Chapter 4
Valuation of Agroforestry Services

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Rural communities and lands are particularly vulnerable to climate change (Lal et al. 2011). Changes in the viability of plants and animals; arid land expansion; reductions in water quantity and quality; increased threats from pests, diseases, and wildfire; and more frequent extreme weather events may induce a variety of economic and social impacts on rural communities. These impacts include increased uncertainty of food and fiber production, reduced supply of ecosystem services, changes in employment opportunities, and human (and nonhuman) population relocations (Lal et al. 2011). Reducing the vulnerability of rural communities requires developing agricultural and forestry production systems that are resilient to changing environmental conditions (Lin et al. 2008, Verchot et al. 2007). Chapters 2 and 3 of this assessment demonstrate the potential for agroforestry to mitigate climate change (through increased carbon sequestration and reduced greenhouse gas [GHG] emissions) and assist rural communities in adapting to climate change by providing alternatives to conventional agricultural that are more resilient to the impacts of extreme weather events, changes in rainfall patterns, and increased risks from pests and diseases. Agroforestry, however, will make a significant contribution to mitigating or adapting to climate change only if landowners across the landscape adopt it in the United States (Scherr et al. 2012).

Economic theory predicts that farmers (who are price sensitive) will invest in agroforestry when the expected returns from the new system are higher than all other alternatives for the use of their land, labor, and capital. A large empirical literature confirms that a host of other factors also determine the extent of agroforestry adoption; these factors include household preferences, resource endowments, market incentives, biophysical factors, and risk and uncertainty (Mercer 2004, Mercer and Pattanayak 2003).[1] The role of risk and uncertainty, in particular, appears to be more important in agroforestry-adoption decisions compared with annual cropping innovations because of the long periods before the returns to tree growing are realized (Pannell 2003, Pattanayak et al. 2003).

Agroforestry systems also produce a number of important ecosystem services, such as carbon sequestration, biodiversity conservation, soil enrichment, and protection of air and water (Jose 2009). The value of these services to society is potentially quite high, but rarely are landowners paid for them. In many cases, agroforestry systems will be economically viable only when landowners are paid for producing these nonmarket services (Frey et al. 2010). Under these circumstances, it may be optimal for society to provide incentives to adopt agroforestry as evidenced by a number of Federal programs promoting agroforestry adoption (Godsey et al. 2009). Determining the optimal size of these incentives requires estimates of the value of the ecosystem services produced by agroforestry systems.

This chapter provides an overview of research on the economic valuation of agroforestry in North America. Economists have two approaches for valuing land-use systems: (1) financial analysis examines returns to investments from the landowner's perspective and typically focuses on enterprise- or farm-level outcomes and (2) economic analysis expands the analysis to include societal impacts beyond the farm boundaries (i.e., externalities) (Thompson and George 2009). We organize this chapter using this typology. First, we examine the current literature on the valuation of agroforestry from the landowner's perspective focusing on this question: "Under what conditions is agroforestry a viable financial enterprise for landowners?" We briefly review the various tools used for this type of analysis, including capital budgeting, production frontier analysis, and linear programming and their application to agroforestry. The second section of the chapter synthesizes the literature on the value of agroforestry from society's perspective, emphasizing the valuation of the ecosystem services and both positive and negative externalities associated with agroforestry. Then, we review the recent literature on the role and impact of risk and uncertainty on the adoptability of agroforestry in the United States and end with a summary of key findings and information needs.

[1] Economic theory can also be used to explain the impact of these factors.

Valuation of Financial Returns to the Landowner

A range of methods and analytical tools has been used to estimate the financial returns to landowners from adopting agroforestry systems. These tools are summarized in table 4.1 and discussed individually in the following paragraphs.

