemical properties and microbial resilience in agroforestry systems: effects on wheat growth under controlled drought and flooding conditions. Science of The Total Environment. 463–464: 51–60. http://doi.org/10.1016/j.scitotenv.2013.05.071.

This paper describes a study comparing soil properties and responses in agroforestry systems and conventional agricultural systems to determine whether soil differences in terms of biochemical properties would affect crop productivity under extreme soil water conditions (flood and drought). Two sites represented established agroforestry practices: an 18-year-old windbreak and an 8-year-old TBI system. Higher extractable-P, total N, and mineralizable N were in agroforestry soils compared with conventional soils. The metabolic quotient was also lower in agroforestry soils, indicating greater microbial substrate use efficiency. Under water stress, the windbreak-associated wheat exhibited higher aboveground biomass and number of grains per spike than in conventional systems. At the TBI site, this increase (compared with conventional under stress) in biomass, yield, and grains per spike was observed only in drought treatments. Relationships between soil biochemical properties and soil microbia resilience or wheat productivity were strongly dependent on the site. The authors suggest that, given the positive effect on soil biochemical properties and microbial resilience in agroforestry systems under stress, agroforestry could have a beneficial impact on crop productivity and tolerance to severe water stress.

Smith, J.; Pearce, B.D.; Wolfe, M.S. 2013. Reconciling productivity with protection of the environment: is temperate agroforestry the answer? Renewable Agriculture and Food Systems. 28(1): 80–92. http://doi.org/10.1017/S1742170511000585.

This review paper presents evidence supporting the use of agroforestry in temperate countries as a sustainable alternative to industrialized agriculture. According to the evidence, agroforestry provides regulating services that contribute to climate change mitigation (air quality regulation, climate regulation, C sequestration, GHG abatement) and climate change adaptation (erosion regulation, reduction of the impact of natural hazards and extreme events). Implementing agroforestry can help to mitigate many of the negative impacts of agriculture, for example, by regulating soil, water, and air quality, supporting biodiversity, reducing inputs by natural regulation of pests, and more efficient nutrient cycling and by modifying local and global climates.

Smith, P.; Haberl, H.; Popp, A. [et al.]. 2013. How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? Global Change Biology. 19(8): 2285–2302. http://doi.org/10.1111/gcb.12160.

This study explores the agricultural and forestry sectors contributions to GHG mitigation and the maintenance of food supply capacity, while using the same limited land base. It examines the uses of supply- and consumption-side measures and the interactions between them to address the dual challenges of food security and climate change. The article identifies options to reduce GHG emissions through changes in food demand (e.g., reduction in losses and wastes of food in the supply chain and final consumption, as well as changes in diet toward less resource-intensive food and reducing overconsumption). Although supply-side mitigation measures (reducing the net GHG emissions from agriculture and forestry by changes in land management) can either enhance (e.g., improved timing of fertilization and nitrification inhibitors and C sequestration) or negatively impact food security (e.g., reduced fertilizer inputs), demand-side mitigation measures (change in food and fiber demand) should benefit both food security and GHG mitigation. However, more research is needed into demand-side, consumption-based measures, which have been less researched than supply-side measures.

Stavi, I.; Lal, R. 2013. Agroforestry and biochar to offset climate change: a review. Agronomy for Sustainable Development. 33(1): 81–96. http://doi.org/10.1007/s13593-012-0081-1.

This article reviews the potential to sequester C with conservation farming, agroforestry systems, and soil application of biochar in temperate and tropical regions. The article presents the limitations of some farming conservation practices and the potential of agroforestry systems and biochar application to boost sequestration of organic C and, in addition, increase fertilizer efficiency, enhance productive capacity, and advance global food security. At the same time, these practices can support a range of ecosystem services such as decreased soil erosion, reduced contamination of offsite water sources and increased species diversity and ecosystem health, and therefore, can be utilized in reclamation of degraded lands. Payments to farmers and land managers for sequestrating C and improving ecosystem services is an important strategy for promoting the adoption of practices like agroforestry systems and biochar application.

Upson, M.A.; Burgess, P.J. 2013. Soil organic carbon and root distribution in a temperate arable agroforestry system. Plant and Soil. 373(1–2): 43–58. http://doi.org/10.1007/s11104-013-1733-x.

This study evaluated the effect of tree establishment and intercropping treatments on the distribution of roots and SOC to a depth of 1.5 m. A poplar (*Populus* sp.) silvoarable agroforestry experiment including arable controls was established on arable land in lowland England in 1992. The trees were intercropped with an arable rotation or bare fallow for the first 11 years, thereafter grass was allowed to establish. Coarse and fine root distributions were measured in 1996, 2003, and 2011. The amount and type of soil C to 1.5 m depth was also measured in 2011. The trees, initially surrounded by arable crops rather than fallow, had a deeper coarse root distribution with less lateral expansion. In 2011, the combined length of tree and understory vegetation roots was greater in the agroforestry treatments than the control, at depths below 0.9 m. Between 0 and 1.5 m depth, the fine root C in the agroforestry treatment (2.56 t ha^{-1}) was 79 percent greater than that in the control (1.43 t ha^{-1}). Although the SOC in the top 0.6 m under the trees (161 t C ha^{-1}) was greater than in the control (142 t C ha^{-1}), a tendency for smaller soil C levels beneath the trees at lower depths, meant that no overall tree effect existed when a 1.5 m soil depth was considered. From a limited sample, no tree effect existed on the proportion of recalcitrant SOC. The observed decline in soil C beneath the trees at soil depths greater than 60 cm, if observed elsewhere, has important implication for assessments of the role of afforestation and agroforestry in sequestering C.

Winkler, J.A.; Cinderich, A.B.; Ddumba, S.D. [et al]. 2013. Understanding the impacts of climate on perennial crops. Climate Vulnerability. 2: 37–49. http://doi.org/10.1016/B978-0-12-384703-4.00208-2.

This comprehensive book chapter reviews research on the impacts of climate on perennial crops. The goals are to (1) highlight vulnerable growth stages and industry components, (2) investigate climate impacts on perennial crops, (3) summarize current understanding of temporal trends in freeze risk, heat stress, and the timing of growth stages, and (4) identify knowledge gaps. Identified key vulnerabilities include winter chill requirements, springtime freeze risk, climate-related constraints on pollination, heat stress, and disease and insect pest pressure. A myriad of methods have been employed to evaluate the past and future climate vulnerability of perennial crops. Modeling efforts remain largely empirical and impacts assessments are currently handicapped by the lack of process-based models. Although climate-related risk varies with crop type and location, assessment of historical climate variability suggests earlier dates for bloom and other phenological stages and for some locations a reduction in spring and early fall freeze risk. Fruit quality appears to have suffered in some regions and winter injury has increased in high latitude growing regions. Plausible future impacts of a warmer climate include fewer chilling hours, earlier bud break and bloom, changes in fruit quality as temperatures surpass optimal ranges, reduced frequency of winter but not necessarily springtime, cold temperature damage. Increased pest and disease risk may occur due to increase in number of insect generations per season. Climate assessments for perennial crops need to move beyond local and regional scales and recognize that these crops constitute an international market system with varying climate-related risk factors.

2014

Asbjornsen, H.; Hernandez-Santana, V.; Liebman, M. [et al.]. 2014. Targeting perennial vegetation in agricultural landscapes for enhancing ecosystem services. Renewable Agriculture and Food Systems. 29(02): 101–125. http://doi.org/10.1017/S1742170512000385.

This paper synthesizes the current scientific evidence for integrating perennial vegetation into agroecosystems as a management tool for maximizing multiple benefits to society. Perennialization, by increasing biodiversity of both plants and biological organisms, provides one mechanism for enhancing agroecosystem resilience and stability under climate change. The authors focus on the U.S. Corn Belt region as a model system, and also draw comparisons with other climatically diverse regions of the world. The paper addresses enhancement of five ecosystem services from perennialization: hydrologic regulation and water purification, climate regulation and climate change mitigation, biotic regulation, soil quality and nutrient cycling, and provisioning services.

Baah-Acheamfour, M.; Carlyle, C.N.; Bork, E.W.; Chang, S.X. 2014. Trees increase soil carbon and its stability in three agroforestry systems in central Alberta, Canada. Forest Ecology and Management. 328: 131–139. http://doi.org/10.1016/j.foreco.2014.05.031.

This paper compares the N and SOC storage potential in three of the most common agroforestry systems in Alberta, Canada—hedgerow, shelterbelt, and silvopasture. Forest and adjacent agriculture cropland plots were sampled for N and SOC in whole soils and in three particle-size fractions. Within each agroforestry system, the forested land use consistently had greater total SOC in all size fractions than the agricultural component, although the highest levels of SOC and N were found in the fine fraction where C is more stable, with the least found in the coarse fraction, regardless of the agroforestry system studied. C storage in the hedgerows and silvopasture were significantly greater than in the shelterbelts, although this disparity may in part be due to the younger age of the shelterbelts and higher concentration of conifers compared with other forest systems studied. Between land uses, SOC concentration was 31 percent higher ($P=0.02$) in forest soils compared with their agricultural counterpart, indicating the potential for atmospheric CO_2 mitigation where agroforestry systems are integrated into the agricultural landscape.

Blandford, D.; Gaasland, I.; Vårdal, E. 2014. The trade-off between food production and greenhouse gas mitigation in Norwegian agriculture. Agriculture, Ecosystems & Environment. 184: 59–66. http://doi.org/10.1016/j.agee.2013.11.025.

Norwegian agriculture, dominated by livestock production, accounts for only 0.3 percent of the country's gross domestic product but makes a significant contribution (about 9 percent) to the country's GHG emissions. Using a detailed economic model based on representative farms, the study assesses the impact of a targeted reduction of 30 percent in GHG emissions on agricultural activity. Implications of mitigation are examined both for a representative dairy farm and for the sector as a whole. Although the numerical results are specific to the Norwegian setting, they are illustrative of issues facing other countries where ruminants dominate agriculture. A first strategy, a C tax on emissions from agricultural activity, would result in a reduction of agricultural production in Norway, particularly for GHG-intensive commodities (extensification of agricultural production), resulting in lower emissions per unit of output and per hectare. An alternative strategy, rewarding farmers for C sequestration activities (specifically agroforestry), would lead to intensification, as more inputs are applied to the land remaining in agriculture. Emissions per unit of agricultural land would increase but would decline per unit of output. For a given targeted reduction in agricultural GHG emissions, overall production will be higher under an intensification strategy.

Cardona, C.A.C.; Ramírez, N.F.J.; Morales, T.M.A. [et al.]. 2014. Contribution of intensive silvopastoral systems to animal performance and to adaptation and mitigation of climate change. Revista Colombiana de Ciencias Pecuarias. 27(2): 76–94. http://www.scielo.org.co/scielo.php?pid=S0120-06902014000200003&script=sci_arttext&tlng=es.

