The Future of Temperate Agroforestry in the United States

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Abstract Agroforestry has been practiced in the United States since the 1930s in the form of windbreaks; however, science-based agroforestry research and practice gained attention only in the1970s. Even then, the progress of agroforestry and its acceptance by practitioners, farmers, and policy makers were hindered by the paucity of hard evidence to support the practice. The scientific foundation that has been laid, over the past decade in particular, has elevated agroforestry's role as an integral component of a multifunctional working landscape in the United States. Recent trends in the agriculture sector necessitate farm diversification as an essential strategy for economic competitiveness in a global market. The realization that agroforestry systems are well suited for diversifying farm income while providing environmental services and ecosystem benefits has increased receptivity on the part of some landowners. Agroforestry systems offer great promise for the production of biomass for biofuel, specialty and organic crops, pasture-based dairy, and beef, among others. Agroforestry also offers proven strategies for carbon sequestration, soil enrichment, biodiversity conservation, and air and water quality improvement not only for the landowners or farmers but for society at large. The USDA Agroforestry Strategic Framework released in 2011 identifies agroforestry as an important component of a much-needed national strategy to "enhance America's agricultural landscapes, watersheds, and rural communities." Minor shifts in national agricultural policy can serve to catalyze the growth of agroforestry further. In an era of environmental sustainability and green business, the realization that agroforestry is an environmentally sound, ecologically sustainable, and economically viable alternative to traditional farming will propel its adoption to newer heights in the coming decades.

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Introduction

In order to understand the future of agroforestry in the United States, one must first understand its past. Even though windbreaks took on great prominence following the "dust bowl" years (Droze 1977), and landowners have known the value of their woodlands for livestock management for decades (DenUyl and Day 1934; Chandler 1940), the use of science-based agroforestry technology in the United States is of very recent origin. J. Russell Smith created early interest in the US agroforestry in his classic work *Tree Crops: A permanent Agriculture* (1950). While the book primarily emphasized "tree-based" agriculture as a source of food for livestock, attention was drawn to the potential ecosystem services that could result from the integration of trees with agricultural crops. Smith argued that "an agricultural economy based almost entirely upon annual crops such as corn and wheat is wasteful, destructive of soil fertility and illogical." However, it was not until the mid-1960s and -1970s that agroforestry had its beginning as a science in the United States. It was at this time that dedicated research began in the southeast to study the potential benefits of integrating pine (*Pinus* spp.) with pastures (Silvopasture: Hart et al. 1970) and in the Midwest to study the interactions between black walnut (*Juglans nigra* L.) and conventional row crops (Alley Cropping: Garrett and Jones 1976). From these beginnings, agroforestry in the United States has grown into an integrated science that also includes the practices of riparian and upland buffers, windbreaks, and forest farming (Garrett 2009).

With the increased understanding of the strengths and weaknesses of agroforestry practices has come an increased receptivity on the part of landowners to explore its use to address farm-related, environmental issues (Udawatta et al. 2002), conservation and wildlife needs 1), and economic gain (Alavalapati and Mercer 2004). While many agroforestry proponents believe that the US agroforestry is best adapted to provide ecosystem services (e.g., carbon sequestration; soil, air, and water quality; biodiversity conservation), agroforestry practices can also result in great economic value when tree species that produce a marketable annual crop are matched with the appropriate companion crop. In particular, combining tree crops such as pecan (*Carya illinoinensis* (Wangenheim) K. Koch) or chestnut (*Castanea mollissima* Blume) with specialty crops (e.g., botanicals, ornamentals, small fruits) or biomass for energy crops (herbaceous or woody species) can provide a competitive and sustainable source of income while yielding multiple conservation benefits. The scope of this chapter is to discuss some of these potential benefits and future applications of agroforestry in the United States. Beginning with a brief overview of the five recognized temperate agroforestry practices in the United States and followed by specific examples for integrating production agriculture and forestry to create more productive and ecologically beneficial land-use strategies, the chapter challenges the reader to think creatively—a tree becomes a great deal more than just a tree when properly used.

Agroforestry Practices in the United States

In the United States and Canada, agroforestry is defined as 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). The five agroforestry practices commonly found in the United States (Table 1) are described below.

Table 1 Five categories of agroforestry practices in the United States and potential area available for each practice

Practice	Predominant region(s)	Use(s)	Associated technologies	Potential area[a] (million ha)
Riparian and upland buffers	All regions	Ameliorate non-point-source pollution, abate soil erosion and nutrient loading, protect watersheds	Streambank bioengineering	1.69
		Modify microenvironments and protect aquatic habitats	Constructed wetlands	
		Create wildlife corridor		
Windbreaks	Great plains	Protect and enhance production of crops and animals, control soil erosion, distribute snowfall	Living snow fences	8.95
		Trap snow		
Alley cropping	Midwest	Increases and diversifies farm crops and income, creates wildlife habitat	Plantation management	17.9
Silvopasture	All regions	Economic diversification, improve animal health, fire protection, timber management	Pine straw harvest	77.7
Forest farming	All regions	Income diversification	Forest management	37.35

[a]Potential area as given in Udawatta and Jose (2011)

Fig. 1 A riparian buffer at the Bear Creek watershed in Iowa. It includes mixed hardwood trees, shrub species, and a native prairie mix of about 15 different grass and forb species. The picture was taken when the buffer was 13 years old (Photo credit: Iowa State University NREM Buffer Team)

Riparian and Upland Buffers

Riparian and upland buffers are strips of permanent vegetation, consisting of trees, shrubs, grasses, and forbs that are planted and managed together. Riparian buffers are placed between agricultural land (usually crop land or pastureland) and water bodies (rivers, streams, creeks, lakes, wetlands) to reduce runoff and nonpoint source pollution (NPSP), stabilize stream banks, improve aquatic and terrestrial habitats, and provide harvestable products (Fig. 1). Upland buffers are placed along the contour within agricultural crop lands to reduce runoff and non-point-source pollution, improve internal drainage, enhance infiltration, create wildlife habitat and connective travel corridors, and provide harvestable products (Schultz et al. 2009) (Fig. 2).