Capital Budgeting

Capital budgeting (cashflow or cost-benefit analysis) is the most widely used method for comparing the efficiency (profitability) of alternatives with different inputs and outputs (Klemperer 1996). Net present value (NPV), the sum of the discounted periodic net revenues per unit of land during a given period, is the most common decisionmaking criteria in capital budgeting studies. When the NPV is higher for agroforestry than are all feasible alternatives, it is potentially adoptable. The soil expectation value (SEV), the net return per acre assuming perpetual rotations, is more appropriate when the time horizons of alternatives vary (for example, when comparing annual cropping to agroforestry). Multiplying SEV by the interest rate gives the annual equivalent value, which can be used to compare alternatives yearly. Other capital budgeting criteria include the benefit-cost ratio, which compares discounted benefits to costs as a ratio rather than a difference, and the internal rate of return, which is the discount rate at which the present value of benefits equals the present value of costs (i.e., the discount rate that makes the NPV equal zero).

Frey et al. (2010) applied capital budgeting techniques to compare financial returns from eight agroforestry and seven forestry systems with annual cropping on marginal lands in the Lower Mississippi Alluvial Valley. With few exceptions, annual cropping produced higher returns than agroforestry and forestry, even in the absence of Federal agricultural support payments. A few forestry and agroforestry systems, however, were competitive on marginal agricultural lands, assuming landowners could sell carbon sequestration credits. Holderieath et al. (2012) developed cashflow models to assess the adoptability of silvopasture and alley cropping in Missouri, with and without payments for carbon credits. They found that additional incentives from selling carbon credits were not sufficient to encourage adoption of silvopasture or alley cropping practices because the financial returns were so much lower than annual cropping. Godsey et al. (2007) applied cashflow analysis to compare the costs of converting upland hardwood forests in the Missouri Ozarks to silvopasture with the cost of traditional improved pasture and found that silvopasture can produce positive NPVs. Ares et al. (2006) examined nut, timber, and forage production and the economics of managed pecan silvopasture in southeastern Kansas. They estimated discounted cashflows and NPVs from 20-year Monte Carlo simulations of four agroforestry scenarios for pecan/cattle silvopasture operations. Using current nut and beef prices and discount rates of 6 and 8 percent, cashflows were positive during the 20-year simulation, but NPVs were negative; however, adding timber production to the system produced positive NPVs.

Stamps et al. (2009) used cashflow analysis to compare alley cropping alfalfa with black walnut to conventionally grown alfalfa in Missouri. Although cashflows for black walnut plantations were negative for decades, adding alfalfa production in wide alleys between the walnut trees produced positive cashflows. The annual equivalent value for alfalfa monoculture, however, was almost 50 percent higher than for the agroforestry system, and, without payments for the ecosystem services produced from the agroforestry system, widespread adoption was deemed unlikely.

Table 4.1. Financial valuation methods.

Methods	Definition	Agroforestry examples
Capital budgeting	Economic analysis to determine the relative profitability of investment alternatives. Decision criteria include net present value (NPV), soil expectation value (SEV), and annual equivalent value (AEV).	Frey et al. (2010) Holderieath et al. (2012) Godsey et al. (2007) Ares et al. (2006) Stamps et al. (2009) Benjamin et al. (2000) Graves et al. (2007, 2011) Susaeta et al. (2012)
Linear programming	Optimization of an outcome based on some set of constraints using a linear mathematical model.	Stainback et al. (2004) Wojtkowski et al. (1988) Mudhara and Hildebrand (2004) Thangata and Hildebrand (2012) Dhakal et al. (2012)
Production frontier analysis	Parametric and nonparametric econometric techniques for measuring the technical efficiency of alternative production systems.	Frey et al. (2012) Pattanayak and Mercer (1998) Yin and Hyde (2000) Lindara et al. (2006) Gockowski et al. (2010) Jahan et al. (2013)

Benjamin et al. (2000) used a discounted cashflow analysis to compare returns to hardwood (walnut) alley cropping systems with traditional forest plantation, row crop monoculture (corn), and annual crop rotations (corn-soybean-wheat) in the U.S. Midwest. During a 68-year rotation, widely spaced alley cropping systems produced the highest NPVs (with a 5-percent discount rate) followed by traditional walnut plantations, both of which were more than twice as high as the returns for annual crops during the same period.