This review outlines projections for the effects of climate change on livestock industries in Latin American countries, presents concepts on GHG flow, and highlights evidence in support of the conclusion that intensive silvopastoral systems (ISS) is an option that may enable livestock sectors in the region to adapt to climate change and mitigate some of its effects. ISS is associated with four-fold increases in meat production per hectare, higher protein content, and greater DM degradability compared with grass-only pastures. The research reviewed, including both sociopolitical and biophysical components of ISS in Latin America, also suggests that ISS can contribute to GHG mitigation (adoption of ISS may help remove up to 26.6 tons of CO_2e ha^{-1} yr^{-1} from the atmosphere), and suggests making efforts to determine differences between avoidable, reducible, and compensable emissions with each farming system.

Duguma, L.A.; Minang, P.A.; van Noordwijk, M. 2014. Climate change mitigation and adaptation in the land use sector: from complementarity to synergy. Environmental Management. 54(3): 420–432. http://doi.org/10.1007/s00267-014-0331-x.

In this review paper, the authors explore the concepts of synergy as a more effective means to provide climate change and adaptation in the land use sector, particularly in forestry and agriculture. Mitigation and adaptation measures are typically handled separately. They make the case that synergy should emphasize functionally sustainable landscape systems like agroforestry in which adaptation and mitigation are optimized together as part of multifunctional strategy. Often, an enhanced outcome results when the components interact with each other, increasing effectiveness, minimizing costs, and ensuring continuity of production and service provision by minimizing risks. The authors suggest the move from complementarity to synergy needs to capture four key elements: (1) identifying the practices; (2) understanding the processes; (3) addressing tradeoffs; and (4) formulating supportive policies. They use a case study on silvopasture from Tanzania to illustrate synergistic approach.

Fisher, K.; Jacinthe, P.A.; Vidon, P. [et al.]. 2014. Nitrous oxide emission from cropland and adjacent riparian buffers in contrasting hydrogeomorphic settings. Journal of Environment Quality. 43(1): 338–348. http://doi.org/10.2134/jeq2013.06.0223.

This study monitored N_2O fluxes along three transects at two agricultural riparian buffers and a crop field in the White River watershed in Indiana to assess the impact of land use and HGM attributes on emission. Season, land use (riparian forest buffer in alluvium and grassed riparian buffer in tile-drained till plains versus crop field), and site geomorphology were identified as the major indicators of N_2O fluxes. N mineralization related to N_2O fluxes was found at both crop field and riparian buffer sites, although other nutrient cycling indicators (C/N ratio, DOC, microbial biomass C) were detected only at the riparian forest buffer site. N_2O emission peaks occurred in late spring and early summer as a result of flooding and N fertilizer application on crop fields. Crop fields showed the highest annual N_2O emission despite that riparian buffer soil properties are favorable to N_2O production, due to higher mineral N availability in crop fields. The riparian forest buffer also showed higher N_2O emission than the grassed riparian buffer due to higher flooding incidence at the nontile-drained site. Based on the authors' conclusion that landscape geomorphology and flood potential are drivers of N_2O emission in riparian buffers, they recommend that an HGM-based approach should be used for determining regional N_2O budget in riparian ecosystems.

Franzluebbers, A.J. 2014. Climate change and integrated crop–livestock systems in temperate-humid regions of North and South America: mitigation and adaptation. In: Fuhrer, J.; Gregory, P., eds. Climate change impact and adaptation in agricultural systems. Wallingford, United Kingdom: CABI Publishers: 124–139. http://doi.org/10.1079/9781780642895.0124.

This book chapter reviews the effects of integrated crop-livestock systems, such as silvopasture, on climate change mitigation and adaptation. The chapter focuses primarily on the temperate-humid regions of North and South America. Forages can play an important role in soil C sequestration, and the lack of tillage in these systems may be vital for enhancing SOC accumulation rather than simply to maintain it. Perennial forages also extend the growing season compared with annual cash crops, thereby photosynthesizing, depositing rhizosphere C inputs, and drying soil during longer periods of time than annual crops. The overall effect of integrated crop-livestock systems on GHG emissions is still largely unknown. Although ruminant animals emit CH_4, the quantity of emission is roughly the same per animal whether in feedlot or on pasture. A reduction of N_2O emission is likely to exist in pasture-based systems compared with feedlot-based systems due to the lower intensity of manure deposition on a much larger landscape area. Reduction in N fertilizer inputs required for crops in rotation with forages will reduce N_2O emissions. Integrated crop-livestock systems offer large gains in SOC with perennial pastures as a key mitigation strategy and are also a key adaptation strategy to overcome drought and partially control flooding by improving soil quality when forages are distributed appropriately across a landscape scale. The diversity of farming operations in integrated crop-livestock systems reduces the overall risk of failure, despite any one farming component being affected negatively, as in specialized agricultural systems. This diversity also offers resilience of the farming system against perturbations caused by extreme weather events and climate change.

Hallema, D.W.; Rousseau, A.N.; Gumiere, S.J. [et al.]. 2014. Framework for studying the hydrological impact of climate change in an alley cropping system. Journal of Hydrology. 517: 547–556. http://doi.org/10.1016/j.jhydrol.2014.05.065.

The authors used a hydrological framework for simulating local hydrology in an experimental alley cropping system in southern Quebec, Canada. The study evaluated whether this alley cropping system will experience more or less critically dry or wet episodes in the future period between 2041 and 2070 compared with the present day. The simulation combined recent local data and local climate change scenarios with a model of soil water movement, root uptake, and evapotranspiration. The simulations indicate that the alley cropping system will possibly suffer drier conditions in response to higher temperatures and increased evaporative demand. However, these conditions are not necessarily critical for vegetation during the snow-free season. More studies are needed to identify the relationship between the attenuation of variations in temperature and the difference in water uptake between alley cropping and traditional row cropping.

Karki, U.; Goodman, M.S. 2014. Microclimatic differences between mature loblolly-pine silvopasture and open-pasture. Agroforestry Systems. 89(2): 319–325. http://doi.org/10.1007/s10457-014-9768-4.

This research quantified the microclimatic differences between mature loblolly-pine (*Pinus taeda*)-bahaiagrass (*Paspalum notatum*) silvopasture and open bahiagrass pasture on the Coastal Plain of the Southeast United States. Air temperature, soil temperature at 5- and 10-cm depths, wind speed, gust speed, wind direction, humidity, dew point, rainfall, soil-moisture content, total solar radiation, and photosynthetically active radiation data were collected during 3 years. Seasonal, monthly, and diurnal differences between pasture types indicated 29 to 77 percent lower evapotranspiration rates, 29 to 66 percent lower wind speed, 39 to 61 percent lower gust speed, and 17 to 31 percent lower water content in silvopasture compared with open-pasture in all seasons due to the presence of 18- to 20-year-old trees. Overall, milder microclimatic conditions were found consistently in the silvopasture areas compared with open pasture, which may benefit performance and lower stress to grazing animals.

Lasco, R.D.; Delfino, R.J.P.; Espaldon, M.L.O. 2014. Agroforestry systems: helping smallholders adapt to climate risks although mitigating climate change. Climate Change. 5(6): 825–833. http://doi.org/10.1002/wcc.301.

This basic review article considers the benefits and tradeoffs of agroforestry systems to help farmers adapt to climate change. Evidence indicates that trees and agroforestry lead to efficient water utilization, improvement of microclimates, enhanced soil productivity and nutrient cycling, control of pest and diseases, and improved farm incomes through crop diversity, decreased productivity loss, and increased farm productivity. These services are critical in improving farmer capacity to cope with the impacts of climate change. At national and global scale, agroforestry systems have the potential to reduce atmospheric C by storing it in the aboveground biomass of trees, in SOC and, indirectly, by reducing pressure for forest clearance. Potential agroforestry benefits are not without tradeoffs both economically and ecologically. Tradeoffs can include light and nutrient competition due to unfavorable tree-crop interaction and allelopathic effect from trees, which do not discriminate between crops and pests. At the farm scale, increasing trees may also lower productivity, and thus, farm income. Productivity of agroforestry often cannot compete with the productivity of monoculture farm income on a short-term basis. Agroforestry, as a long-term strategy, requires farmers to have stable land tenure rights and economic means to be able to realize net profitability after a number of years.

Lin, B.B. 2014. Agroforestry adaptation and mitigation options for smallholder farmers vulnerable to climate change. In: Benkeblia, N., ed. Agroecology, ecosystems, and sustainability. Boca Raton, FL: CRC Press: 221–238. http://doi.org/10.1201/b17775-12.

This book chapter examines the various ways in which agroforestry systems serve as a mitigation and adaptation strategy under climate change. Examples are provided from coffee agroforestry systems that illustrate adaptation benefits from mitigating temperature variation, preventing soil water loss and increasing water capture, and protection from storms. The author also summarizes the potential of agroforestry systems to reduce GHG emissions through C sequestration and mitigating N_2O and CO_2 emissions from soils and increasing the CH_4 sink capacity compared with annual cropping systems. In addition to the adaptation and mitigation services provided, the author describes other ecosystems services that can benefit farmers.

Lorenz, K.; Lal, R. 2014. Soil organic carbon sequestration in agroforestry systems: a review. Agronomy for Sustainable Development. 34(2): 443–454. http://doi.org/10.1007/s13593-014-0212-y.

The authors review and synthesize the current knowledge about SOC sequestration processes and their management in agroforestry systems. The main points are that (1) useful C sequestration in agroforestry systems for climate change mitigation must slow or even reverse the increase in atmospheric concentration of CO_2 by storing some SOC for millennia, (2) soil disturbance must be minimized and tree species with a high root biomass-to-aboveground biomass ratio or N-fixing trees planted when SOC sequestration is among the objectives for establishing the agroforestry system, (3) sequestration rates and the processes contributing to the stabilization of SOC in agroforestry soils need additional data and research, (4) retrospective studies are often missing for rigorous determination of SOC and accurate evaluation of effects of different agroforestry practices on SOC sequestration in soil profiles, and (5) the long-term SOC storage is finite as it depends on the availability of binding sites, as influenced by a soil's mineral composition and depth. Based on this improved knowledge, site-specific SOC sequestering agroforestry practices can then be developed.

Luedeling, E.; Neil Huth, K.K. 2014. Agroforestry systems in a changing climate—challenges in projecting future performance. Current Opinion in Environmental Sustainability. 6: 1–7. http://doi.org/doi:10.1016/j.cosust.2013.07.013.