Windbreaks

Trees or shrubs are planted as barriers to reduce wind speed. Windbreak practices include shelterbelts, timberbelts, and living snow fences. Windbreaks are planted and managed as part of a crop or livestock operation. Field windbreaks are used to protect a variety of wind-sensitive row, forage, tree, and vine crops, to control wind

Fig. 2 An upland buffer with trees and grasses at the Greenley Memorial Research Center of the University of Missouri (Photo credit: Ranjith Udawatta, The Center for Agroforestry, University of Missouri)

erosion, and to provide other benefits such as improved bee pollination of crops and wildlife habitat. Livestock windbreaks help reduce animal stress and mortality, feed and water consumption, and odor. Timberbelts are managed windbreaks designed to increase the value of the forestry component (Brandle et al. 2009).

Living snow fences or snowbelts are strategically placed living barriers that have been specifically designed and planted to reduce blowing and drifting snow to improve public safety and emergency services, decrease road maintenance costs, and reduce livestock and wildlife mortality.

Alley Cropping

This practice combines trees planted in single or multiple rows with agricultural or horticultural crops cultivated in the alleyways between the tree rows (Fig. 3). High-value hardwoods such as oak (*Quercus* spp.), walnut (*Juglans* spp.), chestnut (*Castanea* spp.), and pecan (*Carya illinoinensis* (Wangenh.) K. Koch) are favored species in alley cropping practices, and many can provide high-value lumber or

Fig. 3 A pine-cotton alley cropping in Northwest Florida (Photo credit: Shibu Jose, The Center for Agroforestry, University of Missouri)

veneer logs. Crops grown in the alleys, and nuts from walnut, chestnut, and pecan trees, provide annual income from the land while the longer-term wood crop matures. When specialty crops such as herbs, fruits, vegetables, nursery stock, or flowers are grown in the alleys, the microclimate created by the trees enhances the economic production of these sensitive high-value crops in stressed environments (Garrett et al. 2009).

Silvopasture

This practice combines trees with forage (pasture) and livestock production (Fig. 4). Silvopasture can be established by adding trees to existing pasture or by thinning an existing forest stand and adding (or improving) a forage component. The trees are often managed for high-value products (e.g., sawlogs, veneer, posts, and poles), and at the same time, they provide shelter for livestock, protecting them from temperature stresses and reducing food and water consumption. Forage and livestock provide short-term income while at the same time a high-value tree crop is being grown, providing a greater overall economic return from the land (Sharrow et al. 2009).

Fig. 4 A silvopastoral system with hardwood trees at the Wurdack Farm of the University of Missouri (Photo credit: Dusty Walter, The Center for Agroforestry, University of Missouri)

Forest Farming

High-value specialty crops are cultivated under the protection of a forest overstory that has been modified and managed to provide the appropriate microclimate conditions. Shade-tolerant specialty crops like ginseng (*Panax quinquefolium* L.), log-grown shiitake mushrooms *(Lentinula edodes* (Berkeley) Pegler), decorative ferns, and spring ephemerals grown in the understory are sold for nutritional supplement, food, decorative/handicraft, and landscaping products. Overstory trees are managed for high-value timber or veneer logs (Chamberlain et al. 2009).

Agroforestry for Biomass and Biofuel Production

One of the commodities agroforestry is well suited to producing is biomass for bioenergy. The Energy Independence and Security Act Renewable Fuels Standard Version 2 (RFS2)[1] mandates that annual biofuels use nearly triple from the current 45–136 billion L by 2022, with nearly 80 billion L coming from advanced biofuels. Billions of dollars are being invested annually by major private companies, venture capitalists, and the federal government in the development of new technology to convert woody and nonwoody species into advanced, drop-in biofuels such as butanol, jet fuel, and green diesel. Major US companies are seeking to purchase large volumes of advanced biofuels. However, the development of a sustainable feedstock system with minimal impacts on existing food and fiber sectors has been a bottleneck in which the technology cannot be deployed until the feedstock production is in place. In the past 5 years, there have been massive investments in both corn (*Zea mays* L.) ethanol and soybean (*Glycine max* (L) Merr.) biodiesel facilities throughout the Midwestern United States. In 2007 and again in 2010, due to the surge in demand for biofuels and increased oil prices, commodity prices for corn and soybeans spiked to near record levels. The fear of losing productive agricultural land to short rotation woody crops and other bioenergy crops such as switchgrass (*Panicum virgatum* L.) is real but can be negated by adopting integrated approaches such as alley cropping or other relevant agroforestry systems in which food and bioenergy production could be combined.

Incorporating the agroforestry model for biomass production into the traditional agriculture model, however, is challenging. While overcoming the logistical, financial, and cultural obstacles will be an uphill task, it may be an attractive option for many farmers on marginal crop lands. For example, marginal floodplain land is ideal for biomass production using an agroforestry model. Such land could be placed into an alley cropping or riparian buffer system that would integrate rows of short rotation, high yielding woody crops such as willow (*Salix* spp.) and poplar (*Populus* spp.) with alleys of perennial and/or annual grasses (Table 2). Marginal floodplain land is ideal for this type of land use because the land is oftentimes poorly suited for annual agricultural production and better suited for perennial plants (Groninger 2005; Thelemann et al. 2010). In addition, many of these areas are currently out of production because of participation in federal programs such as Conservation Reserve Program (CRP), and biomass could be produced in these areas to meet the goals of the EISA RFS2 without taking additional agricultural land out of production (Volk et al. 2004). Furthermore, these lands are abundant (e.g., nearly 47 million ha of frequently flooded highly erodible land along the Mississippi River alone) and easily identifiable on the landscape, and agroforestry systems for biomass production could be concentrated so that they would not interfere with traditional agricultural operations.

While agroforestry holds great promise for integrating food production with biomass for fuel, little attention has been placed on this subject (Henderson and Jose 2010). Of all the common North American agroforestry practices (Garrett 2009), windbreaks, riparian buffers, and alley cropping appear to be the most promising for maximizing biomass production in the United States, without sacrificing food production. Although none of these practices incorporating biomass production is currently widespread, small-scale examples exist throughout the United States.

