ABSTRACT

FREY, GREGORY ERIC. Economic Analyses of Agroforestry Systems on Private Lands in Argentina and the USA. (Under the direction of Dr. Frederick W. Cubbage.)

Agroforestry in sub-tropical and temperate regions of the world has often been advocated as an environmentally-friendly class of land-use systems. However, private landowners are unlikely to adopt them to a great extent if they do not provide economic benefits. This dissertation analyzes agroforestry systems in two extra-tropical regions to see if they are a potentially beneficial use of land for private landowners. The first main section of this dissertation contains *ex-post* analyses of a single specific agroforestry system, silvopasture, in northeastern Argentina. The second main section contains *ex-ante* analyses of several agroforestry and forestry systems in the Lower Mississippi Alluvial Valley, USA. Both sections investigate the private costs and benefits of agroforestry systems compared to conventional systems such as agriculture and forestry.

The first chapter of the first section considers farmers' subjective perceptions of the advantages and disadvantages of silvopasture systems in Argentina. Ordinal probit statistical models are used to determine the factors that explain their perceptions, and a binary logit model is used to determine how those perceptions might affect disadoption of the system. Most adopters have a positive view of the system and indicate that they will likely continue in the future. Small and medium farmers tend to have a more positive view of the cash flow and risk characteristics of silvopasture, while annual crop farmers have a more negative view of cash flow and less educated farmers have a more negative view of its risk. While we do not gain a good understanding of the factors that influence farmers'

perceptions of costs and returns of silvopasture, those two perceptions were the most important factors in determining the likelihood of continuance.

The second chapter investigates whether silvopasture is a more efficient use of resources for farmers than conventional systems such as pasture and plantation forestry in Argentina. A non-parametric technique based on linear programming called data envelopment analysis is used to estimate the relative technical efficiencies of the different systems. Then, non-parametric statistics are used to compare the systems within farms. Silvopasture is found to be a more efficient use of resources than conventional cattle ranching, but results were inconclusive with regards to conventional forestry.

The first chapter of the second section compares the profitability and feasibility numerous agroforestry and production forestry systems to agriculture in the Lower Mississippi Alluvial Valley. The feasibility of these systems for the future is assessed. A panel of experts helps define the most appropriate systems and delineate market conditions in the LMAV. A deterministic model of profits is used to identify the most profitable systems and expert opinion is used to assess other factors not directly tied to profitability. Some agroforestry and production forestry systems are shown to have potential for adoption on the most marginal land, but cannot compete with agriculture on average land unless incentives are paid to landowners.

The final chapter uses stochastic models to compare those same systems in the LMAV. These stochastic models use measures of the variability of returns to different systems to understand how farmers' decisions may be affected. A mean-variance model is employed to understand whether risk aversion might drive farmers to diversify their farms

to produce agroforestry outputs. A real options model utilizes measures of variability and the costs of switching between agriculture and forestry or agroforestry to estimate how farmers might value flexibility. It is found that diversification into forestry or agroforestry may help reduce the risk inherent in agriculture. However, the real options analysis shows that farmers are unlikely to adopt either forestry or agroforestry systems on anything but the most marginal land.

Economic Analyses of Agroforestry Systems on Private Lands in Argentina and the USA

by
Gregory Eric Frey

A dissertation submitted to the Graduate Faculty of
North Carolina State University
In partial fulfillment of the
Requirements for the degree of
Doctor of Philosophy

Forestry

Raleigh, North Carolina

2009

APPROVED BY:

Frederick W. Cubbage
Committee Chair

D. Evan Mercer

Robert C. Abt

Ben A. Bergmann

Mitchell A. Renkow
Minor Representative

DEDICATION

To Zulema,

You have my whole heart and appreciation for the love and support you have given me;

And to Erin Alicia,

May you grow in strength and wisdom, but most of all, in love.

I Corinthians 13: 1-13; 16: 13-14

BIOGRAPHY

Gregory E. Frey was born in Winston-Salem, NC on 11 October 1978. As a youth, Gregory was particularly interested in community service and the environment. He was active in the Boy Scouts of America and the Order of the Arrow, a Boy Scout affiliated honor organization, where he achieved the rank of Eagle Scout and was awarded the Vigil Honor. Gregory spent most summer days through his high school and college years at Raven Knob Scout Reservation, in the foothills of the North Carolina Blue Ridge Mountains, where he taught younger scouts about ecology, forestry, conservation and geology.

Although his undergraduate studies at Wake Forest University led him to the fields of chemistry and mathematics, Gregory never lost his passion for the environment or service to the needy. Upon graduation from Wake Forest in 2000, he entered the United States Peace Corps as an Environmental Education Volunteer. He was sent to Paraguay, where he taught children and trained teachers about environmental concepts in a rural community. However, some of his most meaningful relationships and fulfilling projects were with small farmers, who demonstrated a connection with the land and a sense of responsibility to future generations. Gregory extended his service in the Peace Corps for one additional year beyond the typical two-year term to serve as the Environment Sector Volunteer Coordinator, based in the capital of Asunción.

In Paraguay, Gregory met Zulema Zalazar, an English teacher and native of Asunción. After a two-year courtship, they married on 1 November 2003. In 2004, Gregory and Zulema moved to North Carolina where he could pursue an advanced degree related to environmental conservation and poverty reduction and she could pursue a degree in education. They happily decided to attend North Carolina State University.

Gregory and Zulema are currently living in Fairfax County, Virginia, where Gregory works as a Forest Carbon Specialist for the World Bank, helping countries in Latin America design programs to reduce carbon emissions from deforestation and degradation. Their daughter, Erin Alicia, was born 10 February 2009.

ACKNOWLEDGMENTS

First, I would like to thank the members of my PhD Advisory Committee, Fred Cubbage, Bob Abt, Evan Mercer, Mitch Renkow and Ben Bergmann. They have all provided immensely helpful support and feedback for this dissertation, other academic work, and life in general. The helped keep me on track and kept me and my research funded. In particular, I feel that Fred Cubbage has been the most supportive, positive and flexible advisor any student could ask for.

In Argentina, I was aided immensely by colleagues at the *Instituto Nacional de Tecnología Agropecuaria*, the Argentine agricultural and forestry research and extension service. In particular, Hugo Fassola, Luis Colcombet and Nahuel Pachas at EEA Montecarlo immediately befriended me and provided constant help in terms of thoughtful commentary, data and logistical support. In addition, Alejandra Carvallo at Bernardo de Irigoyen, Santiago Lacorte and Clory Peruca at CM Misiones, Roque Toloza and Miguel Correa at Puerto Rico, Jose Luis Horiet at Cerro Azul, Horacio Babi at San Javier, Valentín Kurtz at Eldorado, and numerous others provided support. I have yet to find an institution in any country with such helpful, knowledgeable and friendly staff.

Oscar Pérez, a student at the *Facultad de Ciencias Forestales* of the *Universidad Nacional de Misiones* in Eldorado was instrumental in providing logistical support for the surveys.

Most importantly in Argentina, I would like to thank the Argentine farmers who allowed me to enter their homes and spent hours answering tedious questions about farm management. They were friendly and courteous.

In the USA, the USDA National Agroforestry Center (NAC) funded the research. Michael Dosskey and Michele Schoeneberger made the grant possible.

Very heartfelt thanks are due to the panelists who participated in the Delphi panels. They suffered through hours of in-depth questions and provided insightful responses and feedback. In addition, several NC State faculty and graduate students pre-tested the Delphi assessments.

Robert Dubman at the USDA Economic Research Service and Tony Dorn at the Raleigh office of the National Agricultural Statistics Service facilitated my use of the USDA ARMS dataset.

Most of all, I thank my wife, Zulema. She has been with me through the joys and suffering of being a student, and has been my constant emotional support and guide.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I INTRODUCTION

Defining the term agroforestry is no easy matter. Although the word "agroforestry" dates back only to the 1960s, many agroforestry practices have been utilized for centuries or millennia (King 1987). From its roots, we know that agroforestry has something to do with agriculture and forestry. But what makes agroforestry a unique field?

In the inaugural issue of the journal Agroforestry Systems, the editorial board asked key agroforestry experts to give their definitions of "agroforestry" (Editors 1982). There is a wide range of concepts used to try to explain what agroforestry really is. Also, very many national and international organizations related to agroforestry, such as the World Agroforestry Centre (ICRAF 2007), the Association for Temperate Agroforestry (AFTA 2007) and the USDA National Agroforestry Center (NAC 2007), have each provided their own definitions to try to elucidate the concept.

At the mention of the word agroforestry, many, including some of the most experienced experts, automatically think of the tropics. Indeed, agroforestry lends itself well to use in tropical countries and cultures, which traditionally manage small parcels intensively, with manual labor and animal traction. However, agroforestry may also be a potentially efficient use of land in extra-tropical (sub-tropical and temperate) regions of the world. This dissertation analyzes some agroforestry systems in two extra-tropical regions to see if this is the case.

While there is no single definition of agroforestry, in extra-tropical regions agroforestry includes, but is not limited to, the following classes of production systems and their variants (AFTA 2007; NAC 2007):

- Alley Cropping: The cultivation of annual crops between rows of trees.
- Forest Farming: The cultivation of specialty crops in the understory of natural or planted forests.
- Riparian Forest Buffers: The cultivation of trees and other vegetation planted in strips between agricultural lands and waterways to protect water quality.
- Silvopasture: The intensively-managed, integrated combination of trees, livestock and forage.
- Windbreaks: The cultivation of trees planted in rows on farms to help reduce the velocity of wind.

This main body of this dissertation is divided into two sections, each of which contains two chapters. While the two chapters in each section build upon each other, each chapter is written to stand alone, in the general style of a scholarly publication.

The two larger sections are also designed independently, but do complement each other in a general sense. Section II contains *ex-post* analyses of a specific agroforestry system (silvopasture) in the northeastern provinces of Misiones and northern Corrientes, Argentina. Section III contains *ex-ante* analyses of several agroforestry and alternative forestry systems in the Lower Mississippi Alluvial Valley, USA. Both sections investigate the private costs and benefits of agroforestry systems compared to conventional systems.

Chapter II.A considers the way farmers perceive the advantages and disadvantages of silvopasture systems in Argentina. Statistical models are used to determine the factors that explain their perceptions, the way those perceptions change with experience of the system, and how those perceptions might affect disadoption.

Chapter II.B investigates whether silvopasture is a more efficient use of resources for farmers than conventional systems such as pasture and plantation forestry in Argentina. A non-parametric technique based on linear programming called data envelopment analysis is used to estimate the relative efficiencies of the different systems. Then, non-parametric statistics are used to compare the systems within farms.

Chapter III.A compares the profitability and feasibility numerous agroforestry and production forestry systems to agriculture in the Lower Mississippi Alluvial Valley (LMAV). While none of the systems are widely adopted, the goal of this chapter is to assess feasibility of these systems for potential in the future. A panel of experts was consulted to help define the most appropriate systems and delineate market conditions in the LMAV. A deterministic model of profits, based on net present value, is used to identify the most profitable systems and expert opinion is used to assess other factors not directly tied to profitability.

Chapter III.B uses stochastic models to compare those same systems in the LMAV. These stochastic models use measures of the variability of returns to different systems to understand how farmers' decision may be affected by these factors. A mean-variance model is employed to test whether risk aversion might drive farmers to diversify their farms to produce outputs that are consistent with agroforestry systems. A real options model utilizes measures of variability and the costs of switching between agriculture and forestry or agroforestry to estimate how farmers might value flexibility.

The theme of all four chapters is to compare agroforestry systems to other, more conventional systems such as agriculture or forestry, to determine whether they are beneficial uses of private land for small farmers.

LITERATURE CITED

AFTA. 2007. Association for Temperate Agroforestry. Available from http://www.aftaweb.org/ (accessed March 2007).

Editors. 1982. What is agroforestry? Agrofor.Syst. 1(1):7-12.

ICRAF. 2007. World Agroforestry Centre. Available from http://www.worldagroforestrycentre.org/ (accessed March 2007).

King, K. F. S. 1987. The history of agroforestry. Pages 3 in H. A. Steppler and P. K. R. Nair, editors. Agroforestry: a decade of development. International Council for Research in Agroforestry (ICRAF), Nairobi.

NAC. 2007. USDA National Agroforestry Center. . Available from http://www.unl.edu/nac/ 2007).

II SILVOPASTURE SYSTEMS IN NORTHEASTERN ARGENTINA

Chapters II.A and II.B deal with silvopasture system perceptions and management in the northeastern provinces of Misiones and northern Corrientes, Argentina. The study region is marked in Figure II. 1. It is a subtropical, humid region.

Figure II. 1. Study region for Section II: Misiones and northern Corrientes, Argentina.

Silvopasture systems in this region commonly include pine species (*Pinus taeda*, *P. elliottii* or the hybrid *P. caribaea* x *elliottii*), eucalypts (*Eucalyptus* spp.), or the native araucaria (*Araucaria angustifolia*). Forage species typically are grasses including natives (*Axonopus compressus*, *Hypoginium vigatum*) and exotics (*A. catarinensis, Brachiaria* spp., *Cynodon* spp., *Pennisetum purpureum*). Livestock is almost exclusively cattle, primarily the breed of Hereford, Braford and Zebu, as well as mixed breeds. A fairly typical system of *Pinus caribaea* x *elliottii*, *Brachiaria brizantha* and cattle is shown in Figure II. 2.

Figure II. 2. A typical silvopasture system in Misiones/Corrientes.

Pinus caribaea x elliottii, Brachiaria brizantha and cattle.

A semi-structured farm survey of silvopasture adopters was conducted in the Misiones and northern Corrientes provinces of northeastern Argentina during June and July of 2006 and June of 2008. All questions were reviewed with a focus group of extension agents and research scientists of the *Instituto Nacional de Tecnología Agropecuaria* (INTA) from the region. After the focus group, the survey interview was practiced with producers of varying scales to test for understanding and accuracy.

Due to the diffuse physical location of adopters, and because no complete list of adopters is available, a random sample was impossible. A stratified, purposive sample of adopters was selected throughout the region (Figure II. 3). Adopters were chosen in order to represent diverse farm scales in various sub-regions throughout the larger study region. These were identified by researchers and extension agents with INTA in each sub-region. We visited the relevant communities where the producers lived, and interviewed them on the farms. Most of the individuals identified by INTA for possible interviews did accept, but in a few cases other farmers in the community were selected as alternates.

In total, 47 silvopasture practitioners of varying scales were interviewed, producing 44 usable responses. Farm size (including all properties of the same owner in relatively close proximity) ranged from 15 to 14,000 hectares with a mean of 1,253 ha and a median of 233 ha. Surveyed farmers were classified into three groups using natural clusters: small-scale (15-50 hectares), medium-scale (75-800 ha) and large-scale (>1100 ha). There were 16 small-, 16 medium- and 12 large-scale farmers in the sample (Figure II. 3).

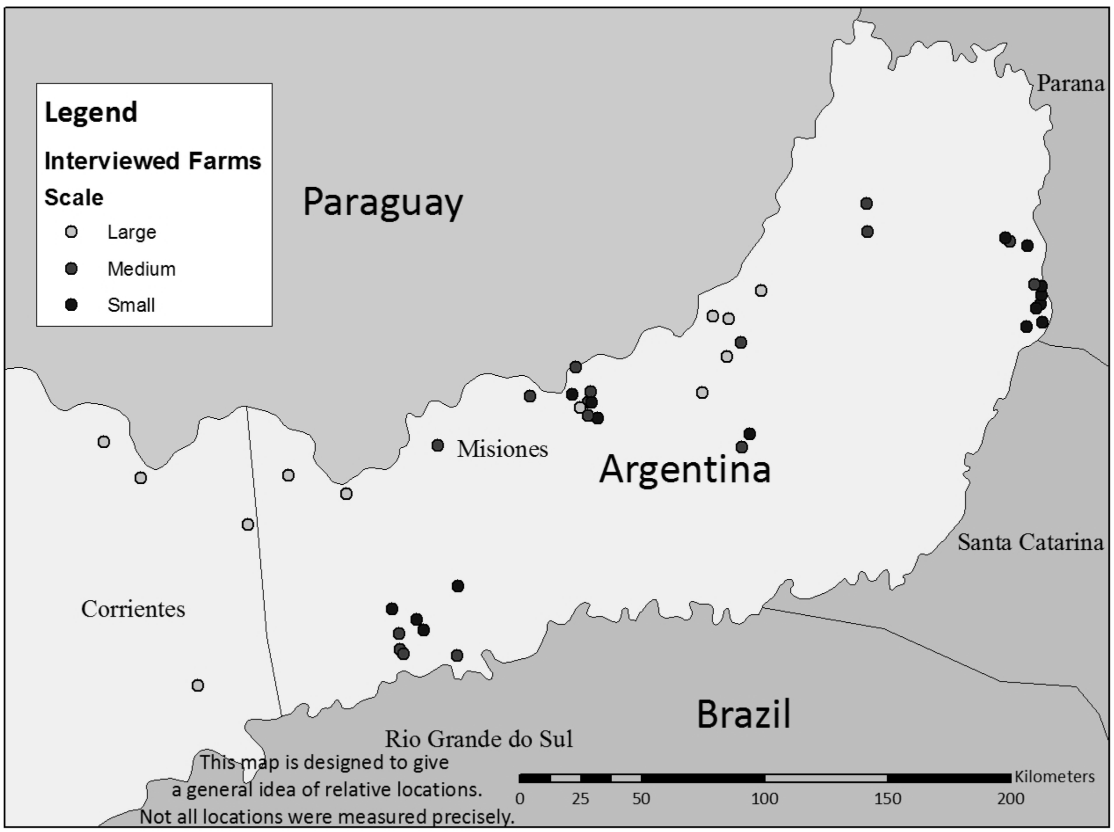

Figure II. 3. Interviewed farms in Misiones/Corrientes.

II.A Changing Perceptions of Silvopasture Systems among Adopters in Northeast Argentina

Gregory E. Frey[1], Hugo E. Fassola[2], A. Nahuel Pachas[2], Luis Colcombet[2], Santiago M. Lacorte[3], Frederick W. Cubbage[1] and Oscar Pérez[4]

[1] Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC, USA
[2] Instituto Nacional de Tecnología Agropecuaria, EEA Montecarlo, Argentina
[3] Instituto Nacional de Tecnología Agropecuaria, CR Misiones, Posadas, Argentina
[4] Universidad Nacional de Misiones, Facultad de Ciencias Forestales, Eldorado, Argentina

II.A.1 INTRODUCTION

In many parts of the world, agroforestry adoption has proceeded slowly despite apparent benefits. This has prompted significant research focusing on the factors that affect adoption (Pattanayak et al. 2003). Studies have shown that, in addition to market, biological and demographic factors, farmers' subjective perceptions of technologies play a key role in agricultural technology adoption (Rogers 1962; Fliegel & Kivlin 1966; Adesina & Baiduforson 1995; Ajayi 2007; Khan et al. 2008). Adopters' perceptions can, in turn, be influenced by their experiences and social networks with other people (Kearns 1992; German et al. 2006). These might include other farmers in cooperatives, neighbors, extension agents and others.

Previous studies of farmers' views of agroforestry systems have focused almost exclusively on the question of whether farmers adopt a technology or do not adopt, and viewed from a single point in time. However, as Kiptot et al. (2007) point out, a classification system of only adopters vs. non-adopters is an oversimplification of the temporal processes that are involved with the way farmers understand and use new technologies. Discontinuance or disadoption is a very real possibility for systems that do not meet expectations (Parthasarathy & Bhattacherjee 1998; German et al. 2006; Kiptot et al. 2007). Also, many farmers will test a technology on their fields or wait to see results from neighbors' fields before deciding fully to adopt. The "testing period" for some technologies may be relatively short (Spiller et al. 2007), but for technologies with long, discrete waiting periods for full benefits to be achieved, such as is the case with systems that include a tree component grown for timber, testing periods are likely to be longer, perhaps as long as the timber rotation period. We should be aware that use of agroforestry technology, even for a number of years, does not necessarily mean that the technology will be continued in the future.

Furthermore, adopters' perceptions of the technologies they use can and will change over time as they learn more about the benefits and challenges a technology creates (Bhattacherjee 2001). This may be one of the key driving forces behind discontinuance, and has not received a consistent treatment in the agroforestry diffusion literature. However, evidence from information technology adoption literature suggests that initial perceptions (at the time of adoption) can be strong predictors of future discontinuers (Parthasarathy & Bhattacherjee 1998). Also, whether or not an adopter uses social networks to make the adoption decision or makes the decision primarily on his/her own can help predict discontinuance, with those who make the decision internally being more likely to continue than those who make decisions via social networks (Parthasarathy & Bhattacherjee 1998). These hypotheses have not been tested with agroforestry continuance/discontinuance.

Other factors may influence farmers' perceptions of the agroforestry technology. Pérez (2006) found that while large, medium and small-scale farmers in Honduras manage silvopasture systems in similar ways, their total net revenues and net revenues from forestry versus livestock were quite different. We should be aware of the different roles agroforestry systems play for distinct types of farms.

The primary objective of this study is to investigate the factors that affect farmers' perceptions of an agroforestry technology, specifically silvopasture systems in northeastern Argentina, at the time of adoption, and how their perceptions of the technology may change over the course of time. We test explanatory variables such as the farm scale, the farm type (what kinds of products it was generally producing before adopting silvopasture), and the types of people the farmers stated were important in helping them make the decision to adopt, such as extension agents and other farmers. In addition to farm scale and farm type, we hypothesize that these "influential" people had an impact on the expectations of farmers towards the system to be adopted. In particular, farmers who were influenced in their decision to a large extent by extension agents might reflect the opinions of those same agents. As opposed to much of the previous work on perceptions of agricultural technology, we do not compare the perceptions of adopters vs. non-adopters, but rather that of different groups of adopters at different points in time. We hope to contribute towards a future framework to understand how changing perceptions affect continuance vs. discontinuance among different types of adopters.

A second objective of our study is to estimate a model for predicting which adopters might discontinue use of the system. While discontinuance has been studied in fields such as information technology adoption, it has largely been ignored in agroforestry adoption literature, with a few notable exceptions (Keil et al. 2005; Kiptot et al. 2007). Part of the reason that discontinuance is not fully investigated in agroforestry is that, if the trees in the system are eventually to be utilized for timber or some other long-term investment, farmers are unlikely to discontinue use of a system in the middle of a rotation since they have invested many resources in the production of an output that is relatively highly valued at harvest. Research in agroforestry systems in many cases has not reached the length of time necessary to complete a timber rotation, and in general institutional research programs do not last for such a long period of time. Our study uses farmers' stated likelihood of future continuance or discontinuance of the system as a proxy for what they will actually do once they are able to harvest the timber.

Finally, we hope to extend knowledge about the benefits and costs of silvopasture systems in particular. While a few studies have revealed the ways farmers perceive silvopasture, adoption in many countries has only been moderate, creating a need for a greater understanding of how farmers perceive the system and how those perceptions change over time. We discuss the literature about farmers' views and opinions of silvopasture in the Americas below.

II.A.1.1 *Perceptions of Silvopasture*

A study by Shrestha et al. (2004) in Florida, USA found that silvopasture systems had the strengths and opportunities of providing a strong sense of stewardship and satisfaction to adopters, aiding in environmental protection and helping to diversify income. On the other hand, characteristics such as fire hazard, uncertainty about government regulations and the length of the silvopasture investment were the major weaknesses of and threats to silvopasture (Shrestha et al. 2004). While the method used by Shrestha et al. (2004) of interviewing opinion leaders is beneficial for obtaining a quick assessment of system potential, they note that surveying a larger sample is desirable to gather a more representative view of heterogeneous opinions among adopters or potential adopters.