Due to the long planning horizons required for adequate management of tree-based ecosystems, a need exists for methods to project climate change impacts on agroforestry systems. This article summarizes challenges and opportunities of three known approaches to project impacts of climate change on agroforestry systems. The main approaches presented are process-based models, species distribution models, and climate analogue analysis. Knowing the pro and cons of various projection approaches can aid in designing the adaptation strategies. Process-based models are the most likely tools to produce robust and credible projections of climate change impacts on agroforestry systems. Species distribution models and climate analogue analyses are less reliable, but their use is much cheaper, faster, easier, and more flexible. Combined approaches may lead to more robust projections than application of each individual projection strategy.

Schnell, S.; Altrell, D.; Ståhl, G.; Kleinn, C. 2014. The contribution of trees outside forests to national tree biomass and carbon stocks—a comparative study across three continents. Environmental Monitoring and Assessment. 187(1): 1–18. http://doi.org/10.1007/s10661-014-4197-4.

This paper provides an analysis of National Forest Monitoring and Assessment inventory data from 11 countries across three continents related to TOF, which is typically not included in national monitoring of tree resources or is fragmented with different institutions and stakeholders dealing with various TOF types. These data showed that in six countries, greater than10 percent of national aboveground tree biomass is accumulated outside of forests. The highest value (73 percent) was observed for Bangladesh (total forest cover 8.1 percent, average biomass per hectare in forest 33.4 t ha^{-1}) and the lowest (3 percent) was observed for Zambia (total forest cover 63.9 percent, average biomass per hectare in forest 32 t ha^{-1}). Although average TOF biomass stocks were estimated to be smaller than 10 t ha^{-1}, these stocks can add up to considerable quantities in many countries. The authors suggest that the extension of national forest monitoring programs, to include TOF, would generate a more complete picture of national tree biomass, C pools, and regional wood resources, especially critical in the context of climate change mitigation measurements.

Van Laer, E.; Moons, C.P.H.; Sonck, B.; Tuyttens, F.A.M. 2014. Importance of outdoor shelter for cattle in temperate climates. Livestock Science. 159: 87–101. http://doi.org/10.1016/j.livsci.2013.11.003.

The review provides an overview of the most relevant climatic factors, animal characteristics, and adaptation strategies that should be taken into account when assessing the need for mitigating measures for cattle on pasture in temperate regions. Belgian climatic data were used to show that conditions outside the thermo-neutral zone of certain cattle types could lead to cold or heat stress and impairment of production if persistent. Such thermal stress is likely to become more common in the future, due to global warming and cattle's decreased capacity for thermoregulation caused by selection for high productivity. Recent research demonstrated that the traditional climatic indices and threshold values of the associated heat stress risk classes are outdated, too strongly focused on hot climates, and too general to evaluate heat stress in the different cattle types bred in temperate areas. The available knowledge on the effect of adverse weather on pastured cattle in temperate climates suggests that providing shelter will benefit their welfare and productivity. Further research is needed, however, to estimate the effectiveness of different types of shelter for different types of cattle.

Van Noordwijk, M.; Bayala, J.; Hairiah, K. [et al.]. 2014. Agroforestry solutions for buffering climate variability and adapting to change. In: Fuhrer, J.; Gregory, P., eds. Climate change impact and adaptation in agricultural systems. Wallingford, United Kingdom: CABI Publishers: 216–232. http://www.cabi.org/cabebooks/ebook/20143234527.

This book chapter provides a review on increasing the adaptive capacity of agricultural systems in tropical and subtropical regions through agroforestry. The authors focus their review around the buffering capacity provided by trees and review literature on modifying wind speed, air temperature, and soil-water balance with trees. Although wind is a near-horizontal flux and tree effects can extend beyond 20 times the canopy height, the shading effect on temperature is restricted to a few multiples of tree height, depending on the solar elevation. Compared with open-field agriculture, all land use systems with trees have reduced daily amplitude of air temperature, with a gradual dampening of the amplitude within the top layers of the soil. In regards to soil water balance, many publications so far indicate that hydraulic lift can mitigate, but not reverse, the drying of soil layers, postponing the emergence of water stress. Biophysical buffering effects of trees on microclimate will not be sufficient in the face of progressive climate change. Trees can also aid in buffering socio-economic processes related to social and human capitals. The authors provide examples of buffering across the five capitals of livelihood systems; natural, social, human, physical infrastructure, and financial.

Wotherspoon, A.; Thevathasan, N.V.; Gordon, A.M.; Voroney, R.P. 2014. Carbon sequestration potential of five tree species in a 25-year-old temperate tree-based intercropping system in southern Ontario, Canada. Agroforestry Systems. 88(4): 631–643. http://doi.org/10.1007/s10457-014-9719-0.

This study measured C sequestration potential for five tree species commonly used in TBI systems in southern Ontario, Canada, and a soybean sole-cropping system. Total C pool measures—including SOC, soil respiration, litterfall, and litter decomposition—aboveground and belowground tree C content (with a density of 111 trees ha^{-1} and at 25 years after establishment) amounted to 113.4, 99.4, 99.2, 91.5, 91.3, and 71.1 t C ha^{-1} for hybrid poplar, white cedar, red oak, black walnut, Norway spruce, and the sole soybean crop, respectively. Although hybrid poplars may reach their peak C pools at 25 years, the slower growing species, such as Norway spruce, showed increasing C pools as they age, with expected sequestration of atmospheric CO_2 until harvest age (60 years or more). A relay planting or staggered planting management practice is suggested, based on these results, in order to maximize short- and long-term C sequestration.

2015

Agostini, F.; Gregory, A.S.; Richter, G.M. 2015. Carbon sequestration by perennial energy crops: is the jury still out? BioEnergy Research. 8(3): 1057–1080. http://doi.org/10.1007/s12155-014-9571-0.

This review paper focuses on the role of perennial plants in capturing and storing SOC. Authors collated evidence for dedicated perennial energy crops to sequester C and quantitative data to parameterize stored SOC turnover models. The annual net SOC storage change exceeds the minimum mitigation requirement (0.25 Mg C ha^{-1} yr^{-1}) under herbaceous and woody perennials (1.14 to 1.88 and 0.63 to 0.72 Mg C ha^{-1} yr^{-1}, respectively). Long-term time series of field data are still needed to verify sustainable stored SOC enrichment, as the physical and chemical stabilities of stored SOC pools remain uncertain.

Altieri, M.A.; Nicholls, C.I.; Henao, A.; Lana, M.A. 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development. 35(3): 869–890. http://doi.org/10.1007/s13593-015-0285-2.

This review paper provides an overview of traditional farming systems that can serve as a source of strategies to help modern agricultural systems become more resilient to climatic extremes. Many of these agroecological strategies that reduce vulnerabilities to climate variability include crop diversification, maintaining local genetic diversity, animal integration, soil organic management, water conservation and harvesting, etc. Agroforestry is one type of farming system that can provide these agroecological functions. Observations of traditional farming systems after extreme climatic events, such as hurricanes and droughts, have revealed that resiliency to climate disasters is closely linked to farms with increased levels of biodiversity. Field surveys and results reported in the literature suggest that agroecosystems are more resilient when inserted in a complex landscape matrix, featuring adapted local germplasm deployed in diversified cropping systems managed with organic matter rich soils and water conservation-harvesting techniques. The effective diffusion of these agroecological technologies likely will determine how well and how fast farmers adapt to climate change.

Baah-Acheamfour, M.; Chang, S.X.; Carlyle, C.N.; Bork, E.W. 2015. Carbon pool size and stability are affected by trees and grassland cover types within agroforestry systems of western Canada. Agriculture, Ecosystems & Environment. 213: 105–113. http://doi.org/10.1016/j.agee.2015.07.016.

This paper reports the study of mineral SOC and N in bulk soil, and organic C and N distribution among the light, occluded, and heavy fractions in 0-to-10 cm and 10-to-30 cm soil layers of forested versus cropland land cover types in three agroforestry systems (hedgerow, shelterbelt, and silvopasture) common to Western Canada. The study found that *Populus*-based silvopasture systems have the greatest C stock in surface mineral soils and in the labile light fraction of SOM, whereas *Picea*-based shelterbelt systems had the largest C stock in the more stable heavy fraction of SOM, both of which may be used in an otherwise annual cropping system to enhance the stable SOC pool. Within each agroforestry system and across soil depths, treed areas consistently stored more C and N in all soil density fractions than the adjacent cropland without trees. This increased C and N was particularly evident in the light fraction at both soil depths, where soil bulk density in treed areas was lower than that in adjacent croplands indicating a greater degree of soil aggregation and potential for reduced compaction from vehicles or livestock or both.

Bangura, A.; Oo, Y.L.; Kamara, C.S. [et al.]. 2015. Effect of shelterbelt and land management on soil carbon sequestration in shelterbelt-pasture system at Charles Sturt University, Orange Campus, New South Wales Australia. American Journal of Experimental Agriculture. 7(1): 36–44. http://doi.org/10.9734/AJEA/2015/14497.

The goal of this study was to compare TOC in soils and labile C quantities under shelterbelt plantings of native species and long-term pasture. SOC levels in three pastures and adjacent 12-year-old shelterbelts on a campus farm in New South Wales were measured in September 2011 and March 2012, using $KMnO_4$ oxidation methods. The spring sampling showed no significant difference in TOC percent nor labile C percent between shelterbelt and pasture at all three sites; however, SOC was higher during autumn sampling than spring sampling in all three sites and at both 10 cm and 10-to-20 cm depths due to microbial activity, higher vegetation and warmer climate in autumn. Both fractions of C decreased with depth. Topography and tree species contributed to differences in TOC percent and labile C percent between sites.

Barbeau, C.D.; Oelbermann, M.; Karagatzides, J.D.; Tsuji, L.J.S. 2015. Sustainable agriculture and climate change: producing potatoes (*Solanum tuberosum* L.) and bush beans (*Phaseolus vulgaris* L.) for improved food security and resilience in a Canadian Subarctic First Nations Community. Sustainability. 7(5): 5664–5681. http://doi.org/10.3390/su7055664.

A short growing season limits agriculture in northern subarctic and arctic regions of Canada, making it difficult for communities to locally produce crops. A warming climate may produce opportunities to replace expensive and environmentally unsustainable imported food with local agricultural production. This study explores the feasibility of sustainably growing potatoes and green bush beans using agroforestry practices through a case study in Fort Albany First Nation in northern Ontario, Canada. Potatoes and green beans were planted on three sites, two of them within mature parallel rows of willow growing on the banks of old drainage ditches and one open field. Potato crops grew during a 2-year period and were rotated into plots planted with green bush beans. Results showed that potatoes and bush beans could grow successfully in the subarctic without the use of greenhouses, with yields comparable with more conventional high-input agricultural methods. Moreover, the agroforestry sites produced greater potato and bean yields than the open site, and the potatoes were larger. This study concluded that a warming climate in the northern regions of Canada and the use of agroforestry practices offer opportunities to sustainably grow local foods to promote food security.