Field windbreak systems require linear rows of trees evenly spaced, typically anywhere from 150 to 300 m apart, across a landscape. Normally, one to three rows of fast-growing trees are established within each windbreak. In order for a windbreak to be effective in both biomass production and increased crop yields, a minimum of

Table 2 Production of annual and perennial biomass species within the US North Central region

Species	Annual yield (Mg ha^{-1})	Rotation	Location	Citation
Agricultural crop				
Maize (*Zea mays*) grain	7–9	Annual	Illinois	Tollenaar and Lee (2002)
Sorghum (*Sorghum bicolor*) grain	4.5	Annual	United States	USDA-NASS (2010)
Sorghum biomass	8–16	Annual	Missouri	Stevens and Holou (2010); Houx, personal communication (2011)
Sorghum biomass	16	Annual	Iowa	Hallam et al. (2001)
Alfalfa (*Medicago sativa*)	10	Annual	Iowa	Hallam et al. (2001)
Tree species				
Black locust (*Robinia pseudoacacia*)	13	5 years	Kansas	Geyer (1989)
Cottonwood (*Populus deltoides*)	11.8	5 years	Kansas	Geyer (1989)
Populus deltoides x P. trichocarpa	15.1–22.7	4 years	Wisconsin	McLaughlin et al. (1987)
(*Populus*) clones NE-41	14.5	3 years	Vermont	Laing (1985)
Honey locust (*Gleditsia triacanthos*)	6.1	Annual	Kansas	Geyer (2006)
Silver maple (*Acer saccharinum*)	9.7–12.8	2–5 years	Kansas	Geyer (1989)
Silver maple	9.0	3 years	Vermont	Laing (19 85)
Willow (*Salix alba*)	12.5	1 year	New York	Adegbidi et al. (2001)
Salix alba	21.7	3 years	New York	Adegbidi et al. (2001)
Grass				
Miscanthus (*Miscanthus x giganteus*)	40	Annual	Illinois	Pyter et al. (2007)
Miscanthus (*Miscanthus x giganteus*)	32.3	Annual	Missouri	Houx, personal communication (2011)
Switchgrass (*Panicum virgatum*)	12	Annual	Iowa	Vogel et al. (2002)
Switchgrass	9–12	Annual	Indiana	Wright and Turhollow (2010)
Giant cane (*Arundo donax*)	30–40	Annual	Arkansas	Burner, personal communication (2011)
Big bluestem (*Andropogon gerardii*)	8.5	Annual	Iowa	Hallam et al. (2001)
Eastern gamagrass (*Tripsacum dactyloides*)	14.6	Annual	Missouri	Roberts and Kallenbach (1999)

Source: Modified from Holzmueller and Jose (2012) two tree rows would be necessary. Windbreak effectiveness is a function of tree height, and increased crop yields per hectare would decrease, and perhaps disappear, if the entire windbreak was harvested for biomass. Therefore, as one row is harvested for biomass, the second row would be left in place until the previously harvested row would be tall enough to be effective. Longer rotations would be necessary to ensure adequate tree height; however, this might actually increase perennial biomass production as most short rotations of woody biomass occur before the culmination of the mean annual growth (Riemenschneider et al. 2001; Goerndt and Mize 2008).

Riparian buffers are a common feature of the landscape in the US North Central Region in particular. Because agricultural runoff has been identified as a key contributor to non-point-source water pollution, including the hypoxia in the Gulf of Mexico, riparian buffers are a heavily subsidized, agroforestry practice by federal cost-share programs such as the CRP, Environmental Quality Incentives Program (EQIP), Wetlands Reserve Program (WRP), Conservation Stewardship Program (CSP), and Wildlife Habitat Incentive Program (WHIP). Landowners receive financial incentives to take land within highly erodible or riparian areas and plant perennial vegetation (riparian buffers) that reduce non-point-source pollution and increase wildlife habitat. Although land within these programs is oftentimes used to grow perennial biofuel species, harvesting of these crops is not allowed under CRP until after the contract ends. For the other programs, harvesting may be allowed as long as the function of the buffer for water quality or other purposes is not lost. While in the past, farmers have been hesitant to take fertile agricultural land adjacent to waterways out of production without financial incentive, increased market values for biomass could potentially increase voluntary participation for establishing riparian buffers that would not have the harvest restriction of current government-sponsored programs. Although establishment of additional riparian buffers would take land out of grain production, these areas would likely yield the greatest amounts of perennial biomass given the fertile soils of riparian areas (Tufekcioglu et al. 2003; Goerndt and Mize 2008; Thelemann et al. 2010).

Properly designed and applied alley cropping can "overyield" compared to its component species in monocultures (Jose et al. 2004). Although somewhat common in tropical regions, alley cropping has had limited adoption in the United States. Most of existing examples have used primarily high timber value species such as black walnut, and these tree species are unlikely to be used for biomass production (Garrett et al. 2009). While there are several studies that have investigated short-term yields of annual crop and tree biomass species in alley cropped systems in the US North Central Region (Miller and Pallardy 2001; Delate et al. 2005; Reynolds et al. 2007), review of the existing literature did not reveal any published crop/biomass production estimates over a long-term period (series of multiple rotations for annual crops and biomass species) for these systems.

The limited research that has been conducted on temperate alley cropping systems does suggest grain yield decrease in these systems as the trees mature (Gillespie et al. 2000; Garrett et al. 2009). However, switching from a summer crop (e.g., corn) to a spring crop (e.g., winter wheat; *Triticum aestivum* L.) can increase phenological complementarily and high grain yields in alley cropping systems (Chirko et al. 1996). Given the high price of maize in recent years, this may be a challenging proposition for many landowners in the Midwestern United States. Substitution of maize with cool season grasses or legumes may also help maintain biomass yields once the trees are older. Typically, cool season grasses and legume species utilizing C_3 photosynthesis are more shade tolerant than C_4 species. In a study of several cool season grasses including orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Shreb.), and clover (*Trifolium* spp.) in Missouri, Lin et al. (1999) reported minimal yield reductions under 50 % shade. While mixing fast-growing woody crops such as willow, poplar, and pines with perennial grasses could be an attractive alternative to traditional row cropping on marginal land, further research needs to be conducted across a broad range of site conditions to see if greater annual biomass production per hectare can be achieved. Several trials are in place throughout the United States, but results are preliminary at this stage. Adoption of such biomass feedstock production systems in the United States will depend primarily on the production economics in comparison to traditional row crops.