Linear Programming

Linear programming (LP) models differ from capital budgeting in two important ways: (1) they analyze the entire farm, not just the activity of interest, and (2) they can account for farm diversity. Farm types are modeled separately and aggregated to evaluate potential adoptability across a landscape. When the landowners' objective is to maximize long-term profits from the entire farm under multiple constraints, LP is usually the preferred analytical tool. LP models have been widely applied to agroforestry systems in the tropics (examples include Dhakal et al. 2012, Mudhara and Hildebrand 2004, Thangata and Hildebrand 2012, Wojtkowski et al. 1988), but we could find only one study that applied LP in temperate zones. In this study, Stainback et al. (2004) used dynamic optimization models to compare the profitability of silvopasture with conventional cattle ranching in southern Florida, with and without taxes on phosphorous runoff and payments for carbon sequestration. In the absence of taxes and carbon payments, traditional ranching produced higher SEVs than the silvopasture systems. Although phosphorous taxes alone were not enough for silvopasture to compete economically with traditional ranching, payments for carbon sequestration with or without phosphorous taxes could make silvopasture competitive.

Production Frontier Analysis

The production frontier, the maximum output that can be produced for any given level of input, is used to measure technical efficiency (TE). In one input/one output cases, TE is simply the slope of the line through the origin to any point on the production frontier. Measuring relative efficiency when faced with multiple inputs and outputs, however, is much more difficult. One approach is to use the ratio of the weighted inputs to weighted outputs. If all outputs and inputs have market values, the prices are the weights and TE is equivalent to the benefit-cost ratio. For situations in which markets are thin (small number of buyers and sellers), prices do not exist, and/or farmers may lack access to markets, benefit-cost ratios may not be comparable between farms. In these cases, two methods (parametric and nonparametric) are available. Although a large and growing literature is applying parametric methods to analyze agroforestry in the tropics (e.g., Gockowski et al. 2010, Jahan et al. 2013, Lindara et al. 2006, Pattanayak and Mercer 1998, Yin and Hyde 2000), we were unable to find any studies applying this approach to agroforestry in temperate regions.

Data envelopment analysis (DEA), the most common nonparametric alternative, uses LP to calculate the weights that maximize technical (or profit) efficiency. DEA is suited for comparing the efficiency of alternatives, even when market prices are not available for all inputs and outputs. DEA determines the weights (relative shadow prices) for each input and output that maximize efficiency. Although no studies in the United States using DEA could be found, Frey et al. (2012) applied DEA to compare the relative efficiency among silvopasture, conventional pasture, and plantation forestry in Argentina, after which, they applied nonparametric statistical analysis to compare the systems within farms. Silvopasture was found to be more efficient than conventional cattle ranching, but results were inconclusive for conventional forestry.

Valuation of Ecosystem Services and Externalities From Agroforestry

In addition to providing financial benefits to landowners, agroforestry can also generate substantial ecosystem services to the public, including carbon sequestration; biodiversity conservation; and protection of soil, air, and water (Jose 2009). Ecosystem services, however, typically are not sold in markets and, therefore, cannot be valued directly with market prices. Designing optimal agroforestry policies (from society's perspective) for mitigating and adapting to climate change requires estimating the value of these nonmarket ecosystem service benefits and applying them in benefit-cost analyses.

Nonmarket valuation methods have been widely used to estimate the value of ecosystem services, such as biodiversity, water quality, and recreation. Valuation methods are usually based on either stated or revealed preferences. Stated preference approaches, including contingent valuation and choice modeling, rely on surveys to directly elicit values from respondents. Revealed preference approaches like hedonic analysis use actual choices people make in real markets to infer how much they are willing to pay for environmental goods and services associated with those choices. Although demand for nonmarket valuation studies of ecosystem services from agroforestry is increasing, only a limited number of studies applied to U.S. agroforestry currently exist. Table 4.2 summarizes the available methods.

Table 4.2. Nonmarket valuation methods.

