Economic Potential of Agroforestry and Forestry in the Lower Mississippi Alluvial Valley with Incentive Programs and Carbon Payments

Gregory E. Frey, D. Evan Mercer, Frederick W. Cubbage, and Robert C. Abt

ABSTRACT

Conversion of bottomland hardwood forests in the Lower Mississippi Alluvial Valley (LMAV) to agricultural land has caused a loss of ecosystem services. The primary approaches to reverse this have been the Wetlands Reserve Program and the Conservation Reserve Program, which provide financial incentives to landowners to reforest. However, other forest production regimes and forestry financing mechanisms will be necessary to meet reforestation goals. Using capital budgeting techniques, we estimated financial returns from eight agroforestry and seven forestry systems to compare to returns from agriculture on marginal and average lands in the LMAV, as an indicator for potential adoption. In all but a few cases, agriculture had higher returns than agroforestry and forestry, even on marginal lands, and this is especially true when considering federal agricultural payments. We then estimated the break-even carbon net revenue per metric ton that would create a large enough financial incentive to favor forestry or agroforestry systems over agriculture. Given prospective moderate prices from carbon credits from afforestation and reforestation activities and high costs for implementing those activities, a few forestry and agroforestry systems might have potential on marginal agricultural land in the LMAV, subject to requirements such as providing evidence that reforestation would not have taken place without carbon payments. Regimes that maintain a large carbon stock on site by avoiding clearcutting performed better under carbon markets.

Keywords: soil expectation value, net present value, carbon emissions reductions, Wetlands Reserve Program, Lower Mississippi Alluvial Valley, bottomland hardwoods

The Lower Mississippi River Alluvial Valley (LMAV), the historical floodplain of the Mississippi River below the Ohio River (Figure 1), was once the largest area of bottomland hardwood forests (BLH) in the United States. Today, only a quarter of the original BLH area remains because of conversion to agriculture and other land uses, and the remaining forests have been degraded by fragmentation, altered hydrology, sedimentation, water pollution, invasive exotic plants, and indiscriminant timber harvesting (Twedt and Loesch 1999, King et al. 2006).

Natural BLH provide many ecosystem services, including wildlife habitat, clean water, flood mitigation, groundwater recharge, and a host of biogeochemical processes, including nutrient uptake, sediment deposition, and carbon sequestration (Walbridge 1993). However, the existing forest base in the LMAV has been reduced to the point where it can no longer provide important ecosystem services (Murray et al. 2009). For instance, nitrogen from agricultural runoff from the LMAV and other parts of the Mississippi River Basin generates hypoxia in the Gulf of Mexico; this could be mitigated with forested conservation buffers (US Environmental Protection Agency 2007). Murray et al. (2009) estimated the value to society provided by ecosystem services from reforesting 226,000 ha currently enrolled in the Wetlands Reserve Program (WRP) to be over $339 million.

Starting in the 1970s, government and nongovernment organizations have used a variety of initiatives to restore BLH, the foremost examples being the Conservation Reserve Program (CRP) and the WRP (Llewellyn et al. 1996, Stanturf et al. 1998, 2000, King and Keeland 1999, King et al. 2006). Although a small but significant amount of reforestation has occurred, many areas are still characterized by continued deforestation (Llewellyn et al. 1996, Schoenholtz et al. 2001, Groninger 2005). Productive forestry and agroforestry systems may augment BLH restoration in the LMAV by restoring trees on agricultural lands and producing at least some of the ecosystem services of natural BLH, such as wildlife habitat and improved water quality (Angelsen and Wunder 2003).

Widespread adoption of agroforestry depends on developing and promoting systems that produce financial returns that are at least equal to those obtained from the annual crops they would replace. However, little research has compared returns from agroforestry, production forestry, and annual cropping in the LMAV. Stanturf and Portwood (1999) and Huang et al. (2004) showed that cultivation of eastern cottonwood (*Populus deltoides*) for pulpwood and cherrybark oak (*Quercus pagoda*) for timber in the LMAV can produce positive returns, but they did not compare these figures to agricultural returns. Amacher et al. (1997) showed that Nuttall oak (*Quercus texana*) and cottonwood grown for timber can have positive returns net of the opportunity cost of forfeited soybean production on certain frequently flooded soils.

Anderson and Parkhurst (2004) compared long-term WRP forest easements, hunting leases, and agricultural crops (e.g., soybeans,

Manuscript received August 25, 2009, accepted May 19, 2010.