Agroforestry for Specialty and Organic Crop Production

Specialty Crops

The Specialty Crop Competitiveness Act of 2004 and the Food, Conservation, and Energy Act of 2008 define specialty crops as "fruits and vegetables, tree nuts, dried fruits, horticulture, and nursery crops (including floriculture)." Eligible plants must be intensively cultivated and used by people for food, medicinal purposes, and/or aesthetic gratification to be considered specialty crops.[2] Specialty crop growers nationwide face fierce competition and low prices. Making a living from traditional commodity production is also difficult for the small- and medium-sized family farm. In many regions, there are large acreages of farmland available for specialty crop production. Profitable and value-added enterprises provide alternatives for the family farm. Profitability allows future generations to remain on or return to the farm and can strengthen rural communities. Agroforestry practices enable landowners to generate income from the production of a wide range of conventional and specialty products while simultaneously protecting and conserving soil, water, and other natural resources (Gold et al. 2004, 2009; Aguilar et al. 2010). For example, within riparian buffers, there are potentially profitable market-based opportunities, including linear production acreage of woody florals, elderberry, and perennial biomass.

Many observers have examined the potential of dual-purpose market-driven conservation systems in North America, including Chamberlain and Hammett (1999), Kays (1999), Josiah et al. (2004), and Gold et al. (2009). Products produced through agroforestry practices, including specialty or nontimber forest products, are produced from trees, within forests, or in myriad combinations with trees or shrubs, crops, and/or animals (Garrett 2009). Many of these products have proven economic value but have been overlooked by, or are unknown to, agricultural and forest landowners. Examples of developing specialty crop industries using an agroforestry system include eastern black walnut, Chinese chestnut, pecan, American elderberry *(Sambucus canadensis* L.), American hazelnut (*Corylus americana* Walter), and pawpaw (*Asimina triloba* (L.) Dunal). Farmers are planting these emerging specialty crops in the Midwest and throughout the United States in response to increasing market opportunities. In the majority of cases, these farmers are taking substantial risks due to the lack of sound horticultural and market information. Farmers who purchase emerging specialty crop nursery stock may be planting unimproved varieties or material not adapted or tested for their site. Detailed financial decision-making information is lacking for most specialty crops. Knowledge networks and supporting industry infrastructure are also lacking.

To successfully launch specialty crop industries, a comprehensive, multifaceted, and long-term approach is required. It will be necessary to develop, test, and deploy the best cultivars. Orchard production and best management practices must be developed for each specialty crop. Market-, consumer-, and value-added research must be conducted. Consumer awareness and demand ("market pull strategy") must be increased. Financial decision models must be created to convince both prospective growers and agricultural lenders that a given specialty crop is truly an economically profitable enterprise. Finally, to launch the industry, beginning and advanced grower training workshops must be offered including models of business development such as new-generation cooperatives and other information needs.

While specialty crop production using agroforestry has great potential in the United States, their widespread adoption requires multiple, integrated approaches. These include a culture of entrepreneurship, readily available market information through the USDA Agriculture Marketing Service, and private sector investments providing "nurture capital" to create an infrastructure for investing in local food systems (e.g., Slow Money[3]; Rudolf Steiner Foundation Social Finance[4]). In addition, the growth of specialty crop industries will require the development of knowledge networks similar to those already in place for larger and more mature agriculture industries (e.g., state pecan growers associations, the California Walnut Board). Knowledge networks will combine high-tech, long-term, targeted research support from the federal government including funding sources and ideas drawn from the USDA Specialty Crop Research Initiative and Know Your Farmer Know Your Food[5] and bottom-up grassroot "high touch" one-on-one outreach programming that includes landowner innovation and support through USDA's Sustainable Agriculture Research and Education program and Land Grant University Extension services. New industries will need to consider creating active partnerships such as new-generation cooperatives, the development of value-added products to ensure long-term industry growth, and ongoing consumer education to grow the market in the long term.

Organic Crops

According to the Organic Trade Association[6], the Agriculture Marketing Service (AMS), and the Economic Research Service (ERS), there has been enormous growth in the market for locally grown and organic food products in both fresh and value-added form within the United State (Green and Dimitri 2009).[7] Organic and locally grown foods are perceived by consumers as healthier and safer for both people and the environment. Organic food market retail sales growth has grown 20 % annually since 1990. There was a sixfold increase in retail sales of organic food products from 1997 to 2008. Both within the United States and globally, concerns about industrial agriculture practices, food quality, and links to human health have fostered interest in new, alternative, local, and more sustainable agricultural practices which offer great opportunities to include agroforestry as an organic farming option. The pace of conversion of cropland from conventional to organic has failed to keep up with growth in sales. The United States imported $1.5 billion in organic products in 2006. This trend provides a burgeoning opportunity for US farmers to enter this market and is reflected in a major increase in the number of certified organic operations and land devoted to organic production in recent years (Eades and Brown 2006).

Consumers are also strongly interested in consuming products that are locally grown (Kirby et al. 2007; Brown 2003; Loureiro and Hine 2002). Farm diversification through agroforestry can help farmers produce fruits, nuts, and vegetables from small and large farms alike. Brown (2003) indicated that marketing local products should stress quality and freshness and the consumers are willing to pay a premium price to support local farmers: 16 % of the study respondents would pay a 5 % premium, and 5 % of respondents would pay a 10 % premium for local foods. Similarly, Schneider and Francis (2005) found that consumers were willing to pay a 10 % price premium for locally grown foods. A nationwide survey conducted by the Leopold Center (Pirog and Larson 2007) indicates that American consumers are skeptical about the safety of the global food system, and many believe that local foods are safer and better for their health than foods from abroad. Respondents placed high importance on food safety, freshness, and pesticide use with 85 % stating that local foods were somewhat safe or safe compared to 53 % who perceived foods grown elsewhere in the world as somewhat safe or safe. Consumers concerned about the origin of products they buy and how they were produced are willing to pay a premium for locally grown or sustainably produced products (Yue and Tong 2009). Aguilar et al. (2009, 2010) showed that consumers are 15–20 times more likely to choose locally grown Missouri chestnuts compared to imported nuts. Additionally, the odds of consumers choosing organically grown chestnuts are 5.2 times higher than for conventionally grown chestnuts.