Methods	Definition	Agroforestry examples
Contingent valuation	Stated preference method that asks the respondents whether they would like to pay (or accept) a set amount of money for certain environmental condition.	Grala et al. (2012) Shrestha and Alavalapati (2004a) Qiu et al. (2006)
Choice experiments	Stated preference method that asks people to make choices based on two or more hypothetical conditions. A set of attributes, including environmental conditions, is described in each choice.	Shrestha and Alavalapati (2005) Mercer and Snook (2004)
Hedonic analysis	Revealed preference methods based on the assumption that the prices of household properties represent the sum of values associated with property attributes, including the environmental assets.	Bastian et al. (2002) Shrestha and Alavalapati (2004b) Vanslembrouck et al. (2005)
Benefit transfer	Transfer of available information from existing literatures conducted in another location or conditions to estimate the benefit value of the current research condition.	Porter et al. (2009) Kulshreshtha and Kort (2009)

Contingent Valuation

Contingent valuation is a survey method for estimating nonuse and passive use values in which respondents are asked how much they would be willing to pay or willing to accept for changes (positive or negative) in ecosystem service production under alternative land-use scenarios (Bateman et al. 2002, Mitchell and Carson 1989). Grala et al. (2012) employed contingent valuation to estimate the willingness of Iowa's residents to pay for the aesthetic benefits associated with field windbreaks. Depending on their perceptions about the visual appeal and abundance of field windbreaks, Iowa residents were willing to donate on average from $4.77 to $8.50 to a fund to pay landowners to plant windbreaks. Qiu et al. (2006) valued the benefits of riparian buffer zones in a suburban watershed of St. Louis, MO. Respondents were willing to pay an additional $1,400 to $1,625 to live in a community accessible to a riparian buffer and $6,100 to $6,858 for properties adjacent to a riparian buffer. The above two cases showed that residents are willing to sacrifice part of their income to support the establishment of agroforestry for the externalities provided, such as aesthetic values.

Contingent valuation surveys also have been used to estimate farmers' willingness to accept payments to supply various ecosystem services. For example, Shrestha and Alavalapati (2004a) investigated incentives for ranchers to adopt silvopasture in Florida. They found that natural attributes, such as wildlife presence, recreational hunting opportunities, and the presence of creeks increased the probability that ranchers would adopt silvopasture. To adopt silvopasture, however, ranchers would require an average price premium of $0.15 per pound for beef or a direct payment of $9.32 per acre per year. Buckley et al. (2012) investigated the willingness of farmers in the Republic of Ireland to install 10-meter-wide riparian buffer zones over 5 years. Of farmers surveyed, 47 percent were willing to adopt the proposed riparian buffer zone if paid, on average, $1.51 per linear meter per year.

Choice Experiments

In contrast with contingent valuation, in which people are directly asked to state their willingness to pay (or accept; WTP) for changes in ecosystem services, choice experiments require respondents to choose from a series of two or more choice sets with options that contain various combinations of attributes for each choice (Hanley et al. 2001). Based on the statistical analysis of the respondents' sets of choices, the impact of each attribute on willingness to pay for an ecosystem service can be estimated. The WTP for a specific policy scenario is the sum of the WTP for all its attributes. Choice experiments can be especially useful in evaluating policies with a varying set of possible characteristics.

Two studies employed the choice experiment method to evaluate the preferences for several agroforestry attributes from the public's and landowners' perspectives. In the first study, Shrestha and Alavalapati (2005) used a choice experiment to estimate how much households in south-central Florida would be willing to pay for environmental goods and services produced by installing silvopasture systems in the Lake Okeechobee watershed of Florida. Three attribute levels were provided for each of the following environmental characteristics: (1) water-quality improvement, (2) carbon sequestration, and (3) wildlife habitat protection. The results indicated that an average household in south-central Florida would be willing to pay $30.24 to $71.17 per year for 5 years for the environmental benefits produced by silvopasture adoption. In the second study, Mercer and Snook (2004) describe a choice experiment to assess how different attributes of an agroforestry system influenced farmers' willingness to adopt agroforestry in Campeche, Mexico. The attributes included labor requirements, technical assistance, forest conservation, plant availability, and production resources. The results showed that farmers had a strong preference for increasing forest cover to bequeath a better world to their children and that important factors for adopting agroforestry included technical assistance; accessibility of tree seedlings; and a mix of products, including timber, crops, and fruit trees. Choice experiment studies are able to estimate the respondents' preferences toward both negative and positive attributes associated with agroforestry land—essential information for balancing different impacts in policy design.