Pérez (2006) noted the benefits and limitations that silvopasture adopters in Copán, Honduras perceived, using a sample of 29 adopters. The economic and ecological benefits of silvopasture were perceived as being approximately equally important, and there was no significant difference in the perceptions of the benefits of silvopasture for small, medium and large-scale farmers. In terms of the limitations of silvopasture systems, the lack of the ability to obtain seedlings or cuttings cheaply for tree planting was important, especially for small and medium-scale farmers. Several silvopasture adopters also lamented the lack of support from agricultural institutions, the amount of labor involved in managing silvopasture, and tree mortality.

Calle (2008) conducted surveys of 28 farmers involved with silvopasture programs in Quindío, Colombia to investigate farmers' motivations for adoption and benefits they presently perceive in silvopasture systems, and the changes in attitudes they underwent after practicing silvopasture systems. Calle (2008) noted that the principal benefits perceived by silvopasture adopters are both private benefits such as reduced used of inputs such as fertilizer and improved conditions for cattle such as more plentiful food, and public environmental benefits such as increased wildlife biodiversity. The main barriers to silvopasture adoption noted by the adopters were the high cost of establishment and the lack of information and knowledge about the system. Calle (2008) also observed the changes in farmers' attitudes over time with participation in silvopasture extension programs. The study showed that farmers because more accepting of the fact that trees and pasture can coexist in a single plot. More notably, however, is the way that farmers reported gaining a greater understanding of biological/ecological processes, the importance of the environment in general and sustainable practices.

Given the previous studies on perceptions of silvopasture systems in various parts of the world, it is reasonable to ask whether or not there is anything to gain, in a general sense, from one more study of perceptions of silvopasture. We believe that there is, even aside from the aforementioned necessities of understanding the factors that affect perceptions, how they change over time, and the factors, including perceptions, which can affect discontinuance of the technology. We feel that other regions of the world where silvopasture has been promoted can learn from the Argentine experience, by understanding the way Argentine farmers perceive the technology. Argentina is one of the few places in the world where silvopasture using planted trees is at least moderately adopted by numerous different scales types of farms, from small, annual-cropping, semi-subsistence farms all the way to large, corporate forestry firms and cattle ranches. Pérez (2006) noted some differences between "small" and "large" scale farms in Honduras, but the variability in size is quite small compared to Argentina. Shrestha et al. (2004) interviewed a small and large scale farmer in Florida, but adoption in that region is relatively low.

Within Argentina, there are potential benefits of this study. Extension to new potential adopters can be aided by understanding the way more experienced farmers view the technology. There are several possible barriers to adoption of silvopasture systems, such as the high front-end investment requirement in capital and labor (Dagang & Nair 2003; Pagiola et al. 2004). If we are to expect good adoption of agroforestry systems, we should properly understand the motivations and expectations of the farmers who may be adopting them (Dagang & Nair 2003).

II.A.2 MATERIALS AND METHODS

II.A.2.1 *Description of the Study Area*

Misiones and northern Corrientes have experienced moderate adoption of silvopasture systems in recent years among farms of all scales. While some adoption did take place in Misiones and Corrientes in the 1970s, silvopasture became more widely investigated by researchers and farm and forestland administrators in the 1980s. Research has improved management of the forage, livestock and timber components, and has improved the viability of the practice (Fassola et al. 2004b). Silvopasture implementation had reached an extent of over 20,000 hectares by 2008.

This region of Argentina is a humid, subtropical zone. Annual precipitation ranges from 1600-1900mm, with no pronounced dry season. Average temperature is approximately 15 C in July and 27 C in January.

Fassola et al. (2004a) found that silvopasture in Misiones and Corrientes has the potential to allow producers to diversify products, improve quality of products, reduce management costs, and other benefits. Indeed, cost-benefit analyses of silvopasture in Argentina demonstrate that silvopasture could be quite productive economically, in comparison with traditional agricultural systems (Esquivel et al. 2004; Fassola et al. 2004a).

A diversity of farm types exists in Misiones and Corrientes. Northern Corrientes and southwestern Misiones are relatively flat prairie-land, which has been traditionally used for extensive cattle grazing and is now operated by large *estancias*. Central and northern

Misiones consists of the Upper Paraná Atlantic Forest eco-region (locally known as the *Selva Paranaense* or *Selva Misionera*), an inland extension of the Atlantic Forests of the coasts of Brazil. This is a dense, humid forest zone, which was only settled to a large extent in Argentina starting in the 1920s, with some of the more remote areas still relatively undisturbed. This area is utilized by small and medium scale semi-subsistence and cash cropping farmers of either perennials such as tea (*Camellia sinensis*) and yerba mate (*Ilex paraguariensis*), or annuals such as tobacco (*Nicotiana spp.*), and, since the 1970s, has been increasingly occupied by of forest-product firms, who primarily plant exotic pine species (*Pinus spp.*) for timber.

Pagiola et al. (2004) posited that a relatively small payment at the time of establishment to offset some of the cost of investment would be enough to convince farmers in tropical America to adopt silvopasture for the long-term. In order to encourage the forest-product industry in Misiones, the national government of Argentina authorized cost-share programs in 1992 and again in 2000 to offset a portion of the costs of site preparation and plantation. This program aided silvopasture adoption among cattle ranchers, and annual and perennial cash croppers, and functioned fairly well until the Argentine financial crisis of 2001, when the government defaulted on debt. Many of those who adopted after the financial crisis, and forest plantation firms, who would have been receiving forestry incentive payments regardless of silvopasture adoption, adopted silvopasture with little outside help.

Apart from the national cost-share program, several smaller silvopasture programs have been started through extension programs in several municipalities. These smaller special extension programs include in-kind provision of capital inputs such as tree seedlings, pasture seed or transplants, and fencing materials. Many small-scale farmers in various regions within the province of Misiones have begun to adopt the practice following the extension/support programs.

II.A.2.2 *Farm Survey*

A semi-structured farm survey of silvopasture adopters was conducted in the Misiones and northern Corrientes provinces of northeastern Argentina during June and July of 2006 and June of 2008. The surveys were approved by the NC State University Institutional Review Board for research with human subjects. All questions were reviewed with a focus group of extension agents and research scientists of the *Instituto Nacional de Tecnología Agropecuaria* (INTA) from the region. After the focus group, the survey interview was practiced with producers of varying scales to test for understanding and accuracy.

Due to the diffuse physical location of adopters, and because no complete list of adopters is available, a random sample was impossible. A stratified, purposive sample of adopters was selected throughout the region. Adopters were chosen in order to represent diverse farm scales in various sub-regions throughout the larger study region. These were identified by researchers and extension agents with INTA in each sub-region. We visited the relevant communities where the producers lived, and interviewed them on the farms. Most of the individuals identified by INTA for possible interviews did accept, but in a few cases other farmers in the community were selected as alternates.

In total, 47 silvopasture practitioners of varying scales were interviewed, producing 44 usable responses. Farm size (including all properties of the same owner in relatively close proximity) ranged from 15 to 14,000 hectares with a mean of 1,253 ha and a median of 233 ha. Surveyed farmers were classified into three groups using natural clusters: small-scale (15-50 hectares), medium-scale (75-800 ha) and large-scale (>1100 ha). There were 16 small-, 16 medium- and 12 large-scale farmers in the sample.

Farms were also classified into "farm types" according to their principal alternative production system (either what the majority of their land was at the time of the interview, or before beginning silvopasture, in the case that the farm currently practices mostly silvopasture). Farms were classified into four types: forest plantation farms, cattle farms, perennial cash crop farms (principally yerba mate and tea) and annual cash crop farms (principally tobacco and staples such as maize and cassava).

Among other questions, farmers were asked about the advantages and disadvantages that they perceived in the silvopasture system at two points in time, at the time of the adoption decision and at the present (i.e. at the time of the survey, after several years of system implementation). Farmers were asked about their perceived advantages and disadvantages of the system at the time of adoption after being asked several questions about the year of first adoption, in order to put them in the frame of mind to remember their past perceptions.

The farmers were asked about people who influenced them in their decision to adopt agroforestry. After a series of questions eliciting responses about the actual management of a selected silvopasture parcel from establishment to the present, the survey contained questions about their perceived advantages and disadvantages of silvopasture systems at the present time.

Each of the previous questions was open-ended, and farmers were permitted to give as many responses as they felt appropriate. This was to allow farmers to fully express themselves and not bias their responses with the expectations or opinions of the researchers. For this reason, percentages do not add up to 100%. After conducting the survey, similar responses were pooled.

In addition, farmers were asked whether they are likely to continue or discontinue practicing silvopasture systems given the current prices and incentive policies, and if they would continue the practice if all cost-share and in-kind support programs were terminated.

II.A.2.3 *Classification of Perceptions and Influential People*

Farmers' responses to open-ended questions about their views of the positives and negatives of silvopasture systems generally refer to specific attributes of the technology. This is important for comparison with other silvopasture studies, which also generally refer to specific attributes. However, in many cases, two farmers might cite two distinct specific attributes that are appreciated by the farmers for the same underlying reason. For instance one farmer may say that there is a greater quantity of pasture is available and another that shade reduces heat stress on cattle in silvopasture system. In the end, both of these specific benefits are appreciated because they increase revenues from the sale of beef. Therefore, we used a system to classify responses into categories by the underlying motivations for which they are seen as positive or negative.

Farmers' responses for the positives and negatives they perceived at the two points in time (at time of adoption and at the time of the survey) were classified into six categories, using a classification similar to those pioneered by Rogers (1962), and which are commonly used in technology characterization and perception literature (Fliegel & Kivlin 1966; Parthasarathy & Bhattacherjee 1998). We use a classification drawn from Fliegel and Kivlin (1966), with some modifications. The adapted classification system is as follows:

Costs – Perceptions about whether the technology has a relatively high (disadvantage) or relative low (advantage) level of costs. This includes both start-up costs and continuing costs.

Returns – Perceptions about whether the technology is more (advantage) or less (disadvantage) profitable relative to alternatives.

Flow – Perceptions about whether the way in which revenues flow to the investor over time is good or bad. Farmers may believe that either long- or short-term returns, or a mix of both, are preferable. Cash flow is an important aspect of agroforestry systems, because forestry offers a long term "bank account" but few options for annual income, and agriculture offers annual income but few opportunities for long-term investment, while agroforestry offers some of both (Ajayi 2007). In the Fliegel & Kivlin (1966) classification, cash flow is lumped into the "returns" category, but in reality, for many farmers and foresters, the total returns of a system is quite distinct from the time period over which it is paid.

Risk – Perceptions about whether a technology is more or less risky than alternatives. This might include risk due to variability in yields and prices, or risk due to a lack of information.

Complexity – Perceptions about how difficult the technology is to manage relative to alternatives.

Compatibility – Perceptions about how the system fits into the user's values and beliefs and within the set of other activities and technologies he/she is using.

Recalling that the interview questions were open-ended, allowing farmers to respond to the question of perceived positives and negatives in any way they saw fit, in many cases, farmers cited multiple positives or negatives from the same category. If we assume that each positive or negative that a farmer cites is of approximately equal importance to him or her, then it is possible to generate an index of perceptions. The total number of both positive and negative responses for each category was counted. The total count of responses for positive and negative perceptions in each category was taken to represent that farmer's perception of how advantageous or disadvantageous the technology is for that category of system characteristics (*Costs*, *Returns*, *Flow*, etc.), relative to his/her alternatives.

The count of perceived positive and negative characteristics in each category was used to calculate an index of the relative perceived net benefit of silvopasture for that class of characteristic. This net perception index is equal to the total number of positive responses in a category minus the total number of negative responses. When the number of positive responses greatly outweighs the number of negative responses, this is a proxy for the fact that the farmer perceives that the technology has a net advantage or benefit over other systems. Therefore, we refer to the number of positive minus the number of negative responses as the net perception of silvopasture with regards to a specific category.

Admittedly, the net perception index as described here may not be the ideal measure of a farmer's perceptions, as it is based on the assumption, noted above, that the farmer places approximately equal weight on the importance of each of the different factors he or she mentions. We believe that a farmer who cites three positive aspects of silvopasture returns and one negative aspect (net perception index for returns = 2) is more likely to have a favorable outlook towards the returns characteristics of the system than another farmer who cites zero positive return aspects and one negative (net perception for returns = -1). Therefore, we do not believe that this measure is systematically biased in any way, and it is the best available measure of farmers' perceptions given the limited time available with each respondent to deal with subjective perceptions.

Our method of grouping and counting similar phrases is in principle and practice parallel to the quantitative content analysis method, commonly used in sociological and communication research. Quantitative content analysis involves the coding of key words and phrases in verbal or written communication, and counting these statements to compare how different groups communicate (Berelson 1952). To our knowledge, adding and subtracting positive and negative statements in quite this way has not been undertaken in published research literature, but we believe the principle is similar. Shiferaw & Holden (1998) and Sall et al. (2000) used ordinal scales of perceptions in terms of agricultural technology adoption, although the variables were created in a different manner than we have used them here.

Our index creates an ordinal variable, with increasingly negative integers representing increasingly negative perceptions, and increasingly positive integers representing increasingly positive perceptions. We discuss the use of this variable below.

Farmers' responses about influential people in their adoption decision were classified into three categories: *Professional*, *Farmer* and *None*. "*Professional*" primarily included government agency (INTA) extension agents, but also consultants such as veterinarians and consulting foresters. The "*Farmer*" category included anyone who influenced the adopter as a peer land manager, including neighbors and friends, and other members of a farm cooperative or association. "*None*" indicates a situation in which the farmer may have seen the system practiced, but did not have any in-depth conversations with others about the system before deciding to adopt. The decision was made primarily made after observations, and the farmer did not receive strong opinions from outside sources that influenced his or her decision. Some adopters indicated that both professionals and other farmers helped them make their decision, so the sum of the percentages of *Professional*, *Farmer* and *None* do not add up to 100%.

II.A.2.4 *Hypothesis Testing with Ordinal Perception Variable*

Several hypotheses were tested with regards to the factors explaining perceptions at the time of adoption, the factors explaining changes in perceptions over time, and the perceptions explaining the likelihood of discontinuance.

The first group of hypotheses has to do with the factors that affect farmers' perceptions of silvopasture at the time of adoption. The first hypotheses are that other people who were influential in the adoption decision, whether they were professionals (e.g. extension agents) or other farmers (e.g. neighbors) might explain some of the differences in perception of positives and negatives between adopters. The second group of hypotheses is that a farmers' farm scale might influence the way he/she understands the positives and negatives. The third group of hypotheses is that the type of farm a farmer operates (the type of productive systems he/she typically uses) explains how he/she perceived the positives and negatives of silvopasture.

To test the aforementioned factors explaining farmers' perceptions at the time of adoption, each category of perceptions was regressed on farm scale (dummy variables representing two of the three scales), farm type (dummies representing three of the four farm types) and dummies for the *Professional* and *Farmer* categories of influential people. These hypotheses were tested using an ordinal probit regression in SAS (Bender & Benner 2000), and a log likelihood value was derived for each of these unrestricted models. Then, restricted models were calculated, excluding each set of variables, to test whether that set of variables was significant in helping to explain the variability in perceptions. The null hypothesis (that the set of variables does not help to explain perceptions) was tested using a likelihood ratio statistic:

$$\Lambda = 2 \cdot \left(\ln(L_{ur}) - \ln(L_r) \right),$$

Where Λ is the likelihood ratio statistic, and $\ln(L_{ur})$ and $\ln(L_r)$ are the log-likelihood values of the unrestricted and restricted models, respectively. Λ is distributed as a chi-squared variable with degrees of freedom equal to the number of explanatory variables excluded from the restricted model (Wooldridge 2006).

The net perception variable was modeled with an ordinal probit model, which uses the underlying assumption of a normally-distributed dependent variable. This is because the net perception variable could be negative or positive, with more observations in the middle of the range (usually 0 or +1), so an ordinal probit regression is likely to fit the data better than an ordinal logit (assumption of uniform distribution) or an ordinal complementary log-log (assumption of a distribution skewed towards one end) regression.

To test the perceptions that explain farmers' likely discontinuance, farmers' views of whether or not they are likely to continue assuming no cost-share payments or in-kind support programs was regressed on the perception categories and the other farm/famer characteristics previously mentioned, using a binomial logit model. Because only one farmer indicated he would discontinue assuming continued cost-share and in-kind support, there was not enough variability to perform a regression analysis under the assumption of continued government support.

II.A.3 RESULTS AND DISCUSSION

II.A.3.1 *Classification of Perceptions*

Because the survey was open-ended, there were a large number of distinct responses for the positive and negative perceptions of silvopasture. Specifically, there were 23 distinct positive responses and 27 distinct negative responses. Table II.A.1 shows the overall response rate for each of the perceived positives at the time of adoption (before) and at the time of the survey several years later (after). Negative responses are shown in Table

II.A.2. From the increases and decreases in the frequency of specific responses over time, it is apparent that many of the farmers' perceptions of the advantages and disadvantages changed over time from the moment of adoption to the time of the survey several years later.

Among the benefits listed, farmers mentioned producing two outputs from one plot of land most often (50% of the farmers interviewed). Farmers cited lower risk from fires (18%) and reduced heat stress on cattle because of shade (18%) second most frequently. Weed reduction and erosion control (16% each) were the next most common, followed by payment of government incentives (14%).

Table II.A.1. Categories and rate of responses for farmers' positive perceptions of silvopasture.

Category	Response	Before*	After
COSTS	Government provides cost sharing incentives	14.0%	2.3%
	Silvopasture helps reduce the amount of weeds	16.3%	22.7%
	There are fewer leaf-cutter ants when a dense pasture and cattle are maintained in the stand	2.3%	0.0%
	People in stands to monitor things	0.0%	2.3%
	More grass available in winter (frost protection)	7.0%	11.4%
RETURNS	More profitable than other systems	14.0%	18.2%
	Shade helps the livestock (less heat stress)	18.6%	27.3%
	Joint production: Two outputs are produced from one plot	51.2%	29.5%
	Higher quality pasture (more tender) in summer	7.0%	11.4%
	Erosion control maintains soil quality	16.3%	9.1%
	Higher cattle stocking rate than open-air systems	4.7%	0.0%
	Higher timber quality	2.3%	4.5%
	Better timber growth	0.0%	2.3%
FLOW	Long-term investment	7.0%	18.2%
	Cattle provide quick income	11.6%	27.3%
	Thinning provides quick income	2.3%	2.3%
RISK	Income diversification	2.3%	4.5%
	Lower risk of fire because cattle keep grass short and green	18.6%	20.5%
	Fewer livestock health problems	0.0%	2.3%
COMPLEX	System is practical	7.0%	4.5%
COMPATIBILITY	Environmental benefits	2.3%	0.0%
	Pleasurable work	2.3%	2.3%
	Desire to reforest	2.3%	0.0%

* At the time of adoption ("Before") and at the time of the survey ("After").

Once the farmers had practiced silvopasture for several years, their perceptions changed considerably. The frequency at which farmers cited the benefit of joint production dropped, but remained tied for most important with that of shade reducing heat stress on cattle (27%). Weed reduction was perceived as important more frequently than before adoption based on farmer experience (23%), as was the production of fast income from cattle (23%), and lower risk of fire (21%). Experience also raised the perceived value of greater profits from 11% before adoption to 16% after adoption. Aside from the joint production perception, the main perception of benefits that decreased in frequency was erosion control (from 16% to 9%).

Table II.A.2. Categories and rate of responses for farmers' negative perceptions of silvopasture.

Category	Response	Before*	After
COSTS	High capital investment	7.0%	9.1%
	Lack of time to manage the plot	4.7%	4.5%
	Watering livestock is time-consuming/costly	2.3%	2.3%
	Ant control	0.0%	2.3%
RETURNS	Not enough light for good pasture growth	30.2%	13.6%
	Soil compaction	2.3%	0.0%
	Animals harm trees	4.7%	4.5%
	Competition between grass and trees	4.7%	2.3%
	Poor timber growth and form	0.0%	4.5%
	Cattle prefer sun in winter	0.0%	2.3%
	Long time for timber returns	2.3%	0.0%
FLOW	Lack of land available to dedicate to agroforestry	7.0%	2.3%
	Loss of use of pasture while trees are established	4.7%	4.5%
RISK	Risky markets for livestock	0.0%	2.3%
	Trees may fall on fence	2.3%	0.0%
	Government often does not pay cost-share incentives	7.0%	9.1%
	Lack of information or studies available	4.7%	4.5%
	Animal health suffers amongst trees (more parasites)	4.7%	4.5%
	One specific tree species' seeds may cause spontaneous abortion in cattle	2.3%	0.0%
	Institutional insecurity of government (may raise agriculture taxes, etc.)	0.0%	4.5%
	Cattle thefts more frequent with trees	0.0%	2.3%
COMPLEXITY	Forest management is difficult	16.3%	9.1%
	Pasture management is difficult	2.3%	2.3%
	Livestock management is difficult	7.0%	4.5%
	Compatibility between trees and pasture	9.3%	11.4%
COMPATIBILITY	Desired tree species were not allowed in the program	2.3%	0.0%
	Livestock less docile after time amongst trees	0.0%	2.3%
	Cleaning up pruned branches is tedious	0.0%	2.3%

* At the time of adoption ("Before") and at the time of the survey ("After").

Table II.A.3 summarizes the six categories of the net perceptions variables. Relative to the number of perceived benefits, farmers identified disadvantages of silvopasture systems less frequently, before and after adoption. We take this to mean that the adopters generally have a favorable view of the system. However, since the sample is only adopters, these perceptions are not generalizable to the larger population of all farmers. It is likely that the adopters had better perceptions of the system to begin with, which is why they chose to adopt. The largest perceived problem before adoption was that was that forest management was difficult (18% of the farmers surveyed), followed distantly by cattle management being difficult (6.8%), and underfunded government incentives (6.8%). After adoption, the most commonly perceived problems were compatibility between trees and pasture (11% of those surveyed), not enough light for good pasture growth (11%), capital requirements (9%), forest management is difficult (9%), and underfunded government incentives (9%). As will be examined further in more detail, the findings differed somewhat by farm size, type and the people who influenced farmers' decisions.

Another interesting result in Table II.A.1 and Table II.A.2 is very few farmers cited advantages or disadvantages in the *Compatibility* category. This is in contrast to much of the adoption diffusion literature, where a technology's compatibility with an adopter's values and habits is generally seen as one of the key factors in adoption (Katz et al. 1963). This study does not allow us to generalize to the greater population of adopters and non-adopters. It is possible that *Compatibility* characteristics are a key driver of non-adoption for silvopasture, if non-adopters feel that the technology does not fit in with their farming styles and values. This is an interesting realm for more research.

The consequence of having few responses in the *Compatibility* category is that there is generally not sufficient variability to generate good predictive models with compatibility as the dependent variable, or to include compatibility as an independent variable in the logit model for likely discontinuance.

Table II.A.3. Summary statistics of net perception indices (dependent variables) before and after adoption.