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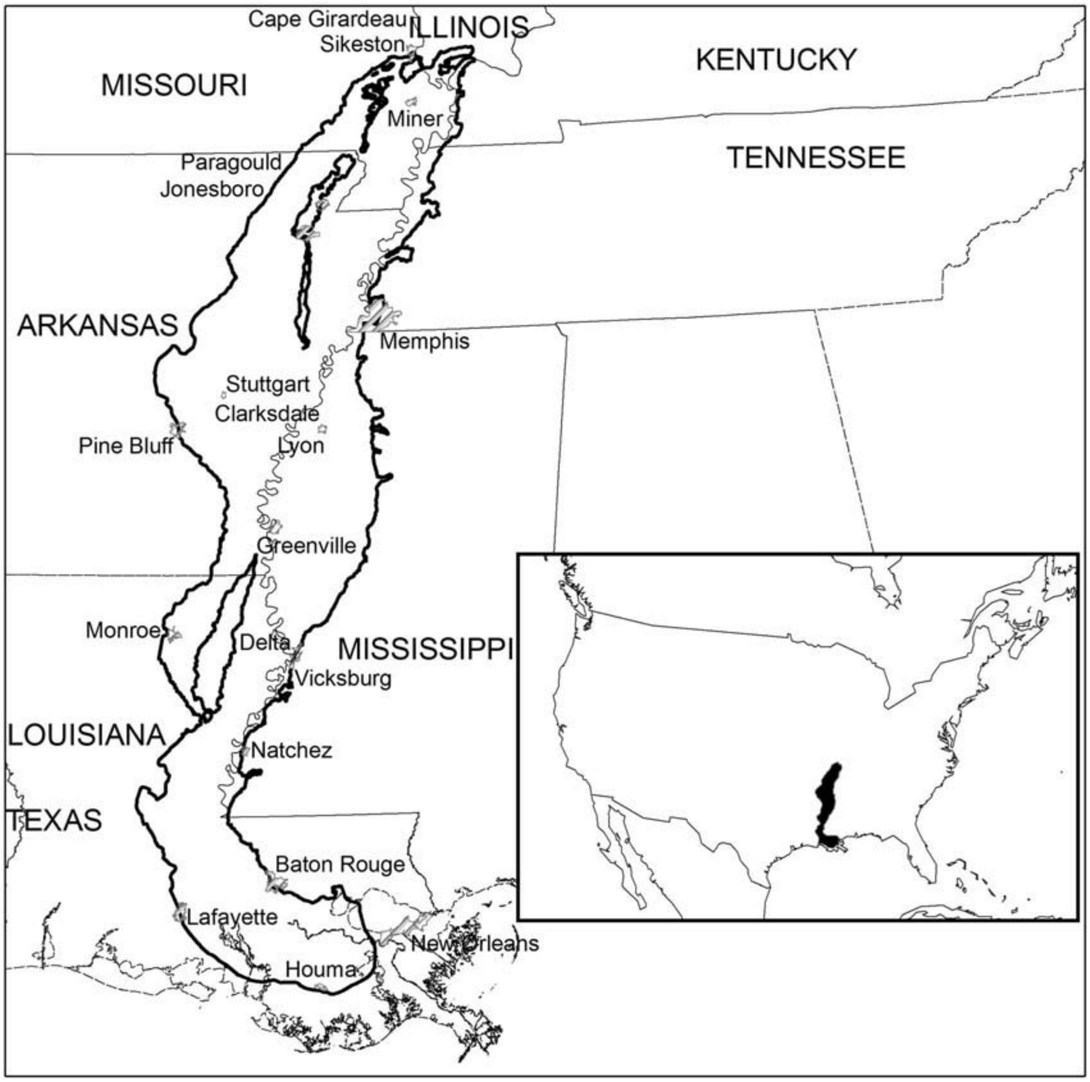

Figure 1. Geographic extent of the Lower Mississippi Alluvial Valley (Lower Mississippi Valley Joint Venture 2002).

rice, cotton) and found that WRP forest easements can be competitive or even more profitable than crop production with commodity payments and much less risky for the producer. Ibendahl (2008), on the other hand, found that commodity crop production is likely to be more profitable than WRP enrollment on average land, but this study did not include revenue streams such as hunting leases. Murray et al. (2009) estimated the value of ecosystem services associated with BLH in the LMAV, with a focus mainly on public benefits. In this research, we compared private profitability of agroforestry, production forestry, and annual cropping to evaluate the economic incentives for landowners to adopt agroforestry or productive forestry systems in the LMAV and the impacts of government policy and programs on the adoption decision.

Methods

Data

Because of lack of data on agroforestry production in the LMAV, we organized three panels of experts on forestry, agriculture, and agroforestry in the LMAV for a Delphi assessment [1] to provide inputs on key factors such as yields, costs, prices, and management regimes. Delphi panelists selected included landowners and farmers, forestry and agricultural extension agents and others who deal directly with landowners and farmers (e.g., federal, state, and county agencies; nonprofit entities), and forest and agricultural researchers and economists. Panelists provided justification for their estimates and were asked to read the estimates and justifications of other panelists and adjust their estimates if appropriate. When external sources of information (such as crop budgets from university extension services or case studies) were available, panelists were provided with this information, and the facilitators ensured that there was a reasonable level of consistency among panelists' estimates and between aggregated panel estimates and external information.

External sources for validating estimates of returns from agricultural crops included aggregate crop return data from phase III of the Agriculture Resource Management Survey (ARMS) (ERS 2009) by the USDA Economic Research Service, and crop budget worksheets for input and output prices (Mississippi State University 2008, Paxton 2009, University of Arkansas 2009, University of Missouri 2009, University of Tennessee, Knoxville 2009). The Soil Survey Geographic database of the USDA Natural Resource Conservation Service provided input on timber and crop yields on various site classifications (NRCS 2008), and the Louisiana Quarterly Timber Price Report provided hardwood and softwood timber and pulpwood prices (Louisiana Department of Agriculture and Forestry

Table 1. Forestry and agroforestry systems selected for financial analysis by the expert panels.

System name	Species 1	Species 2	Rotation (years)	Prunings	Thinnings	Hunting lease (2008 $/ha/year)	Management notes
Cottonwood plantation for pulpwood	Eastern cottonwood (*P. deltoides*)		10	None	None	None	Coppice and resprout (with resprout control) at end of rotation.
Cottonwood plantation for sawtimber	Eastern cottonwood		20	None	2	7.50	
Short-rotation woody crop	Soft hardwood[a]		3	None	None	None	Coppice and resprout (with resprout control) at end of rotation.
Hard hardwoods plantation	Hard hardwood[b]		50	None	2	15.00	After 50 years, the site could be clearcut or managed with small, periodic, sustainable harvests, maintaining a mature, intact stand.
Cottonwood and oak interplanting (Gardiner et al. 2004)	Eastern cottonwood	Oak[c]	50	None	Oaks 2, cottonwood 2 coppices	15.00	Cottonwood clearcut after 20 years to allow oak growth. Harvest options same as above.
Pecan silvopasture	Pecan (*Carya illinoinensis*)	Hay first years, other forage after	50	None	None	No	Grazing begins age 4, nut harvest begins age 8.
Hard hardwoods silvopasture	Hard hardwood[b]	Hay first years, other forage after	50	3	2	15.00	Grazing age 4–20, hunting lease after.
Pine silvopasture	Loblolly pine (*Pinus taeda*)	Hay first years, other forage after	30	3	4	No	Grazing begins age 3
Hard hardwoods riparian buffer	Hard hardwood[b]	Grass filter strip on outer edge	50	None	2	22.50	No clearcut. Interior of buffer closest to stream left unmanaged. Buffer at least 10 m wide on each side of the stream. No mechanical competition control.
Cottonwood and oak riparian buffer	Eastern cottonwood	Oak[c]	50	None	Oaks 2, cottonwood 2 coppices	22.50	Same as above.
Pecan alley cropping	Pecan	Agricultural crop	50	None	None	No	Nut harvest begins age 8, timber not sold.
Hard hardwoods alley cropping	Hard hardwood[b]	Agricultural crop	50	3	2	15.00	Alley crop years 0–10, hunting lease after.
Cottonwood alley cropping	Eastern cottonwood	Agricultural crop	23	3	3	7.50	Alley crop years 0–9, hunting lease after.