Hedonic Analysis

The hedonic price method is a revealed preference method based on the assumption that the prices of real estate are determined by the values associated with property attributes, including environmental amenities (Palmquist 1991). The hedonic method has been used to estimate economic damages associated with air pollution or water pollution, the economic benefits of aesthetic views, and the value of nearby recreational opportunities. For instance, if people who live near agroforests value increased wildlife habitat or the aesthetics of including trees in an agricultural landscape, the property values of nearby residences would be higher than more distant residences.

Three studies estimated the benefits from agroforestry generated by the price premium in real markets, such as land value, rent, or hunting license revenues. In the first study, Bastian et al. (2002) employed a hedonic model to examine the impact of wildlife habitat, angling opportunities, and scenic vistas on the value of agricultural land in Wyoming. The results showed that visually diverse lands generate higher prices relative to those landscapes dominated by agricultural production. In the second study, Shrestha and Alavalapati (2004b) investigated the effect of ranchland attributes, such as parcel size, tree cover, and proximity to urban centers, on recreational hunting in Florida. The results suggest that the additional tree and vegetation cover for silvopasture practices could increase hunting revenues. For example, maintaining 22 percent tree cover on ranchlands could increase hunting lease revenues by $16.15 per acre per year, an opportunity to supplement income from cattle. In the third study, Vanslembrouck et al. (2005) analyzed the effect of rural landscapes on the demand for rural tourism in Flanders, Belgium. Results indicate that some agricultural activities, such as meadows and grazing cattle, have a positive impact on how much tourists are willing to pay for rural accommodation, but intensive annual crop cultivation has a negative impact.

Benefit Transfer

Benefit transfer techniques are commonly used to indirectly estimate values for ecosystem services when it is not feasible (because of time or resource constraints) to conduct studies on the site in question. A benefit transfer study collects data and results from previous studies performed in other locations or under different sets of conditions. The values of the benefits under study are then estimated by adjusting the results from the previous studies based on the similarities and differences between the studies' geographic and socioeconomic focus and methodological approaches.

Although the benefit transfer method is much less costly than conducting new research, care must be taken when extrapolating results from one setting to another. Both the geographical and socioeconomic characteristics of study sites may influence the estimates of values for ecosystem services (De Groot et al. 2012, Smith and Kaoru 1990). Instead of applying per-unit value estimates directly from the existing literature, it is preferable to use the functional forms and parameter estimates in a meta-analysis to derive values specific for the new study.

Porter et al. (2009) estimated the value of pollination, biological control, and food production from a combined food and energy agroforestry system in Taastrup, Denmark, based on previous estimates for agricultural ecosystem services by Costanza et al. (1997). Kulshreshtha and Kort (2009) employed the benefit transfer method to estimate the value of soil-erosion reduction, air-quality improvements, GHG-emission reductions, improved water quality, enhanced biodiversity, and enhanced recreation activities in prairie shelterbelts in Canada based on information in published literature. The total benefits for the external value from shelterbelts were found to be more than $140 million Canadian ($90.5 million U.S.) at 2001 exchange rates (OZF Foreign Exchange Services 2016). The previous two studies employed benefit transfer to value ecosystem services from agroforestry; however, the value used from previous literature may have been based on agricultural or forest land. The study did not distinguish between different land scenarios.