	Before Adoption				After Adoption			
	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
COSTS	0.26	0.49	-1	1	0.20	0.70	-1	2
RETURNS	0.70	1.08	-2	3	0.75	1.14	-3	3
FLOW	0.09	0.75	-2	3	0.41	0.79	-1	2
RISK	0.00	0.65	-1	2	0.00	0.89	-3	2
COMPLEXITY	-0.28	0.67	-3	1	-0.23	0.60	-2	1
COMPATIBILITY	0.05	0.30	-1	1	-0.02	0.15	-1	0

II.A.3.2 *Qualitative description of conversations with farmers*

Qualitatively, conversations with farmers of all types led us to believe that they feel silvopasture has been and will continue to be beneficial for them. Many, particularly small-scale annual-croppers, based on their conversations with extension agents, hoped that silvopasture would be able to produce levels of timber and livestock that would each be comparable to the amount that would be produced in a single production system. However, they were somewhat skeptical that this could actually be achieved because of the effects of shade on the pasture, reducing the forage availability for livestock. After having practiced the system for a number of years, most farmers believed that an adequate amount of forage could be produced in the partial shade; in fact, a good number of farmers believed that forage production might even be higher under partial shade than in full sun. For these farmers, the cost of maintaining forage on the silvopasture plots is intensive management of the trees through thinning and pruning. While the silvicultural management involves tedious work and is difficult to master, most farmers found it to be worthwhile because livestock can be maintained.

Although it has often been noted by researchers, very few farmers noted that this intensive silvicultural management inherently leads to a high-quality timber product. That is, thinning leads to fewer, larger-diameter, higher-value logs; and pruning increases the volume of timber that is free of knots.

There were a few farmers who dissented from the opinion that managing for timber and livestock on the same plot of land was beneficial in terms of joint production of the two products. In particular two farmers stand out (one large-scale and one small-scale), who believed that timber production came at the expense of livestock production, or vice versa, and the trade-off was not worthwhile. In their opinion, timber production and livestock should be managed separately on distinct plots.

Among those farmers who traditionally raise cattle, conversations lead us to believe that recent historic low cattle price was a major factor in driving their decision to diversify sources of income. Among those who are timber growers, one of the main benefits of adding cattle was the reduction of the risk of fire.

Table II.A.4 compares the most frequently cited positives and negatives of silvopasture from previous studies in comparison with this study. One of the results that particularly stands out is that farmers in Argentina seem less concerned with the possible environmental benefits of silvopasture systems than in Florida, USA (Shrestha et al. 2004), Copán, Honduras (Pérez 2006), or Quindío, Colombia (Calle 2008). While several of the responses from our study were about the within-farm environment (improved microclimate, for instance), only one farmer in our sample mentioned that public environmental benefits such as water quality, biodiversity or carbon sequestration were among the reasons he decided to adopt silvopasture systems. Furthermore, none mentioned public environmental changes as an important benefit of the system now that they have had some years of experience. One possible explanation that farmers in Argentina may view silvopasture as a productive system rather than an environmental system is that the majority of adopters use exotic tree species, in contrast to systems in USA and Honduras that use primarily native species, which probably have a more positive impact on biodiversity conservation. Still, silvopasture systems in Argentina aid carbon sequestration (Fassola et al. 2009 (In press)), help prevent eroded soil from entering water sources, and may be of moderate biodiversity value in some situations.

Another possible explanation that environmental values are not high on Argentines' list of positives and negatives of silvopasture compared to adopters in other American countries might be that researchers have focused more on increased productivity in the economic sense.

Table II.A.4. Comparison of principal positive and negative perceptions from the literature on silvopasture systems.

Study	Principle Positive Perceptions	Principal Negative Perceptions
Shrestha et al. (2004)	Sense of stewardship, environmental protection, diversify income	Fire hazard, uncertainty about government regulations, length of investment
Pérez (2006)	Economic (timber, firewood, posts, shade) and ecological (water quality) goods and services	Lack of cheap seeds/seedlings, lack of support from institutions, high labor investment, tree mortality
Calle (2008)	Reduced used of inputs, improved conditions for cattle, increased wildlife diversity	High capital investment, lack of information and knowledge
This study: Before adoption	Joint production of two outputs, less heat stress on livestock, lower forest fire risk	Not enough light for good pasture growth, difficulty of managing trees to allow light
This study: After adoption	Joint production of two outputs, less heat stress on livestock, quick income from livestock, reduced quantity of weeds, lower forest fire risk	Not enough light for good pasture growth, compatibility of trees and pasture, high capital investment, difficulty of managing trees to allow light

II.A.3.3 *Explanatory variables for perceptions*

Table II.A.5 summarizes the explanatory variables. Most adopters in our survey (63.6%) indicated that they had contact with professionals such as INTA extension agents, veterinarians or consulting foresters, who influenced their decision to adopt the silvopasture system. About 20.5% indicated that conversations with other farmers had influenced their decision, and 27.3% stated that they had no in-depth conversations prior to adoption that influenced their decision.

Table II.A.5. Summary of explanatory variables for ordinary probit models explaining farmers' perceptions of silvopasture.

Category	Variable	Description	Mean
Influential person (dummy)*	**Professional**	Adoption decision was influenced by an extension agent or professional consultant	62.7%
	Farmer	Adoption decision was influenced by another farmer	20.9%
	None	Adoption decision was independent, not strongly influenced by others	27.2%
Farm scale (dummy)	**Small**	15-50 hectares (sum of all land owned in the study region)	37.2%
	Medium	75-800 hectares	37.2%
	Large	>1100 hectares	25.6%
Farm type (dummy)	**Perennial**	Principal farm output before beginning silvopasture was perennial crop (yerba mate, tea)	20.9%
	Cattle	Principal farm output was cattle	34.9%
	Crops	Principal farm output was annual crops (tobacco, corn, cassava, etc.)	30.2%
	Forestry	Principal farm output was timber	14.0%
Education	**Education**	Years of formal education	10.5

* Some farmers were influenced by both professionals and other farmers, so some farmers have the value 1 for both of these variables. The total of the three variables does not sum to 100%.

Based on our conversations with the farmers, and knowledge of the different explanatory factors, we developed several hypotheses about the how perceptions might be explained by those factors.

First, we hypothesized that the "Influential person" factor would affect perceptions at the time of adoption, but possibly not so after practicing the system. It is logical that extension agents, for instance, might collectively emphasize certain aspects of the system, based on information and research they have received from within the extension institution. After practicing the system for several years, we would expect that the impact of having been influenced by someone at the time of adoption would be reduced by the effect of the passing of time and by experience.

Second, we hypothesized that small scale farmers might be more concerned with the cash flow properties of the system, since many farmers are constrained by cash in the short-term. From our conversations, this seemed to be an important benefit of silvopasture systems for them. We also hypothesized that the costs of the system might be a negative to small farmers for the same reason.

II.A.3.4 *Explanatory models of perceptions, at time of adoption*

For the ordinal probit model of the net perceived advantages of silvopasture in Table II.A.6, we tested restrictions on the full models by excluding each group of explanatory variables ("Influential" people in the adoption decision, Farm "Scale", Farm "Type") and using the log-likelihood value of the restricted and unrestricted model to calculate the likelihood ratio statistic. There was no group of explanatory variables that was easily excluded from all the models. In addition, even when using the restricted model for specific characteristic categories, where the likelihood ratio statistic suggested it might be appropriate, there were only minor changes in statistical significance, and all coefficients that were significantly different from zero at any alpha ≤ 0.1 do not change sign or approximate magnitude. It was decided to use the unrestricted models for all categories.

Table II.A.6. Coefficients and log-likelihood values of the ordinal probit models for net perceptions (count of positive responses minus count of negative responses) for each category of perception, at time of adoption.

	Costs	Returns	Flow	Risk	Complexity	Compatibility
Professional	0.25	-0.49	0.42	-0.67	0.04	11.29
Farmer	0.22	-0.52	0.62	0.92 *	-0.49	-1.77
Small	-0.24	1.08	-2.08 **	-0.83	-0.08	-1.95
Medium	0.22	0.39	-1.39 **	-0.30	-0.61	0.92
Perennial	-0.01	0.15	1.13	1.20	-0.15	1.81
Cattle	0.45	-0.73	0.79	1.24 **	-0.14	2.17
Crops	0.24	-0.38	1.63 **	0.80	0.51	-1.56
Education	-0.02	0.06	-0.06	-0.19 ***	0.01	-0.13
Unrestricted model Log-likelihood	-29.08 [1]	-56.71 [1]	-32.62 [1]	-31.70 [1]	-31.90 [1]	-8.31 [1]
Restricted model w/out Influential	-29.32	-58.15	-33.66	-34.52 *	-32.35	-14.05 ***
Restricted model w/out Scale	-29.37	-57.80	-35.83 **	-32.19	-32.60	-9.85
Restricted model w/out Type	-29.50	-58.48	-35.03	-34.08	-32.78	-11.49 *

Model is for the probabilities of the dependent variable having lower ordered values, i.e. a positive value for the coefficient represents that an increase in that independent variable increases the probability of the dependent variable having a lower value.

*, **, *** represent statistical significance at the 0.1, 0.05 and 0.01 alpha-levels. For the log-likelihood statistics of restricted models, a significant outcome means that there is evidence to reject the null hypothesis that the coefficients of the excluded variables are all equal to zero.

[1] Both Pearson and Likelihood Ratio χ^2 lack-of-fit statistics have a large p-value (> 0.1), demonstrating that there are no problems with the fit of the model.

[2] Pearson and Likelihood Ratio χ^2 statistics have divergent values, suggesting the data are too sparse to use either statistic to measure goodness-of-fit.

The lack of statistical significance of the Professional and Farmer influential people coefficients in virtually all the models does not provide evidence to support the hypothesis that the type of people who influence the adoption decision has a strong effect on the perceptions of silvopasture. That is to say, there is no evidence that professionals (extension agents, consultants, etc.) and other farmers consistently alter the adopters' perceptions. It may be the case that one specific extension agent, for example, alters prospective adopters' perceptions in a consistent way, but there is no evidence to support that they do as a group.

Here we remind the reader that the signs of the coefficients, as calculated in our model, represent the effect of the explanatory variables towards a lower ordered value of the dependent variable, which is a convention from the statistical software utilized in the analysis (SAS). In other words, a negative (positive) sign on the coefficient of an explanatory variable means that a higher value of that variable makes the dependent variable less (more) likely to have a lower value. For our dummy explanatory variables, a negative (positive) coefficient means that if a farm/farmer falls into that category, then he is more likely to have said more (fewer) negative things and fewer (more) positive things.

In the models for Costs, Returns, Complexity and Compatibility, none of the explanatory variables were statistically different than zero. Also, we could not reject the null hypotheses that any of the set of variables had coefficients that were all equal to zero for the Costs, Returns and Complexity models. This indicates that our models do not do a good job explaining farmers' perceptions based on the characteristics in those models. We could not detect any difference between farmers influenced in their adoption decision by different types of people, farms of differing scale or type, or the education level of the farmer.

However, some of the signs of the coefficients in these models are of interest, even if not statistically significant. In the costs perception model, farmers who typically raise cattle or annual crops were more likely to have said more negative things and fewer positive things about the costs of silvopasture than forest farmers. This is logical because many of the initial costs of silvopasture, including site preparation and seedlings, are more directly related to the forestry aspect of the system. Forest farmers would be more accustomed to these costs. However, the high costs of forestry practices also lead to high returns, which may explain the negative sign on cattle and annual crop farmers in the returns model, meaning they were likely to have a higher number of positive perceptions and fewer negatives.

The model for Flows showed the most significance among the coefficients of the explanatory variables. Of particular note, small and medium-scale farmers were more likely to have stated positive things about the cash flow characteristics of silvopasture than large-scale farmers (at alpha = 0.05). This is intuitive, because smaller-scale farmers are probably more constrained for cash in the short-term. Also, large farmers can produce yearly income even with systems that have poor cash flow by having numerous parcels, staggered temporally, so the cash flow of any particular parcel is not particularly important. A small or medium-scale farmer cannot do this because timber harvest on an exceedingly small area becomes costly. This places a premium on systems that inherently generate income on a frequent basis. In addition, annual croppers were less likely than forest farmers to say positive things about silvopasture's cash flow properties (significant at alpha = 0.05), and cattle ranchers and perennial farmers (the perennials in this case still have annual harvest, although the plant remains intact) showed the same tendency, but the difference was not significant. This is intuitively appealing since these systems all produce income on an annual basis, which would generally be viewed more favorably than forestry or silvopasture, which may not produce income during the first few years since cattle are not introduced into the system until trees are large enough to withstand them.

The Risk model also showed that several explanatory variables had predictive power in explaining the variability in the number of positive and negative perceptions with regards to risk. The variable with the highest level of statistical significance is education (significant at alpha = 0.01). Farmers with higher levels of education were more likely to have a positive perception of the risk involved with silvopasture. The reason why this might be the case is not completely clear. In addition, cattle famers were less likely than forest farmers to have a positive perception of silvopasture's risk (alpha = 0.05). Annual and perennial farmers showed the same tendency, but without statistical significance. This is logical because one of the principal risk factors is forest fire. Forest farmers see silvopasture as positive in terms of risk because adding cattle to the forests they already have reduces the risk of forest fires. However, cattle ranchers would be less likely to perceive this as a relative benefit since they previously had the cattle but not the trees.

II.A.3.5 *Explanatory models of perceptions, after several years of experience with the technology*

In the probit model of net perceptions several years after adoption (Table II.A.7), influences by professionals such as extension agents or consultants in the adoption decision only had a significant impact at the alpha = 0.1 level in the Costs model. Farmers who were influenced by extension agents were more likely to have a more negative view of silvopasture's costs. This is quite counterintuitive because those farmers who are more connected to extension agents are probably the farmers who are most likely to have received incentive payments or in-kind material support to begin silvopasture implementation. However, further thought leads us to believe that this result may, in fact, be reasonable. If a farmer is receiving in-kind support of supplies, he has little control over where the extension agents obtain the materials and for what price, and the extension agents probably have an incentive to provide high-quality material, even if relatively expensive (high-quality tree seedlings from a government or private nursery, etc.), because they need to demonstrate positive results to the farmers. If farmers receiving in-kind support believed that using high-quality material is truly the best way to implement the system, they might rightly decide that it would have been quite expensive if they were to have to do it on their own. On the other hand, farmers left to obtain supplies on their own might find ways to obtain the materials relatively more cheaply. For instance, they might dig up naturally-regenerated tree seedlings from a neighbor's forestry plot, or collect seeds and start their own micro-nursery.

Having been influenced by other farmers at the time of adoption does have a significant impact on farmers' net views of the return characteristics of silvopasture system. In the Returns model we could reject the null hypothesis that being influenced by professionals and/or other farmers at the time of adoption has no effect on perceptions several years later. Specifically, adopters who were influenced by other farmers at the time of adoption were less likely to have a lower net perception for returns. We believe that this is most likely due to some underlying causal factor that we have not controlled for in our model. For instance, it is possible that those farmers who were influenced by other farmers at the time of adoption may be more likely to be members of a cooperative or other group that would have longer-term impacts on their views. The quite low level of significance in most of the models is intuitive and can be explained by the fact that influences from the time of adoption are less likely to continue influencing farmers' perceptions of the technology, after having several years to practice it.

As in the models for perceptions at the time of adoption, the models that demonstrated the most predictive power of explanatory variable were the Flow and Risk models. In addition, the Complexity model had some variables with significant predictive power. We could not estimate a model for Compatibility because of insufficient variability in the dependent variable. Costs and Returns models showed some significance in the influential people variables as explained above.

Table II.A.7. Coefficients and log-likelihood values of the ordinal probit models for net perceptions (count of positive responses minus count of negative responses) for each category of perception, at time of the survey (several years after adoption).

	Costs	Returns	Flow	Risk	Complexity	Compatibility
Professional	0.70 *	-0.57	0.41	-0.43	0.88	
Farmer	0.43	-0.92 **	0.63	0.16	0.06	
Small	0.65	0.90	-2.31 **	-1.14	0.60	
Medium	0.23	0.34	-1.37 **	-1.40 **	1.22	
Perennial	0.74	0.30	-0.06	1.48 **	-1.17	
Cattle	-0.07	0.22	0.04	0.78	-1.75 **	
Crops	-0.83	0.20	1.36 *	1.23 *	-0.31	
Education	-0.01	0.00	-0.03	-0.09 *	0.13 *	
Unrestricted model Log-likelihood	-39.53 [1]	-59.31 [1]	-36.81 [1]	-45.70 [1]	-24.21 [1]	
Restricted model w/out Influential	-41.31	-62.47 **	-37.97	-46.32	-25.50	
Restricted model w/out Scale	-39.89	-60.09	-40.42 **	-48.90 **	-25.76	
Restricted model w/out Type	-43.31 *	-59.43	-40.68 *	-48.16	-27.33	

Model is for the probabilities of the dependent variable having lower ordered values, i.e. a positive value for the coefficient represents that an increase in that independent variable increases the probability of the dependent variable having a lower value.

*, **, *** represent statistical significance at the 0.1, 0.05 and 0.01 alpha-levels. For the log-likelihood statistics of restricted models, a significant outcome means that there is evidence to reject the null hypothesis that the coefficients of the excluded variables are all equal to zero.

[1] Both Pearson and Likelihood Ratio χ^2 lack-of-fit statistics have a large p-value (> 0.1), demonstrating that there are no problems with the fit of the model.

Small and medium farmers were more likely than large farmers to have a higher net perception of silvopasture's cash flow. Annual cash cropping farmers were more likely to have a negative view of silvopasture's risk characteristics than forest managers. These results are quite similar to the model of perceptions before adoption.

The model of the perceptions of Risk after several years practicing the system is somewhat different than before adoption. Farm scale has an impact on perceptions of risk, with small and medium scale farmers less likely to have a negative perception of silvopasture risk (only medium scale farmers had a statistically significant coefficient value, but the sign is the same for small scale farmers and the magnitude is still relatively large). We believe this is partially because of the role of government support in silvopasture adoption among the different scales, and farmers' expectations. Smaller scale farmers primarily received in-kind support, and their expectations for support were met, based on their participation in farmers' committees. Small and medium scale farmers who were not members of farmers' committees in many cases did not even bother to apply for support, so they did not view lack of support as a risk. Many of the larger-scale farmers, however, believed that they would receive financial support. If it was not received, this would be attributable to government institutional insecurity. Also, perennial and annual crop farmers were more likely to have a negative view of silvopasture's risk than forest farmers. This is also compatible with the institutional insecurity problem. Forest farmers would be accustomed to dealing with the difficulties of requesting government aid for tree planting, while perennial and annual croppers would not be. More years of formal education had the effect of making farmers less likely to perceive negatively the risk of silvopasture.

In the model of Complexity, cattle farmers were less likely to have a negative view of silvopasture's complexity than forest farmers, and more educated farmers were more likely to have a negative view. In our conversations with the farmers, we noted that forest farmers recognized that they had to change the way they managed their trees (more pruning, thinning, etc.). Cattle farmers, on the other hand, did not think that their management of the cattle was any more difficult than before, since they apply the same vaccines, waterings, supplemental feeding, etc. This is somewhat counter-intuitive because one might expect that by adding trees to cattle farms, cattle farmers' operations become more complex. However, it seems that farmers are more willing to accept complexity created by an added component that provides new benefits than to accept a more complex management of a component they already manage on a day-to-day basis. Tree farmers find it harder to accept a more complex tree management.

II.A.3.6 *Change in perceptions over time*

It is clear from Table II.A.1 and Table II.A.2 that the perceptions of the overall group of adopters changed over time, from the time of the adoption decision to several years later. Many of the positive perceptions increased somewhat. The perceptions that the cash flow characteristics of silvopasture are beneficial generally increased over time. Another notable increase in positive perceptions is an increase in positive perceptions relating to microclimate (shade helps cattle and grass from heat, frost protection).

Perhaps the most notable change in positive perceptions is in the Returns category, where the frequency of the response that silvopasture was beneficial because it provides two outputs from one piece of land decreased from 51% to 30% over time. Also, there was a decrease in the number of farmers believe that government subsidies were an important advantage of silvopasture, probably because the government did not end up paying many of the requested subsidies.

Most of the negative perceptions that had relatively high frequencies before adoption decreased in frequency after several years. Prominently, many fewer farmers stated that there would not be enough light in silvopasture systems to have good pasture growth. Also, the number of farmers who believed that forest and livestock management were difficult decreased somewhat.

It can be seen by comparing the results of the net perceptions models at adoption and later that some of the coefficients on the explanatory variables had changed in either sign or statistical significance. Perhaps the most notable changes were in the farmers' net perceptions of Returns. The coefficient for small farmers became significantly positive and the coefficient for medium farmers changed from negative to positive (though not significant). This indicates a lowering expectation of small and medium farmers for advantageous returns from silvopasture relative to large farmers. From observing the data, this change seems to be mainly driven by a lower proportion of small and medium farmers believing that a major benefit of silvopasture is that two products come from the same piece of land, and an increase in the proportion of large farmers who stated that shade helps cattle and forage perform better in the summer. Also in the "returns" model, the coefficients for *Cattle* and *Crops* changed from negative and significant to positive and insignificant. Managers of cattle and annual cash crop farms were no longer more likely than forest managers to believe that silvopasture systems had beneficial returns properties.

As mentioned previously, the variables for *Influential* people at the time of adoption lost significance in explaining farmers' net perceptions of "complexity".

II.A.3.7 *Likelihood of Continuance*

The majority of farmers indicated that they had received help starting the silvopasture system either through government cost-share programs or in-kind support. By a wide margin, farmers indicated that they would probably increase the area of land given to silvopasture if cost-share or in-kind support programs continued. Only one farmer responded that he would likely decrease the amount of his land given to silvopasture in the future even with support programs.

In addition, the majority of farmers (83%) indicated that they would continue increase or maintain the area under silvopasture systems, even if no government support were provided. This is a good indication that these farmers believe that silvopasture is beneficial to them. These data suggest that the hurdle of convincing farmers to install silvopasture is a one-time barrier.

We constructed several logit models to determine the factors that explain farmers' stated likely discontinuance, if support programs were to be discontinued. Unfortunately, it was impossible to include all the potential explanatory variables (net perceptions at adoption, net perceptions after several years of using the system, influential people, farm type, farm scale) in a single model, because this resulted in quasi-complete separation of the data points, due to the relatively small sample size and large number of explanatory variables. Therefore, we tested each group of explanatory variables separately.

The only group of variables that had satisfactory explanatory power (likelihood ratio p-value < 0.1) was the group of net perceptions after several years of using the system. It was necessary to exclude the *Compatibility* perception variable because of the extremely limited variability (there was only a total of one positive and two negative *Compatibility* responses), which caused separation problems with the model. The results of the logit model are given in Table II.A.8.

Our models do not provide support for the hypothesis supported for informational technology diffusion (Parthasarathy & Bhattacherjee 1998), that potential discontinuers can be identified by their social networks and perceptions at the time of adoption

Table II.A.8. Results of the binary logit model for farmer's stated likely continuance or discontinuance.

	Coefficient	
Costs	-3.762	**
Returns	-3.257	**
Flow	-2.185	
Risk	-0.665	
Complex	-0.036	
Log-likelihood	-19.279	***

*, **, *** represent statistical significance at the 0.1, 0.05 and 0.01 alpha-levels. For the log-likelihood statistics a significant outcome means that there is evidence to reject the null hypothesis that the coefficients are all equal to zero.