[a] Soft hardwood: Eastern cottonwood (*P. deltoides*), black willow (*Salix nigra*), or American sycamore (*Platanus occidentalis*).
[b] Hard hardwood: Nuttall oak (*Q. texana*), cherrybark oak (*Q. pagoda*), water oak (*Q. nigra),* green ash (*Fraxinus pennsylvanica*), baldcypress (*Taxodium distichum*), others, or a mixture of species.
[c] Oak: Nuttall oak, cherrybark oak, water oak, or other bottomland oak species.

2008). Estimates of cottonwood growth and yield were taken from Cao and Durand (1991), and Baker and Broadfoot (1979) provided guidelines for estimating site indices for numerous hardwood species.

Based on the Delphi assessment, the production forestry and agroforestry systems described in Table 1 were selected for analysis. These were compared with two typical agricultural systems for marginal and average land, which were determined by the agriculture Delphi panel: rice (conventional variety, conventional tillage, drill seeded) and soybeans (Roundup Ready, conservation tillage, early planted).

Panelists estimated typical cost and returns for each crop and for forestry and agroforestry systems in the LMAV. Estimates of establishment costs and trees planted per hectare are listed in Table 2. Plantations of hard hardwoods, such as oaks, are generally the least expensive to establish because they involve less site preparation than cottonwood or pine. Agroforestry systems such as silvopasture and alley cropping generally have lower establishment costs than production forestry systems of the same tree species because fewer trees are planted per hectare. However, pecan systems, despite including fewer trees per hectare, have the highest establishment costs because of an intensive cultivation, insecticide, and fungicide regime.

We adjusted the expected normal-weather returns from rice and soybeans to account for the possibility of catastrophic weather events (Amacher et al. 1997) and for projected commodity price changes (USDA Interagency Agricultural Projections Committee 2009). Establishment costs for agroforestry and forestry systems were also adjusted for possible mortality due to flooding. Future timber and pulpwood price indices were derived from the Subregional Timber Supply model (Abt and Cubbage 2008).

We were unable to gather a panel on livestock in the LMAV, as it is relatively uncommon. Furthermore, published estimates were widely variable. Some estimates showed a negative expected return to cattle-raising in the LMAV from 1996 to 2007 (ERS 2009). Other estimates of returns per head ranged from a loss of $434 to a gain of $120, depending on management (Brister et al. 2002, Boucher and Gillespie 2007). The base case assumed returns of $35 per head, an optimistic scenario based on Brister et al. (2002). Given the variability in estimates of expected returns, we conducted a sensitivity analysis using a range from $35 to −$50 per head.

Panelists decided that the Land Capability Class (LCC) system, "a system of grouping soils primarily on the basis of their capability to produce common cultivated crops and pasture plants without deteriorating over a long period of time" (NRCS 2007, p. 622-1), was most appropriate for classifying sites in the LMAV. LCC range from 1 to 8, with LCC 1 soils being the most well-suited for agricultural purposes and LCC 8 the least. LCC 1 and 2 include the most productive lands, about 25% of LMAV area (NRCS 2008), and are therefore unlikely to be converted to any type of forestry or

Table 2. Parameters for tree plantations in forestry and agroforestry in the Lower Mississippi Alluvial Valley, as estimated by Delphi assessment panel of experts: trees planted per hectare, establishment costs,[a] and typical merchantable timber aboveground biomass growth rate on Land Capability Classes (LCC) 3 and 5.

Species/System/years of rotation	Trees/ha	Establishment cost (2008 \$/ha)[a]	LCC 3 timber growth rate	LCC 5 timber growth rate
			......(Green metric tons/ha/year)......	
Cottonwood plantation	746	944	17.7	19.3
Cottonwood in short-rotation woody crop	1,500	1,319	19.1	21.0
Cottonwood in agroforestry	173	768		
Years 0–10			10.1	11.0
Years 10+			17.7	19.3
Cottonwood and oak interplanting		1,363		
Cottonwood Years 0–20	746		16.0	17.4
Oak,[b] years 0–20	373		3.3	3.3
Oak,[b] years 20+			7.2	7.2
Oak[b] plantation	746	763	7.2	7.2
Oak[b] in agroforestry	358	530		
Years 0–20			4.2	4.2
Years 20+			7.2	7.2
Loblolly pine in silvopasture	444	925		
Years 0–20			8.1	8.1
Years 20+			16.1	16.1
Pecan	67	1,467	2.0	2.0

[a] Includes site preparation, planting, competition control, fungicide, and pesticide in the first 3 years.
[b] Oak: Nuttall oak, cherrybark oak, water oak, or other bottomland oak species.

agroforestry system. LCC 3 and 5 soils together account for approximately 60% of LMAV area (NRCS 2008) and include moderately productive to marginal soils. Other classes (LCC 4, 6–8) have limited area in the LMAV or virtually no potential for agriculture. Therefore, we focused our analysis on LCC 3 and 5. LCC 3 lands have "severe limitations that reduce the choice of plants or require special conservation practices" (NRCS 2007) and typically consist of rarely flooded lands with poor drainage in the LMAV (NRCS 2008). LCC 5 lands have "limitations that limit their use mainly to pasture, range, forestland, or wildlife food and cover" (NRCS 2007) and typically consist of frequently flooded, very poorly drained land (NRCS 2008). Despite the limitations of LCC 5 lands, they have frequently been used for soybeans in the LMAV (Amacher et al. 1997).