Borland, A.M.; Wullschleger, S.D.; Weston, D.J. 2015. Climate-resilient agroforestry: physiological responses to climate change and engineering of crassulacean acid metabolism (CAM) as a mitigation strategy. Plant, Cell & Environment. 38(9): 1833–1849. http://doi.org/10.1111/pce.12479.

Crassulacean acid metabolism is a photosynthetic CO_2 fixation pathway that maximizes water use efficiency providing an opportunity to engineer both enhanced photosynthetic performance and water-use efficiency into bioenergy crops. Fast-growing, short-rotation forestry bioenergy crops such as poplar (*Populus* spp.) and willow (*Salix* spp.) are particularly susceptible to hydraulic failure following drought stress due to their isohydric nature and relatively high stomatal conductance. The introduction of bioengineered crassulacean acid metabolism into short-rotation forestry bioenergy trees is a potentially viable path to sustaining agroforestry production systems in the face of a globally changing climate.

Bussotti, F.; Pollastrini, M.; Holland, V.; Brüggemann, W. 2015. Functional traits and adaptive capacity of European forests to climate change. Environmental and Experimental Botany. 111: 91–113. http://doi.org/10.1016/j.envexpbot.2014.11.006.

This paper reviews different ways European forests respond to climate change, identifies functional traits related to climatic stress responses and their physiological significance, and examines the distribution of such traits among the most important European tree species. Based on this review, climate change may have favorable impacts on boreal forests but detrimental impacts on the Mediterranean ones. Current modeled simulation of future forest distribution suggests the expansion of forests at the highest latitudes and altitudes, alongside with a reduction in the hottest and driest Mediterranean regions of South Europe. Southern genotypes may replace forest species in Western and Central Europe. Natural migration of species beyond their current ecological and geographical limits may be hampered by several unpredictable factors like extreme weather events, including severe winter and late spring frost at the higher latitudes and altitudes. Adaptive strategies and forest management ideas are presented to help forests cope with the new environmental conditions.

Cardinael, R.; Chevallier, T.; Barthès, B.G. [et al.]. 2015. Impact of alley cropping agroforestry on stocks, forms and spatial distribution of soil organic carbon—a case study in a Mediterranean context. Geoderma. 259–260: 288–299. http://doi.org/10.1016/j.geoderma.2015.06.015.

This study of SOC in intercropped hybrid walnuts (Juglans regia x nigra) with durum wheat (Triticum turgidum) in an 18-year-old Mediterranean agroforestry plot was compared with SOC in adjacent pots of durum wheat alone using a geostatistical framework. In the intercropped system, additional SOC stocks quantified to 2.0 m depths were greatest at 0 to 30 cm, with additional storage rates of 350 ± 41 kg C per ha^{-1} yr^{-1} at 0 to 100 cm. More than 50 percent of additional SOC storage was in tree rows, where soil was not tilled, although distance to the closest tree in intercropped and control rows had no significant effect on SOC concentrations. Most additional SOC in the agroforestry plot was in coarse fractions (less than 50 μm). Highest SOC concentrations in topsoil layers and labile organic fractions in tree rows demonstrate the importance of deeper soil layers for storing SOC.

Chendev, Y.G.; Sauer, T.J.; Gennadiev, A.N. [et al.]. 2015. Accumulation of organic carbon in chernozems (Mollisols) under shelterbelts in Russia and the United States. Eurasian Soil Science. 48(1): 43–53. http://doi.org/10.1134/S1064229315010032.

This study identifies and analyzes changes in the organic C content of chernozems (Mollisols) at six sites in the forest-steppe, meadowsteppe, and meadow landscapes of the Central Russian Upland and U.S. Great Plains, comparing virgin plots, shelterbelts, and plowlands. On all the studied plots, the shelterbelt humus profile was reliably thicker (15 cm thicker on average) than under adjacent plowed fields. An increase in the hydrothermic coefficient value by 0.15 accompanied the increased humus-accumulative layer in the shelterbelt soils. For most plots, the organic C pools under shelterbelts were also significantly higher than adjacent plowlands, and in some cases, higher than or comparable to virgin plots, although the pools of organic C decrease from the central point of the shelterbelt by an average of 7.3 t ha^{-1} per 10 m. Due to active dehumification in the shelterbelt soils, the organic C pool is distributed from 0 to 100 cm, whereas a higher concentration of the TOC pool is in the first 0 to 50 cm in virgin plots. The authors concluded that chernozems and Mollisols under planted shelterbelts or forest plantations are enriched in organic matter; thus, agroforest reclamation favors the sequestration of atmospheric CO_2 into forest phytomass and SOM.

Davidson, M.M.; Howlett, B.G.; Butler, R.C. [et al.]. 2015. The influence of shelterbelts in arable farmland on beneficial and pest invertebrates. New Zealand Plant Protection. 68: 367–372. https://www.cabdirect.org/cabdirect/abstract/20153279567.

This study investigated the effect of radiata pine (*Pinus radiata*) and Monterey cypress (*Cupressus macrocarpa*) shelterbelts on the relative abundance and diversity of beneficial and pest invertebrates commonly found in arable crops. Window intercept, yellow sticky, and pitfall traps were placed next to shelterbelts or post and wire fences and also 50 m from these borders into adjacent crops on two arable farms. The abundance of given species and taxa varied considerably depending on farm location, season, and field border type. However, the mean number of beneficial insect species and taxa per trap did not vary markedly between field border types or adjacent crops, although traps at shelterbelts or their adjacent crops caught more of some pest species and taxa than traps beside fences. The pine and cypress shelterbelts did not markedly increase relative abundance or diversity of beneficial insects.

Ehret, M.; Bühle, L.; Graß, R. [et al.]. 2015. Bioenergy provision by an alley cropping system of grassland and shrub willow hybrids: biomass, fuel characteristics and net energy yields. Agroforestry Systems. 89(2): 365–381. http://doi.org/10.1007/s10457-014-9773-7.

In the temperate zone, alley cropping is promoted as a climate change-resilient agroforestry practice for bioenergy production. The authors assessed the performance of alley cropping systems to produce biofuels feedstock. The systems consisted of clover-grass, a native diversity-oriented grassland mixture, and multiple rows of willows. They were compared with a willow and grassland control. Three different conversion technologies were applied to biomass feedstock and analyzed for relevant quality parameters. Net energy balances were calculated to determine the potential of the cropping systems. The grassland control had the highest triennial yield (18 t DM ha^{-1}), whereas pure willow stands were less productive with 7 t DM ha^{-1}. Alley cropping was intermediate with 12 t DM ha^{-1} on average. Net energy yields of agroforestry systems were clearly lower compared with pure grassland systems, due to low yields from the willows. This study covered only the establishment phase of the willows, and expected growth and productivity will increase during the coming years.

Fortier, J.; Truax, B.; Gagnon, D.; Lambert, F. 2015. Biomass carbon, nitrogen and phosphorus stocks in hybrid poplar buffers, herbaceous buffers and natural woodlots in the riparian zone on agricultural land. Journal of Environmental Management. 154: 333–345. http://doi.org/10.1016/j.jenvman.2015.02.039.

This study evaluated C, N, and P stocks in three types of riparian vegetation cover (9-year-old hybrid poplar buffers, herbaceous buffers, and natural riparian woodlots) across four agricultural sites in Quebec. Results suggest that 9-year-old poplar buffers have stored 9 to 31 times more biomass C, 4 to 10 times more biomass N, and 3 to 7 times more biomass P than adjacent nonmanaged herbaceous buffers, with the largest differences observed on the more fertile sites. The conversion of these herbaceous buffers to poplar buffers could respectively increase C, N, and P storage in biomass by 3.2 to 11.9 t ha^{-1} yr^{-1}, 32 to 124 kg ha^{-1} yr^{-1}, and 3.2 to 15.6 kg ha^{-1} yr^{-1} during 9 years. Soil NO_3 and P supply rates during the summer were respectively 57 percent and 66 percent lower in poplar buffers than in adjacent herbaceous buffers, potentially reflecting differences in nutrient storage and cycling between the two buffer types. Biomass C ranged from 49 to 160 t ha^{-1} in woodlots, 33 to110 t ha^{-1} in poplar buffers, and 3 to 4 t ha^{-1} in herbaceous buffers.

Guo, L.; Dai, J.; Wang, M. [et al.]. 2015. Responses of spring phenology in temperate zone trees to climate warming: a case study of apricot flowering in China. Agricultural and Forest Meteorology. 201(February): 1–7. http://doi.org/10.1016/j.agrformet.2014.10.016.

This study explored apricot tree responses to temperature variation based on decades of phenological observations coupled with meteorological data at five climatically contrasting sites in China. Results indicated that in cold climates, forcing conditions almost entirely determine spring timing of apricots, with warmer springs leading to earlier bloom. However, for apricots at warmer locations, chilling temperatures were the main driver of bloom timing, implying that further warming in winter might cause delayed spring phases. The nonlinear responses to warming that the authors detected, especially for warming during the chilling phase, imply that the advances in spring phases that currently prevail in most places might eventually slow or even turn into delays, as warming continues. This phenomenon seems particularly likely in relatively warm temperate locations, where winter temperatures are already marginal for chill-requiring plants. As global warming progresses, current trends of advancing phenology might slow or even turn into delays for increasing numbers of temperate species.

Helling, A.P.; Conner, D.S.; Heiss, S.N.; Berlin, L.S. 2015. Economic analysis of climate change best management practices in Vermont agriculture. Agriculture. 5(3): 879–900. http://doi.org/10.3390/agriculture5030879.

Farmer perceptions of risk and profitability of best management practices are key determinants of adoption, which traditional incentive programs like the Environmental Quality Incentive Program attempt to address by providing financial and technical support. To ensure that payments offered through these programs maximize adoption, regional incentive payments must be based on locally established costs. This paper evaluates the cost of implementing three climate change specific best management practices for 12 diverse farms in Vermont. The practices include cover cropping, MIRG, and riparian buffer strips. Results show the average cost for cover cropping is $129.24 per acre, MIRG is $79.82 per acre, and a tree-based riparian buffer strip cost $807.33 per acre. Authors conclude that existing incentive payments for cover cropping and MIRG are below costs, likely resulting in underadoption. The comparison between costs and the public's willingness to pay for riparian buffer strips indicates a relatively more adequate payment level.

Jacinthe, P.A.; Vidon, P.; Fisher, K. [et al.]. 2015. Soil methane and carbon dioxide fluxes from cropland and riparian buffers in different hydrogeomorphic settings. Journal of Environment Quality. 44(4): 1080–1090. http://doi.org/10.2134/jeq2015.01.0014.