Nationwide, farmers markets have increased from 1,755 in 1994 to 6,132 in 2010, growing over 26 % from 2009 to 2010.[8] Numerous surveys report that consumers shop at farmers markets primarily because of product quality and the fact that the food is locally grown (SAN 2003). All five recognized temperate agroforestry practices, intensively managed to incorporate a diverse number of crops, can be designed to produce locally grown and/or organic crops in both fresh and value-added form for these growing markets. It has been proven that agroforestry can increase soil organic matter, improve nutrient cycling and plant-water relations, and increase the density and diversity of beneficial insects compared to monoculture cropping systems (Bugg et al. 1991; Smith et al. 1996; Stamps and Linit 1997; Brandle et al. 2004; Jose 2009). These attributes will help agroforestry gain popularity as an organic farming option.

Agroforestry for Ecosystem Services

Widespread concerns over environmental issues including nonpoint source pollution, loss of wildlife habitat, and climate change have resulted in a wide array of mitigation efforts. Riparian and upland buffers and windbreaks are agroforestry practices widely known for their positive environmental impacts; however, all five recognized agroforestry practices, when properly implemented, directly address each of these major environmental issues. Godsey et al. (2009) and Alavalapati and Mercer (2004) describe the values of nonmarket goods and services that can be realized through increased use of agroforestry practices. The US Farm Bill incentive programs have provided cost share for landowners to establish agroforestry practices on their land. USDA Economic Research Service conservatively estimates CRP benefits of $1.3 billion per year, excluding carbon sequestration, ecosystem protection, and other less easily quantified benefits.[9] Farm Service Agency (FSA) estimates that, compared with 1982 erosion rates, the CRP has reduced erosion by more than 412 Tg per year on 14 million ha of program land. Through April 2006, CRP had also restored 1 million ha of buffers and planted 1.1 million ha of trees. Also, the USDA Natural Resources Conservation Service (NRCS) documented conservation benefits include the sequestration of more than 48 Tg of carbon annually, more than 1.3 million ha of wildlife habitat established, and a reduction in the application of nitrogen (by 681,000 Mg) and phosphorus (by 104,000 Mgs) (Cowan 2010). Markets for carbon credits are well established in Europe while still under development in the United States. All of these provide landowners with substantial opportunities to incorporate agroforestry as part of their farm management. A discussion on some of these ecosystem services to demonstrate agroforestry's potential follows.

Carbon Sequestration

Of all the acknowledged ecosystem service benefits of agroforestry, C sequestration has received the least attention in the United States. Carbon sequestration involves the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, vegetation, or soils) through physical or biological processes. The incorporation of trees or shrubs in agroforestry systems can increase the amount of C sequestered compared to a monoculture field of crop plants or pasture (Sharrow and Ismail 2004; Kirby and Potvin 2007). In addition to the significant amount of C stored in aboveground biomass, agroforestry systems can also store C belowground. Carbon sequestered in agroforestry systems could be sold in carbon credit markets where such opportunities exist. The largest amount and most permanent form of carbon may be sequestered by increasing the rotation age of trees and/or shrubs and by manufacturing durable products from them upon harvesting.

The potential of agroforestry systems to sequester C varies depending upon the type of the system, species composition, age of component species, geographic location, environmental factors, and management practices. A large number of studies have appeared in recent years that report C sequestration potential of agroforestry systems from the tropics. While such studies are scarce in the United States, a recent attempt by Udawatta and Jose (2011) has provided a review and synthesis of the available literature; they estimated that the potential for C sequestration under agroforestry systems in the United States is 548.4 Tg year^{-1}.

Based on their analysis, Udawatta and Jose (2011) concluded that silvopastoral systems, the most common form of agroforestry in North America (Clason and Sharrow 2000; Nair et al. 2008; Sharrow et al. 2009), had the greatest potential to sequester C in the United States. Using a sequestration potential of 6.1 Mg C ha^{-1} year^{-1} on 10 % marginal pasture land (23.7 million ha) and 54 million ha of forests, they estimated total C sequestration potential for silvopastoral lands in the United States as 474 Tg C year^{-1}. Similarly, Udawatta and Jose (2011) estimated that alley cropping could be practiced on 10 % of the 179 million ha cropland (USDA NRCS 2007; USDA NASS 2008) in the United States, which could sequester 60.9 Tg C year^{-1}. Based on several published studies (e.g., Boggs and Weaver 1994; Harner and Stanfoord 2003; Naiman et al. 2005), they estimated that the average aboveground C sequestration potential was 2.46 Mg C ha^{-1} year^{-1} for riparian buffers. This estimate was lower than the maximum reported by Hazlett et al. (2005) for a riparian buffer in Canada (269 Mg ha^{-1}) but higher than that reported by Schroeder (1994) for another temperate riparian buffer (63 Mg C ha^{-1} aboveground storage with a 30-year cutting cycle). The total river and stream length in the United States is approximately 5.65 million km (3.533 million miles).[10] Lakes and estuaries occupy 16.8 and 22.7 million ha, respectively. If a 30-m-wide riparian buffer is established along both sides of 5 % of total river length, it would occupy 1.69 million ha. Using a conservative estimate of 2.6 Mg C ha^{-1} year^{-1} accrual rate for above, below, and soil C sequestration by riparian buffers, the potential C sequestration by riparian buffers along rivers in the United States could be as high as 4.7 Tg C year^{-1}. Like other agroforestry practices, windbreaks also offer promise for C sequestration (Schoeneberger 2009). In addition to C sequestered by trees, windbreaks provide additional C sequestration due to improved crop and livestock production and energy savings (Kort and Turnock 1999). Udawatta and Jose (2011) estimated that the total C sequestration potential for windbreaks was 8.79 Tg C year^{-1}.

Overall, the C sequestered by agroforestry could help offset the current US emission rate of 1,600 Tg C year^{-1} from burning fossil fuel (coal, oil, and gas) by 34 %. These estimates indicate the important role of agroforestry as a promising CO_2 mitigation strategy in the United States and possibly in other parts of North America.

Agroforestry for Water Quality Enhancement

More than three decades after the implementation of the Clean Water Act in the 1970s, non-point-source pollution from agricultural watersheds continues to impact the nations' water bodies (Udawatta et al. 2011). Despite adoption of conservation practices, managed fertilizer application, and crop rotations, large losses of nutrients still occur in runoff (Udawatta et al. 2006). Agricultural surface runoff can result in excess sediment, nutrient, and pesticide delivery to receiving water bodies and is a major contributor to eutrophication in the Gulf of Mexico. According to the latest report of the USEPA (2010), 50, 66, and 42 % of rivers, lakes, and reservoirs, respectively, are impaired. The loss of productivity due to loss of arable land in the United States is nearly $37.6 billion per year (Pimental 2006).