Financial Calculations

We used an accepted capital budgeting approach to estimate returns for alternative investments in the LMAV. In particular, we used cash flow methods to estimate the soil expectation value (SEV, also called land expectation value) for each alternative (Klemperer 1996, Kapp 1998), based on net present value (NPV). NPV is defined as the sum of the discounted periodic net revenues over a given time horizon (Klemperer 1996):

$$\text{NPV} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + r)^t},$$

where B_t and C_t are benefits (e.g., revenues from timber harvest or hunting lease) and costs (e.g., site preparation and maintenance) per hectare accrued in year t, T is the total number of time periods, and r is the annual discount rate. In systems that are clearcut after a fixed rotation period, T, SEV was calculated as if the project, once finished, would be repeated over and over throughout an infinite time horizon (Klemperer 1996):

$$\text{SEV} = \text{NPV}\left[1 + \frac{1}{(1 + r)^T - 1}\right].$$

In contrast, for systems that do not involve a fixed rotation that ends with clearcutting, such as a mature stand with periodic sustainable harvest, SEV should be estimated differently because there is no finite rotation age. First, we calculated the NPV of inputs required to produce a mature stand, which is achieved at time $T - 1$. Then, we approximated the periodic sustainable harvest as a yearly harvest exactly equal to the mean annual increment of merchantable timber. An SEV for the yearly sustainable return was calculated (from time T and beyond) and discounted back to the present. This was added to the NPV up to time $T - 1$:

$$\text{SEV}_{\text{sust}} = \left[\sum_{t=0}^{T-1} \frac{B_t - C_t}{(1 + r)^t}\right] + \left[\frac{B_T - C_T}{r} \cdot \frac{1}{(1 + r)^T}\right].$$

Base Case (No Government Payments)

A base case SEV was calculated for each production forestry, agroforestry, and agriculture scenario, assuming no policy interventions and two categories of flooding frequency (NRCS 2007). Flooding can cause a number of agricultural scenarios depending on the severity and timing, and its effects on soybean crops on frequently flooded (LCC 5) lands are described by Amacher et al. (1997). On LCC 5 lands, we assumed some flooding that affects the crop returns (to a varying degree) about 85% of the time (Amacher et al. 1997). On LCC 3 lands, flooding occurs with lower frequency; about 90% of LCC 3 lands fall into the "rarely flooded" category. The chance of flooding on rarely flooded land is 1–5% in any year (NRCS 2007). Conservatively, we assumed an 85% chance of no flooding on LCC 3 land and 15% chance of flooding causing a lost soybean crop. We included catastrophic insurance coverage for agriculture in both the base and policy cases, with premiums paid by the federal government. We assumed that flooding would create a need to replant tree species 30% of the time on LCC 5 and 5% of the time on LCC 3.

Hussain et al. (2007) found that although hunting lease rates vary somewhat by site specifications, on bottomland hardwood stands in northeast Mississippi (a core section of the LMAV), hunters pay an average of approximately $15/ha per year. Hussain et al. (2007) did not find a statistically significant difference for prices of leases for various species or season and those that were open to hunt all game species throughout the year. Therefore, we used $15/hectare as the typical value for bottomland hardwood hunting leases in the LMAV. For certain tree species and systems, we adjusted lease prices, as shown in Table 1. Specifically, cottonwood and pine systems were assumed to have lower lease prices ($7.50/ha per year) because of less mast for wildlife, whereas riparian buffer systems had higher prices ($22.50/ha per year) because proximity to water could make hunting potentially more attractive because of a greater number of game species.

Government Payments

We also examined the effects of government incentive payment for the Average Crop Revenue Election (ACRE) program and Fixed Direct Payment (FDP) program for agricultural systems, and WRP and CRP for forestry and agroforestry systems. Expected values of ACRE and FDP payments were calculated using formulas from ERS (2008). Data for the LMAV from ARMS (ERS 2009) were used to estimate the ACRE payments.

The WRP is the principal program for reforesting private lands via permanent easements that provide a one-time easement payment and 100% of restoration costs (King et al. 2006). We assumed an easement payment of $2,223/ha, the geographic rate cap used in Mississippi and Louisiana. No timber harvest or livestock grazing is allowed on WRP lands, but the landowner is permitted to sell a hunting/recreation lease, which was included in our financial calculations.

CRP funds Conservation Practice 22 (CP22) to support 10–15-year contracts to establish and maintain riparian buffers (Godsey 2005). We assumed a 15-year contract and soil rental rates of $111/ha for the LCC 5 soils and $222/ha for LCC 3 soils (Delta Wildlife 2008).

Carbon Markets

One potential market for ecosystem services from reforested LMAV land would be a future carbon market. The United States has not participated in the Kyoto Protocol, and at the time of writing, there was no national regulatory market for carbon, so the scale of carbon markets in the LMAV was limited to voluntary programs. However, in 2009, legislation was passed by the US House of Representatives that would create a cap-and-trade mechanism for greenhouse gas emissions (ACES 2009). Similar legislation had been introduced to the US Senate Committee on Environment and Public Works (Clean Energy Jobs and American Power Bill, no date). Both bills would permit carbon offsets from afforestation and reforestation activities. Although the ultimate fate of this particular legislation is uncertain, the US Environmental Protection Agency also asserted in 2009 that it had the obligation to regulate greenhouse gases, so some type of regulatory carbon market with a role for forestry seems likely.

Under the bills, the methodology and rules for forest carbon accounting in a future US regulatory carbon market would be determined by the USDA or other agency designated by the president. Most likely, the rules created under a federal cap and trade program would be consistent with one or more of the common international carbon accounting methodologies, of which one of the most prominent was the Kyoto Protocol's Clean Development Mechanism (CDM), which registers certified emission reductions (CER) for market. One difference between the potential US and the current CDM carbon accounting may be the treatment of permanence of credits from afforestation and reforestation activities. Because carbon dioxide (CO_2) sequestered from the atmosphere by trees could be released, for instance by a forest fire, hurricane, or harvest, the CDM issues temporary credits, which must be replaced when they expire. The US legislation, however, requires that afforestation and reforestation credits be permanent (ACES 2009, sec. 502.b.2). Permanence would be ensured by creating buffers, setting some credits aside as reserves, or purchasing insurance.

Permanence of potential carbon credits has several implications for carbon accounting. First, the costs of buffers, reserves, and insurance would be borne by the project manager/landowner, reducing the net revenues generated per ton of CO_2 sequestered. Second, accounting for temporary forestry credits under the CDM generally uses a stock change method, which gives credits incrementally as carbon is actually sequestered relative to a baseline level of carbon stored on the land without the project. However, a credit representing a permanent land-use change would lend itself to an average storage method, which estimates an average level of carbon stored per unit of land relative to a baseline level over time. The average storage method also is appropriate for systems that may have fluctuating carbon stocks over time, such as a forest plantation that sequesters carbon but is then clearcut and replanted (IPCC 2000).