This study compared soil CO_2 and CH_4 fluxes in adjacent crop fields and riparian buffers in both a flood-prone forest and a flood-protected grassland along an incised channel in central Indiana to evaluate the impact of biotic and abiotic drivers of GHG fluxes in riparian zones. Significantly higher CO_2 emissions (0.02 to 11.67g CO_2 $m^{-2}d^{-1}$) observed in riparian areas compared with adjoining croplands were associated with warmer soil temperatures, where the forest site exhibited warmer soil temperatures during the dormant season, and the grassland site exhibited warmer soil temperatures during the growing season. Of all environmental, landscape, and soil factors measured, water table depth was the only factor significantly related to daily CH_4 flux. Flood events under warm soil conditions produced the greatest CH_4 emission, although cooler soil temperatures in early spring revealed a less pronounced effect. Overall, annual CH_4 emission averaged between +0.04 ± 0.17 kg CH_4 ha^{-1} in croplands and +0.92 ± 1.6 kg CH_4 ha^{-1} in flood-affected riparian forest sites where the less than 8 percent total area topographic depression accounted for 78 percent of the annual CH_4 emission. On the other hand, the nonflooded riparian grassland was a net CH_4 sink, possibly due to the presence of subsurface tile drains and a dredged or incised channel. Although hydrological alterations may contribute to improved CH_4 sink strength, the authors suggest that water quality maintenance functions and other ecological services from the riparian buffers also be carefully considered.

Johnson, M.F.; Wilby, R.L. 2015. Seeing the landscape for the trees: metrics to guide riparian shade management in river catchments. Water Resources Research. 51(5): 3754–3769. http://doi.org/10.1002/2014WR016802.

The authors assessed the relative significance of landscape and riparian shade on thermal behavior of two upland rivers in the United Kingdom using a network of high-resolution Tw measurements and topographic shade modeling. Based on this study, riparian shade is most beneficial for managing Tw at distances 5 to 20 km downstream from the source of the rivers where discharge is modest, near-surface hydrological pathways dominates flow, wide floodplains with little landscape shade exist, and cumulative solar exposure times are sufficient to affect Tw. The authors found that approximately 0.5 km of complete shade is necessary to offset Tw by 1°C during July (the month with peak Tw) at a headwater site; whereas, 1.1 km of shade is required 25 km downstream. Although these findings are based on two specific catchments, they may indicate the general relationship of Tw and riparian shade in other similar settings.

Mader, T.L.; Griffin, D. 2015. Management of cattle exposed to adverse environmental conditions. Veterinary Clinics of North America: Food Animal Practice. 31(2): 247–258. http://doi.org/10.1016/j.cvfa.2015.03.006.

This review paper reports on strategies for managing cattle exposed to adverse weather conditions. The emphasis is on aiding animals in the winter to keep the body temperature elevated throughout the day and in the summer to reduce the peak body temperature during the day or help animals drive down the body temperature at night. For heat events, access to shade improved the welfare and performance of cattle, and these benefits are greater in areas with higher temperatures and solar radiation. Although the review did not address shade provided by agroforestry practices, it is likely the benefits would be achieved. In regards to cold weather, cattle that were provided protection from wind had better performance during winter. In general, cold stress will stimulate intake; however, with less daylight in the winter combined with the cold conditions, cattle may not aggressively go to feeding areas, thus feed intake is not always increased. Under these conditions, windbreaks are useful, especially for heavyweight cattle. It is important to design windbreaks to keep snow out of the areas where cattle are held. Wind protection needs to be far enough away to prevent snow from dumping into areas holding cattle.

Medinski, T.V.; Freese, D.; Böhm, C. 2015. Soil CO_2 flux in an alley-cropping system composed of black locust and poplar trees, Germany. Agroforestry Systems. 89(2): 267–277. http://doi.org/10.1007/s10457-014-9764-8.

This study investigates soil CO_2 fluxes in an alley-cropping system composed of tree strips of black locust (*Robinia pseudoacacia*) and poplar (*Populus nigra × P. maximowiczii*) trees and adjacent crop strips of lupines and a catch crop mix (*Lupinus/Solarigol*). In all sampling areas, soil CO_2 flux increased from May to July, showing a significant positive correlation with air and soil temperature, which can be a reflection of increase in photosynthesis, and therefore supply of carbohydrates from leaves to rhizosphere, during the warm summer months. A positive correlation between CO_2 flux and soil moisture during the warm period indicates an enhancing role of soil moisture on microbial mineralization and root respiration. Despite a seasonal variation in CO_2 flux, average CO_2 flux for the study period showed no significant differences between the young trees hedgerows and adjacent crop strips. A greater C loss with soil respiration from trees hedgerows in summer may be compensated by greater C assimilation and storage in woody biomass and the greater respiration from crops after tillage in autumn. A longer time investigation at different locations and soil conditions is warranted to validate this pattern and to assess changes in microclimate and root density with the increasing age of trees hedgerows and their influence on soil respiration.

Nasielski, J.; Furze, J.R.; Tan, J. [et al.]. 2015. Agroforestry promotes soybean yield stability and N_2-fixation under water stress. Agronomy for Sustainable Development. 35(4): 1541–1549. http://doi.org/10.1007/s13593-015-0330-1.

This study examines the effect of a full season water deficit on soybean N_2-fixation, nodulation, and yield in the tree crop zone of a mature agroforestry system in Ontario, Canada. Soybean yields within the agroforestry system were lower compared with monoculture. However, agroforestry system soybean yields were stable with rainfall reduction, where monoculture water deficit induced a significant decline in yields. Soybeans in the tree-crop zone also captured more atmospheric N_2-fixation compared with monoculture (91 versus 63 percent), although both showed significant decline in total fixed N under rainfall reduction. Overall, N cycling is enhanced in the tree-crop competitive zone compared with monoculture, especially under water deficit. The study demonstrates that as growing conditions are predicted to become drier and less evenly distributed, yields in the tree-crop competitive zone of agroforestry systems will not be further reduced, thus increasing the viability of these methods for climate change adaptation.

Pumariño, L.; Sileshi, G.W.; Gripenberg, S. [et al.]. 2015. Effects of agroforestry on pest, disease and weed control: a meta-analysis. Basic and Applied Ecology. 16(7): 573–582. http://doi.org/10.1016/j.baae.2015.08.006.

The authors conducted a meta-analysis of 42 studies to assess the effects of agroforestry on abundance of invertebrate pests, weeds, natural enemies, and plant damage due to pests and diseases. They also tested whether effects of agroforestry were dependent on crop type (annual or perennial), type of pest association (aboveground or belowground), and weed type (parasitic Striga weeds or nonparasitic weeds). Only two studies were from temperate regions, and the rest were from tropical regions. A recorded 125 observations existed concerning the effects of agroforestry on pest management: 28 on pest abundance; 20 on proportion of plant damage due to pests and diseases; 29 on abundance of natural enemies; 11 on diversity of natural enemies; 7 on proportion of pests predated or parasitized; and 21 on weed abundance. Agroforestry practices resulted in lower abundances of both parasitic and nonparasitic weeds and in higher abundances of natural enemies. The effects of agroforestry on invertebrate pests and diseases were dependent on crop type. In perennial crops (e.g., coffee, cocoa, and plantain), agroforestry was associated with lower pest abundances and less plant damage. However, the effects were not significant in annual crops (e.g., maize, rice, and beans). Only two studies investigated if the effects of agroforestry on pest control translated to increased crop yield, and they both found a positive effect. Most of the studies showed no effect of agroforestry on enemy diversity. Most of the studies were done in either coffee or maize (more than 80 percent of studies) and, thus, it is possible that the results are partly dependent on the crop types studied. In addition, the authors detected a publication bias with regards to agroforestry reducing plant damage and suggest this result be treated with care.

Raza, M.M.; Khan, M.A.; Arshad, M. [et al.]. 2015. Impact of global warming on insects. Archives of Phytopathology and Plant Protection. 48(1): 84–94. http://dx.doi.org/10.1080/03235408.2014.882132.

This paper examines the literature on the potential effects of rising temperatures and elevated CO_2 levels on insects. Rising temperatures will influence the insect behavior, distribution, development, survival, reproduction, geographical range, and end population size, although elevated CO_2 will alter chemical plant defenses, parasitism, reproduction, and insect developmental rates. Models estimated that a 2 °C increment in temperature might result in one to five additional life cycles per season and may contribute to increased insect outbreaks. The authors recommend different tactics to manage insects under changing climate scenarios: modifying integrated pest management, monitoring, modeling prediction, risk rating, genetic diversity, and breeding for resistance.

Rivest, D.; Vézina, A. 2015. Maize yield patterns on the leeward side of tree windbreaks are site-specific and depend on rainfall conditions in eastern Canada. Agroforestry Systems. 89(2): 267–277. http://doi.org/10.1007/s10457-014-9758-6.

This study investigated the spatial distribution of maize grain yield in the leeward side of mature (average age of 30 years) single-tree row windbreaks that were on four farm sites in southern Quebec, Canada. The authors determined whether the sign and magnitude of windbreak effects on spatial patterns of maize yield varied across contrasting years with respect to rainfall conditions. The greatest yield variation was observed at the tree-crop interface (within 0.5 to 1 H, where H = tree height), where substantial yield reductions occurred. In two sites, the magnitude of negative windbreak effects on maize yield at the tree-crop interface decreases in the wetter years. They found maize yield variation among sampling positions between 2H and 20H (here considered as the shelter zone), with yield values often significantly higher than at 24H (here considered as a control zone with negligible tree shelter effects). The magnitude of this yield variation in the shelter zone generally decreased in the wetter years. It is estimated that the net effect of windbreak on maize yield (0.5 to 20 H versus 24 H) was negligible. No dry years occurred during the study period, which may have produced greater yield benefit.

Sánchez, I.A.; McCollin, D. 2015. A comparison of microclimate and environmental modification produced by hedgerows and dehesa in the Mediterranean region: a study in the Guadarrama region, Spain. Landscape and Urban Planning. 143: 230–237. http://doi.org/10.1016/j.landurbplan.2015.07.002.

This study compares two traditional Mediterranean agroforestry systems, dehesa and hedged fields, for boundary microclimate and environmental characteristics that assess respective differences related to climate modification, SOC, and soil water content. *Fraxinus angustifolia*-dominated sites were observed in the Guadarrama Mountains of Spain with simultaneous sampling under both dehesa and hedgerows. Temperature profiles were similar in both systems, but hedgerows had higher soil water content, lower wind speeds, and higher total SOC in both open fields and under trees compared with dehesa. Hedged fields are tending to be replaced by dehesa due to labor costs, but based on these results, hedged field systems have potential to modify boundary layer climates on a broader scale than dehesa, and thus provide greater natural capital and environmental benefit than dehesa. Although limited in scope of the habitat studied, the authors suggest that this system resilience may be critical for ameliorating effects of climate change.