We first note that the logit model shows negative signs on all the coefficients of the net perceptions. This is the expected sign, which means that farmers with more positive net perceptions were less likely (negative sign) to want to discontinue, or conversely, those with positive net perceptions were more likely to state they wanted to continue silvopasture. The two variables with the greatest magnitude and the only two that are statistically significant at an alpha-level of 0.1 are the net perceptions of returns and of costs. The large magnitude on the coefficient of *Returns* is particularly satisfying from an economic point of view, because it lends support to the axiom that these farmers are truly seeking to be profit-maximizers. The coefficient on *Costs* is also satisfactory from an economic viewpoint, since it is often thought that farmers, particularly in developing regions, have constraints on the amount of capital they have to invest, and in their access to credit. *Flow*, while not statistically significant, has a relatively large coefficient, which might suggest that constraints work in the opposite direction, as well, that is, farmers feel they need to have a certain amount of income at relatively frequent intervals in order to get by. *Risk* and *Complexity* seemed less important in the continuance/discontinuance decision.

The question of whether or not the front-end investment in silvopasture is a major disadvantage of the system that prevents widespread adoption, as discussed in Dagang and Nair (2003) and Pagiola et al. (2004), is still an interesting one and merits more precise research. Our model suggests that the perception of high costs is a predictor of discontinuance. This may mean that some adopters will discontinue after the first rotation of timber if they do not receive cost-share payments to prepare and plant the trees for the future silvopasture rotations.

II.A.4 CONCLUSIONS

At the time of adoption, farmer's perceptions of the cash flow and risk of silvopasture are colored by several factors including the scale of the farm they operate, the type of farm they operate and their number of years of formal education. Somewhat surprisingly, the type of person who influenced the decision to adopt did not seem to have a large impact on farmers' perceptions. We were unable to detect a significant impact of any of these factors on farmers' perceptions of costs, returns, complexity or compatibility of silvopasture at the time of adoption.

In general, small, medium and large farmers in Northeastern Argentina demonstrated different perceptions of the advantages and disadvantages of silvopasture systems. Once adopters had had several years of practicing silvopasture, smaller-scale farmers were more likely than large-scale farmers to have a positive net perception of silvopasture's cash flow, while larger-scale farmers were more appreciative than small-scale farmers of silvopasture's total returns.

Over time, cattle-ranchers and annual croppers became less likely to believe that silvopasture systems had beneficial returns, relative to forest managers. However, both cattle-ranchers and annual cash croppers became less likely to see the costs of silvopasture as a problem over time. Perennial croppers' opinions seemed to mirror forest managers', as there were no significant differences in any of the models.

The only factors that appeared to be powerful explanatory variables for farmers' likely discontinuance of silvopasture were their perceptions of returns and costs after they had experienced the system for several years. Social contacts from the time of adoption, perceptions at the time of adoption, farm scale and farm type were not good predictors of likely discontinuance.

Extension agents and researchers should keep in mind the benefits farmers believe to be the most important when conversing with potential future adopters. In particular, an extensionist speaking to small-scale farmers would do well to stress particularly the advantages of short-, medium- and long-term cash flow offered by silvopasture through frequent sale of livestock, semi-frequent sale of timber thinning and infrequent clear-cutting of sawtimber. When speaking to medium- and large-scale farmers, the extensionist should stress the technical benefits of improved microclimate (including reduced heat stress on livestock, improved palatability of forage and protection of forage from winter frosts), reduced likelihood of forest fire and reduction of weed species.

Overall, the results of this study do indicate that silvopasture systems have significant benefits to the farmers who adopt them, although perceptions of those benefits do change and evolve over time. These findings in Argentina differ somewhat from those found in the Southern United States. Further research in other countries in Latin America may help determine their applicability in other locations where good livestock and forest products markets exist. We do feel that, with extension and education, silvopastoral activities may be viewed favorably by farmers in areas such as southern Brazil and Uruguay, Chile, Central America, etc. The results also can inform future research on economic analyses of silvopasture systems and differences by ownership size.

II.A.5 LITERATURE CITED

Adesina, A. A., and J. Baiduforson. 1995. Farmers' perceptions and adoption of new agricultural technology - Evidence from analysis in Burkina-Faso and Guinea, West-Africa. Agricultural Economics **13**(1)**:**1-9.

Ajayi, O. C. 2007. User acceptability of sustainable soil fertility technologies: Lessons from farmers' knowledge, attitude and practice in southern Africa. Journal of Sustainable Agriculture **30**(3)**:**21-40.

Bender, R., and A. Benner. 2000. Calculating ordinal regression models in SAS and S-plus. Biometrical Journal **42**(6):677-699.

Berelson, B. 1952. Content analysis in communication research. Free Press, Glencoe, Ill.

Bhattacherjee, A. 2001. Understanding information systems continuance: An expectation-confirmation model. MIS Quarterly **25**(3)**:**351-370.

Calle, A. 2008. Using PES and technical assistance to promote Silvopastoral Systems in Quindío, Colombia: Attitude change as a key to permanent adoption. M.E.S. thesis, Yale University, School of Forestry and Environmental Studies, New Haven, CT.

Dagang, A. B. K., and P. K. R. Nair. 2003. Silvopastoral research and adoption in Central America: Recent findings and recommendations for future directions. Agroforestry Systems **59**(2)**:**149-155.

Esquivel, J., H. E. Fassola, S. M. Lacorte, L. Colcombet, E. H. Crechi, N. Pachas, and A. Keller. 2004. Sistemas silvopastoriles - Una sólida alternativa de sustenabilidad social, económica y ambiental. 11as Jornadas Técnicas Forestales y Ambientales - FCF, UNaM - INTA: EEA Montecarlo. 7-9 October 2004, Eldorado, Misiones, Argentina.

Fassola, H. E., E. H. Crechi, M. A. Pinazo, D. Videla, A. E. Keller, and S. Barth. 2009 (In press). Acumulación de biomasa y producción de madera de calidad en *Pinus taeda*: Dos objetivos que imponen la silvicultura y los regímenes silvopastoriles actuales. in S. M. Lacorte and P. Peri, editors. 1er Congreso Nacional de Sistemas Silvopastoriles. 14-16 May 2009, Posadas, Misiones, Argentina.

Fassola, H. E., S. M. Lacorte, J. Esquivel, L. Colcombet, F. Moscovich, E. H. Crechi, N. Pachas, and A. Keller. 2004a. Sistemas silvopastoriles en Misiones y NE de Corrientes y su entorno de negocios. INTA EEA Montecarlo, Montecarlo, Misiones, Argentina.

Fassola, H. E., S. M. Lacorte, N. Pachas, and A. Keller. 2004b. Experiencias Sobre Manejo Silvopastoril en Misiones y NE de Corrientes, Argentina. 11as Jornadas Técnicas Forestales y Ambientales - FCF, UNaM - INTA: EEA Montecarlo. 7-9 October 2004, Eldorado, Misiones, Argentina.

Fliegel, F. C., and J. E. Kivlin. 1966. Attributes of innovations as factors in diffusion. American Journal of Sociology **72**(3)**:**235-248.

German, L., J. Mowo, and M. Kingamkono. 2006. A methodology for tracking the "fate" of technological interventions in agriculture. Agriculture and Human Values **23**(3)**:**353-369.

Katz, E., M. L. Levin, and H. Hamilton. 1963. Traditions of research on the diffusion of innovation. American Sociological Review **28**(2)**:**237-252.

Kearns, K. P. 1992. Innovations in local government: A sociocognitive network approach. Knowledge, Technology, and Policy **5**(2)**:**45-67.

Keil, A., M. Zeller, and S. Franzel. 2005. Improved tree fallows in smallholder maize production in Zambia: Do initial testers adopt the technology? Agroforestry Systems **64**(3)**:**225-236.

Khan, Z. R., D. M. Amudavi, C. A. O. Midega, J. M. Wanyarna, and J. A. Pickett. 2008. Farmers' perceptions of a 'push-pull' technology for control of cereal stemborers and striga weed in western Kenya. Crop Protection **27**(6)**:**976-987.

Kiptot, E., P. Hebinck, S. Franzel, and P. Richards. 2007. Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. Agricultural Systems **94**(2)**:**509-519.

Pagiola, S., P. Agostini, J. Gobbi, C. de Haan, M. Ibrahim, E. Murgueitio, E. Ramírez, M. Rosales, and J. P. Ruíz. 2004. Paying for Biodiversity Conservation Services in Agricultural Landscapes. Environment Department Paper No. 96. The International Bank for Reconstruction/World Bank, Washington.

Parthasarathy, M., and A. Bhattacherjee. 1998. Understanding post-adoption behavior in the context of online services. Information Systems Research **9**(4)**:**362-379.

Pattanayak, S. K., D. E. Mercer, E. Sills, and J. C. Yang. 2003. Taking stock of agroforestry adoption studies. Agroforestry Systems **57**(3)**:**173-186.

Pérez, E. 2006. Caracterización de sistemas silvopastoriles y su contribución socioeconómica a productores ganaderos de Copán, Honduras. MS thesis. CATIE, Turrialba, Costa Rica.

Rogers, E. M. 1962. Diffusion of innovations. Free Press of Glencoe, New York.

Sall, S., D. Norman, and A. M. Featherstone. 2000. Quantitative assessment of improved rice variety adoption: The farmer's perspective. Agricultural Systems **66**(2)**:**129-144.

Shiferaw, B., and S. T. Holden. 1998. Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: A case study in Andit Tid, North Shewa. Agricultural Economics **18**(3)**:**233-247.

Shrestha, R. K., J. R. R. Alavalapati, and R. S. Kalmbacher. 2004. Exploring the potential for silvopasture adoption in South-central Florida: An application of SWOT-AHP method. Agricultural Systems **81**(3)**:**185-199.

Spiller, J., A. Vlasic, and P. Yetton. 2007. Post-adoption behavior of users of internet service providers. Information & Management **44**(6)**:**513-523.

Wooldridge, J. M. 2006. Introductory Econometrics: A Modern Approach. 3rd edition. Thomson South-Western, Mason, OH.

II.B A Within-Farm Efficiency Comparison of Silvopasture Systems to Conventional Pasture and Forestry Systems in Northeast Argentina

Gregory E. Frey[1], Hugo E. Fassola[2], Luis Colcombet[2], A. Nahuel Pachas[2], Mitch A. Renkow[3], and Frederick W. Cubbage[1]

[1] Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC, USA
[2] Instituto Nacional de Tecnología Agropecuaria, EEA Montecarlo, Argentina
[3] Department of Agricultural and Resource Economics, North Carolina State University, Raleigh, NC, USA

II.B.1 INTRODUCTION

Agroforestry systems are land use systems that combine annual crops and/or livestock with trees or other woody perennials. A particular type of agroforestry, called silvopasture, is the combination of livestock and forage with trees on the same plot of land. Researchers and extension agents have encouraged the adoption of silvopasture systems in numerous regions throughout the world, including the northeast region of Argentina, under the assumption that they are more productive, or efficient, than other conventional land uses such as forest plantations or full-sun pasture (Esquivel et al. 2004; Fassola et al. 2004a). However, adoption levels have only been moderate, raising the question of whether farmers are actually realizing the purported high levels of productivity.

The primary objective of this study is to measure the efficiency of real silvopasture systems relative to forest plantations and full-sun pasture, to test the hypothesis that silvopasture is more efficient in the northeastern region of Argentina.

Previous studies comparing the efficiency of agricultural systems have used data envelopment analysis (DEA) or stochastic frontier analysis (SFA) to estimate an average technical efficiency score for groups of farms, then compare the averages (Mathijs & Swinnen 2001; Latruffe et al. 2004). In many instances this method can be flawed. In general, if an entire group of farmers produces less revenue per unit of inputs (as implied by inefficiency as used in DEA and SFA), it may be because of any number of factors that are not included in the efficiency analysis. For instance, farm groups might be located on different soil types that are suited to different productive activities (Bhalla & Roy 1988; Rodriguez-Diaz et al. 2004), or one group of farmers might have different cultural values.

These factors may be different or impossible to observe or measure. We might also consider when comparing a new farm technology to a more conventional one from an efficiency standpoint that there may be an adopter bias. If we compare two sets of farmers in developing countries, one which has adopted the new technology and one which has not, it is quite often the case that the adopters themselves are more innovative farmers and are more connected to extension programs, and do a better job of farming in general.

Some studies try to control for these factors using a regression after the efficiency analysis (e.g. Otsuki et al. 2002; Latruffe et al. 2004; Davidova & Latruffe 2007). While it is possible to regress DEA efficiency on numerous control variables, there is always the risk of omitting important variables, and even in a more general sense the results this second-step regression may be biased, for reasons explained in more detail below (Just 2003).

Therefore, if one of our objectives is to compare technologies, we must find a way to more adequately control for unobserved factors. One way is to compare technologies within farms that utilize two or more of the technologies. By using paired comparisons of technologies within farms, we control for these unobserved factors, in the same way as fixed-effects methods with panel data (Fraser & Cordina 1999; Zhang 2002; Luo 2003). In this study we utilize a non-parametric Wilcoxon signed-rank test to compare the DEA efficiency of silvopasture, plantation forestry and full-sun pasture within farms.

A second objective of this study is to conduct an analysis of the nature of returns to scale of silvopasture systems. Agroforestry systems are often advocated as potentially beneficial for small-scale farmers. However, anecdotal evidence in Argentina suggests that large-scale producers are the main innovators, and that small-scale farmers often require numerous incentives for adoption. Two logical explanations are that (1) small-scale farmers are more highly constrained than large-scale farmers and cannot afford the initial cost of adoption, or (2) silvopasture exhibits increasing returns to scale. While DEA does not address farm-level constraints directly, it can be used to find whether each particular parcel of land is operating under increasing (+) constant (0) or decreasing (-) returns to scale. We use a sign test to determine the general overall nature of returns to scale for the three technologies.

II.B.2 MATERIALS AND METHODS

II.B.2.1 *Study Area*

The research was conducted on farms in the provinces of Misiones and the northeastern portion of Corrientes in northeastern Argentina. Misiones and northern Corrientes have experienced moderate adoption of silvopasture systems in recent years (Esquivel et al. 2004; Fassola et al. 2004a). While some adoption did take place in Misiones and Corrientes in the 1970s, silvopasture became widely investigated by researchers and farmland administrators in the 1980s. Research has improved management of the forage, livestock and timber components, and the total viability of the practice (Fassola et al. 2004b). Silvopasture implementation had reached an extent of over 20,000 hectares by 2008.

This region of Argentina is a humid, subtropical zone. Annual precipitation ranges from 1600-1900mm, with no pronounced dry season. Average temperature is approximately 15 C in July and 27 C in January.

A diversity of farm types exists in Misiones and Corrientes. Northern Corrientes and southwestern Misiones are flat prairie land, which has been traditionally used for cattle grazing since the 16^{th} century, and in the 19^{th} century was converted into private cattle ranches. Central and northern Misiones consists of the Upper Paraná Atlantic Forest eco-region, an inland extension of the Atlantic Forests of the central coasts of Brazil. This is a dense, humid forest zone, which was only settled to a large extent in Argentina starting in the 1920s, with some of the more remote areas still relatively undisturbed. This area is utilized by cash croppers of tea (*Camellia sinensis*), yerba mate (*Ilex paraguariensis*) and tobacco (*Nicotiana* spp.) and numerous subsistence crops, and, since the 1970s, has been increasingly occupied by varying scales of forest-product firms, who primarily plant pine species (*Pinus* spp.) for timber. There are farmers of all the aforementioned farm types who have adopted silvopasture systems (Fassola et al. 2004b).

II.B.2.2 *Farm Survey*

A farm survey of silvopasture adopters was conducted in the Misiones and northern Corrientes provinces of northeastern Argentina during June and July of 2006, and June 2008. The survey was principally aimed at eliciting information about costs and benefits of silvopasture compared to other production systems used in the region. The survey questions were approved by the NC State University Institutional Review Board for research with human subjects. All questions were reviewed with a focus group of extension agents and research scientists of the *Instituto Nacional de Tecnología Agropecuaria* (INTA) from the region. After the focus group, the survey interview was practiced with six producers of varying scales to test for understanding and accuracy of the question wording.

Due to the diffuse physical location of adopters, and because no complete list of adopters is available, a random sample was impossible. A stratified, purposive sample of adopters was selected throughout the region. Adopters were chosen in order to represent diverse farm scales and types in various sub-regions throughout the larger study region. These were identified by researchers and extension agents with INTA in each sub-region. We visited the relevant communities where the producers lived, and interviewed them on the farms. Most of the individuals identified by INTA for possible interviews did accept, but in a few cases other farmers in the community were selected as alternates.

In total, 47 silvopasture practitioners of varying scales were interviewed, producing 44 usable responses about silvopasture plots, 33 about full-sun pasture and 14 about plantation forestry. Surveyed farmers were classified into three groups using natural clusters: small, medium and large (Table II.B.1). Total farm size for all farms (including all non-contiguous properties managed by the same nuclear family or firm within the province) ranged from 15 to 14,000 hectares, with a mean of 1253 ha and median of 233 ha.

Table II.B.1. Descriptive statistics of farm scale groups.

Scale	n	Smallest farm (ha)	Largest farm (ha)	Mean Farm Area (ha)
Small	16	15	49	30.1
Medium	16	75	788	343.7
Large	12	1,108	14,000	4,096.5

II.B.2.3 *Classification and calculation of inputs and outputs to each system*

On the larger scale, Misiones and Corrientes, Argentina have fairly-well functioning markets for most of the relevant inputs and outputs of silvopasture systems. However, in some specific areas, particularly for small farms, markets may not exist or have high transaction costs. This has implications for our study, as explained below. Here I describe markets for the various inputs and outputs of the production systems we analyze, whose selection is explained in more detail below.

Land – Generally, land is available for purchase in most regions within the study area. However, in many cases farmers' land tenure was unclear or in any one of a number of possible stages between "squatting" and full ownership. Land with less than full title commands a much lower market price than it would otherwise. Very few of the farmers had ever rented in or rented out land. The reason may be that the legal framework for land rental is not clear, especially for land that is not titled, or that renting land is not typically practiced within the culture.

Labor – Markets for labor existed in all the communities we visited in the study area. However, there is vast variability in the price of labor, mostly depending on the size and legal status of farm. Small-scale farms are able to hire neighbors on an informal basis, usually for about 15 pesos/day. Large-scale farm firms, on the other hand, are forced to comply with minimum wage laws, which pushed the base cost of labor to about 39 pesos per day, and the firm may have to pay additional social taxes, food and housing, depending on its legal status.

Capital inputs – Capital inputs for silvopasture, pasture and forestry systems include the following: tree seedlings; grass seed and/or transplants; fencing materials, either posts and wire for conventional fences or posts, insulators, and electrifying equipment for electric fences; herbicide, ant pesticide; use of equipment including tractors, bulldozers, chainsaws, chemical sprayers, pruning saws; and transportation of supplies and outputs. These supplies are of relatively high value, so transaction costs such as traveling back and forth to the nearest town were low relative to the value of the products, and farmers in all communities indicated that they had access to most of these inputs.

In many cases, several of the capital inputs, including fencing supplies, tree seedlings, grass seed/transplants, herbicide and ant pesticide, were given to small-scale farmers for their participation in the silvopasture program.

Cattle feed – Most large and medium-scale farmers indicated that they purchased feed to supplement the cattle's diet, particularly in winter months. This included sunflower and wheat pellets, and other commodities. Small-scale farmers, on the other hand, almost exclusively supplemented the cattle's diet with commodities grown in their own fields, including corn, cassava and sugar cane. In fact, the crops that small-scale farmers feed to cattle are generally the ones that are produced primarily for on-farm consumption rather than for sale. It is probably the case that the transaction costs for these subsistence crops in remote communities are high enough relative to the value of the crops that the markets are thin.

In principle, it would have been appropriate and desirable to utilize the land, labor and capital inputs used to produce the cattle feed (days of labor, hectares of land, etc. used to produce the corn that was fed to the livestock) as the inputs of the DEA model, rather than the cattle feed itself. However, this would have required a quite laborious detailing of the inputs into each crop that was fed to the cattle. After already having given quite detailed accounting of timber and cattle management labor, capital, etc., many of our respondents (as well as the researchers) were suffering from fatigue of answering (and asking) tedious questions.

Beef – Beef is fairly openly traded in all the communities. Even in the most rural communities, farmers indicated that buyers from the towns would drive out to purchase cattle for slaughter.

Milk – Misiones and Corrientes are not in a milk-producing region, so there are few opportunities for farmers to sell milk. Some small-scale farmers may sell milk to neighbors, but this is the exception rather than the rule; most milk was produced for on-farm household consumption. Large and medium-scale farmers mostly did not bother to milk the cows. Still, milk should be considered an important output from the silvopasture and pasture systems, as it contributes to many families' dietary needs.

Timber – Misiones and Corrientes have good markets for sawtimber, particularly for pine, which was the genus of choice for most of the farmers. Even small farmers in remote areas were able to find ways to market sawtimber to small sawmills, which are numerous in the area. However, low-value small timber was less likely to find a market. There are only a few paper mills in the area, and for farms located more than about 100 km from one of these mills, the transportation cost would outweigh the value of the pulpwood. In these cases, farmers did find uses for some of the small logs (which result from thinning timber plantations), such as siding for barns, but in a few cases, the thinned logs were wasted.

The data from the surveys were compiled to estimate the inputs and outputs of the three systems. We used a rate of 7% to discount the inputs and outputs that occur in different years within the system rotation, which is a common discount rate utilized for comparing profitability of systems in Misiones (Esquivel et al. 2004). As described more in the explanation of DEA, the variable-weights property of the methodology permits variability in individuals' discount rates. Each one of the discounted inputs and outputs was calculated in perpetuity, using the capital budgeting criterion for the soil expectation value (SEV) (Klemperer 1996).

In many of the cases with the forestry and silvopasture, in order to calculate outputs, we predicted future output of timber by using a growth and yield simulation based on current measurements of timber, and farmers' estimates of thinning and harvest years and percentages of volume to be thinned. This was estimated with the Simulador Forestal computer program (Crechi et al. 1997) for *P. taeda*, *P. elliottii* and *A. angustifolia*, and published growth and yield equations for *P. caribaea* and *Eucalyptus* spp. (Ferrere & Fassola 1999; Ferrere et al. 2001; Barth et al. 2002; Fassola et al. 2007), calibrated to current measurements for each plot. Future pasture yields due to shade was calibrated to present yield and estimated with published data (Fassola et al. 2002; INTA 2002).

An agroforestry system can have dozens of distinct inputs and outputs. In theory, DEA is able to handle many inputs and outputs, but in practice, with a small sample size, the methodology loses power to identify the inefficient decision-making units (DMUs, which in our case represent farm plots) as the number of variables increases (Kao et al. 1993; Sowlati 2005). Ideally, we would split our inputs and outputs into as many categories as possible. For instance, labor might be broken into types of labor, such as skilled and unskilled labor, or by the time of year during which labor is required, because in certain months there may be a higher demand for labor in other areas of the farm, making labor more valuable. Timber output might be divided into classes such as small, medium and large diameter and by year of harvest, and livestock output could be divided into milk and beef, and by year.

We chose as inputs land area of the system, discounted labor in person-days, discounted value of field crops used as livestock feed in 2006 Argentine pesos, and discounted value of capital and supplies invested in pesos. Field crops were separated from the other capital supplies because many small-scale farmers produce these crops for on-farm use and not for sale, so market prices may not adequately represent their value with respect to other supplies such as herbicide or diesel fuel. However, we used market prices to combine the crops such as maize, cassava and sugar cane in a single variable. In this case, the market prices do not represent the value of the crop, but rather an approximation of the relative cost of production.