Sequestration of carbon for carbon credits would be site-specific, and validation and verification of credits would require initial estimates followed by on-the-ground measurements. However, it was possible to estimate carbon sequestration by site class, species, and regime, based on the data previously described and methods provided by the Intergovernmental Panel on Climate Change (IPCC 2003). The estimate of average merchantable timber green mass (in metric tons) over time was converted to dry mass using the ratio of green to bone-dry densities (Fonseca 2005) [2]. This was converted to average forest carbon stored over time using a standard carbon accounting equation and default coefficient values (IPCC 2003) [3]. Average metric tons of forest carbon stored over time were converted to average metric tons of CO_2 stored over time by multiplying by 3.67 [4]. Then, a baseline value of 9.2 metric tons average CO_2 stored per hectare of annual cropland was subtracted from the average CO_2 stored over time in each forestry/agroforestry system (IPCC 2003).

Once the average number of tons of CO_2 stored over time was calculated for each system, we estimated the break-even net revenue per metric ton of CO_2 sequestered that would need to be achieved for the SEV of each forestry or agroforestry system to equal the SEV of soybeans, using the Microsoft Excel Solver application. The net revenue is the total revenue per metric ton of CO_2 sold, minus carbon finance project costs, including designing and registering the project; independent validation and verification; and buffers, reserves, and insurance to ensure permanence.

Biomass Price/Short-Rotation Woody Crop

Another way in which climate change/clean energy policy could affect the economic feasibility of tree crop systems is by increasing demand for biomass. Twenty-four states and the District of Colombia have enacted laws that require energy firms to produce a certain percentage of output from renewable sources (renewable portfolio standards) (US DOE 2009), which may include biomass for direct

Table 3. Estimated typical average yield under good weather and mean agricultural returns to land, management, and risk,[a] including poor weather, for rice and soybeans on Land Capability Classes (LCC) 3 and 5 in the Lower Mississippi Alluvial Valley.

	LCC 3		LCC 5	
Crop	Yield under good weather (metric tons [bushels]/ha)	Mean returns including poor weather (2008 $/ha)	Yield under good weather (metric tons [bushels]/ha)	Mean returns including poor weather (2008 $/ha)
Rice	10.0 [492]	388	8.1 [398]	−38
Soybeans	2.8 [102]	257	2.7 [100]	46

[a] Returns to land, management, and risk equal total revenue minus all costs except the cost of land, management, and insurance.

combustion or for conversion to cellulosic ethanol. In many states, the required percentage from renewable sources will increase over time. Currently, none of the main states in the LMAV (Arkansas, Louisiana, Mississippi, Tennessee) have renewable portfolio standards (US DOE 2009), but this could potentially change. Furthermore, if fossil fuel prices increase, this may increase demand for biomass alternatives. In either case, the price of woody biomass may increase, driving demand for systems that can rapidly produce woody biomass, such as short-rotation woody crops.

In the base case calculation, we used the price of pulpwood as a proxy for the biomass price. To determine the feasibility of the short-rotation woody crop system under increased biomass prices, we calculated the break-even biomass price for which that system attained an SEV equal to soybeans with federal payments, using the Microsoft Excel Solver.

Results and Discussion

One of the most basic results of the Delphi assessment was for the panel to select the systems (agriculture, forestry, agroforestry) for analysis. These results are shown in Table 1**.** Typical tree-planting densities and estimated establishment costs, along with timber (merchantable green biomass) growth rates, are shown in Table 2. Five forestry systems were selected for analysis, based on regimes that were common or had shown promise in research in the LMAV. In addition, two of these systems (hard hardwoods, and cottonwood and oak intercrop) were analyzed under two different harvesting regimes. After 50 years, the site could be either clearcut and replanted, or managed with small, periodic, sustainable harvests, maintaining a mature, intact stand.

Agroforestry systems are uncommon in the region, but this research sought to determine which might be economically feasible. Eight agroforestry systems were selected by the panelists on the basis of research results and adoption in other parts of the US South and Midwest and on the panelists' expert opinion on the types of systems that might be practicable and feasible in the LMAV. These systems included alley cropping (the cultivation of annual crops between rows of trees), silvopasture (raising livestock among trees), and riparian buffers (maintaining corridors of trees and herbaceous cover around waterways in an agricultural landscape). Pecan orchards seemed promising for agroforestry, because pecans are widely spaced, allowing a relatively large amount of light to pass through to the ground. Indeed, allowing cattle to graze native pecan orchards is one of the few agroforestry-type systems where practical experience exists in the LMAV, although practitioners may not consider it agroforestry. Other alley crop and silvopasture systems with pine, cottonwood, or hard hardwoods may also be feasible. In these systems, the annual crop or livestock component may be limited to the first 10–20 years of the timber rotation, after which time the lower light levels favor managing the plot for trees only. In this case, the agroforestry aspect is more of a short-term option that allows early income while producing an end result similar to more traditional forestry.

Riparian buffers were modeled slightly differently, on the basis of the fact that the buffers themselves are a spatially distinct component of landscape-level agroforestry. They were modeled as spatially distinct from the agricultural fields around the buffer. The buffer was essentially modeled as a forestry system, but it was classified as an agroforestry system because buffers are an integral part of landscape-level agroforestry.

Table 3 reports the estimated yield and expected value of agricultural returns to land, management, and risk, including risk from weather events, based on the Delphi assessment. These estimates demonstrated that agricultural returns on LCC 5 lands can be significantly lower than on LCC 3, not necessarily because the soils are much less fertile but rather because LCC 5 soils are much more negatively affected by poor weather, particularly flooding.

Base Case (No Government Payments)

Table 4 presents results from the base case financial analysis, which did not include government payments. In the absence of incentive payments, few forestry or agroforestry systems were competitive with agriculture on either type of land under any discount rate. On the most marginal land (LCC 5) at the lowest discount rate (5%), three agroforestry and production forestry systems (i.e., pine silvopasture, cottonwood alley cropping, and cottonwood for sawtimber) had higher expected returns (measured with SEV) than agriculture, assuming no policy interventions. However, panelists participating in the Delphi assessment noted that market problems existed for both cottonwood and pine. Low-value hardwood (cottonwood) markets have been in decline in the LMAV. Softwood markets are located outside the LMAV, so access would be limited for landowners in the LMAV. Only land that is geographically located near larger pine markets (e.g., on the edge of the LMAV near the coastal plains of Mississippi) would have potential for marketing pine. Other systems with positive SEV at a 5% discount rate (i.e., the internal rate of return was greater than 5%) were hard hardwood silvopasture and the cottonwood and oak interplanting system.