Choosing which nonmarket valuation techniques to use to value ecosystem services from agroforestry should be based on the available information and program circumstances. Stated preference techniques usually rely on surveys to investigate hypothetical scenarios of agroforestry programs. Conversely, revealed preference techniques use observations on actual choices that people made in existing markets to measure preferences. Contingent valuation and choice experiments are usually used to evaluate the nonconsumptive value of ecosystem services, such as biodiversity or cultural values. By contrast, the hedonic method is usually used to evaluate the consumptive values of agroforestry, such as aesthetic value or recreation. The limitation with stated preference methods is that the results are sensitive to numerous sources of bias in survey design and implementation. Although hedonic models avoid the potential problem with hypothetical responses, it requires a large amount of data that is largely limited to observable states of the world. In addition, hedonic results may be of limited value when markets are distorted, choices are constrained by income, or information about environmental conditions is scarce. Benefit transfer methods are used when resources and time are limited, such as when a large number of ecosystem services are being valued over a large area, and when sufficient numbers of previous studies are available to draw on.

Risk and Uncertainty

Variability in returns and the ability to change or postpone decisions when conditions change are important decision criteria for landowners. Because deterministic models assume that landowners/managers have perfect foresight of future conditions, they are not appropriate in the face of risk or uncertainty. A variety of stochastic models, however, can be used to incorporate risky or uncertain future conditions. Using both stochastic and deterministic models can provide important insights about financial decisions (Frey et al. 2013). Table 4.3 lists the available methods with examples from the agroforestry literature.

Mean-Variance Analysis

Mean-variance analysis (often referred to as E-V for "expected value/variance") can identify the set of "efficient" alternatives that either minimize risk for any given level of returns or maximize returns for any given level of risk. Although E-V is a powerful tool for decisionmaking, the underlying assumptions about utility functions and distributions of returns often conflict with economic theory. Nevertheless, E-V is appropriate under a wide variety of utility functions and common levels of risk aversion (Kroll et al. 1984). Lilieholm and Reeves (1991) used E-V to model the efficient allocation of agroforestry within the whole farm and used simulation to show that adopting agroforestry can be optimal for certain levels of risk aversion.

Frey (2009) applied E-V to examine the tradeoffs between returns and risk in the Lower Mississippi Alluvial Valley and the potential for reducing risk by adopting agroforestry systems. He found that diversifying annual row crop production with cottonwood, pecan, and silvopasture can reduce whole-farm risk substantially, particularly on marginal land. The farmers, however, face a tradeoff between reducing variation of returns (with agroforestry) or maximizing the expected value of the returns (annual cropping). Additional research is needed to determine when, where, and why farmers would be willing to choose agroforestry in these circumstances. We could find no other temperate zone E-V analyses of agroforestry. Analyses for tropical agroforestry include Ramirez and Sosa (2000) and Babu and Rajasekaran (1991).

Stochastic Dominance

Because of less restrictive assumptions, stochastic dominance (SD) can be used when E-V is inappropriate (Hadar and Russell 1969). Results are less deterministic than E-V but typically provide only a partial ranking of efficient and inefficient alternatives. Therefore, SD is commonly used to estimate a partial ordering based on partial information for initial screenings of alternatives (Hildebrandt and Knoke 2011). No examples of studies assessing temperate zone agroforestry with SD were found; however, Castro et al. (2013) and Benítez et al. (2006) applied SD to analyze the uncertainties associated with using conservation payments to preserve shade coffee in Ecuador.

Real Options

Management flexibility varies widely between land-use alternatives, and the ability to change or postpone actions can be crucial to the decision to adopt one system rather than another. One approach for incorporating uncertain future conditions is to apply real options (RO) techniques to estimate the value of flexibility for the alternatives. The key difference between RO and capital budgeting is the recursive nature of the RO decisionmaking process; i.e., RO provides an estimate of the value of being able to delay current-year decisions until future conditions are known (e.g., timber harvest and reforestation decisions).

Frey et al. (2013) used RO to analyze how the variability of returns and the flexibility to change or postpone decisions (option value) affect the returns to forestry and agroforestry systems, the adoption potential, and disadoption risk of agroforestry and production forestry in the Lower Mississippi Alluvial Valley. Due to the higher opportunity costs associated with converting from forests to agriculture, the option value provided by agriculture outweighed the forestry and agroforestry systems. The adoption potential of forestry and agroforestry was reduced when landowners took into account the flexibility provided by annual cropping systems as compared with tree-based systems, suggesting that simple cashflow analyses may overstate the adoptability of agroforestry in some cases.