Thiel, B.; Smukler, S.M.; Krzic, M. [et al.]. 2015. Using hedgerow biodiversity to enhance the carbon storage of farmland in the Fraser River delta of British Columbia. Journal of Soil and Water Conservation. 70(4): 247–256. http://doi.org/10.2489/jswc.70.4.247.

This study quantifies the C biomass and soil C storage potential of PH relative to RH and neighboring annual crop production fields (PF) on eight sites in the Fraser Valley of British Columbia, Canada between 2012 and 2014. No significant difference existed in the biomass C in the two hedgerow types, despite age differences with PH having a mean total aboveground and belowground biomass of 76 ± 32 t C ha^{-1} and RH 124 ± 21 t C ha^{-1}. Aggregate stability was similar in both hedgerow types and was significantly greater than neighboring production fields. Woody vegetation biodiversity was significantly greater in PH than RH for richness, Shannon, and Simpson measures. PH stored significantly greater soil C than RH to 1.2 t m^{-2} standard soil mass with values being 175.9 ± 13.2 t C ha^{-1} and 132.7 ± 7.3 t C ha^{-1}, respectively. The authors conclude that these results favor farm-scale management practices and landscape-scale policies that promote nonproduction hedgerows for climate change mitigation on agricultural land.

Thiessen Martens, J.R.; Entz, M.H.; Wonneck, M.D. 2015. Review: redesigning Canadian prairie cropping systems for profitability, sustainability, and resilience. Canadian Journal of Plant Science. 95(6): 1049–1072. http://doi.org/10.4141/cjps-2014-173.

This review paper presents a wide variety of ecologically based crop production practices and discusses their potential role in enhancing the profitability, environmental sustainability, and resilience of Canadian prairie cropping systems. The authors reviewed agroforestry practices, including shelterbelts, ecobuffers, and alley cropping. In general, farming systems that most closely mimic natural systems through appropriate integration of diverse components, within a context of supportive social and economic structures, appear to offer the greatest potential benefits. Authors contend that a need exists to shift prairie cropping systems to more permanent agriculture based on diversified systems and effective crop livestock integration.

Thomas, S.M.; Griffiths, S.W.; Ormerod, S.J. 2015. Beyond cool: adapting upland streams for climate change using riparian woodlands. Global Change Biology. http://doi.org/10.1111/gcb.13103.

The authors conducted cross-sectional analyses at two scales (region and within streams) to investigate whether four types of riparian management, including those proposed to reduce potential climate change impacts, might also affect the composition, functional character, dynamics, and energetic resourcing of macroinvertebrates in upland Welsh streams in the United Kingdom. Riparian land use across the region had only small effects on invertebrate taxonomic composition, although stable isotope data showed how energetic resources assimilated by macroinvertebrates in all functional guilds were split roughly 50:50 between terrestrial and aquatic origins irrespective of riparian management. Streams draining the most extensive deciduous woodland had the greatest stocks of coarse POM and greater numbers of shredding detritivores. Stream-scale investigations showed that macroinvertebrate biomass in deciduous woodland streams was around twice that in moorland streams and lowest of all in streams draining nonnative conifers. Results indicate planting deciduous riparian trees along temperate headwaters as an adaptation to climate change can modify macroinvertebrate function, increase biomass, and potentially enhance resilience by increasing basal resources where cover is extensive (more than 60 m riparian width).

Vidon, P.; Marchese, S.; Welsh, M.; McMillan, S. 2015. Short-term spatial and temporal variability in greenhouse gas fluxes in riparian zones. Environmental Monitoring and Assessment. 187(8): 503. http://doi.org/10.1007/s10661-015-4717-x.

This study evaluated GHG fluxes (N_2O, CO_2, CH_4) in two North Carolina agricultural riparian zones (one restored, one unrestored). The estimates of the average GHG flux at the site scale varied by one order of magnitude, depending on whether the mean or the median is used as a measure of central tendency. Because the median tends to mute the effect of outlier points (hot spots and hot moments), the authors suggest that both must be reported or that other more advanced spatial averaging techniques (e.g., kriging, area-weighted average) should be used to estimate GHG fluxes at the site scale. Results also indicate that short-term temporal variability in GHG fluxes (a few days) under seemingly constant temperature and hydrological conditions can be as large as spatial variability at the site scale, suggesting that the scientific community should rethink sampling protocols for GHG at the soil-atmosphere interface to include repeated measures during short periods of time at select chambers to estimate GHG emissions in the field. Although recent advances in technology provide tools to address these challenges, their cost is often too high for widespread implementation. Until technology improves, sampling design strategies will need to be carefully considered to balance cost, time, and spatial and temporal representativeness of measurements.

Winans, K.S.; Tardif, A.-S.; Lteif, A.E.; Whalen, J.K. 2015. Carbon sequestration potential and cost-benefit analysis of hybrid poplar, grain corn and hay cultivation in southern Quebec, Canada. Agroforestry Systems. 89(3): 421–433. http://doi.org/10.1007/s10457-014-9776-4.

This study compared the cost benefit and C sequestration potential of a hybrid poplar and hay intercropping system, a hybrid poplar plantation, and two agricultural systems—corn and hay. NPP in aboveground and belowground biomass was calculated based on literature on average yields in the study region and was used to estimate C sequestration as plant residue integrated into the stable SOC pool with residence time of more than 100 years. This method excluded indirect emissions related to farm operations and, thus, does not represent a complete C balance. C sequestration potential varied based on site-specific growing conditions and management practices; however, potential was highest for hybrid poplar grid plantations (NPP of 19.80 to 31.01 Mg C ha^{-1}), followed by hybrid poplar hay intercrop (NPP of 9.14 to 11.18 Mg C ha^{-1} with 17 to 32 percent of NPP from trees), grain corn (NPP of 7.51 to 10.73 Mg C ha^{-1}), and hay (NPP of 0.28 to 0.72 Mg C ha^{-1}). Economic benefits, calculated using replacement chain and equivalent annual annuity approaches, were greatest for grain corn, followed by hay and hybrid poplar-hay intercrop, hybrid poplar grid plantation. The authors conclude that the financial attractiveness of TBI systems in Quebec will require C-trading programs to increase the profitability of afforestation with hybrid poplar cultivation.

Zhou, X.; Schoeneberger, M.M.; Brandle, J.R. [et al.]. 2015. Analyzing the uncertainties in use of forest-derived biomass equations for open-grown trees in agricultural land. Forest Science. 61(1): 144–161. http://doi.org/10.5849/forsci.13-071.

Data from open-grown green ash (*Fraxinus pennsylvanica*), Austrian pine (*Pinus nigra*), and eastern red cedar (*Juniperus virginiana*), representing major morphological types of agroforestry tree species in the northern Great Plains, were used in this analysis of the uncertainties in the use of both regional and nonregional forest-derived equations for open-grown trees. At lower diameter ranges, forest-derived equations provided accurate estimates of trunk biomass, but larger diameters resulted in overestimation of biomass up to 40 percent for individual trees. Across all diameter ranges, use of the forest-derived equations resulted in underestimates of individual tree branch biomass 29 to 82 percent, and underestimates of whole tree biomass at least 18 percent for individual trees. Adjustment factors of forest- to open-grown tree biomass exhibit a power function with diameter and a constant with whole-tree biomass. Use of the constant factor to adjust biomass estimations for open-grown trees represents an effective approach to converting forest-derived equations for open-grown trees in agricultural land, although equations developed specifically from open-grown tree measurements would improve accuracy.

2016

Amadi, C.C.; Van Rees, K.C.; Farrell, R.E. 2016. Greenhouse gas mitigation potential of shelterbelts: estimating farm-scale emission reductions using the Holos model. Canadian Journal of Soil Science. (Spec. issue): 1–15. http://dx.doi.org/10.1139/cjss-2016-0017.

The authors estimated the potential of three shelterbelt tree species—hybrid poplar, white spruce, and caragana—at five planting densities, to reduce GHG emissions in a model farm (cereal–pulse rotation). They used the Holos model, a Canadian farm-level GHG calculator developed by Agriculture and Agri-Food Canada, to estimate shelterbelt effects on farm GHG emissions during a 60-year timeframe. The planting densities of the shelterbelts represented 0, 0.5, 1.0, 3.0, and 5.0 percent of the total area of an average (688 ha) Saskatchewan farm. The greatest reduction in farm GHG emissions was estimated for hybrid poplar (23.0 percent) followed by white spruce (17.5 percent) and caragana (8.2 percent)—all at the highest planting density. The GHG mitigation by the shelterbelts was attributable primarily (90 to 95 percent of GHG reduction) to C sequestration in tree biomass and in SOC pools, with the remainder due to lower N_2O, CH_4 emissions, and a reduction in farm energy use. The GHG estimates from Holos agree with field measurements and suggests that species selection will be important for maximizing C sequestration and GHG mitigation potential of shelterbelt systems. Conversely, shelterbelt removal from the agricultural landscape suggests an increase of onfarm GHG emissions.

Amadi, C.C.; Van Rees, K.C.; Farrell, R.E. 2016. Soil–atmosphere exchange of carbon dioxide, methane and nitrous oxide in shelterbelts compared with adjacent cropped fields. Agriculture, Ecosystems & Environment. 223: 123–134. http://dx.doi.org/10.1016/j.agee.2016.02.026.

This study quantified soil CO_2, CH_4, and N_2O fluxes from shelterbelts and compared them with emissions from adjacent cropped fields to assess their potential for GHG mitigation. Soil GHG fluxes were monitored from nine shelterbelts and their associated cropped fields at three locations within the Boreal plains and Prairies Ecozones of Saskatchewan Canada. Mean cumulative CO_2 emissions from shelterbelt soils were significantly ($P < 0.0001$) greater than those from cropped fields (i.e., 4.1 and 2.1 Mg CO_2 ha^{-1} yr^{-1}, respectively). However, SOC storage (0–30 cm) was 27 percent greater—representing an increase of 28 Mg ha^{-1}—in the shelterbelts than in the cropped fields. Soil CH_4 oxidation was greater ($P < 0.0001$) in shelterbelts than in adjacent cropped fields (i.e., −0.66 and −0.19 kg CH_4 ha^{-1} yr^{-1}, respectively) and cropped soils emitted significantly ($P < 0.0001$) greater quantities of N_2O than the shelterbelts (i.e., 2.5 and 0.65 kg N_2O -N ha^{-1} yr^{-1}, respectively). Total seasonal exchange of non-CO_2 GHGs was reduced by 0.55 Mg CO_2e ha^{-1} yr^{-1} in shelterbelts as compared with cropped fields, 98 percent of which was soil-derived N_2O. Patterns of soil temperature, moisture and organic matter distribution beneath shelterbelts suggest a modification in soil micro-environment due to shelterbelt establishment and root activity that, in turn, may be responsible for the observed increase in soil CO_2 emissions and CH_4

oxidation. These data suggest that shelterbelts have substantial potential to mitigate GHGs by enhancing C storage and reducing N_2O emissions, and maintaining a strong CH_4 sink.