At higher discount rates of 7–10% on LCC 5, soybean crops had more favorable returns than all agroforestry and production forestry systems. The only systems with positive SEV at a 7% discount rate were pine silvopasture, cottonwood alley cropping, and cottonwood for sawtimber. All agroforestry and production forestry systems had negative SEV at a 10% discount rate. This suggests that the more impatient the landowner, the more likely he or she is to favor agriculture over forestry or agroforestry, as one would expect. On LCC 3 soils, assuming no policy interventions, none of the agroforestry or production forestry systems were competitive with agriculture at any discount rate. However, SEV for most of these systems, particularly agroforestry systems, were substantially higher than on LCC 5 soils. In particular, alley cropping systems, including pecan and

Table 4. Soil expectation values for production systems with no policy interventions and varying discount rates, on Land Capability Classes (LCC) 3 and 5 in the Lower Mississippi Alluvial Valley.

	LCC 3			LCC 5		
	Discount rate, %			Discount rate, %		
System	5	7	10	5	7	10
	(2008 $/ha)					
Soybeans	5,150	3,679	2,575	925	661	463
Rice	7,771	5,551	3,886	−768	−548	−384
Cottonwood for pulpwood	−257	−499	−689	−338	−625	−844
Cottonwood for sawtimber	1,180	275	−347	1,210	205	−479
Short-rotation woody crop	−2,217	−1,839	−1,565	−2,253	−1,941	−1,713
Hard hardwoods (clearcut)	52	−495	−758	−129	−667	−922
Hard hardwoods (sustainable)	−179	−613	−794	−357	−783	−957
Cottonwood and oak interplanting (clearcut)	158	−495	−885	18	−649	−1,048
Cottonwood and oak interplanting (sustainable)	−12	−589	−915	−158	−743	−1,077
Pecan silvopasture	1,020	−918	−2,255	−28	−1,864	−3,106
Hard hardwoods silvopasture	811	190	−122	321	−246	−513
Pine silvopasture	2,512	951	−12	1,861	404	−477
Hard hardwoods riparian buffer	−333	−652	−784	−510	−822	−947
Cottonwood and oak riparian buffer	−590	−956	−1,138	−769	−1,135	−1,317
Pecan alley crop	2,355	7	−1,640	−235	−2,000	−3,191
Hard hardwoods alley crop	843	275	−13	−8	−467	−656
Cottonwood alley crop	2,144	1,076	362	1,367	393	−234

cottonwood, had SEV over $2,000/ha at the lowest discount rate (5%). Therefore, in the absence of incentive payments, landowners would be more likely to adopt agroforestry than forestry systems on moderately marginal land (LCC 3), whereas on the most marginal land (LCC 5), results for agroforestry and production forestry were similar. Still, the low SEV for agroforestry compared with agriculture predicted little success for agroforestry or forestry on these lands. The estimates for forestry systems were less favorable for forests than those of earlier studies by Amacher et al. (1997) and Anderson and Parkhurst (2004) because we have accounted for the probability of tree seedling mortality during the first year and the increase in agricultural crop prices since earlier studies.

When comparing alley cropping and silvopasture systems with forestry systems with the same timber species (cottonwood alley crop versus cottonwood for pulpwood or sawtimber; hard hardwoods silvopasture or alley crop versus hard hardwoods), the agroforestry systems appeared more attractive. The short-term agricultural or livestock returns in agroforestry were enough to offset any reduction in timber production. These results indicate that without incentive payments, certain agroforestry systems may be more likely to be adopted than forestry systems. This would be especially true for farmers with a time preference that favored early income (i.e., high discount rate), because agroforestry would provide more income opportunities in early years.

The same was not true of riparian buffer systems. This is because of the way we modeled the riparian buffers—as spatially distinct from the agricultural fields around the buffer. Returns were lower for buffers than for forestry systems because a portion of the buffer land would be planted to herbaceous filter strips and because there would be restrictions on timber harvesting in the areas closest to the waterway.

Table 5 shows results of the sensitivity analysis on returns per head of cattle on SEV for silvopasture systems. Silvopasture SEV were quite sensitive to changes for returns per head of cattle. On LCC 5 lands, with a 5% discount rate, a reduction in profitability of cattle reduced the SEV of pine silvopasture from being much higher than the reference soybean SEV (from Table 4) to being significantly lower. These results suggested that silvopasture returns were sensitive to numerous management decisions. Therefore, a landowner or farmer without experience in cattle-raising may be unlikely to adopt silvopasture because of the risk of incurring significant losses.

Table 5. Soil expectation values for silvopasture under varying cattle returns on Land Capability Classes (LCC) 3 and 5 in the Lower Mississippi Alluvial Valley.

	LCC 3			LCC 5		
	Cattle returns ($/head)			Cattle returns ($/head)		
System	35	0	−50	35	0	−50
	(2008 $/ha, 5% discount rate)					
Pecan silvopasture	1,020	323	−673	−28	−596	−1,408
Hard hardwoods silvopasture	811	373	−251	321	−35	−544
Pine silvopasture	2,512	1,838	874	1,861	1,311	526

Government Payments

Table 6 reports SEV including incentive payments from ACRE and FDP for agriculture, WRP for reforestation, and CRP CP22 for riparian buffers. The ACRE and FDP programs together increased the value of agriculture significantly, approximately 15% for LCC3 and 60% on LCC 5 lands. The only agroforestry/forestry with higher SEV in Table 4 than soybeans with federal payments is pine silvopasture on LCC 5 land at a 5% discount rate, assuming optimistic returns per head of cattle. These federal payments, therefore, raised the bar for potential adoption of forestry or agroforestry, making them more difficult to rationalize economically.