The outputs were discounted timber value, discounted beef value and discounted milk value. Milk was separated from beef because it is generally used for household consumption, not for sale.

II.B.2.4 *Profitability comparisons of silvopasture in the literature*

In agroforestry literature, efficiency is usually measured with cash-flow analyses such as net present value (NPV). In the case of silvopasture, numerous cash-flow studies have shown that silvopasture can be more profitable than or at least competitive with other land uses both in Misiones and Corrientes (Colcombet et al. 2004; Esquivel et al. 2004; Fassola et al. 2004a) and around the world (Husak & Grado 2002; Dagang & Nair 2003; Clason & Sharrow 2006).

There are two problems with these cash-flow analyses. First, these analyses often tend to use idealized production scenarios for silvopasture rather than real empirical data about true on-farm production. This is mostly because of the low level of adoption in many parts of the world, leading estimates of profitability to be based on research station production or pure hypothetical models. There is a need for a productivity analysis based on true empirical data.

Second, these cash-flow techniques are appropriate measures of efficiency when market prices drive decisions, and the prices are consistent for all farms in the sample. However, when prices vary from region to region or decisions are made based on non-market values, there are difficulties in estimating an NPV. For these reasons, data envelopment analysis is an appealing tool for comparing the technical efficiency of silvopasture to other production systems, as outlined below.

II.B.2.5 *Data Envelopment Analysis*

Over the past 30 years, data envelopment analysis (DEA) has emerged as one of the primary ways of measuring technical productive efficiency. The method was pioneered by Charnes et al. (1978) and Banker et al. (1984), based on Farrell's (1957) seminal work on the measurement of inefficiency. In essence, efficiency is measured as a weighted ratio outputs to inputs, weighted in such a way that none of the decision-making units pass 1, or 100% technical efficiency.

Numerous review and meta-analysis papers (e.g. Coelli 1995; Thiam et al. 2001; Sowlati 2005; Bravo-Ureta et al. 2007) and books (e.g. Townsend et al. 1998; Ramanathan

2003; Cooper et al. 2004; Ray 2004) have been written on the subject of data envelopment analysis. A brief explanation of the methodology follows.

Debreu (1951) explained the measurement of technical efficiency with what he termed the coefficient of resource utilization. The basic concept was the foundation of Farrell's (1957) work and the entire DEA methodology. Debreu described the coefficient of resource utilization as follows:

> "This number, equal to 1 if the situation is optimal, smaller than 1 if it is nonoptimal, measures the efficiency of the economy and summarizes (1) the underemployment of physical resources, (2) the technical inefficiency of production units, and (3) the inefficiency of economic organization (due, for example, to monopolies or a system of indirect taxes or tariffs)."

This coefficient is essentially what we want to measure. Primarily, we want to know whether one farm technology represents a more productive employment of physical resources (system inputs).

Farrell (1957) noted that total efficiency could be split into two types of efficiency: *technical efficiency*, which corresponds to Debreu's (1951) coefficient of resource utilization; and price efficiency, also called *allocative efficiency* in later literature. Allocative efficiency is "the extent to which a firm uses the various factors of production in the best proportions, in view of their prices" (Farrell 1957).

If productive systems had only one input and one output, it would be simple to calculate a technical efficiency statistic. It would be the ratio of outputs to inputs: $E = y/x$, where y is the output and x is the input. A decision-making unit (DMU) that manages to produce the most output per unit of input would be rated as having the highest efficiency, and the statistic could be rescaled so that the highest efficiency is rated 100%. In this sense, a rating of 100% efficiency only means that the DMU is producing more output per unit of input *than the other DMUs*. It is quite possible that there would be ways that a DMU that is rated at 100% relative technical efficiency could increase output per unit input even further in an absolute sense. If this were to happen, we would rescale the efficiency rating so that DMU was once again rated 100%. If the other DMUs had not changed their output to input ratio, then their relative efficiency score would decrease by comparison, even though their absolute output per unit input had not changed. The fact that efficiency measurement is only relative within a sample is important because it means that the average efficiencies of two distinct samples are not comparable, except in certain cases explained below.

With multiple inputs and outputs, relative efficiency measurement becomes more complicated. An efficiency statistic might be the ratio of the weighted inputs to weighted outputs:

$$E = \frac{\sum_{i=1}^{I} w_i \cdot y_i}{\sum_{j=1}^{J} v_j \cdot x_j} \qquad (1),$$

where E is the efficiency, y_i and x_j are the inputs and outputs and the w_i and v_j are weights. If both the outputs and inputs have market values, the weights can be prices, making E a benefit-cost ratio. A benefit-cost ratio includes information both on prices and on the quantities consumed and produced, so the measure combines allocative and technical efficiency into a single hybrid efficiency measure. This is not necessarily a bad thing if we are interested evaluating the amount of profit certain technologies generate.

However, if no market prices exist for some of the inputs or outputs, the benefit-cost ratio cannot be calculated. More likely, markets do exist, but some are not utilized by the farmers because of high transaction costs. In this case, the market values may not accurately reflect the true value of the product. In addition, unobservable non-market preferences, such as time preference or simply preferring one output or input to another may affect the way farmers allocate resources. Also, prices may vary from region to region or from subset to subset of DMUs. In this case, a benefit-cost ratio might be calculated for each farm, but the ratios would not be comparable between farms (Frey et al. 2007).

Of interest to this study is whether one farm technology is more productive in general or for some subsets of farmers under robust price/value conditions, including non-market values that are unobservable. The benefit of using a measure of technical efficiency, rather than allocative efficiency, is that we do not need to make assumptions about market values or non-market preferences such as time preference. Data envelopment analysis (DEA) is a technique that has been developed to estimate relative technical efficiency. Later we discuss additional constraints, called the assurance region (AR), which can be added to the DEA formulation to place upper and lower bounds on the relative values of the inputs and outputs. This maintains the benefit of allowing a wide range of possible relative values, but places limits on how high or low they can become, which allows us to make use, to a degree, of our knowledge of market values.

DEA uses linear programming (LP) to find the values of the weights that maximize the DMU's technical efficiency, under the constraint that none of the other DMUs, or linear combinations of the other DMUs can pass 100% efficiency. The basic LP formulation of DEA is from Charnes, et al. (1978) (known as the "CCR" model for the authors):

$$
\begin{aligned}
&\max_{w_i} E_0 = \sum_{i=1}^{I} w_i \cdot y_{i0} \\
&s.t. \\
&\sum_{j=1}^{J} v_j \cdot x_{j0} = 1 \qquad\qquad (2), \\
&\sum_{i=1}^{I} w_i \cdot y_{in} - \sum_{j=1}^{J} v_j \cdot x_{jn} \le 0; \forall n = 1,\ldots, N \\
&w_i, v_j \ge 0; \forall i = 1,\ldots, I; \forall j = 1,\ldots, J
\end{aligned}
$$

where E_0 is the relative technical efficiency of DMU 0, N is the total number of DMUs in the sample. This formulation is called the primal, or multiplier formulation, as opposed to the dual, or envelope formulation below. The CCR LP above is repeated with each DMU taking the place of DMU 0.

Essentially, this model picks weights, which can be viewed as relative shadow prices, for each input and output, in order to maximize the relative technical efficiency with respect to the other firms, none of which, when facing the same shadow prices, are allowed to pass 100% efficiency. That is to say, the selected weights/values give DMU 0 the best possible efficiency measure relative to the other DMUs. This means that the DEA measure assumes optimal *allocation* of inputs and outputs, making the measure a purely *technical* one. If DMU 0 has less than 100% efficiency, it means that some other DMU has a higher weighted output to weighted input measure *even when using the weights that portray the DMU 0 in the best possible light from an allocative efficiency standpoint.*

By allowing the model to pick the weights, we ensure the measure is one of technical efficiency rather than allocative efficiency. Allocative efficiency is that under which a DMU allocates the amount of inputs and outputs it uses and produces in order to maximize profits with respect to the price. Furthermore, allowing the weights to vary provides flexibility that is useful in at least three ways. First, not using market prices to weight the inputs and outputs is especially important in cases where markets may be thin or non-existent because of high transaction costs. In those cases, the market prices that may be derived from some nearby region have little meaning. Second, prices for certain inputs or outputs may vary somewhat from region to region. Choosing a price from one region or using a mean price would affect the efficiency measure. Third, and perhaps most importantly, the preferences of individual farmers may cause him to value a particular input or output differently than the market price suggests.

All this is to say, to utilize only technical efficiency and not allocative efficiency is to make very weak assumptions. It is possible that, among two farm plots that are technically efficient, one may be much profitable because it is more allocatively efficient. It is also possible that one farm plot that is technically inefficient but allocatively efficient may be more profitable than one that is technically efficient but allocatively efficient. However, a technically inefficient plot can always become more profitable by becoming technically efficient. Furthermore, being DEA inefficient demonstrates that there is a way for each technically inefficient firm to maintain the same allocative efficiency while improving technical efficiency. Therefore, no matter its allocative efficiency, a DMU should always want to be more technically efficient.

It is for this reason that under DEA measures of technical efficiency only, we can be less concerned about distortions caused by lack of markets, government subsidies, etc. Technical efficiency avoids utilizing values for inputs and outputs, and only measures whether those particular inputs are being put to optimal use creating outputs, regardless of their value. This is important for our study, because we might otherwise be concerned about distortions in the markets.

The model above is considered the "output-oriented" model because it maximizes the weighted output production per unit of weighted input. An equivalent measure of efficiency can be found with the input-oriented model, which minimizes the weighted input use per unit of output. In the CCR model, the efficiency measures are identical, but they are distinct in the BCC model described below. The measure that is more appropriate depends on the economic perspective of the DMUs. In some cases, DMUs may have a set output they must produce (perhaps based on orders or contracts for a product) and the decisions they must make involve utilizing the fewest resources in order to produce the given amount of output. In this case, an input-oriented approach would be the most appropriate. In the case of farmers in Argentina, however, most are operating with a set, limited amount of some resource (most notably land, because renting land is not common in this region) and trying to maximize the amount of output for sale to the open market. For this reason, we chose to use the output-oriented model.

There are alternate formulations to the one in the linear program (2). While (2) is easier to understand from the point of view of varying shadow prices, an equivalent, dual mathematical formulation places weights on each DMU. This dual formulation is called the envelope formulation

$$
\begin{aligned}
&\min_{E_0,\lambda} E_0 \\
&s.t. \\
&-\sum_{n=1}^{N} y_{in} \cdot \lambda_n + y_{i0} \leq 0; \forall i = 1,\ldots,I \\
&\sum_{n=1}^{N} x_{jn} \cdot \lambda_n \leq E_0 \cdot x_{j0}; \forall j = 1,\ldots,J \\
&\lambda_n \geq 0; \forall n = 1,\ldots,N
\end{aligned}
\qquad (3).
$$

This LP can be best understood intuitively as modeling DMU 0 as a linear combination of the other DMUs. If there is a linear combination of other DMUs that produces at least as much of each output and uses a quantity less than or equal to the inputs used by DMU 0, with at least one strict inequality, then DMU 0 will be rated as inefficient. In other words, the efficient firms and the linear combinations of efficient firms form an envelope, which represents the production possibility frontier. The inefficiency level of an inefficient firm is calculated as the relative distance from the efficient envelope.

The CCR model is based on the assumption of constant returns to scale, that is, small and large scale DMUs are equally capable of achieving 100% efficiency. The model formulated Banker et al. (1984) (called the "BCC" model, for its authors) adds a constraint to the CCR model (3) to allow for variable returns to scale:

$$\sum_{n=1}^{N} \lambda_n = 1 \qquad (4).$$

Adding the constraint (4) to model (3) allows us to assume that the technology has variable returns to scale, and answers the question, "Given the scale of DMU 0, what is DMU 0's technical efficiency relative to DMUs of similar scale?" The resulting efficiency measure factors out any inefficiency that might be due to the scale of the DMU and results in a measure of efficiency that is purely due resource utilization. We will call the efficiency calculated with the BCC model *pure technical efficiency* and denote it E^P.

Once the total technical efficiency and pure technical efficiency have been calculated from the CCR and BCC models, respectively, we can calculate the *scale efficiency*. The scale efficiency represents the portion of the total technical efficiency that is due to the size of the DMU. For example, if a technology has increasing returns to scale, a small DMU will not be able to achieve the same ratio of outputs to input as a large DMU, if both are utilizing their resources efficiency (i.e. if pure technical efficiency = 1). The scale efficiency, E^S, is the ratio of the total technical efficiency to the pure technical efficiency (Banker et al. 1984):

$$E_0^S = \frac{E_0}{E_0^P} \text{, or } E_0 = E_0^P \cdot E_0^S \quad (5).$$

In this manner, each technical efficiency measure (scale, pure and total) is a number between 0 and 1, with 1 representing efficiency. E is the product of E^S and E^P and can only be equal to 1 if both E^S and E^P are equal to 1.

We utilized the output-oriented dual CCR model (Charnes et al. 1978) to estimate the total technical efficiency and the BCC model (Banker et al. 1984) to estimate pure technical efficiency (assuming variable returns to scale) and scale efficiency. The models were programmed using MATLAB.

II.B.2.6 *Theoretical Strengths and Weaknesses of DEA*

DEA offers numerous benefits for efficiency analysis. Often cited as a benefit is the non-parametric nature of DEA, which means that the DEA practitioner does not need to specify a functional form. Also, DEA is suited for comparing the efficiency of "decision-making units" (here: farms or households) in situations with multiple inputs and outputs of which some or all have no market value.

By their very essence, agroforestry systems are multiple-input, multiple-output systems. In many cases, some or all of the inputs and outputs are non-market goods or services. For instance, an agroforestry practitioner may use family labor as an input and receive fuelwood for household consumption, and erosion control as outputs. Prices for some inputs and outputs may vary from region to region, some factors of production may have thin or non-existent markets, or outputs may be used for household consumption. These situations are especially common in rural areas and in developing countries, where agroforestry systems may be useful. For these reasons, DEA is an appropriate efficiency-measuring technique for agroforestry (Alene et al. 2006).

Data envelopment analysis can be used to improve understanding of agroforestry production for researchers, extension agents, and most importantly, farmers. Ideally, this method would be used to show farmers how they can improve upon the efficiency of their own agroforestry parcels and to facilitate farmer-to-farmer interactions (Salehirad & Sowlati 2005; Frey 2008).

One of the key assumptions behind DEA that can be one of its weaknesses is the homogeneity of DMUs. That is, the various DMUs are producing the same outputs with the same inputs, and that there are no underlying, inherent differences between specific DMUs that make one subset less able to achieve maximum output per unit of input, given proper management. For instance, in farming applications, DEA would assume that there are no differences in the quality of soils, climate, etc., from one farm to another, which would make one farm inherently more or less productive than other. This is a very important, potentially fatal, weakness of DEA in farming situations, and one which must be considered. We deal with this below by using only within-farm efficiency comparisons.

Also, the deterministic nature of DEA makes it sensitive to outliers or errors in measurement or stochastic variation (Thiam et al. 2001). Suppose, for example, that one farmer, or some small subset of farmers, had a very good (or bad) year in terms of productivity because of very localized weather conditions. Standard regression techniques would account for this variability theoretically by incorporating an error term. DEA, however, would attribute all of this variability to "efficiency", implying that the differences are due to good or poor management of the resources, even though they might be due to other uncontrollable factors.

In our survey, we accounted for this weakness in DEA with respect to stochastic variability by asking farmers about typical, representative parcels and representative years. Unfortunately, in some cases this may cause some farmers to think rather hypothetically instead of concretely in terms of remembering precise estimates of input use and output production, so there could be some error. Fortunately for our purposes, as explained below, we only compare plots that are operated by the same farmer, so he or she is more likely to have the same hypothetical biases when recounting inputs to and outputs from two systems than would be the case if two separate farmers were reporting on the two systems. However this may not always be the case; a farmer might possibly view one system more favorably because of conversations with extension agents, etc., and unintentionally bias the sample. While this is a potential flaw, it is our belief from conversations with farmers and measurements in the field that these errors are relatively small.

II.B.2.7 *Technical implementation of DEA*

There are numerous practical issues involved with the implementation of DEA for real-world questions with empirical data. There are two points that have not received satisfactory treatment in the literature and have important implications for this study: the comparison of the efficiency of distinct agricultural technologies, and methods for controlling for unobserved differences between farms and farmers.

II.B.2.7.1 *Comparison of the efficiency of distinct agricultural technologies*

DEA provides an estimate of *relative* technical efficiency among the DMUs in the sample, not any type of measure of *absolute* technical efficiency. Because DEA measures efficiency relative to an envelope of the data from the sample, an efficiency score of 1 signifies efficiency relative only to the other observations in the sample, not relative to any theoretical efficiency standard. This has important implications for the comparison of the efficiency of technologies. Some literature has taken a high average DEA score of the set of data being analyzed to mean that those DMUs are more efficient than groups with a lower average score from a separate DEA analysis (e.g. Alene et al. 2006; Binici et al. 2006). A high average DEA efficiency score for a set of DMUs simply indicates a measure of relative homogeneity among the efficiency of the DMUs, not necessarily that the set as a whole is more efficient than another set with a lower average score from a separate DEA efficiency measurement.

Such a situation is demonstrated in Figure II.B.1 though Figure II.B.3. In Figure II.B.1, we present a diagram for one hypothetical set of DMUs. The dotted line is what we term the “true” or “absolute” technical efficiency frontier, which is what DMUs should be able to achieve if they have truly excellent management of resources and utilize the most productive technology. However, in this case, none of DMUs come close to the “true” efficiency frontier. In fact, they are fairly homogeneously poor performers in the absolute sense. The solid line represents the envelope of the data, which would be the efficiency frontier calculated by DEA. In this case, DEA would show that the DMUs have quite high relative technical efficiency on average; that is, the inefficient DMUs are not far from the relatively efficient DMUs. In Figure II.B.2, we have a different scenario. Suppose these firms are producing the same output using the same input as the DMUs in Figure II.B.1, but under a different management scheme. These firms, on average, are closer to the “true” efficiency frontier. However, they are less homogeneous, so the distance to the DEA relative efficiency frontier is further, leading to a low average relative efficiency. If one were to compare the average DEA efficiency of the set of DMUs from Figure II.B.1 to that of Figure II.B.2, one might wrongly conclude that the DMUs of Figure II.B.1 are more efficient, or utilize resources better. The only accurate conclusion one should draw in this case is that the DMUs in Figure II.B.1 are more homogeneous.

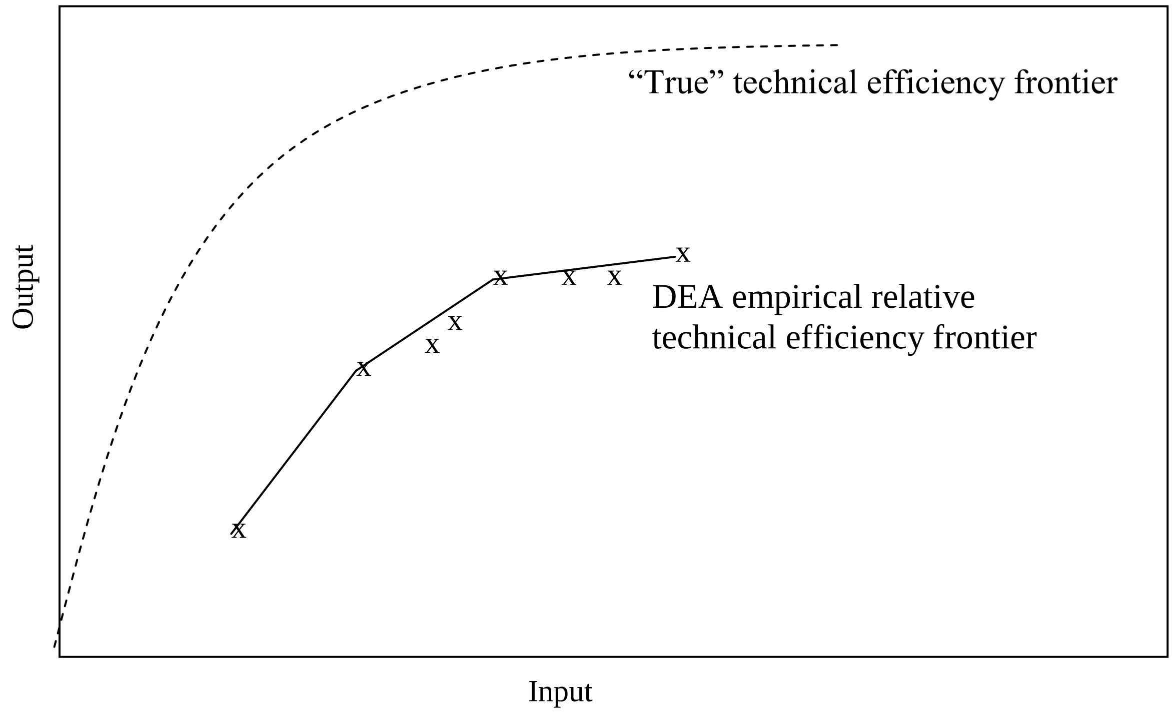

Figure II.B.1. Hypothetical DEA empirical relative technical efficiency frontier, assuming variable returns to scale, for a group of DMUs that are homogeneous, but inefficient in an absolute sense.

DMUs are marked with "x". Note that, because the DMUs are close to each other in terms of output to input ratio, DEA will rate them as relatively efficient (i.e. close to the empirical frontier).

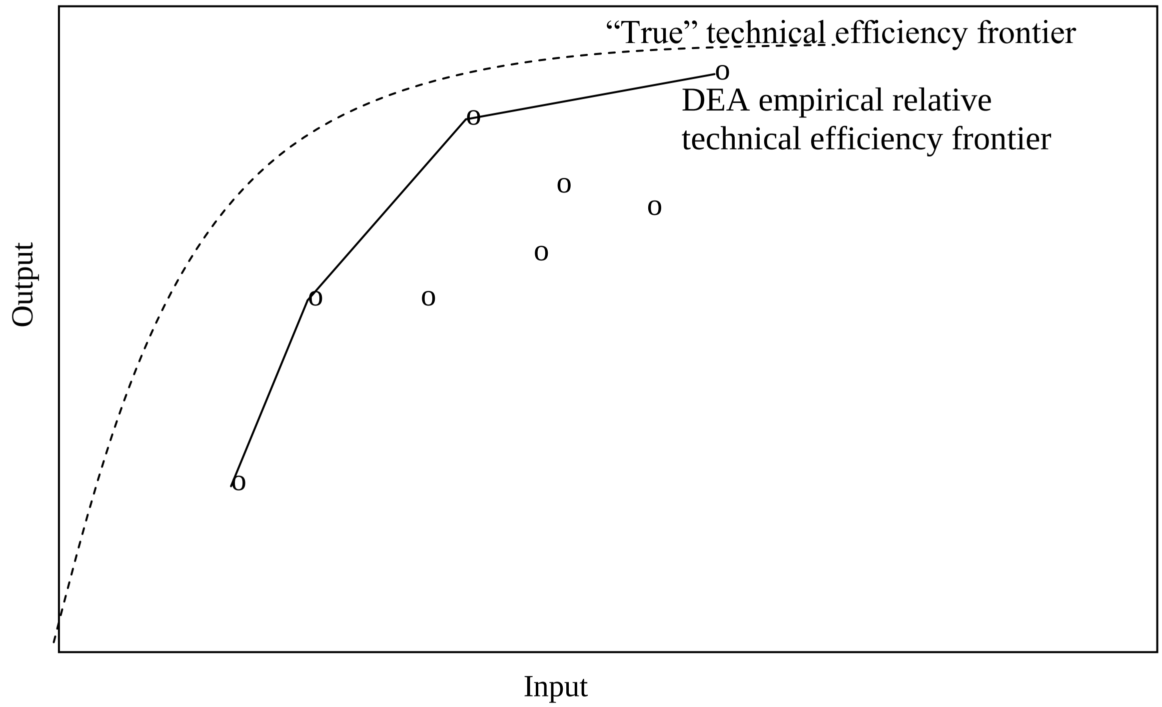

Figure II.B.2. Hypothetical DEA empirical relative technical efficiency frontier, assuming variable returns to scale, for a group of DMUs that are heterogeneous, but fairly efficient in an absolute sense.