Amichev, B.Y.; Bentham, M.J.; Kulshreshtha, S.N. [et al.]. 2016. Carbon sequestration and growth of six common tree and shrub shelterbelts in Saskatchewan, Canada. Canadian Journal of Soil Science. (Spec. issue): 1–14. http://doi.org/10.1139/cjss-2016-0107.

This study quantified the growth characteristics of six common shelterbelt species in Saskatchewan (hybrid poplar, Manitoba maple, Scots pine, white spruce, green ash, and caragana) to estimate C stocks. The researchers use growth curves and C dynamics modeling approaches to simulate shelterbelt growth and estimate the C stocks in 50,439 km of shelterbelts containing the six species. This area represents 83 percent of the total shelterbelt inventory in Saskatchewan (60,633 km). Shelterbelt width ranged from 6.3 to 14.0 m, age ranged from 5 to 100 yr, and tree density ranged from 356 to 791 trees ha^{-1}. The r^2 of the growth curve equations ranged from 28 to 97 percent, with less than 50 percent root-mean-square error and less than 30 percent bias. The total ecosystem C stocks of all shelterbelts of the six species in Saskatchewan were 10.8 Tg C (1 Tg C = 1 million Mg C), of which 3.77 Tg C was sequestered in the soil and shelterbelt biomass since 1990. The climate mitigation potential of the six shelterbelt species, ranging from 1.78 to 6.54 Mg C km^{-1} yr^{-1}, emphasized the important role that trees can have on the agricultural landscape to mitigate GHGs.

Franzluebbers, A.J.; Chappell, J.C.; Shi, W.; Cubbage, F.W. 2016. Greenhouse gas emissions in an agroforestry system of the Southeastern USA. Nutrient Cycling in Agroecosystems. 108(1): 1–16. http://doi.org/10.1007/s10705-016-9809-7.

The authors hypothesized that tree-crop interactions could prevent excess N from being released to the atmosphere as N_2O. They evaluated N_2O and CO_2 emissions, soil temperature, water content, and surface-soil inorganic N in an 8-year-old agroforestry site in North Carolina. The experimental design was a factorial arrangement of soil texture (loamy sand, sandy loam, and clay loam) and canopy cover (cropped alley, margin between crops and trees, and under *Pinus palustris*, *Pinus taeda*, and *Quercus pagoda*) with three replications. Sampling occurred 42 times within a year using static, vented chambers exposed to the soil for 1-hour periods. Soil N_2O emission was lower under tree canopies than in cropped alleys, and margin areas were intermediate. Soil texture, water content, and inorganic N were key determinants of the magnitude of N_2O emission. Soil CO_2 emission was controlled by temperature and water content as expected, but surprisingly, not by their interaction. Soil temperature was 1.8 ± 1.3 °C lower, and soil water content was 0.043 ± 0.15 m^3 m^{-3} lower under tree canopy than in cropped alleys, which helped to reduce CO_2 emission under trees relative to that in cropped alleys. These results provide a foundation for reducing GHG emissions in agricultural landscapes with varying soil texture by introducing timber production without abandoning agricultural operations.

Kim, D.G.; Kirschbaum, M.U.; Beedy, T.L. 2016. Carbon sequestration and net emissions of CH_4 and N_2O under agroforestry: synthesizing available data and suggestions for future studies. Agriculture, Ecosystems & Environment. 226: 65–78 http://dx.doi.org/10.1016/j.agee.2016.04.011.

This review paper analyzed data from 109 observations of net rates of change of biomass or soil C stocks in agroforestry systems from 56 peer-reviewed publications and from 26 datasets from 15 peer-reviewed publications of net changes in the emissions of CH_4 and N_2O. The authors categorized agroforestry into two distinct types—tree-crop coexistence types where trees and agricultural crops are grown together (type 1) and tree-crop rotation type where trees and crops are grown alternately on the same piece of land (type 2). They assessed the changes in C storage and net GHG emissions between agriculture and type 1 agroforestry. The data showed high variability in net C sequestration rates in both biomass and soils depending on the type of agroforestry, with reported C increments ranging from 0.3 to 7.7 t C ha^{-1} y^{-1} in biomass and 1.0 to 7.4 t C ha^{-1} y^{-1} in soils. On average, type 1 stands sequestered 3.8 ± 1.3 t C ha^{-1} y^{-1} in aboveground biomass, with no evidence of changed rates for stands aged 5 to 25 years. All available studies exclusively reported increases in soil C stocks, with highest reported soil C sequestration rates of more than 8 t C ha^{-1} y^{-1} for the first year after agroforestry establishment. Averaged across all observations, soil C sequestration rates were about 2 t C ha^{-1} y^{-1} in youngest stands that gradually diminished with time since stand establishment. Overall, type 1 agroforestry stands (at an average age of 14 years) sequestered 7.2 ± 2.8 t C ha^{-1} y^{-1}, with biomass and soil C sequestration contributing about 70 percent and 30 percent of that increment, respectively. Soils under agroforestry also oxidized 1.6 ± 1.0 kg CH_4 ha^{-1} y^{-1} and emitted 7.7 ± 3.3 kg N_2O ha^{-1} y^{-1}. Comparing agroforestry and adjacent agricultural lands, the authors found only minor differences in net CH_4 and N_2O emissions, with no clear overall direction of change. Overall, agroforestry was estimated to contribute to mitigating 27 ± 14 t CO_2e ha^{-1} y^{-1} at least for the first 14 years after establishment.

Possu, W.B.; Brandle, J.R.; Domke, G.M. [et al.]. 2016. Estimating carbon storage in windbreak trees on U.S. agricultural lands. Agroforestry Systems. 90(5): 889–904. https://link.springer.com/article/10.1007/s10457-016-9896-0.

Assessing C sequestration in windbreaks has been limited, in part, due to the lack of suitable data and associated models for estimating tree biomass and C for species growing under more open-grown conditions such as windbreaks. The authors evaluated 15 allometric models using destructively sampled ponderosa pine (*Pinus ponderosa*) data from field windbreaks in Nebraska and Montana. Several goodness-of-fit metrics were used to select the optimal model. The Jenkins et al. (2003) model was then used to estimate biomass for 16 tree species in windbreaks projected during a 50-year time horizon in nine continental U.S. regions. C storage potential in the windbreak scenarios ranged from 1.07 ± 0.21 to 3.84 ± 0.04 Mg C ha^{-1} yr^{-1} for conifer species and from 0.99 ± 0.16 to 13.6 ± 7.72 Mg C ha^{-1} yr^{-1} for broadleaved deciduous species during the 50-year period. Estimated mean C storage potentials across species and regions were 2.45 ± 0.42 and 4.39 ± 1.74 Mg C ha^{-1} yr^{-1} for conifer and broadleaved deciduous species, respectively. This information should enhance the predictive capacity of C sequestration potential of windbreaks in the United States.

Thiel, B.; Krzic, M.; Gergel, S. [et al.]. 2016. Soil CO_2, CH_4 and N_2O emissions from production fields with planted and remnant hedgerows in the Fraser River Delta of British Columbia. Agroforestry Systems 91 (6): 1139–1156. http://doi.org/10.1007/s10457-016-9990-3.

The objectives of this study were to (1) compare CO_2, CH_4, and N_2O emissions from two types of hedgerows and adjacent annual agricultural production fields and (2) better understand how climate, soil properties, and plant species configurations affect hedgerow GHG emissions. At eight study sites in the lower Fraser River delta of British Columbia, the authors measured emissions from soil in both PH and RH, as well as in adjacent annual crop production fields during 1 year using a closed-static chamber method. CO_2 emissions were 59 percent higher in PH than RH, yet no significant differences exist of relative emissions of CH_4 and N_2O. The environmental variables that explained the variation in emissions differed for the three GHGs. CO_2 emissions were significantly correlated with soil temperature. CH_4 and N_2O and CO_2 emissions were marginally significantly correlated with SOC and soil water-filled pore space, respectively. Emissions were not significantly correlated with hedgerow plant species diversity. Although hedgerows sequester C in their woody biomass, the study demonstrated that it is critical to measure hedgerow emissions to accurately ascertain their overall GHG mitigation potential. The results indicate no CO_2e emission differences between the management options that plant new diverse hedgerows or conserve existing hedgerows.

Winans, K.S.; Whalen. J.K.; Rivest, D. [et al.]. 2016. Carbon sequestration and carbon markets for tree-based intercropping systems in southern Quebec, Canada. Atmosphere. 7(2): 17. http://doi.org/10.3390/atmos7020017.

Two experimental 10-year-old TBI systems and adjacent non-TBI systems in southern Quebec, Canada, were evaluated in this study based on C stocks from soil, crop and crop roots, litterfall, tree, and tree roots. In addition, a calculation of the financial benefits of C sequestration under Quebec's Cap and Trade System for Greenhouse Gas Emissions Allowances (C & T System) was used to assess the capital incentives of TBI systems. The TBI systems were found to hold 33 to 36 percent more C than non-TBI systems, and financial benefits after 10 years totaled between $1,568 and $1,913 (276 trees ha^{-1}) and between $2,259 and $2,758 (500 trees ha^{-1}) at each respective TBI site under the C & T System, which is calculated based on emission units that are directly related to C sequestration. The estimated C stored in the branches, foliage, and wood of trees in the TBI systems accounted for 56.09 and 26.38 t C ha^{-1} in poplar, and 13.22 and 3.61 t C ha^{-1} in hardwoods at respective sites. This evaluation revealed that TBI systems can provide cash flow as trees grow, but lower crop yield and growth rates of slower growing trees may result in a net cost of TBI systems. The authors suggest that payments to farmers for ecosystem services, including water quality and pollination, can help overcome this revenue gap.

Ziegler, J.; Easter, E.; Swan, A. [et al.]. 2016. A model for estimating windbreak carbon within COMET-Farm™. Agroforestry Systems. 90(5): 875–887. http://doi.org/10.1007/s10457-016-9977-0.

The authors developed a modeling process for estimating C fluxes occurring within windbreak systems. The modeling framework incorporates a set of species- and region-specific growth models to account for tree C sequestration, paired with models to describe tree death and C cycling. The model is generalized by region and species group, allowing users to run scenarios for any common tree species in any location within the contiguous United States. Integrated into the agricultural GHG accounting tool, COMET-Farm™, the windbreak component gives landowners and land managers power to view agroforestry systems in the same context as agricultural operations and provides an alternative to intensive biomass inventories.

2017

Abbas, F.; Hammad, H.M.; Fahad, S. [et al.]. 2017. Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. Environmental Science and Pollution Research. 24(12): 11177–11191. http://doi:10.1007/s11356-017-8687-0.