However, when including federal conservation payment programs, such as WRP and CRP, converting agricultural lands to forest was competitive with agriculture on marginal LCC 5 land. CRP CP22 had an SEV slightly less than WRP, at 5% discount rates. A higher discount rate made WRP more competitive because the WRP easement subsidy is paid up front, whereas agriculture and CRP CP22 receive annual returns. Therefore, time preference (i.e., high discount rates) may partially explain why WRP has been more

Table 6. Soil expectation values for production systems under existing incentive policies: soybeans with the Average Crop Revenue Election (ACRE) and Fixed Direct Payment (FDP) programs, hard hardwoods with the Wetlands Reserve Program (WRP), and hard hardwoods riparian buffer with Conservation Reserve Program (CRP) CP22, on Land Capability Classes (LCC) 3 and 5 in the Lower Mississippi Alluvial Valley.

System	No policy	ACRE and FDP	WRP	CRP CP22
	. . . .(2008 $/ha, 5% discount rate)			
LCC 3				
Soybeans	5,150	5,950		
Hard hardwoods	52		2,233	
Hard hardwoods riparian buffer	−333			3,696
LCC 5				
Soybeans	925	1,478		
Hard hardwoods	−129		2,233	
Hard hardwoods riparian buffer	−510			2,184

popular than CP22, as well as the fact that fewer lands qualified for CP22, because they have to be along streams.

On LCC 3 lands, WRP was less competitive with agriculture, because of the $2,223/ha rate cap, which is less than 40% of the SEV for soybeans on those lands. CRP CP22, on the other hand, pays annually on the basis of the typical land rental rate, which is higher for LCC 3 lands. Therefore, CP22 was somewhat more competitive than WRP on these moderate soils. Still, both CRP CP22 and WRP have lower SEV than soybeans on LCC 3 lands, with or without federal agricultural payments, meaning that they face economic barriers to adoption on moderate soils.

On the basis of these estimates, therefore, in the absence of other policy measures or reductions in federal agricultural payments, WRP and CRP would be likely to be commonly adopted on LCC 5 soils but not on LCC 3. However, given the fact that land classes are spatially interspersed in the LMAV, landowners may be willing to group marginal and moderate soils together in forestry plots to make management easier. Furthermore, landowners may be motivated by factors other than simply selecting the land use that creates the highest financial return. Delphi panelists noted that this was especially true for absentee landowners—such as professionals living in nearby or far-away urban areas—who may simply want an investment property or a place to escape the city, without the weekly concerns of managing or renting farmland. In these cases and others, WRP and CRP may be an attractive option, providing higher income than forestry or agroforestry production systems but being more in line with landowners' preferences than farming.

There are limits to the amount of land that can be enrolled in WRP and CRP. No more than 25% of the land in any county can be in either WRP or CRP. In addition, no more than 10% of the land in any county can be under permanent WRP easement. These limits may pose additional barriers to extension of WRP and CRP programs in areas with a high proportion of streamside and wetland areas.

Carbon Markets

Table 7 shows the break-even net revenue per metric CO_2 ton at which each production forestry and agroforestry system attained an SEV equal to soybeans, including ACRE and FDP payments, on LCC 3 and 5. That is, at any CO_2 net revenue higher than noted in the table, that system became economically more attractive than soybeans. Break-even net revenues were lower on LCC 5 lands because the soybean SEV was relatively lower, making it easier to reach that threshold. In general, forestry systems had lower break-even values than agroforestry systems. This reflects lower average carbon storage per hectare in agroforestry systems because of lower plantation densities and more frequent thinning. This is true despite the fact that agroforestry systems tended to have higher SEV in the base case calculations.

Table 7. Break-even net revenue per metric ton CO_2 in various forestry and agroforestry systems compared to soybeans with Average Corp Revenue Election and Fixed Direct Payment payments, on Land Capability Classes (LCC) 3 and 5 in the Lower Mississippi Alluvial Valley.

System	LCC 3	LCC 5
	. .(2008/$/metric ton CO_2) . .	
Cottonwood for pulpwood	59.58	15.90
Cottonwood for sawtimber	32.47	1.66
Short-rotation woody crop	254.60	102.36
Hard hardwoods (clearcut)	26.59	7.24
Hard hardwoods (sustainable harvest)	15.15	4.54
Cottonwood and oak interplanting (clearcut)	30.87	7.62
Cottonwood and oak interplanting (sustainable)	17.39	4.77
Pecan silvopasture	40.35	12.32
Hard hardwoods silvopasture	29.37	6.61
Pine silvopasture (optimistic returns per head)	35.39	0.00
Hard hardwoods riparian buffer	31.78	10.05
Cottonwood and oak riparian buffer	39.19	13.46
Pecan alley crop	29.42	14.02
Hardwood alley crop	31.55	9.18
Cottonwood alley crop	32.64	0.87

In addition, management regimes that included maintaining a mature stand with a small, periodic, sustainable harvest had lower break-even net revenues in general than regimes that involved a clearcut and replanting. This is because the regime that maintains a mature stand would maintain a larger carbon stock over time and thus would receive more carbon credits. Again, this was in spite of a higher SEV for clearcutting in the base case. The fact that lower break-even prices were found for systems with lower base case SEV (for forestry systems over agroforestry and sustainable harvest over clearcut) demonstrates that future carbon markets could affect the way that land is managed in numerous ways.

The break-even net revenues in Table 7 seemed reasonable at first compared with CER prices during 2008–2009, which ranged from about $10 to $32 per metric ton (European Climate Exchange 2010); however, there are financial barriers to using carbon credits to make forestry and agroforestry systems attractive. First, the costs of verification and registration of credits and implementing measures to ensure permanence (buffers, reserves, insurance) can be substantial, especially for small plots of land. Second, the project manager must demonstrate that the site must not have been forested since 1989, and the manager must offer evidence that reforestation would not have taken place without the carbon payment.

Future carbon prices and project costs are unknown, but costs are likely to be substantial. Compared with a net revenue of $10 per metric ton CO_2, a few systems appeared to have potential on LCC 5 soils, including cottonwood for sawtimber, hard hardwoods (sustainable harvest and clearcut), cottonwood and oak interplanting (sustainable harvest and clearcut), hard hardwoods silvopasture and alley crop, pine silvopasture, and cottonwood alley crop. The hard hardwoods riparian buffer was also close to $10. Short-rotation woody crops required a very high carbon price to break even when only considering the effect of carbon credits for reforestation/afforestation (without an increase in biomass price), because a relatively small amount of carbon per hectare would be stored in such a system on average over time. This means that short-rotation woody crop systems would be largely unaffected by carbon markets that include credits for land-use changes.