DMUs are marked with "o". Note that, because the DMUs are spread farther apart terms of output to input ratio, DEA will rate them as relatively inefficient (i.e. far from the empirical frontier).

The only appropriate way to compare distinct sets of DMUs is to include them in the same model, as in Figure II.B.3. In this case, the DMUs from the set in Figure II.B.1 would be accurately classified as being further from the relative efficiency frontier.

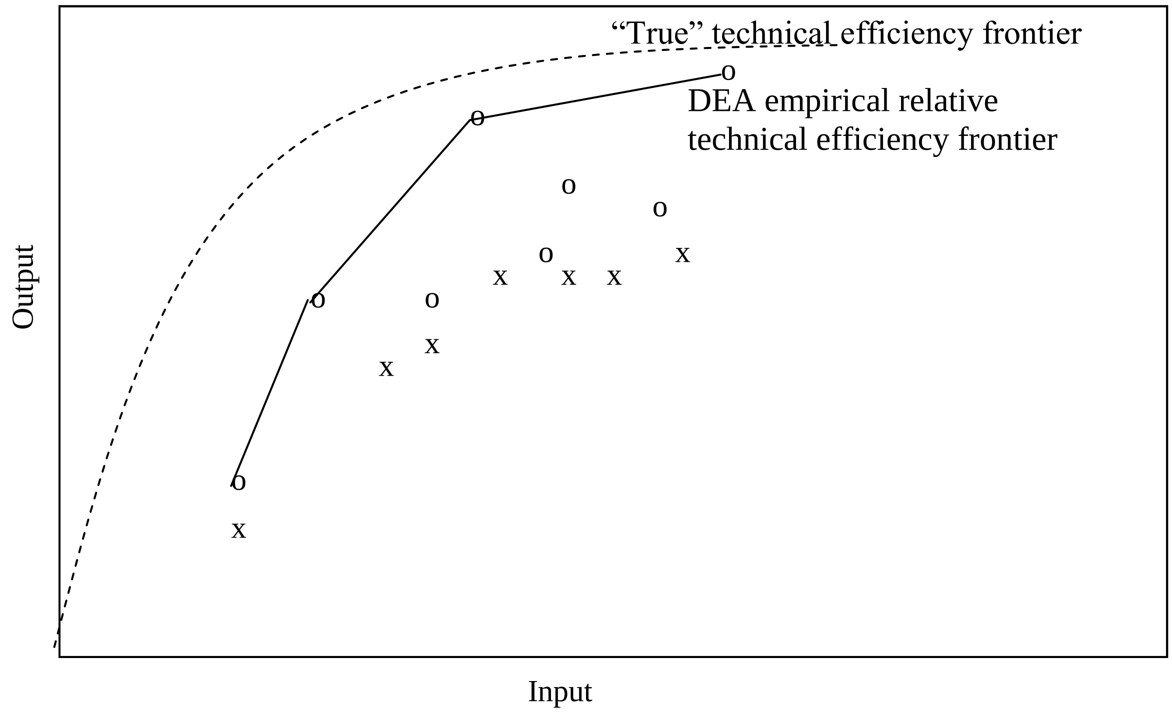

Figure II.B.3. Hypothetical DEA empirical relative technical efficiency frontier, assuming variable returns to scale, combining the DMUs from Figure II.B.1 and Figure II.B.2.

DEA correctly calculates that the set of "x"s is less efficient, on average, than the set of "o"s.

In principle, we can only compare the efficiency score of sets of DMUs when all the DMUs have their efficiency measured together in the same model. This sounds simple enough, but is complicated by the fact that the DMUs must have sufficiently similar inputs and outputs for DEA to be effective (Haas & Murphy 2003). If we think of DEA creating a frontier in an *n*-dimensional space where each of the *n* dimensions represents a distinct input or output, this becomes clear. For instance, if one subset of a sample is dairy farms and the other subset is crop farms as in Latruffe (2004), and none of the farms produce both outputs, then each subset will be measured only along one of the two dimensions, rendering them *de facto* separate DEA sets, even when measured in the same model. In order to maximize each DMU's efficiency, DEA will model each DMU as placing zero value on the output that it does not produce.

Statistical comparisons between the technical efficiency scores of the two subsets would be largely devoid of the meaning a researcher would like to attribute to them, such as that one group of farms or farm technology is more efficient than the other. Latruffe (2004) gets around this by multiplying by price per unit output to get both outputs into common terms (i.e. total revenue). This is satisfactory in some situations where revenue is the important output, but not in the case where each DMU might value different resources differently (such as non-market goods and services), which is the case where DEA is most useful.

II.B.2.7.2 *Assurance region*

A simple compromise between allowing DEA to place zero-value weights on the outputs that are not produced and requiring that all outputs be valued exactly at their market prices is to place limits on the variation of the relative weights. This method, known as the "assurance region" method, was first developed by Thompson et al. (1986). It is very easy to add additional constraints into the DEA primal (multiplier) LP (2) of the form:

$$LB \leq \frac{w_1}{w_2} \leq UB \qquad (6),$$

where the w_i are the weights or values that each DMU places on input or output *i*, and *LB* and *UB* are the lower and upper bounds of the ratio of weights. These can be reformulated for use in the dual (envelope) LP (3) (Ray 2004).

In essence, adding restrictions to the weights used creates a measure of efficiency that is a compromise between a pure technical efficiency measure and a cost-benefit measure. By including some of the a priori knowledge we have from markets, we acknowledge that market prices are likely to be central in farmers' valuation of inputs and outputs, while at the same time by placing upper and lower bounds rather than firm prices, we recognize that farmers also have unobservable non-market values of many items, including time preferences (personal discount rates), cultural values, etc.

Table II.B.2 shows lower and upper bounds we placed on the ratios of weights in this study. No limits were placed on the ratios of input to output weights, only input to input and output to output. In cases where the pair includes two inputs or outputs both expressed in peso terms, it would be expected that the ratio would be approximately equal to one, for instance, farmers value a peso worth of beef the same as a peso worth of timber. However, the goal is to allow some flexibility to allow for differences in farmers preferences, slightly different market prices from one region to another, etc. While the decision for how much flexibility to allow is somewhat arbitrary, it was decided that a ten-fold differential, for instance, a farmer may value a peso worth of beef ten times more than or one-tenth as much as a peso worth of timber, would be more than adequate to encompass farmers' preferences and other factors and still greatly enhance the power of the DEA tool. Therefore, the lower and upper limits for the ratio of weights of the timber to beef are 0.1 and 10, respectively. In the cases where the input or output may not be commonly traded on the market in some communities (labor, field crops, milk), an additional order of magnitude was added to both the upper and lower bound. This allows for up to a two order-of-magnitude differential in relative values in either direction, from 0.01 to 100. This situation applied to all of the remaining inputs and outputs except land and labor. The market value of land was generally considered to range from 1000 to 7500 pesos/ha, depending on tenure and other factors, so the weight was allowed to vary from 500 to 50,000 times the weight of a peso. Labor was valued at 15 to 50 pesos/day, so the weight was allowed to vary from 3 to 300.

Table II.B.2. Upper and lower bounds on the relative weights of inputs and outputs (Assurance region).

INPUTS			OUTPUTS		
Weight ratio	**Lower Bound**	**Upper Bound**	**Weight ratio**	**Lower Bound**	**Upper Bound**
Labor (days) / Land (ha)	0.00006	0.6	Timber (pesos)/ Beef (pesos)	0.1	10
Capital (pesos) / Land (ha)	0.00002	0.002	Timber (pesos)/ Milk (pesos)	0.01	100
Crops (pesos) / Land (ha)	0.000002	0.02	Beef (pesos)/ Milk (pesos)	0.01	100
Capital (pesos) / Labor (days)	0.00333	0.333			
Crops (pesos) / Labor (days)	0.000333	3.333			
Crops (pesos) / Capital (pesos)	0.01	100			

II.B.2.7.3 *Using efficient peers to test whether technologies are acting as de facto separate DEA sets*

In principle, then, using the Assurance Region method in the manner described above can help to unify different technologies, some of which do not use all the inputs or produce all the outputs that the others do. However, we should still be concerned that the separate technologies might remain substantially separated in the DEA efficiency measurement. That is, we should be worried that pasture systems are only being compared to other pasture systems, forestry to forestry and silvopasture to silvopasture. If plots of one technology are mostly being measured against plots in the same technology, then there is no basis for comparison of the efficiency statistics.

Fortunately, we can use a quick check of "efficient peers" to see whether plots are being measured solely or principally against plots of the same technology. Consider that in DEA each inefficient DMU is measured against and compared to a linear combination of efficient DMUs. The DMUs that form this linear combination are called the "efficient peers" of the inefficient DMU, and can easily be output from the DEA linear program (Cooper et al. 2004; Ray 2004). This serves as an easy way to check whether DMUs of one type are only being measured against DMUs of the same type, and thus becoming a *de facto* separate DEA set.

II.B.2.7.4 *Controlling for unobserved differences between farms*

When comparing the efficiency of different farm technologies, one must control for the differences in the farms and farmers utilizing each technology. Some studies try to control for these factors using a regression after the efficiency analysis (e.g. Otsuki et al. 2002; Latruffe et al. 2004; Davidova & Latruffe 2007). While it is possible to regress DEA efficiency on numerous control variables, there is always the risk of omitting important variables, and even in a more general sense the results this second-step regression may be biased. This is because the following question arises when performing an *ex-post* regression on DEA results: Which factors should be included as inputs in the DEA calculation, and which should be included as explanatory variables in the regression (Just 2003)? Just (2003) explains the potential for biased estimates for the coefficient values in the regression:

> "A little-recognized fact is that [the choice of which variables to include in the DEA analysis and which to include in the regression] has an important effect on endogeneity bias. To see this, note that the approach first tries to attribute all variation among firms to efficient behavior of firms. Only then are the implicit residuals regressed on other variables in an ex post analysis, whether with formal regression or informal classification analysis. Stepwise regression, which is conceptually identical, has been discredited long ago. It produces biased results because it first tries to attribute all of the variation to one set of variables, thus biasing their coefficients away from zero, and then tries to attribute only the remaining variation to the remaining set of variables, thus biasing their coefficients toward zero."

Haas and Murphy (2003) discuss several potential methods for controlling for operating conditions, but find that none of them appear to be superior to using the unadjusted CCR efficiency scores, so using the unadjusted scores is preferred.

Econometricians have often used fixed-effects panel methods to control for all unobserved factors related to one particular observation through time. DEA practitioners have also used this concept when observations exist at various points in time. A common practice is to use a Wilcoxon signed-rank test to test whether farms' efficiencies have increased over time, making paired comparisons of the efficiencies of individual farms at two points in time (Fraser & Cordina 1999; Luo 2003).

To my knowledge the Wilcoxon signed-rank test has not been used to test for efficiency differences in multiple farm technologies at the same point in time, but the same logic applies. Since many of these farms practice multiple technologies, we can control for characteristics of individual farms and farmers by making paired comparisons of technologies on the same farms. This test also avoids making parametric assumptions about distributions. First, the difference in efficiency scores, d_i, between the two technologies being compared is calculated for each farm i. The d_is are given rank r_i in order of increasing absolute value. The test statistic, T^+ is calculated by:

$$T^+ = \sum_{i=1}^{n} r_i I(d_i > 0) \qquad (7),$$

where $I(d_i > 0)$ is an indicator function equal to 1 if $d_i > 0$ and 0 otherwise (the test should be altered to calculate T^- using $I(d_i < 0)$, when appropriate). The statistic is used to calculate a p-value assuming that d_i has an equal probability of being positive or negative (Wilcoxon 1945; Siegel 1965). If the p-value is sufficiently small, we can reject the null hypothesis that the two technologies have equal efficiency. We utilized a two-tailed hypothesis test because of competing possible alternative hypotheses: while cash-flow profitability studies suggest that silvopasture systems are a more efficient use of land, the lack of large-scale spontaneous adoption suggests that it could actually be less efficient.

II.B.2.8 *Testing for increasing or decreasing returns to scale*

The sum of the weights of the CCR dual (envelope) model can be used to determine whether a DMU is operating at an efficient scale (if the sum equals 1, constant returns to scale, CRTS), is smaller than the efficient scale for its particular combination of inputs and outputs (sum < 1, increasing RTS) or is larger than the efficient scale (sum > 1, decreasing RTS). The sum was recoded as -1 for DRTS, +1 for IRTS and 0 for CRTS. A sign test, which is slightly different from the Wilcoxon signed-rank test, was used to test whether silvopasture, forestry and pasture were significantly more likely to have increasing or decreasing returns to scale as a group than would be expected under the null hypothesis that increasing and decreasing returns to scale are equally likely. This test was conducted on the entire sample, then on the sub-groups of small-, medium- and large-scale farms separately.

Usually, the sign test, like the Wilcoxon signed-rank test is used to test for differences in paired observations. In this case, however, we utilized the same methodology to test whether a group of single observations (the nature of returns to scale for each plot) is more likely to have positive or negative sign. Zero-valued observations (indicating CRTS) are thrown out, so that all remaining observations are either positively (indicating IRTS) or negatively (indicating DRTS) signed. The sign test statistic (*M*) is simply:

$$M = \frac{n^{+} - n^{-}}{2} \qquad (8),$$

where n^+ and n^- are the number of positively- and negatively-signed observations, respectively. A p-value is determined by the binomial distribution under the null hypothesis that positive and negative signs are equally likely.

II.B.3 RESULTS AND DISCUSSION

II.B.3.1 *Inputs and outputs*

The mean estimated inputs and outputs for silvopasture, (conventional plantation) forestry and (full-sun) pasture for small, medium and large scale farms are given in Table II.B.3. On average, small scale farmers use more labor per hectare for all the systems than medium or large scale farmers. Also, small scale farmers used less capital inputs, except in the case of silvopasture. This was probably distorted by the fact that many small scale farmers received in-kind provision of capital inputs from government programs for silvopasture. Large scale farmers did not cultivate their own crops to supplement the diet of cattle, nor did they produce dairy products.

Table II.B.3. Mean input and output levels for the three production systems on each of the three farm scales.

		INPUTS				OUTPUTS		
Farm Scale	System	Mean System Area (ha)	Mean Discounted Labor (person-days/ ha)	Mean Discounted Capital (pesos/ ha)	Mean Field Crops (pesos/ ha)	Mean Timber Revenue (pesos/ ha)	Mean Beef Revenue (pesos/ ha)	Equivalent Milk Revenue (pesos/ ha)
Small	Silvopast.	5.8	161	4972	1640	17511	2023	3686
	Pasture	9.0	94	1358	2584	0	3579	2916
	Forestry	2.3	78	4513	0	13908	0	0
Med-ium	Silvopast.	92.0	84	9148	377	15357	6539	40
	Pasture	44.5	48	1714	440	0	2904	40
	Forestry	33.5	38	5605	0	12913	0	0
Large	Silvopast.	1136.6	40	3829	0	8915	1925	0
	Pasture	331.6	55	2063	0	0	5496	0
	Forestry	1265.0	71	8964	0	38214	0	0

II.B.3.2 *Total and pure technical efficiency estimation*

DEA total technical efficiency under constant returns to scale assumption was calculated with the CCR model, and scale efficiency and pure technical efficiency under variable returns to scale were calculated with the BCC model for all farm plots in the sample, using an assurance region. The total technical efficiency is appropriate when considering the over-arching productivity of a plot per hectare, while the pure technical efficiency is appropriate to consider how well farmers are using their resources, factoring out inefficiencies that might be due to the scale of the plot. By construction, some of the plots will be rated at 100% efficiency. For total technical efficiency, which is equal to pure technical efficiency times scale efficiency, there were 4 of 44 silvopasture, 1 of 33 pasture and 1 of 14 forestry plots operating at 100% efficiency relative to the full set of silvopasture, pasture and forestry plots. For pure technical efficiency, 5 silvopasture, 2 pasture and 2 forestry were operating at 100% relative efficiency.

II.B.3.3 *Using efficient peers to test whether technologies are acting as de facto separate DEA sets*

It is important to check the efficient peers of the inefficient DMUs to make sure that efficiency comparisons are being made between DMUs of the different technologies (silvopasture, pasture, forestry) rather than simply among them. There was evidence of integration among the all of the three technologies within the DEA measurements, with the forestry plots being the least integrated, especially in the total technical efficiency measurement (Table II.B.4). Unfortunately, there is no simple statistic we can calculate to determine whether or not the three subsets are sufficiently integrated to merit consideration.

Based on the results in Table II.B.4, we should be skeptical of comparisons of that would suggest forestry plots are less efficient than either silvopasture or pasture. 100% of the efficient peers for inefficient forestry plots in the total technical efficiency calculation are other forestry plots, and a large majority in the pure technical calculation. This is highly suggestive that the forestry plots have formed a *de facto* separate DEA set, and are being compared to one another rather than the silvopasture and pasture plots. A low average technical efficiency measurement would suggest a lack of homogeneity among forestry plots rather than forestry being actually less efficient than silvopasture or pasture.

Inefficient silvopasture and pasture plots, on the other hand, had a higher percentage efficient peers that were among other technologies. This suggests that it is fair to compare them to the other technologies. The fact that no pasture plots are efficient peers for silvopasture, but a large number of silvopasture plots are efficient peers for pasture suggests that silvopasture is more efficient than pasture, which is demonstrated more clearly below.

Table II.B.4. Percent of efficient peers for each type of inefficient plot that belong to each technology.

	Total Technical Efficiency Percentage of efficient peers that are:			Pure Technical Efficiency Percentage of efficient peers that are:		
	Silvopasture	Pasture	Forestry	Silvopasture	Pasture	Forestry
Silvopasture	69%	0%	31%	66%	0%	34%
Pasture	80%	20%	0%	71%	10%	19%
Forestry	0%	0%	100%	14%	0%	86%

II.B.3.4 *Comparison of efficiencies*

The average relative total and pure technical efficiency levels for the three technologies (silvopasture, pasture and forestry) are shown in Figure II.B.4. The average total technical efficiency levels for the three technologies at first seem fairly low at 50.9%, 23.4% and 40.0% for silvopasture, pasture and forestry systems, respectively. This means that an average farm produces only 50.9%, 23.4% or 40.0% of the weighed output that a farm on the efficient frontier would produce using the same inputs. Recall that the technical efficiency measure accounts for variable non-market values and preferences that farmers may have for various inputs and outputs. In light of this, it is somewhat disconcerting at first that relative productivity could be so low on average, but we should remember that the farms are operating under quite variable circumstances such as soil quality, education and extension, etc. This clearly reinforces the need to control for differences between farms, which is achieved by using the Wilcoxon signed-rank test.

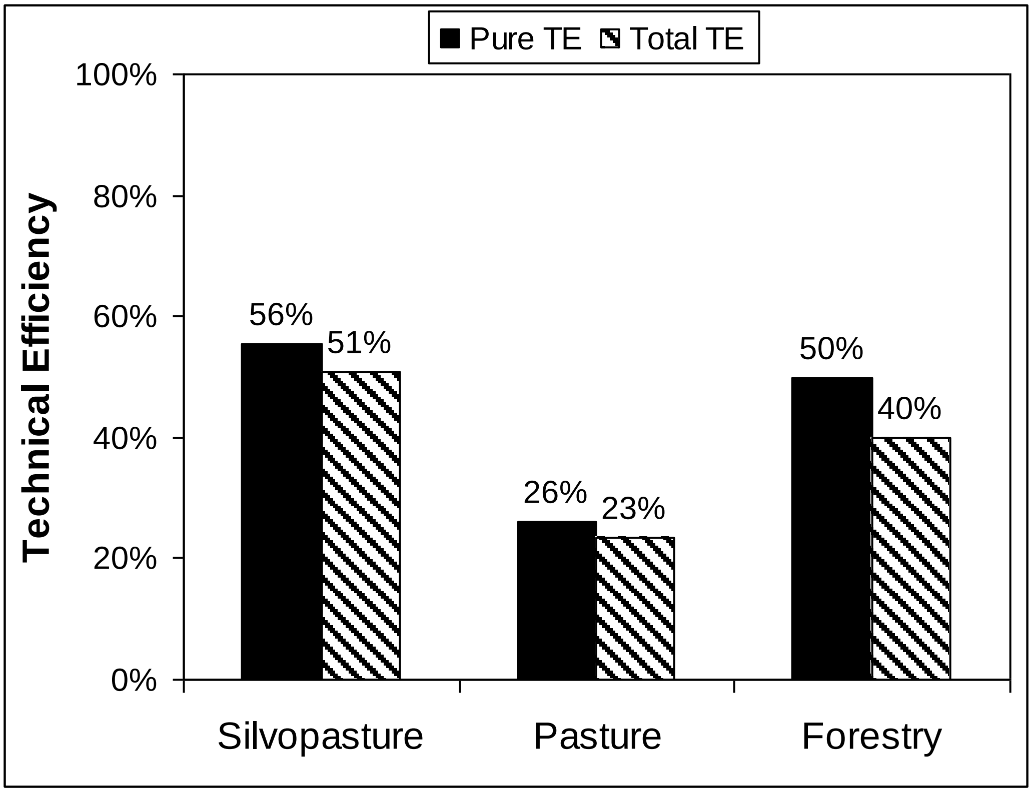

Figure II.B.4. Pure (variable returns to scale, BCC model) and Total (constant returns to scale, CCR model) Technical Efficiency for silvopasture, pasture and forestry systems.

The Wilcoxon signed-rank test statistic (T^+) for pairwise comparisons of silvopasture and pasture (n = 33) was 265.5, corresponding to a two-tailed p-value < 0.0001, meaning that the efficiencies of pasture and silvopasture plots on the same farms were significantly different. It is important to note that if we operate with the alternative hypothesis that silvopasture is more efficient than pasture as net present value comparisons suggest, the p-value would be even smaller. Comparisons between silvopasture and forestry (n = 14) resulted in a T^+ of 25.5 (two-tailed p-value = 0.1189) and between forestry and pasture (n = 12) resulted in a T^+ of 9 (p-value = 0.5186), neither of which were statistically significant. The tendency appears to be that plantation forestry is of intermediate efficiency between pasture and silvopasture, but the sample of forestry plots was not large enough to detect any difference.

When using pure technical efficiency, there is a similar pattern. The pairwise comparison of silvopasture and pasture yields a T^+ of 246, equivalent to a two-tailed p-value < 0.0001, meaning that silvopasture is a more efficient use of resources than pasture, even when factoring out the differences in relative efficiencies due to scale. Comparing silvopasture and forestry yields a T^+ of 11.5 (p-value = 0.5016) and forestry and pasture a T^+ of 16 (p-value = 0.2334), neither of which are statistically significant. Again, plantation forestry appears to be of intermediate productivity between pasture and silvopasture.