The authors reviewed the potential of agroforestry to counter the increasing concentration of atmospheric CO_2 by sequestering it in above- and belowground biomass. Agroforestry systems retain higher quantities of C in above and belowground biomass in comparison to crop and grazing land use systems. At global scale, 630 million ha of unproductive croplands could be used for agroforestry to potentially sequester 586,000 Mg C year^{-1} by 2040. There is a need to incorporate agroforestry in C stocks to precisely estimate the contribution of this neglected pool in current global and national C monitoring protocols. To simulate the potential of agroforestry systems in sequestering C, new models are needed that can precisely predict net uptake of atmospheric CO_2 compared to treeless systems especially under the IPCC scenarios of projected global climate change.

Amadi, C.C.; Farrell, R.E.; Van Rees, K.C. 2017. Greenhouse gas emissions along a shelterbelt-cropped field transect. Agriculture, Ecosystems & Environment. 241:110–120. https://doi.org/10.1016/j.agee.2016.09.037.

Researchers measured changes in soil CO_2, CH_4 and N_2O fluxes along five replicated transects extending from the center of a shelterbelt to the center of the adjacent agricultural field. The shelterbelt was a 31-year-old, two-row hybrid poplar-caragana shelterbelt located in Saskatchewan, Canada. Soil-derived GHG fluxes were measured using non-steady-state vented chambers placed along parallel transects situated within the shelterbelt strip (0H, where H = tree height), at the shelterbelt edge (0.2H), at the edge of the adjacent cropped field (0.5H), and in the cropped field at distances of 40 m (1.5H) and 125 m (5H) from the shelterbelt. Summed over the entire study period, cumulative CO_2 emissions were greatest at 0H (8032 ± 502 kg CO_2-C ha^{-1}) and lowest at 5H (3348 ± 329 kg CO_2-C ha^{-1}). The decrease in CO_2 emissions at increasing distances away from the shelterbelt was irregular, however, with soil temperature and organic carbon distribution being the dominant controls. Soil CH_4 oxidation was greatest at 0H (−1447 ± 216 g CH_4-C ha^{-1}), but decreased as distance from the shelterbelt increased. Conversely, soil N_2O emissions were lowest at 0H (345 ± 15 g N_2O-N ha^{-1}) but increased with increasing distance from the shelterbelt. Patterns of soil CH_4 uptake and N_2O emissions were strongly correlated with root biomass and soil temperature and moisture in the upper 30 cm of the soil profile. Tree root distribution may be a key factor in determining the spatial range of shelterbelt effect on GHG emissions in adjacent fields.

Ballesteros-Possu, W.; Brandle, J.R.; Schoeneberger, M. 2017. Potential of windbreak trees to reduce carbon emissions by agricultural operations in the U.S. Forests. 8(5): 138. http://doi.org/10.3390/f8050138.

In addition to sequestering C in woody biomass, trees on farms can contribute to GHG mitigation through emission avoidance mechanisms. The authors estimated emission avoidance contributions for field and farmstead windbreak designs across the United States, along with GHG emission budgets for corn, soybean, winter wheat, and potato operations. The authors assessed farming scenarios with large (600 ha), mid (300 ha), and small-size (60 ha) farms containing farmsteads built before and after 2000, growing different cropping systems. Windbreak scenarios were assumed to occupy up to 5 percent of the crop area for field windbreaks, while emission avoidance for farmstead windbreaks were assumed to provide a 10- and 25-percent reduction in energy usage for air conditioning and heating, respectively. Total reduction of CO_2e emissions by windbreaks on farm systems ranged from a low of 0.9 Mg CO_2e yr^{-1} for a 60-ha farm with a home built before 2000 to 39.1 Mg CO_2e yr^{-1} for a 600-ha farm with a home built after 2000. By reducing fossil fuel usage from farm operations, windbreaks provide a promising strategy for reducing GHG emissions from agriculture in the United States.

Brandt, P.; Kvakić, M.; Butterbach-Bahl, K.; Rufino, M.C. 2017. How to target climate-smart agriculture? Concept and application of the consensus-driven decision support framework "target CSA". Agricultural Systems. 151: 234–245. http://doi.org/10.1016/j.agsy.2015.12.011.

This paper describes a framework to target CSA integrating quantitative, spatial data, and cross-sectoral stakeholder opinions using analytic hierarchy process and goal optimization. Biophysical, social, and economic CSA suitability indices were used to identify CSA potential and aid informed decisionmaking where agricultural adaptation and mitigation priorities could be targeted. The target CSA spatially explicit multicriteria decision support framework was applied in Kenya with 32 experts from four stakeholder groups (Government, NGO, science, private sector), and revealed regions with consistently high CSA potential, as well as areas with high potential depending on the applied consensus scenario. The exemplary application of target CSA in Kenya revealed that the framework contributes valuable insights to the development of policy and planning for CSA that can be extended and adoptable in other countries with varying biophysical, social, and economic conditions. Further integration of multiple scales of planning for adaptation and mitigation are needed.

Cardinael, R.; Chevallier, T.; Cambou, A. [et al.]. 2017. Increased soil organic carbon stocks under agroforestry: a survey of six different sites in France. Agriculture, Ecosystems & Environment. 236: 243–255. http://dx.doi.org/10.1016/j.agee.2016.12.011.

The researchers assessed C stocks under five silvoarable systems and one silvopastoral system in France. All sites had an agroforestry system with an adjacent, purely agricultural control plot. The land use management in the interrows in the agroforestry systems and in the control plots were identical. The age of the study sites ranged from 6 to 41 years after tree planting. Depending on soil type, the sampling depth ranged from 20 to 100 cm, and SOC stocks were assessed using equivalent soil masses. The aboveground biomass of the trees was also measured at all sites. In the silvoarable systems, the mean organic C stock accumulation rate in the soil was 0.24 (0.09–0.46) Mg C ha^{-1} yr^{-1} at a depth of 30 cm and 0.65 (0.004–1.85) Mg C ha^{-1} yr^{-1} in the tree biomass. Increased SOC stocks were also found in deeper soil layers at two silvoarable sites. Young plantations stored additional SOC but mainly in the soil under the rows of trees, possibly as a result of the herbaceous vegetation growing in the rows. At the silvopastoral site, the SOC stock was significantly greater at a depth of 30-to-50 cm than in the control but was the same at 0-to-30 cm.

Dhillon, G.S.; Van Rees, K.C. 2017. Soil organic carbon sequestration by shelterbelt agroforestry systems in Saskatchewan. Canadian Journal of Soil Science. (Spec. issue): 1–16. http://doi.org/10.1139/cjss-2016-0094.

The objective of this study was to examine SOC sequestration potential of major shelterbelt species, including green ash (*Fraxinus pennsylvanica*), hybrid poplar (*Populus* spp.), Manitoba maple (*Acer negundo*), white spruce (*Picea glauca*), Scots pine (*Pinus sylvestris*), and caragana (*Caragana arborescens*), ranging in age from 5 to 63 years. The authors collected soil samples (0 to 50 cm) for six major shelterbelt species and adjacent agricultural fields and determined SOC concentration. Shelterbelts had a significantly higher amount of SOC compared with adjacent agricultural fields, with an average difference of 18.6 Mg C ha^{-1} in the top 50 cm soil. An additional 3-to-8 Mg C ha^{-1} was contained in the tree litter layer. Younger shelterbelts (age less than 20 years) tended to lose SOC in the early years of shelterbelt establishment. However, the SOC accrual was positively related to shelterbelt stand age. Besides stand age, other shelterbelt stand characteristics, including tree height and diameter, crown width, and amount of surface litter, were also positively correlated with the increase in SOC concentration. The findings of this study support the hypothesis that shelterbelts can lead to a significant amount of SOC sequestration in agroecosystems.

Paul, C.; Weber, M.; Knoke, T. 2017. Agroforestry versus farm mosaic systems–comparing land-use efficiency, economic returns and risks under climate change effects. Science of The Total Environment. 587–588(1): 22–35. http://dx.doi.org/10.1016/j.scitotenv.2017.02.037.

The authors developed a modeling approach to compare the performance of agroforestry and farm mosaic diversification strategies, accounting for tree-crop interaction effects and economic and climate uncertainty. A Modern Portfolio Theory and risk simulation were coupled with the process-based biophysical simulation model WaNuLCAS 4.0. The authors used data from a field trial in Panama as an example application. The results showed that the simulated agroforestry systems (Taungya, alley cropping, and border planting) could outperform a farm mosaic approach in terms of cumulative production and return. Considering market and climate uncertainty, agroforestry showed up to 21 percent higher economic return at the same risk level (i.e., standard deviation of economic returns). Farm compositions with large shares of land allocated to maize cultivation were also more severely affected by an increasing drought frequency in terms of both risks and returns. The study demonstrates that agroforestry can be an economically efficient diversification strategy if the design allows for economies of scope, beneficial interactions between trees and crops, and higher income diversification.

Appendix

Table A–1. Units of measure and conversions

Unit of measure	Explanation
Mg (Megagram)	= 10^6 grams = 1 metric ton = 1 tonne
Mt (Megaton)	=10^6 tons = 1,000,000 tonnes
Tg (Teragram)	= 10^{12} grams = 1 million metric tons = 1,000,000 tonnes
Pg (Petagram)	= 10^{15} grams = 1 billion metric tons = 1,000,000,000 tonnes
ha (hectare)	= 2.471 acres
Mha	= million hectares
ac (acre)	= 0.405 hectares

Table A–2. Names of chemical elements and compounds and their abbreviations

Abbreviation	Name
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
O_3	Ozone
N	Nitrogen
N_2	Nitrogen gas
NH_4	Ammonium
NO_2	Nitrous dioxide
NO_3	Nitrate
N_2O	Nitrous oxide
P	Phosphorus

Table A–3. Abbreviations and acronyms and their definitions

Abbreviation/acronym	Name
ARP	afforestation/reforestation projects
CCS	climate change-integrated conservation strategies
CM	conventional microcropping
CSA	climate-smart agriculture
CO_2e	carbon dioxide equivalent, the amount of global warming potential generated, using carbon dioxide as a reference
DBH	diameter at breast height
DM	dry matter
DOC	dissolved organic carbon
FACE	free-air CO_2 enrichment
GCM	global climate model
GHG	greenhouse gas
HGM	hydrogeomophologic
IPCC	Intergovernmental Panel on Climate Change
MDW	mean dry weight
MIRG	management-intensive rotational grazing
NGO	nongovernmental organization
NPP	net primary production
PH	planted hedgerow
POM	particulate organic matter
RH	remnant hedgerow
RLD	root length density
SOC	soil organic carbon
SOM	soil organic matter
SWC	safe winter chill
TBI	tree-based intercropping
TOC	total organic carbon
TOF	trees outside of forests
Tw	water temperature
UFF	urban food forestry
VOC	volatile organic compound