In addition to farm chemicals, livestock manure also constitutes a major NPSP in the United States. In supplying livestock products, farms in the United States generate more than 350 million t of manure that must be disposed of in some manner (Ribaudo et al. 2003). Jones et al. (1996) estimated that 95 % of cattle waste, 90 % of poultry waste, and 85 % of pig waste are returned to land. On average, poultry manure contains 14–31, 18–25, and 16–19 kg Mg^{-1} N, P_2O_5, and K_2O, respectively (Vest et al. 2004). Dairy manure contains 6.56 g kg^{-1} P, 39.99 g kg^{-1} N, and 2.1×10^6 CFU g^{-1} fecal coliform (Stout et al. 2005). In addition, manure contains bacteria and other microorganisms that can be harmful to humans if they are introduced into waterways or groundwater (Edwards et al. 2000). Poultry litter also contains the hormone 17β-estradiol which may disrupt the health and reproduction of fish and other animals (Nichols et al. 1998). Applying too much manure at the wrong time or improper handling of manure can release nutrients, bacteria, and other undesirable pollutants into the air, groundwater, and surface water. These losses are further exacerbated if manure is applied in fall or winter months (when plant uptake is minimal to none), as it is usually done in order to free up storage volume. When manure is applied to meet plant N requirement, it often exceeds plant P requirements (National Research Council 1993). Soils with excess P levels are vulnerable to releasing environmentally significant levels of P (Nair et al. 2004; Allen et al. 2006) and have been linked to accelerated eutrophication of fresh water bodies (Siddique and Robinson 2003) and an increase in the hypoxic zone in the Gulf of Mexico (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2008). Since less manure is needed to meet the crops' P needs, more land is required to spread manure under P standards than under N standards.

A well-designed riparian or upland buffer is recognized as one of the most cost-effective approaches to mitigate NPSP (Schultz et al. 2009). Enhanced infiltration, trapping efficiency due to flow resistance, root safety net, water use by the buffer vegetation, and denitrification are major mitigation processes by which particulate and dissolved nutrients and herbicides transported in surface and subsurface flow are intercepted (Schultz et al. 2009; Udawatta et al. 2002, 2011). There are several physical, chemical, and biological mechanisms involved in the process of bioremediation within vegetative buffers. Organic pesticides can be intercepted by the roots and residue of the vegetation via sorption and physical filtration (Pestemer et al. 1984; Hoffman et al. 1995). Bacteria growing in the root zone may have the capacity to metabolize herbicides through various biochemical mechanisms including enzymatic oxidation and hydrolysis (Ambus 1993; Mandelbaum et al. 1993, 1995; Struthers et al. 1998). Direct plant uptake may also help to eliminate nutrients and agrochemicals (Burken and Schnoor 1997). Furthermore, the improvement of soil characteristics by vegetation (e.g., increased OM content, improved porosity, and microbial diversity) may enhance the rhizosphere's capacity for sorption and abiotic transformation of pollutants (Seobi et al. 2005; Udawatta et al. 2009).

Proper plant species selection also plays a significant role in buffer effectiveness for mitigating NPSP transport. Plant species selection strongly influences physical, chemical, and biological soil properties that are involved in buffer bioremediation processes (Seobi et al. 2005; Udawatta et al. 2005; 2009). Trees with more vertical roots than horizontal would compete less for resources with crops (Udawatta et al. 2005). The incorporation of warm-season grasses into a buffer encourages sheet flow creating more surface interaction between the grass and the runoff reducing transport of both dissolved and sediment-bound NPSP in surface runoff (Blanco-Canqui et al. 2002; Lin et al. 2007a). For example, Lee et al. (2003) showed that a 7-m-wide switchgrass buffer in Iowa removed 95 % of the sediment, 80 % of the total-N, 62 % of the NO_3–N, 78 % of the total-P, and 58 % of the PO_4–P. These authors also demonstrated in a field study conducted under natural rainfall conditions that a switchgrass + woody buffer (7 m + 9.2 m woody zone) removed 97 % of the sediment, 94 % of the total-N, 85 % of the NO_3–N, 91 % of the total-P, and 80 % of the PO_4–P in the runoff. In a rainfall simulation and a growth chamber study on claypan soils in Missouri, Lin et al. (2005, 2007a, b) reported that 4-m-wide vegetative buffer strips with native warm-season grasses removed 75–80 % of the atrazine, metolachlor, and glyphosate in surface runoff and 63–90 % of the atrazine degradation products in the rhizosphere of warm-season grass species, compared to 24 % degradation in the control. While synthesizing the information from long-term upland buffer studies in Missouri, Udawatta et al. (2011) reported that agroforestry buffers (trees + grasses) always resulted in greater reduction of sediment, total-N, and total-P compared to grass buffers in both row crop and grazed pasture systems (Table 3).

Overall, agroforestry buffers, if properly designed in strategic locations throughout sensitive watersheds, can enhance water quality. For example, the hypoxia issue in the Gulf of Mexico could be alleviated with proper installation of agroforestry buffers and associated conservation practices such as conservation tillage, crop rotation, and nutrient management throughout the Mississippi River Basin.

Table 3 Percentage reduction of sediment, total nitrogen, and total phosphorus losses on grazing and row crop management practices with agroforestry and grass buffers compared to the respective control treatment

	Managements and treatments			
	Grazing management		Row crop management	
Parameter	Agroforestry	Grass buffer	Agroforestry	Contour grass
	%			
Sediment	48	23	30	28
Total nitrogen	75	68	11	13
Total phosphorus	70	67	26	22

Source: Udawatta et al. (2011)

Agroforestry for Improved Air Quality

In recent years, interest in adapting windbreak designs as a potential approach to dealing with livestock odor has received considerable attention (Tyndall and Colletti 2007). The majority of odor-causing chemicals and compounds are carried on aerosols (particulates matter, PM). This very special use of a windbreak has also been called a vegetative environmental buffer (VEB). A VEB can filter airstreams of particulates by removing dust, gas, and microbial constituents. While financial considerations have motivated producers to use confined animal feeding operations (CAFO) as the preferred approach to livestock production, especially in swine and poultry industries in the United States, concerns associated with potential environmental and health effects of odor emissions have also been rising. For example, in an effort to reduce odor emissions from swine CAFOs, 44 of the 50 states in the United States have enacted air emission policies directly or indirectly to reduce odors from these operations (Vander 2001).