The pairwise comparison of plots is an important way to control for between-farm variability, including farmers' education, cultural values and age; the broad land classification; and many other factors. However, it does not control for within-farm variability. It may be possible that silvopasture plots are more often placed on better sites within a farm and pasture plots on worse sites, or different extension agents aid the farmer with different aspects of farming (some extension agents specialize in agroforestry while others work more with livestock). Unfortunately, farm-level soil-survey data does not exist and conducting soil tests on every parcel of every farm would be extremely costly in terms of time and money. Even then, an analysis might be faced with within-plot soil variability. Also, controlling for extension agent differences would be quite difficult.

Even though completely controlling for within-farm variability is difficult, there are some simple things that can be done. While no data exists for the previous state of the pasture plots, it is known that in many cases pastures are implemented on degraded old agricultural fields. Data does exist for the previous state of the silvopasture plots. Of the 44 silvopasture plots, 5 were planted on parcels that were clear-cut high-quality native forest, 5 were clear-cut secondary native forest, 5 were clear-cut plantation forests (pines), 7 were old yerba mate plantations (a perennial woody plant whose leaves are harvested annually), 10 were old agricultural fields and 12 were old pastures.

It may be the case that silvopasture plots and plantation forests in our sample are planted on the worst, most marginal agricultural land. This is certainly the case in many parts of the world, where trees are only planted in areas where the soil is not productive for anything else, including pastures. If this were the case in our sample, it would only further reinforce our finding that silvopasture is more productive that pasture, as it would have been shown to have higher productivity than pasture despite poorer soils. It would perhaps confound further any results from plantation forestry, but since our initial results were inconclusive with plantation forestry, we will ignore it for the time being.

However, despite what we may believe about what types of soils are generally used for silvopasture plots, it is reasonable, or at least possible to think that those silvopasture plots planted on cleared native and plantation forests may have better soil fertility characteristics than pasture plots planted on old agricultural fields. It is likely that the silvopasture plots that were implemented on old pastures, old agricultural fields and cleared yerba mate plantations may more closely reflect the state of soils used for pastures.

A Wilcoxon signed-rank test was conducted using only those silvopasture plots that were planted on old pasture, agricultural or yerba mate fields. The same difference and statistical significance was found between silvopasture and pasture as with the full sample. For the total technical efficiency CCR model, the T^+ was 139 (n = 24), corresponding to a two-tailed p-value < 0.0001. For the pure technical efficiency BCC model, the T^+ was 124.5, corresponding to a two-tailed p-value < 0.0001.

The same analysis was conducted for only silvopasture plots planted on old agricultural fields and pasture, excluding old yerba mate fields. Old yerba fields might retain somewhat more fertility than agricultural fields or pasture because the perennial plant's roots help somewhat to prevent erosion. The same difference was found for the CCR model (two-tailed p-value = 0.0001) and the BCC model (two-tailed p-value < 0.0001).

Recall that the within-farm pairwise comparison holds farmer and farm characteristics constant. While the pairwise comparisons demonstrate that silvopasture is more likely to be technically efficient for any particular farm than pasture, it is important to remember, as noted earlier, that one pasture plot was operating at 100% efficiency relative to the full set of silvopasture, pasture and forestry plots. The same farmer had silvopasture operating at 100% efficiency relative to the other plots. This means that it is possible to operate pasture efficiently in certain circumstances even though in most cases silvopasture is more likely to be efficient. These circumstances might be cases where specific sites or soil types are more suited for pasture, or farmers are more experienced and knowledgeable about livestock than timber.

These results are broadly consistent with the literature that uses cash-flow analyses to compare profitability of the three systems. Esquivel et al. (2004) found that silvopasture had the highest annual equivalent income (AEI) of the three systems, equal to 441 pesos/ha/yr at a 7% discount rate, while forestry had an AEI of 311 pesos/ha/yr and pasture 49.5 pesos/ha/yr.

Because of this relatively high profitability of silvopasture, confirmed by this study's results which suggest that silvopasture is more efficient than pasture under broad relative price conditions, we should expect ongoing adoption. The fact that adoption is only moderate is still somewhat troubling. It is possible that many potential future adopters have adopted a wait-and-see attitude towards silvopasture plots they see on friends' and neighbors' farms. Since silvopasture takes a long time (around 20 years) to produce one of the main outputs, timber, diffusion is likely to be slow. There is still an important role for education and incentive programs. All of the adopters in the survey had at least some contact with governmental extension or professional consultants, suggesting that knowledge of the system is important in adoption. Also, education may be important for good management, in order to obtain the high efficiency rates demonstrated here. Government incentive programs are likely to be especially important for small farmers, who are constrained by up-front capital costs.

II.B.3.5 *Scale efficiency and returns to scale*

The nature of returns to scale (RTS), whether increasing, decreasing or constant, was calculated for each plot using the weights from the CCR model. A sign test was conducted to test whether increasing (IRTS) or decreasing RTS (DRTS) were more common for any of the technologies than would be expected under the null hypothesis that IRTS and DRTS are equally likely. The average scale efficiencies and nature of RTS for each technology by farm scale group is in Table II.B.5. The sign test on the entire set of silvopasture parcels can reject the null hypothesis that IRTS and DRTS are equally likely for silvopasture. IRTS and DRTS are not equally likely; IRTS are more likely for silvopasture. For pasture, we could not reject the null. For forestry, we can reject the null hypothesis. For forestry the positive sign of *M* indicates that IRTS are more likely.

Table II.B.5. Average scale efficiencies, sign test M statistic and two-tailed p-value for returns to scale of three farm technologies by farm scale.

	Silvopasture			Pasture			Forestry		
	Scale Eff.	*M*	p-value	Scale Eff.	*M*	p-value	Scale Eff.	*M*	p-value
Small	93.5%	3.5	0.09	92.3%	0.5	1.00	77.1%	3	0.03
Medium	96.8%	4.5	0.04	98.2%	2	0.39	86.4%	3	0.03
Large	87.2%	1	0.77	70.2%	-2.5	0.13	99.3%	0.5	1.00
All farms	90.3%	9	0.006	86.3%	0	1.000	91.0%	6.5	0.000

Positive *M* values represent increasing returns to scale, negative decreasing.

There are several reasons why forestry might demonstrate IRTS. First, small-scale farmers seemed less able to market low-value products such as timber thinnings for paper pulp. Second, practices such as pruning and thinning are difficult to master and large-scale farms are able to obtain labor that is specialized for the task. Both of these reasons why forestry might have IRTS would also apply to silvopasture. However, the tendency for IRTS for silvopasture is not as strong as for forestry.

A more detailed examination of RTS by farm scale group provides more insights into its nature. The IRTS for forestry are statistically significant for small and medium farms. Large-scale farms appear to be closer to operating at efficient scale for forestry. The same conclusion is true for silvopasture plots. However, silvopasture seems to have weaker IRTS than forestry. This can be observed in the lower statistical significance (higher p-value) of IRTS for small farms with silvopasture. This is despite the smaller sample size for forestry, which makes finding statistical significance more difficult. For pasture plots, large-scale farms are likely to be operating under a portion of the production frontier with DRTS, while small- and medium-scale farms appear to be close to efficient scale. One possible reason for DRTS with pasture systems is that family labor on small farms may develop a more intimate knowledge of each particular animal, making care of the cattle more productive. Perhaps the IRTS for silvopasture are weaker than forestry because silvopasture includes a pasture component, which weakly favors smaller farms.

The existence of IRTS or DRTS does not suggest that forestry or silvopasture is not profitable for small farms, or that cattle-ranching is not profitable for large farms. What this does suggest is that the quantity of output per unit of input in some cases might be limited by the scale of the farm.

These results support the hypothesis that the nature of RTS depend on numerous factors, including the characteristics of the particular technology. Further, the nature of returns to scale may be variable at different points along the production frontier. For some technologies, there may be increasing returns to scale for small farmers, but decreasing returns to scale for large farmers.

Small-scale farmers in the region have expressed a preference for silvopasture over forestry based on a preference for receiving more revenue in the short-term (Frey et al. 2007). According to these results, there may also be reasons for supporting silvopasture over forestry on efficiency grounds. Assuming optimal use of resources at their scale, small-scale farmers using silvopasture produce more weighted output for each unit of weighted input than those using forestry systems (93.5% versus 77.1%).

II.B.4 CONCLUSIONS

The Wilcoxon signed-rank test was a simple and convenient way to compare the efficiencies of the three systems. Because we have used paired comparisons to test the difference in efficiency, we have controlled for variability between farms and farmers. There remains a question as to whether within-farm variability may affect the results; however, even when omitting silvopasture plots that were planted over higher quality sites such as clear-cut native and plantation forests, the efficiency difference between silvopasture and pasture remains.

Data envelopment analysis (DEA) is a useful tool for efficiency analysis. It uses linear programming (LP) to find relative values for inputs and outputs that maximize the output to input ratio with relation to other decision-making units (DMUs). This relative input to output ratio is the technical efficiency, a number between 0 and 1. However, when comparing the DEA relative technical efficiencies for systems or technologies on various farms, one must be careful to control for between-farm differences. This is possible by using paired comparisons with a Wilcoxon signed-rank test. This was demonstrated by my analysis, which shows that silvopasture systems have strong potential in Argentina.

The results of the within-farm comparisons of the three farm technologies demonstrate that silvopasture practices are generally more technically efficient than pasture. We were not able to reject the lack of an efficiency difference between silvopasture and forestry or forestry and pasture. However, the direction of the differences in pairwise comparisons, and the average efficiency scores for forestry suggest that forestry plots are of intermediate efficiency to silvopasture and pasture. This is consistent with cash-flow analyses of the three systems, which show cattle-ranching as the least profitable, then plantation forestry, then silvopasture.

Overall, plots of silvopasture systems were more likely to be operating under increasing returns to scale. There is some evidence to suggest that plots small-scale farms might be able to increase efficiency by increasing scale. Interestingly, this appears to be a combination of the patterns seen in pasture systems, where large-scale farms operated under decreasing returns to scale (though not significantly), and forestry plantations, where small-scale farms operated under increasing returns to scale.

Efficiency or profitability is not necessarily sufficient to guarantee adoption, if there are capital cost or education barriers. If increased silvopasture adoption is viewed as beneficial from the public standpoint, in terms of job creation or environmental services, the government should continue offering extension and incentives to promote adoption. Further research may be helpful to quantify the benefits or deficiencies of silvopasture from a public standpoint, and to what degree the government should be willing to invest in silvopasture programs.

There is also need for further research to evaluate specific practices within the framework of silvopasture are the most productive, such as the following: when and how to prune or thin trees, how to manage cattle within the trees or which species of trees and grass and breeds of cattle perform the best. Research into these aspects is ongoing in Misiones and Corrientes through institutions such as INTA. In light of our study, researchers should consider the different returns properties of silvopasture for various scales of farms, and how this may influence with specific practices are the most productive for them.

II.B.5 LITERATURE CITED

Alene, A. D., V. M. Manyong, and J. Gockowski. 2006. The production efficiency of intercropping annual and perennial crops in southern Ethiopia: A comparison of distance functions and production frontiers. Agricultural Systems **91**(1-2)**:**51-70.

Banker, R. D., A. Charnes, and W. W. Cooper. 1984. Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management Science **30**(9)**:**1078-1092.

Barth, S. R., H. E. Fassola, P. Ferrere, D. Allegranza, and N. Pahr. 2002. Modelos de crecimiento y producción de *Eucalyptus dunnii* (Maid) en la zona de Garuhapé, Misiones. *10as Jornadas Técnicas Forestales y Ambientales*. - FCF, UNaM - INTA: EEA Montecarlo. Eldorado, Misiones, Argentina.

Bhalla, S. S., and P. Roy. 1988. Mis-specification in farm productivity analysis - the role of land quality. Oxford Economic Papers-New Series **40**(1)**:**55-73.

Binici, T., C. R. Zulauf, O. O. Kacira, and B. Karli. 2006. Assessing the efficiency of cotton production on the Harran Plain, Turkey. Outlook on Agriculture **35**(3)**:**227-232.

Bravo-Ureta, B. E., D. Solis, V. H. Moreira Lopez, J. F. Maripani, A. Thiam, and T. Rivas. 2007. Technical efficiency in farming: A meta-regression analysis. Journal of Productivity Analysis **27**(1)**:**57-72.

Charnes, A., W. W. Cooper, and E. Rhodes. 1978. Measuring efficiency of decision-making units. European Journal of Operational Research **2**(6)**:**429-444.

Clason, T. R., and S. H. Sharrow. 2006. Silvopasture increases profit for livestock graziers and woodland owners. Association for Temperate Agroforestry. Available from http://www.aftaweb.org/ (accessed 19 Jan 2007).

Coelli, T. J. 1995. Recent developments in frontier modelling and efficiency measurement. Australian Journal of Agricultural Economics **3**9(3**)**:219-245.

Colcombet, L., E. H. Crechi, H. E. Fassola, S. Lacorte, and M. San Jose. 2004. Resultados del análisis financiero y socioeconómico del manejo forestal y silvopastoril de *Grevillea robusta* en Misiones. Revista Forestal Yvyrareta **12**(Edición Especial 9as Jornadas Técnicas):9-18.

Cooper, W. W., L. M. Seiford, and J. Zhu. 2004. Handbook on data envelopment analysis. Kluwer Academic, Boston.

Crechi, E. H., H. E. Fassola, and A. Freidl. 1997. Simulador Forestal. Sistema de simulación y crecimiento para especies forestales implantadas. INTA EEA Montecarlo, Montecarlo, Misiones, Argentina.

Dagang, A. B. K., and P. K. R. Nair. 2003. Silvopastoral research and adoption in Central America: Recent findings and recommendations for future directions. Agroforestry Systems **59**(2):149-155.

Davidova, S., and L. Latruffe. 2007. Relationships between technical efficiency and financial management for Czech Republic farms. Journal of Agricultural Economics **58**(2):269-288.

Debreu, G. 1951. The coefficient of resource utilization. Econometrica **19**(3):273-292.

Esquivel, J., H. E. Fassola, S. M. Lacorte, L. Colcombet, E. H. Crechi, N. Pachas, and A. Keller. 2004. Sistemas Silvopastoriles - Una sólida alternativa de sustenabilidad social, económica y ambiental. 11as Jornadas Técnicas Forestales y Ambientales - FCF, UNaM - INTA: EEA Montecarlo. 7-9 October 2004, Eldorado, Misiones, Argentina.

Farrell, M. J. 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society Series A-General **120**(3):253-290.

Fassola, H. E., E. H. Crechi, A. E. Keller, S. R. Barth, and T. E. Fernandez. 2007. Funciones y Algoritmos dasométricos para manejo silvícola intensivo, de aplicación en plantaciones forestales orientadas a producción de madera de alto valor agregado: Región Mesopotámica *Pinus elliottii* y *Eucalyptus grandis,* Parcial para *Pinus taeda.* PAN 571. 61. INTA EEA Montecarlo, Montecarlo, Misiones, Argentina.

Fassola, H. E., P. Ferrere, S. M. Lacorte, and A. F. Rodríguez. 2002. Predicción de la producción de un pastizal bajo distintas estructuras de canopia de *Pinus taeda* L. en el noreste de corrientes, argentina. Revista de Investigaciones Agropecuarias **31**(2):73-96.

Fassola, H. E., S. M. Lacorte, J. Esquivel, L. Colcombet, F. Moscovich, E. H. Crechi, N. Pachas, and A. Keller. 2004a. Sistemas Silvopastoriles en Misiones y NE de Corrientes y su Entorno de Negocios. INTA EEA Montecarlo, Montecarlo, Misiones, Argentina.

Fassola, H. E., S. M. Lacorte, N. Pachas, and A. Keller. 2004b. Experiencias Sobre Manejo Silvopastoril en Misiones y NE de Corrientes, Argentina. 11as Jornadas Técnicas Forestales y Ambientales - FCF, UNaM - INTA: EEA Montecarlo. 7-9 October 2004, Eldorado, Misiones, Argentina.

Ferrere, P., and H. E. Fassola. 1999. *Pinus caribaea* var. *caribaea:* Funciones de volúmenes totales, parciales y de forma. INTA EEA Montecarlo, Montecarlo, Misiones, Argentina.

Ferrere, P., H. E. Fassola, E. H. Crechi, and J. Fahler. 2001. Estudio del crecimiento y modelos de producción para *Pinus caribaea* var. *caribaea* en un sitio de Puerto Esperanza, Misiones. Report No. 26. INTA EEA Montecarlo, Montecarlo, Misiones, Argentina.

Fraser, I., and D. Cordina. 1999. An application of data envelopment analysis to irrigated dairy farms in northern Victoria, Australia. Agricultural Systems **59**(3):267-282.

Frey, G. E. 2008. Análisis por envoltura de datos (DEA) como herramienta para comparar la eficiencia técnica relativa de parcelas silvopastoriles. 13as Jornadas Técnicas Forestales y Ambientales. - FCF, UNaM - INTA: EEA Montecarlo. 5-7 June 2008, Eldorado, Misiones, Argentina.

Frey, G. E., H. E. Fassola, N. Pachas, L. Colcombet, S. Lacorte, F. Cubbage, and O. Pérez. 2007. Adoption and economics of silvopasture systems by farm size in Northeastern Argentina. Pages 219-229 in A. Olivier and S. Campeau, editors. When Trees and Crops Get Together. Proceedings of the 10th

North American Agroforestry Conference. Association for Temperate Agroforestry, 10-13 June 2007, Québec City, Canada.

Haas, D. A., and F. H. Murphy. 2003. Compensating for non-homogeneity in decision-making units in data envelopment analysis. European Journal of Operational Research **14**4(3**)**:530-544.

Husak, A. L., and S. C. Grado. 2002. Monetary benefits in a southern silvopastoral system. Southern Journal of Applied Forestry **26**(3):159-164.

INTA. 2002. Evaluación de especies forrajeras gramíneas tropicales en distintos niveles de iluminación bajo monte forestal de pino para uso en sistemas forestoganaderos. INTA EEA Cerro Azul, Cerro Azul, Misiones, Argentina.

Just, R. E. 2003. Risk research in agricultural economics: Opportunities and challenges for the next twenty-five years. Agricultural Systems **75**(2-3):123-159.

Kao, C., P. L. Chang, and S. N. Hwang. 1993. Data envelopment analysis in measuring the efficiency of forest management. Journal of Environmental Management **3**8(1**)**:73-83.

Klemperer, W. D. 1996. Forest resource economics and finance. McGraw Hill, New York.

Latruffe, L., K. Balcombe, S. Davidova, and K. Zawalinska. 2004. Determinants of technical efficiency of crop and livestock farms in Poland. Applied Economics **36**(12):1255-1263.

Luo, X. M. 2003. Evaluating the profitability and marketability efficiency of large banks - an application of data envelopment analysis. Journal of Business Research **56**(8):627-635.

Mathijs, E., and J. F. M. Swinnen. 2001. Production organization and efficiency during transition: An empirical analysis of East German agriculture. Review of Economics and Statistics **83**(1):100-107.

Otsuki, T., I. W. Hardie, and E. J. Reis. 2002. The implication of property rights for joint agriculture-timber productivity in the Brazilian Amazon. Environment and Development Economics **7**(2):299.

Ramanathan, R. 2003. An introduction to data envelopment analysis: A tool for performance measurement. Sage Publications, New Delhi.

Ray, S. C. 2004. Data envelopment analysis: Theory and techniques for economics and operations research. Cambridge University Press, Cambridge, UK; New York.

Rodriguez-Diaz, J. A., E. Camacho-Poyato, and R. Lopez-Luque. 2004. Application of data envelopment analysis to studies of irrigation efficiency in Andalusia. Journal of Irrigation and Drainage Engineering-ASCE **130**(3):175-183.

Salehirad, N., and T. Sowlati. 2005. Performance analysis of primary wood producers in British Columbia using data envelopment analysis. Canadian Journal of Forest Research **35**(2):285-294.

Siegel, S. 1965. Non parametric statistics for the behavioral sciences. McGraw, New York.

Sowlati, T. 2005. Efficiency studies in forestry using data envelopment analysis. Forest Products Journal **55**(1):49-57.

Thiam, A., B. E. Bravo-Ureta, and T. E. Rivas. 2001. Technical efficiency in developing country agriculture: A meta-analysis. Agricultural Economics **25**(2-3):235-243.

Thompson, R. G., F. D. Singleton, R. M. Thrall, and B. A. Smith. 1986. Comparative site evaluations for locating a high-energy physics lab in Texas. Interfaces **16**(6):35-49.

Townsend, R. F., J. Kirsten, and N. Vink. 1998. Farm size, productivity and returns to scale in agriculture revisited: A case study of wine producers in South Africa. Agricultural Economics **19**(1):175.

Wilcoxon, F. 1945. Individual comparisons by ranking methods. Biometrics Bulletin **1**(6):80-83.

Zhang, Y. Q. 2002. The impacts of economic reform on the efficiency of silviculture: A non-parametric approach. Environment and Development Economics **7**:107-122.

III POTENTIAL FOR AGROFORESTRY IN THE LOWER MISSISSIPPI ALLUVIAL VALLEY, USA

Chapters III.A and III.B deal with agroforestry systems in a southern region of the United States of America, known as the Lower Mississippi Alluvial Valley (LMAV). The LMAV is the historic floodplain of the Mississippi River below its confluence with the Ohio River. This region once was the largest forested bottomland area in the continental United States. However, the productive nature of the soils drove large-scale conversion of forestland to agriculture.

There have been numerous programs in the LMAV aimed at restoring some of the bottomland forest, including the Wetlands Reserve Program and Conservation Reserve Program. These programs have had some successes, but there is a perceived need for more forested area to enhance wildlife habitat and water quality. Agroforestry systems may be able to produce these ecosystem services, while at the same time providing income to landowners in the LMAV. The following chapters assess the potential profitability and feasibility for adoption of several agroforestry and forestry systems in the LMAV.

III.A Deterministic models of alternative production forestry and agroforestry systems in the Lower Mississippi Alluvial Valley, USA

Gregory E. Frey[1,2], D. Evan Mercer[3], Frederick W. Cubbage[1], Robert C. Abt[1], Mitch Renkow[4], Ben Bergmann[1]

[1] Department of Forestry and Environmental Resources, NC State University, Jordan Hall, Box 8008, Raleigh, NC, 27695
[2] Corresponding author: freyge00@hotmail.com, 703-859-0959
[3] Southern Research Station, USDA Forest Service, RTP, NC
[4] Department of Agricultural and Resource Economics, NC State University

III.A.1 INTRODUCTION

The Lower Mississippi River Alluvial Valley (LMAV), a geographical region encompassing the historical floodplain of the Mississippi River below the convergence of the Ohio River (Figure III.A.1), once was the largest forested bottomland area in the continental United States, but has since undergone widespread loss of forest through conversion to farmland (Stanturf et al. 1998). This has caused a resulting loss of ecosystem functions and services, including wildlife habitat, hydrology and water quality. Restoration of forest functions and values has been a key conservation goal in the LMAV since the 1970s.