None of the systems appeared to be competitive on LCC 3 soils at plausible net revenues for CO_2 for the near future. This indicated that agriculture would likely remain the dominant land use on moderately productive lands, even if carbon markets function. This does not mean that no forestry or agroforestry would exist on LCC 3 (or LCC 1 or 2) lands; as noted above, there may be numerous reasons why an individual landowner may choose not to use the land for annual crops.

Biomass Price/Short-Rotation Woody Crop

The break-even farm-gate price for biomass that would make the short-rotation woody crop system as profitable as soybeans was estimated to be $16.04 per green metric ton ($43.13 per bone-dry metric ton) on LCC 5 soils (5% discount rate). This was more than 2.5 times the price that was assumed in the base case, which was the price of pulpwood. The break-even price on LCC 3 soils was $26.91 per green metric ton ($79.77 per bone-dry metric ton), more than 4.5 times the price of pulpwood.

When considering the costs of chipping and transporting biomass, and that most biomass needs are currently met with industrial wastes such as slabs, sawdust, etc., short-rotation woody crop systems seemed unlikely to be as profitable as agriculture in the near future in the LMAV, even on marginal soils. Furthermore, even if demand for biomass were to increase somewhat in the LMAV, there is an immense pool already available—agricultural residues—that would simply need to be gathered and transported and that would presumably be cheaper than setting land aside for the sole purpose of growing biomass. In our estimation, demand for biomass would need to grow considerably before those types of systems become feasible.

Conclusions

Using cash flow analyses, we evaluated the economic potential for production forestry and agroforestry systems in the LMAV, without policy and under several policy instruments. Estimates of costs and returns were calculated from inputs provided by three panels of experts, government databases, and reputable institutions in agriculture and forestry in the region.

Absent incentive payments, agroforestry and forestry systems are unlikely to be adopted on the most common LCC areas in the LMAV. Only pine silvopasture, cottonwood for sawtimber, and cottonwood alley cropping were competitive with agriculture, and only on the most marginal lands (LCC 5) and at the lowest discount rate (5%). Furthermore, pine and cottonwood sawtimber have limited markets in many areas in the LMAV. Agroforestry systems performed better than forestry on higher quality sites (LCC 3) but still underperformed compared with conventional agriculture.

Results were somewhat different when including incentive payments. WRP was economically competitive on LCC 5 but not on LCC 3 lands. This is significant because of the large proportion of the LMAV occupied by LCC 3, including many streamside areas. CRP CP22 (riparian buffers) had higher returns for on LCC 3 soils but still lagged behind agriculture in profitability. If markets for carbon sequestration become viable in the future, we would expect an increased interest in forestry, and agroforestry to a lesser extent, but again, mainly only on LCC 5 lands. Carbon markets would also change the forest management regimes that would be the most profitable. For example, forestry systems that maintained a mature stand rather than clearcutting performed the best under carbon markets, because they stored more carbon over time. An increase in price of woody biomass did not seem to make short-rotation woody crop systems financially beneficial compared with agriculture, unless the increase was quite considerable.

Estimating inputs, management regimes, costs, prices, and government programs was complex. The subsequent discounted cash flow analysis results were based on relatively simple deterministic models. They did not take into account variability inherent in agriculture and forestry, which may cause risk. Risk aversion may play a significant role in a landowner's decisions, and other factors related to variation in inputs and outputs combined may change which systems landowners perceive as the most beneficial. Furthermore, many landowners are attuned to values that are not directly financial in nature, which can affect land-use choices.

Our research indicated that forestry and agroforestry in the LMAV, aside from the WRP program, would not likely become common in the near future, absent policy or market changes. Recent increases in agricultural prices would tend to make forestry and agroforestry systems even less adoptable. Markets for carbon and biomass are in their nascent stages. As these markets grow, there may be growth, albeit slow growth, in interest among landowners for forestry and agroforestry. More programs involving direct payments to landowners for ecosystem services could also enhance financial returns and attractiveness for agroforestry systems. This research could provide a basis for future comparisons and analysis of farm programs and ecosystem service markets.

Endnotes

[1] Dalkey and Helmer (1963) of the RAND Corporation created the Delphi method as a technique for fostering dialogue among a panel of knowledgeable subjects to work toward a consensus. The methodology uses an iterative approach and anonymity among panelists.

[2] Average green and bone dry timber densities (from Fonseca 2005, Table 8.1).

	Green density	Bone dry density
	.........(kg/m^3).........	
Bottomland oaks (*Quercus* spp.)	1,249	580
Cottonwood (*Populus deltoides*)	995	370
Loblolly pine (*Pinus taeda*)	1,026	470
Pecan (*Carya illinoinensis*)	1,201	640

[3] IPCC (2003) Equation 3.2.3 is the formula for estimating total forest biomass from merchantable biomass. Annex 3A.1 gives international default conversion factors based on scientific estimates. Adapted Equation 3.2.3: $C = [MBM \cdot BEF_2] \cdot (1 + R) \cdot CF$, where C is total carbon in biomass (metric tons C), MBM is merchantable bone-dry biomass (metric tons), BEF_2 is biomass expansion factor for conversion of merchantable volume to aboveground tree biomass (dimensionless), R is root-to-shoot ratio (dimensionless), and CF is carbon fraction. The default values used for BEF_2 (from IPCC 2003, Table 3A.1.10) are: hardwoods, 1.4; pine, 1.3. The default values used for R (from IPCC 2003, Table 3A.1.8) are: oak, 0.35; other hardwoods, 0.26; pine, 0.23. The default value used for CF is 0.5 (from IPCC 2003, p. 3.25).

[4] The mass of CO_2 sequestered from the atmosphere is greater than the mass of the carbon (C) alone, because C is stored and oxygen (O_2) is reemitted to the atmosphere. The atomic mass of C is 12, and the molecular mass of CO_2 is 44. Therefore, for every 12 metric tons of C stored, 44 metric tons of CO_2 have been sequestered. The conversion factor from C to CO_2 is 44/12 = 3.67.

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