The use of agroforestry VEBs for odor abatement is a new management practice, and the science in support of using VEBs for this purpose is limited. Although the literature on VEBs is scarce, VEBs have been shown to impact odor plume dispersion (Lin et al. 2006, 2009). While reports in the literature strongly suggest that significant quantities of compounds known to correlate highly with malodors can be removed through the use of VEB technology (e.g., 47 and 50 % reduction in ammonia (NH_3)and dust emissions, respectively), the overall effect on reducing odor, based upon the literature, appears to be low (6 %)(Malone et al. 2006). The effectiveness of a VEB is known to be related to its physical location, species composition, density, and geometric configuration. Odor reduction by VEB occurs via physical interception, dilution, and chemical adsorption (Tyndall and Colletti 2007). The VEB canopy encourages the interception of odor carriers, such as dust and organic particulates. In addition, VEB reduces wind speed and facilitates the deposition of PM and bioaerosols (Tyndall and Colletti 2007). The vertical turbulence created by VEB could dilute the odor by forcing the mixing of odor with clean air. The VEBs may also have a sociological impact in which they reduce people's awareness of the CAFOs, thereby subconsciously reducing the smell. In their detailed review on this topic with particular reference to swine odor, Tyndall and Colletti (2007) suggested that when planted in strategic designs, VEBs could effectively mitigate odor in a socioeconomically responsible way. We believe that properly engineered VEBs can be an effective tool for odor abatement when used alone or in combination with other technologies, but improvements in design are required to optimize the benefits.

Agroforestry for Biodiversity Conservation

Ecosystems and species important in sustaining human life and the health of our planet are disappearing at an alarming rate. Consequently, the need for immediate action to design effective strategies to conserve biodiversity is receiving considerable attention worldwide. Scientists and policy makers are becoming increasingly aware of the role agroforestry plays in conserving biological diversity in both tropical and temperate regions of the world (Jose 2009). The mechanisms by which agroforestry systems contribute to biodiversity have been examined by various authors (e.g., Schroth et al. 2004; McNeely 2004; Harvey et al. 2006; Jose 2009). In general, agroforestry plays five major roles in conserving biodiversity: (1) provides habitat for species that can tolerate a certain level of disturbance; (2) helps preserve germplasm of sensitive species; (3) helps reduce the rates of conversion of natural habitat by providing a more productive, sustainable alternative to traditional agricultural systems that may involve clearing wildlife habitats; (4) provides 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 (5) helps conserve biological diversity by providing other ecosystem services such as erosion control and water recharge, thereby preventing the degradation and loss of surrounding habitat. Designing and managing an agroforestry system with conservation objectives would require working within the overall landscape context and adopting less intensive cultural practices to achieve the maximum benefits.

While the literature on the role of agroforestry in conserving biodiversity is growing rapidly in the tropics, such reports are limited from the temperate parts of the world. In the United States, variations in tree-crop combinations and spatial arrangements in agroforestry have been shown to affect insect population density and species diversity. Studies with pecan have looked at the influence of ground cover types on arthropod densities in agroforestry systems (Bugg et al. 1991; Smith et al. 1996; Stamps and Linit 1997). Bugg et al. (1991) observed that cover crops (e.g., annual legumes and grasses) sustained lady beetles (Coleoptera: Coccinellidae) and other arthropods. Brandle et al. (2004) reported greater density and diversity of insect populations in windbreaks. They attributed this to the heterogeneity of the edges that provided varied microhabitats for life-cycle activities and a variety of hosts, prey, pollen, and nectar sources.

Agroforestry practices also provide improved wildlife habitat by increasing structural and compositional plant diversity on the landscape. Windbreak and riparian buffers offer the only woody habitat for wildlife in many agriculture dominated landscapes (Johnson and Beck 1988). In a comparison of corn monoculture to riparian buffer plantings of clover (*Trifolium repens* L.) and orchardgrass (*Dactylis glomerata* L.) with three different tree species in Indiana, Gillespie et al. (1995) observed that the riparian buffers had higher bird density and diversity than corn monoculture. In a recent study in Iowa, Berges et al. (2010) reported a dramatic increase in bird species diversity in a riparian buffer compared to row crop fields and pastures.

As suggested by McNeely (2004) and McNeely and Schroth (2006), the interrelationship between forest ecosystems, agroforestry, and biodiversity can be made more dynamic through adaptive management strategies that incorporate results from research and monitoring in order to feed information back into the management system. Active participation by local landowners and communities is also critical in this context. Agroforestry's role in creating habitats and maintaining and conserving diversity across landscapes is increasingly being recognized in the United States and, as such, will help increase adoption in many parts of the country.

Agroforestry Policies

The United States currently lacks a consistent national policy on agroforestry. And, as was reported by Garrett and Buck (1997), agroforestry development has primarily been guided by an array of agricultural, forestry, environmental, and rural development policies and programs at respective levels of government. Unfortunately, this has resulted in a limited allocation of resources and incentives to individuals, agencies, and organizations interested in agroforestry. And, it has failed to take advantage of the unique opportunities offered by agroforestry to address biophysical and socioeconomic limitations that are often associated with conventional agricultural and forestry enterprises. The lack of policy is, in part, attributed to a lack of understanding of agroforestry benefits on the part of policy makers due to the difficulties and time required to develop and dispense the science of a new technology such as agroforestry—a limitation that is rapidly disappearing in the United States. While consistent policy on agroforestry has been slow to evolve, the need has been discussed by many (Henderson 1991; Garrett et al. 1994; AFTA 1995; USDA 2011).