Table 4.3. Incorporating risk and uncertainty.

Methods	Definition	Examples
Mean-variance analysis	Mathematical analysis of effects of risk and expected returns to a portfolio of investments to identify the set of "efficient" alternatives that either minimize risk for any given level of returns or maximize returns for any given level of risk.	Frey (2009) Lilieholm and Reeves (1991) Ramirez and Sosa (2000) Babu and Rajasekaran (1991)
Stochastic dominance	Method for comparing different distributions of outcomes among alternatives.	Castro et al. (2013) Benítez et al. (2006)
Real options	Method that takes into account strategic management options of alternatives and the flexibility to exercise or abandon the options at different points in time.	Frey et al. (2013) Behan et al. (2006) Isik and Yang (2004) Wolbert-Haverkamp and Musshoff (2014)

Using RO models, Behan et al. (2006) also found that Irish farmers would wait longer to reforest/afforest than suggested by standard discounted cashflow analyses because of high establishment costs and the relative irreversibility of switching to forestry. Isik and Yang (2004) applied RO to examine participation in the Conservation Reserve Enhancement Program in Illinois. Although option values, land attributes, and farmer characteristics significantly influenced participation, uncertainties in crop prices and program payments and irreversibility associated with fixed-contract periods were also crucial. Wolbert-Haverkamp and Musshoff (2014) applied RO analysis to examine farmers' options to integrate short rotation woody crops into traditional agricultural cropping systems in Germany. They found that the conversion triggers calculated with RO analysis are higher than predicted with classical investment theory and that risk-averse farmers would be expected to convert earlier from rye production to short rotation woody crops than risk-neutral farmers.

Summary and Conclusions

Research suggests that agroforestry systems may help mitigate climate change through carbon sequestration, rehabilitation of degraded lands, and stabilization of ecosystems by increasing resilience to climate change impacts through soil and water conservation, nutrient recycling, food security, biodiversity, and climate regulation (Lasco et al. 2014). The impact of agroforestry, however, will be limited by the extent of its adoption across the landscape, which currently remains quite low in the United States. This chapter examines the available economics literature on the value of agroforestry from both a landowner (net revenues) and a societal perspective (value of externalities). Although the literature is very thin, most of the economic studies of agroforestry in the United States that we were able to locate suggest that financial returns to adopting agroforestry are rarely competitive with modern annual agriculture unless incentives or payments for carbon sequestration and other ecosystem services are included. From a societal perspective, a few studies have applied nonmarket valuation techniques to value ecosystem services associated with agroforestry and have found significant willingness to pay by U.S. residents for the external ecosystem services produced by agroforestry. The available literature, however, is too small to make definitive statements concerning the economics and adoptability of agroforestry in the face of climate change.

Key Findings

- Under current policy and economic conditions in the United States, agroforestry has the most promise for soils that are marginal for annual monocultures. It is unlikely to compete financially with modern monocultures on highly productive lands.
- The role of risk and uncertainty appears to be more important for adopting agroforestry than for annual cropping innovations, given the longer planning horizons required for implementing and managing agroforestry. Studies used to assess risk suggest that diversified systems like agroforestry may reduce whole-farm risk but at a cost of lowering total expected returns to the farm.
- An increasing number of studies are employing nonmarket value evaluation methods to measure the value of biodiversity, water quality, recreation, and other ecosystem services from agroforestry systems. Studies indicate that, when incentives or payments for ecosystem services are included, agroforestry can be competitive with conventional cropping and livestock systems.

Key Information Needs

- The literature on the economics of agroforestry in temperate zones and, particularly, in the United States is very limited. Additional information is needed on financial and economic valuation, risk analysis, and how they influence adoptability of agroforestry in the United States.
- More nonmarket valuation studies of ecosystem services produced by agroforestry are needed, especially for those services benefitting society (biodiversity, water quality).
- More studies are needed to compare the ecosystem service benefits of agroforestry ecosystems with modern annual agriculture, plantation forestry, or forested ecosystems.
- Research is needed to quantify and understand future adoptability of agroforestry under a changing climate.

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