Agroforestry policy had its beginning in the United States with the Forest Stewardship Act of 1990, a component of the Food, Agriculture, Conservation, and Trade Act (i.e., 1990 Farm Bill). This legislation called for the US Forest Service to establish a Center for Semiarid Agroforestry whose scope was broadened to include the entire country in 1994 and the center was renamed the National Agroforestry Center (NAC). Moreover, to expand national agency support for agroforestry, in 1995, the USDA NRCS partnered with the Forest Service to provide a technology transfer dimension to the NAC. The center and the Association for Temperate Agroforestry (AFTA), established in 1991, have evolved as the key players in informing and guiding public policy makers on US agroforestry policy needs.

While only limited success has been achieved, gains have been and continue to be made. Although little mention is made of agroforestry, per se, in the most recent US Farm Bill (The Food, Conservation and Energy Act of 2008, FCEA), several USDA programs authorized by this legislation support agroforestry practices. The EQIP, which is designed to address critical resource needs on agricultural land and is especially well suited for agroforestry practices, has provided funding to landowners for establishing riparian buffers, alley cropping, and silvopasture practices. The USDA conservation programs such as the WHIP, Conservation Reserve Enhancement Program (CREP), CRP, and the CSP have also funded agroforestry practices. The CSP, in particular, has targeted practices such as alley cropping, windbreaks, riparian buffers, and silvopasture for wildlife and water quality enhancement benefits. And, recently, "multi-story cropping, sustainable management of nontimber forest plants," a forest farming dimension, was authorized under the CSP.

All of these programs provide private landowners with multiyear contracts with provisions for reimbursing some percentage of establishment costs and have practice incentives and annual rental payments that vary with programs. Other readily recognizable USDA programs such as Sustainable Agriculture Research and Education (SARE), Organic Agriculture Research and Extension Initiative (OREI), and the Specialty Crop Research Initiative (SCRI) all have important roles that they could and should play in agroforestry, but, similar to the previously identified programs, they are either grossly underfunded and too narrow in conception or are too restrictive in execution to have a significant effect on agroforestry.

While agroforestry can and does provide many benefits, it is especially well adapted to address environmental problems, and for that reason alone, incentive-based conservation programs should place a high priority on agroforestry practices. A USDA policy is needed that gives natural-resource-based, sponsored programs (including agroforestry) a value in keeping with their importance and that discriminates against no farmer or crop. While it is appropriate that the majority of USDA funding be used in support of important conventional crop commodities (e.g., wheat, corn, soybeans, cotton), it is inappropriate that our vision for the future of agriculture not include provisions, established by policy, that support (socially, administratively, and financially) the use of agroforestry and other technologies to address conservation and agricultural sustainable development objectives. After all, agricultural-derived contaminants, such as sediment, nutrients, and pesticides, constitute the largest diffuse source of water quality degradation in the United States. Agroforestry bioassimilative strategies have been developed and proven to successfully address the negative impacts of agricultural practices, often at costs considerably less than the dominant alternative strategies (e.g., field terracing) and specific policy in support of using agroforestry to address environmental concerns, is justified and needed.

In addition to the need for funding, it is imperative that obvious disincentives to the practice of agroforestry (e.g., USDA's Direct and Counter-Cyclical Payment; DCP) restrictions on establishing fruit or nut trees on base acreage, programs specifying minimum acceptable tree-planting densities that can effectively exclude many agroforestry practices, provisions that restrict tree management and harvesting of nontimber products, etc. be reevaluated in light of what is known today about the cumulative environmental and economic benefits of agroforestry that far exceed those anticipated earlier by planners and policy makers. There is a need for a national policy that allows and promotes the use of agroforestry under all appropriate USDA conservation programs. This will require a new USDA vision that recognizes and advocates landscape diversification for social, biological, and economic benefits.

The USDA Agroforestry Strategic Framework, Fiscal Year 2011–2016,[11] is designed to create a new USDA vision that recognizes the multiple benefits of agroforestry and supports its implementation. In the Secretary of Agriculture's introductory message, he identifies it as "a roadmap for advancing the science, practice, and application of agroforestry as a means of enhancing America's agricultural landscapes, watersheds and rural communities." Within this framework is found the promise that the USDA "will integrate agroforestry into agency programs and policies to maximize and highlight economic, social, environmental, and conservation benefits" (USDA 2011).

In 1994, a team of agroforestry specialists was asked to prepare the agroforestry component of the Resource Conservation Act Appraisal for the Soil Conservation Service (now the NRCS). That appraisal was entitled, "Agroforestry: An Integrated Land-Use Management System for Production and Farmland Conservation" (Garrett et al. 1994). Within this document, it was acknowledged that agroforestry could not achieve its potential in the United States without the SCS/NRCS assuming ownership and providing leadership. Further, it suggested that development must be guided by USDA-established policy. The recent establishment of the USDA Agroforestry Strategic Framework, Fiscal Year 2011–2016 framework (USDA 2011a, b), is the first step toward the creation of a meaningful, national USDA policy on agroforestry. It "provides new direction on how USDA agencies, partners, and landowners together can significantly expand agroforestry to balance agricultural production with natural resource conservation." That significant instrument is to be followed by a USDA policy statement that will "guide USDA efforts to enhance production of food, feed, fiber and renewable energy; enhance the sustainability and prosperity of rural communities; and protect, conserve, and restore natural resources" through the further development and implementation of agroforestry technologies.

Conclusions

While agroforestry has not yet achieved the success in the United States that it is destined to achieve, there is a heightened awareness of its benefits and an increased willingness on the part of landowners to adopt it. It has been demonstrated to provide landowners a way to plan for the future while meeting the needs of the present (economic, environmental, and social). It enhances resource stewardship and land conservation, while keeping the family farm economically viable. Thus, in the short span of four decades, agroforestry in the United States has transitioned from a little used name and practice to a science-based technology, and it has advanced from a fragmented effort on the part of a few to an area of focus on the part of many through the recent establishment of the USDA Agroforestry Strategic Framework, Fiscal Year 2011–2016. This framework "identifies agroforestry as an important component of a much needed national strategy to enhance America's agricultural landscapes, watersheds, and rural communities" and "provides new direction on how USDA agencies, partners, and landowners together can significantly expand agroforestry to balance agricultural production with natural resource conservation." The future for agroforestry in the United States thus seems to be very promising. From improving our environment to revitalizing rural America, agroforestry offers an attractive option to more conventional management approaches, many of which have resulted in undesirable environmental and economic consequences.

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