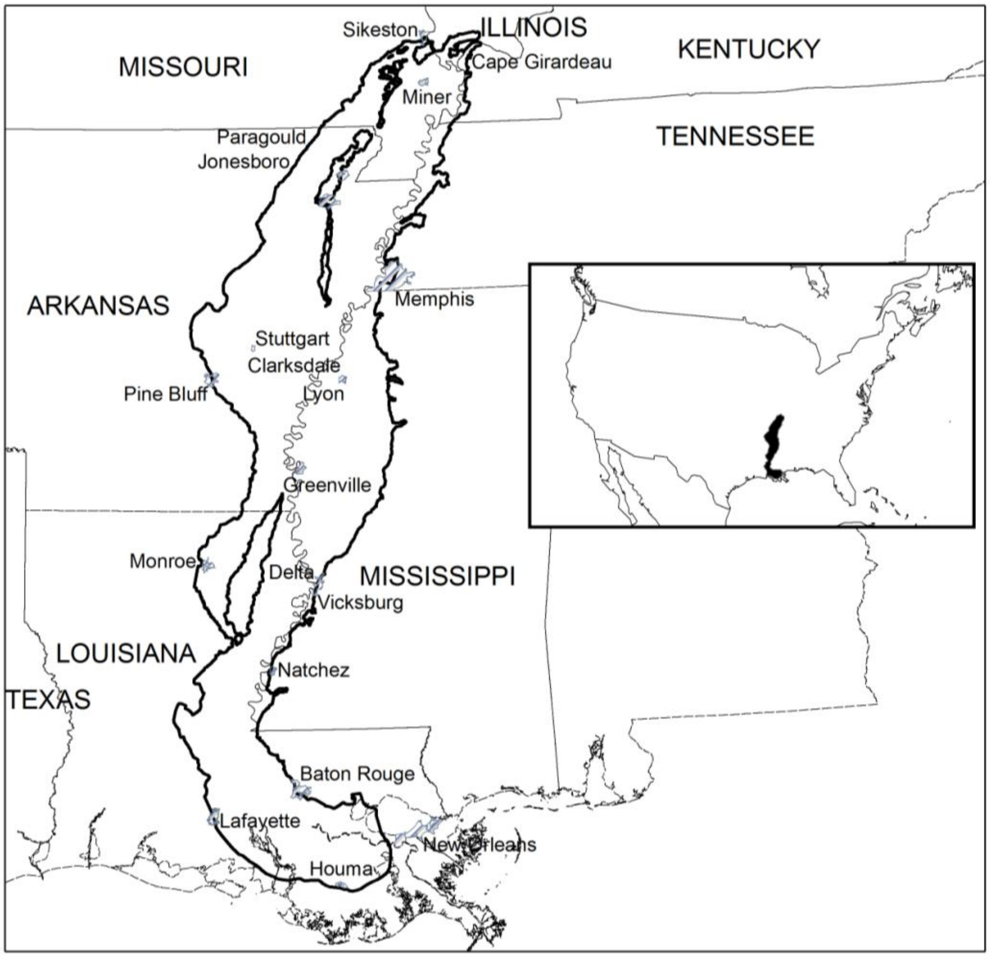

Figure III.A.1. Geographic extent of the Lower Mississippi Alluvial Valley (LMAV) (LMVJV 2002).

III.A.1.1 *Land use in the LMAV*

Natural bottomland hardwood (BLH) forest provides many ecosystem and productive services to the region and the entire river basin, including wildlife habitat, clean water, recreation, and forest products, but the existing forest base has been reduced to the point where these environmental services have been severely reduced. Only a quarter of the original LMAV BLH area remains, mostly due to conversion to agriculture (Twedt & Loesch 1999). Many of the remaining forest areas are degraded by fragmentation, altered hydrology, sedimentation and water pollution, invasive exotic plants, and indiscriminant timber harvesting. The size distribution of forest plots in the LMAV is skewed towards small plots, with most of the larger patches concentrated in the southern end of the region (Twedt & Loesch 1999). Relatively few patches meet the minimum size requirements of 4000, 8000 and 40,000 hectares established for conservation of habitat for three groups of migratory bird species (Mueller et al. 1999).

The environmental functions associated with BLH forests in the southern U.S. include wildlife habitat, improved hydrology leading to flood mitigation and groundwater recharge, a host of biogeochemical processes including nutrient uptake and sediment deposition, and carbon sequestration (Walbridge 1993). It is not surprising then, that there has been a reduction in the ecosystem services provided by BLH forests, such as wildlife habitat, water quality and fisheries (Rabalais et al. 1996; King & Keeland 1999; Gardiner & Oliver 2005; EPA 2007).

Traditionally, most landholdings in the LMAV are utilized for one of a few land-use options. Productive lands generally have been cultivated for annual crops. Figure 2 is a map of land use estimates of the LMAV portions of AR, LA, MS and MO (data for IL, KY and TN are not available) from 2006 based on satellite imagery (NRCS 2006). Historically, agricultural lands in the LMAV have been cultivated principally for cotton, rice and soybeans, and, with the advent of subsidies for corn ethanol production, corn. Lesser crops include grain sorghum and wheat, and in Louisiana, sugarcane and pasture for livestock. Most of the unproductive or extremely wet lands have been left as unmanaged forests. In addition, some farms have diversified into aquaculture, excavating ponds for catfish production.

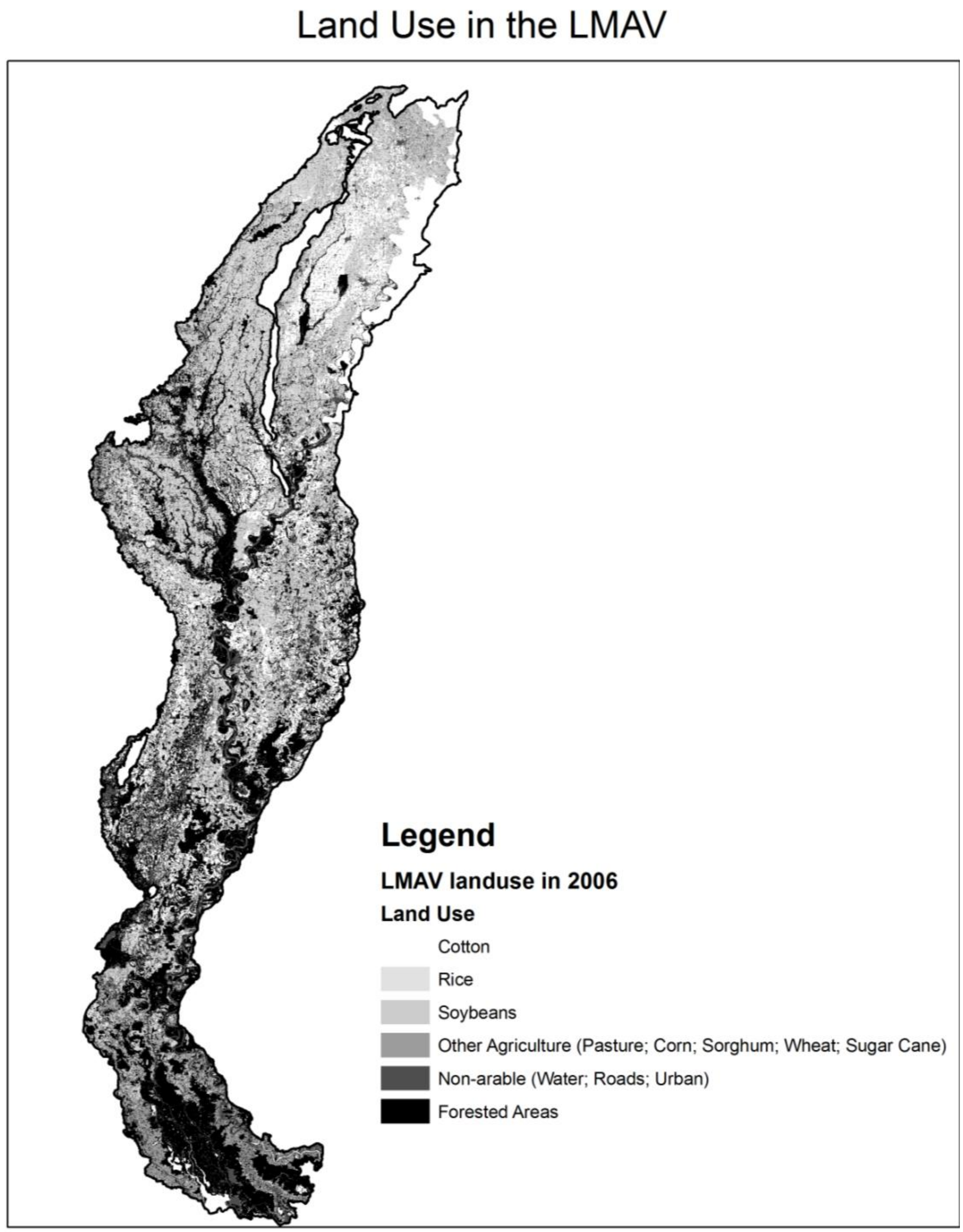

Figure III.A.2. 2006 land use in the Lower Mississippi Alluvial Valley (LMAV) (NRCS 2006). Data not available for Tennessee, Kentucky, Illinois.

III.A.1.2 *Potential of forestry and agroforestry for producing environmental goods and services in the LMAV*

Restoration of marginal agricultural lands to BLH should partially restore critical environmental goods and services. Starting in the 1970s, efforts were concentrated on the LMAV in an attempt to restore the BLH forests, pushed forward by the Conservation and Wetland Reserve Programs (CRP and WRP), NGOs and federal and state agencies (Llewellyn et al. 1996; Stanturf et al. 1998; King & Keeland 1999; Stanturf et al. 2000; King et al. 2006; Twedt et al. 2006). While a relatively small, yet significant amount of reforestation has occurred (Schoenholtz et al. 2001; Groninger 2005), many areas are still characterized by continued deforestation (Llewellyn et al. 1996). Reforestation activity faces two opposing forces. First, there appears to be heightened interest in planting trees on private lands, spurred along by the CRP and WRP programs. On the other hand, farmers are reluctant to take productive agricultural land out of production without adequate financial compensation.

Restoration of ecosystem services is not an all-or-nothing proposition, nor is it necessarily incompatible with economic goals of landowners (Stanturf et al. 2001). Agroforestry and production forestry may be able produce some of the ecosystem services normally attributed to BLH, while also providing a reasonable stream of income for farmers. Environmental benefits due to agroforestry systems have been repeatedly demonstrated in other parts of the U.S. and the world. Generally, the public environmental benefits that can be produced by agroforestry systems fall into four main categories, which are similar to those of bottomland hardwood forest mentioned above (Angelsen & Wunder 2003; Rodriguez Zuniga 2003; Pagiola et al. 2005):

1) Habitat for biodiversity conservation. Agroforestry and production forestry can sustain higher levels of biodiversity compared to sole-crop agriculture (Pimentel et al. 1992; Vandermeer et al. 1998). Furthermore, agroforestry and production forestry may be able to provide buffers around "core" BLH zones in order to increase the effective area of forest patches for wildlife such as birds, which need a relatively large patch of "interior" forest to breed (Mueller et al. 1999; Twedt & Loesch 1999). Finally, agroforestry may provide corridors between existing BLH forests, helping to reduce fragmentation.
2) Improved water quality and hydrology. Riparian forest buffers can significantly reduce non-point source pollution by capturing runoff from agricultural fields (Blanco-Canqui et al. 2004; Schultz et al. 2004; Schoonover et al. 2005). Trees integrated into agricultural fields or pastures can capture nutrients at low soil depths which otherwise would enter ground- and eventually surface-water (Nair et al. 2007). Furthermore, erosion from agroforestry and production forestry plots is typically lower than from agricultural fields.
3) Carbon sequestration (greenhouse gas mitigation). If managed under an appropriate regime, agroforestry and production forestry systems may be able to help sequester carbon from the atmosphere by increasing soil organic carbon and storing carbon in the woody biomass (Dixon et al. 1993; Dixon 1995; Oelbermann et al. 2006).
4) Aesthetics and recreation benefits. Although aesthetics are largely subjective, some

farmers may prefer having more trees around their farms and/or homesteads. Increased animal habitat may provide opportunities for bird-watching, hunting, fishing, hiking, etc.

Depending on the environmental goal of a public program to encourage agroforestry or production forestry, the implementation would vary. If the goal is to produce wildlife habitat, either for biodiversity conservation or recreation, then agroforestry and production forestry might be used to complement large, core forested areas, either as forested "buffer zones" around them or as biological corridors between them (Twedt & Loesch 1999; Twedt et al. 2006). On the other hand, if the goal is to capture nitrogen to prevent nutrient loading in waterways, the trees would better be spread out as buffers along all waterways, rather than clustered around core areas. Finally, if the principal environmental goal is carbon sequestration, then the location is unimportant, but the density of plantation and species selection for speed of biomass growth would be important.

At the management unit scale, implementation would vary as well. For instance, if the goal is to provide improved water quality by planting forested riparian buffers, soil preparation should not include mechanical cultivation which encourages erosion. A plantation forest with the goal of creating wildlife habitat for recreation might include planted food plots for wildlife in gaps or around the stand perimeter.

III.A.1.3 *Land-use Policy*

From a social standpoint, much of the literature and many individuals believe that it would be beneficial to have more agroforestry and production forestry systems on private lands because of the goods and services they provide to the public. However, many of the environmental benefits of agroforestry are reaped by the society at large rather than the person implementing the production system, an effect known as an "externality" in economics (van Noordwijk et al. 2004).

In economics, the equilibrium quantity of a particular good or service produced is determined by the intersection of the marginal benefit (demand) and the marginal cost (supply) curves (Alavalapati et al. 2004). With functioning markets, this is possible because the benefit to the marginal consumer (demand) of a particular good is encapsulated within its price. The market transaction, then, returns benefits to the producer and signals to him his optimal point of production. With an externality, however, no price is usually paid for goods or services that are not traded on the market. The producer of the externality only produces enough of the product to meet the demand for the goods or services that are traded on the market. So, there is likely to be a socially suboptimal level of these non-market services, or externalities, produced (Alavalapati et al. 2004; Pagiola et al. 2005). If these public environmental benefits could be "internalized", or reaped by the land-use manager through some mechanism such as incentive payments, then the area managed under relatively more environmentally-friendly land uses would be increased (Alavalapati et al. 2004). There exists a wide variety of literature on the economic valuation of environmental externalities, including lands in the LMAV (Murray et al. 2009). These types of studies are important when devising policies for management of public lands and for incentives for private land management.

Incentive policies to promote land-use practices such as agroforestry and production forestry on private lands can be beneficial for society and consistent with economic theory to maximize social welfare (Alavalapati et al. 2004). In order to appropriately design effective policies, policy-makers require estimates of the value of ecosystem services associated with alternative land uses.

Murray et al. (2009) estimate three ecosystem services provided by wetland restoration with bottomland hardwood plantations in the LMAV: carbon sequestration, nitrogen mitigation for water and waterfowl habitat. They find that the value to society of ecosystem services provided by wetlands is significant, amounting to almost $1500 per hectare per year.

While Murray et al. (2009) focuses mainly on the public benefits of forestry, our study principally investigates the private benefits, using public environmental benefits as motivation. Our study focuses on the feasibility and private profitability of agroforestry and production forestry systems given present policies in the USA. We recognize that feasibility and private profitability are only two aspects of land-use systems that influence farmers' adoption decisions. Non-market values also influence decisions, including a sense of stewardship among landowners. However, this is an important first step in identifying which systems have adoption potential. Future research should investigate other non-market aspects of agroforestry and production forestry systems that might influence farmers' decisions, such as risk and option value.

Numerous state and U.S. federal policies, relating to both the agricultural and forestry sectors, impact land use decisions. Most profoundly, the federal U.S. "Farm Bills", which have been passed approximately every 5 years (e.g. the Farm Security and Rural Investment Act of 2002 and the Food, Conservation, and Energy Act of 2008), have impacted the profitability and risk of various agricultural and forestry activities. The purpose of this paper is not to conduct a comprehensive review of the Farm Bill, but rather to use some simple tools to estimate some of the effects of a few of its key provisions: the Wetlands Reserve Program and the ACRE program. Also, the 2008 Farm Bill authorized research into the valuation of ecosystem services, potentially paving the way for developing market-based incentive programs.

III.A.1.3.1 *Catastrophic Crop Insurance*

The U.S. Federal Government pays 100% of the premium on catastrophic insurance coverage (CAT), for insured crops. In the event of a catastrophe CAT will pay 55 percent of the established price of the commodity on crop losses in excess of 50 percent. There is a fixed administrative fee ($300 per crop insurance), which may be waived for limited-resource farmers (RMA 2009).

III.A.1.3.2 *Agricultural payments under the Farm Bill*

III.A.1.3.2.1 Fixed Direct Payments (FDP)

Fixed direct payments are not tied to current production or prices and do not require any commodity production on the land. With planting flexibility, farmers are not confined to growing the historically produced crops for which they are receiving direct payments. They could receive a payment based on historical corn acreage, for example, but plant soybeans on those acres. Thus, we assume farmers' planting decisions are based on expected market prices and variable costs of production. A farmer, in theory, could have base acreage that receives FDPs, but in reality is in some other production system, such as forestry or agroforestry. However, a farmer who enrolls land in a conservation program such as the WRP must forfeit all agricultural payments on the enrolled land (Ibendahl 2008).

III.A.1.3.2.2 Marketing Assistance Loans (MAL), Loan Deficiency Payments (LDP) and Counter-Cyclical Payments (CCP)

While the workings are somewhat complicated, the Marketing Assistance Loan, Loan Deficiency Payment (LDP) and Counter-Cyclical Payment (CCP) programs essentially provide payments to farmers when the local (county-level) market price, for MAL and LDP, or the national market price, for CCP, for their crop is below a set target price. However, recent prices for grain commodities have persistently been higher than the target price, driving LDPs and CCPs to zero in most cases (CARD 2009). Of the principle LMAV crops, this would be the case for rice, soybeans and corn, but not necessarily for cotton. In recent years, cotton has suffered lower historical prices, making these price supports more relevant.

III.A.1.3.2.3 ACRE Program

The Average Crop Revenue Election (ACRE) program was authorized in the 2008 Farm Bill. A farmer who chooses to enroll must enroll all commodities he/she produces and must continue in the program until 2012 (when the 2008 Farm Bill expires). Farmers who choose ACRE must give up 20 percent of fixed direct payments (FDPs) and all countercyclical payments (CCPs). ACRE participants are eligible for loan deficiency payments (LDPs), but their loan rates are reduced by 30 percent (ERS 2008). The 30 percent reduction in LDP target prices probably would make them well below any foreseeable market prices for LMAV crops, even for cotton. In almost all cases, then, enrollment in ACRE virtually eliminates both CCPs and LDPs, and reduces FDPs by 20%.

ACRE payments aim to provide payments to farmers when commodity revenue per unit area is down, in contrast to LDPs and CCPs that provide payments when commodity price is down. That is, ACRE considers both price and yield per acre. ACRE payments are triggered when the actual state revenue per unit area is less than the ACRE program guarantee and the actual farm revenue per unit area is less than the benchmark farm revenue per unit area.

III.A.1.3.3 *Wetlands Reserve Program (WRP)*

The Wetlands Reserve Program (WRP) was first authorized by the 1990 Farm Bill to acquire easements on land to provide wildlife habitat, particularly for migratory birds. The WRP is administered by the USDA Natural Resource Conservation Service (NRCS) and is the largest and most prominent reforestation program in the LMAV (Gardiner & Oliver 2005; King et al. 2006). As of 2008, WRP had acquired approximately 10,000 easements totaling almost 810,000 hectares (NRCS 2008b). Landowners may choose to enroll their land in WRP under a permanent easement, a 30-year easement or a restoration cost-share agreement.

III.A.1.3.4 *Conservation Reserve Program (CRP)*

Riparian buffers, which involve planting trees around and along the banks of streams, have become a priority for USDA agencies (Godsey 2005). In particular, the USDA Farm Service Agency (FSA), in coordination with the US Army Corps of Engineers, has made increasing the number of riparian buffers a priority in the LMAV through the

Conservation Reserve Program (CRP) Conservation Practice 22 (CP22): Riparian buffers. The CRP is, like the WRP, a program that pays landowners to take land out of agricultural production and implement conservation practices. While not as prominent as the WRP in the LMAV, the CRP is the most well-known program for retirement of farmland nationwide. While the WRP most commonly provides one-time payments for permanent easements, the CRP usually provides yearly payments, that is, it rents the land, for 10-15 years.

III.A.1.3.5 *Markets for Ecosystem Services*

The 2008 Farm Bill directed the US Department of Agriculture (USDA) to investigate new market-based incentives for conservation (Peterson 2008). The USDA is directed to create,

> "technical guidelines to facilitate the development of environmental services markets, with priority on carbon markets. It directs that the guidelines establish procedures to measure benefits, protocols to report benefits, and a registry to track benefits. It also specifies that the guidelines provide for verification of the benefits, including possibly by independent third parties. While not establishing markets for environmental or ecosystem services (discussed below), the guidelines would likely create the infrastructure to allow such markets to develop." (Gorte 2008)

Existing programs such as the WRP and CRP are already paying landowners for the ecosystem services they are producing. It can be said that the WRP site selection criteria and value appraisal process places a value on specific services that individual sites will create. However, the creation of new market-based incentives could provide an annual payment to landowners and further systematize the valuation of those services. Therefore, forest landowners in the future may be able to access annual revenues for the ecosystem services they provide: carbon sequestration or reduction of emissions, water quality and wildlife habitat. Some of these private markets already exist, but mostly in a rudimentary stage of development (Murray et al. 2009).

III.A.2 MATERIALS AND METHODS

This study analyzes potential of restoring BLH forests on privately-owned farmland in the LMAV. We used a capital budgeting approach to estimate returns for alternative investments in the LMAV, based on extensive collection of data from the literature, secondary sources, and a Delphi panel of experts in the region, which provided the inputs for he discounted cash flow analyses. We drew on previous research by Amacher et al (1997), who used a net present value (NPV) approach to compare returns to various forestry systems to soybean returns on frequently flooded soils. We calculated returns for each system on two soil classifications.

III.A.2.1 *Data*

In some areas, there is a great deal of literature and information about production and conservation activities in the LMAV. For other topics, there is little information available, and some is quite generalized or relatively out-of-date. In some other areas, virtually no information is available, or it is unreliable. Finally, for some other topics, it is impossible to have verified information, such as projections of the future. We discuss each class of information below.

III.A.2.1.1 *Well known - Specific information widely available*

Well-known information is characterized by the availability of numerous data sources, which are largely consistent with one another. Well-known information for the LMAV includes agricultural costs and yields as well as hardwood timber production input and output prices. Here we summarize some of the available data sources.

The USDA Natural Resource Conservation Service (NRCS) maintains a database with estimates of average yield for various crops and tree species on each soil type (NRCS 2008a). However, it does not provide information on prices of inputs and outputs. Agricultural economics departments at Mississippi State University, Louisiana State University, the University of Arkansas, the University of Tennessee-Knoxville and the University of Missouri produce yearly crop budget worksheets (MSU 2008; Paxton 2009; U of AR 2009; UM 2009; UTK 2009). These provide estimates of the current year's costs and revenues per acre based on the known input and output prices and yields from previous years and the knowledge base of academics and extension agents in each university. These crop budgets are general and provide yield and cost estimates for "average" land, but are flexible enough that a user can adjust the estimates based on his or her own knowledge of sites.

The USDA surveys farmers annually in the Agriculture and Resource Management Survey (ARMS). A subset of the farmers surveyed is asked to complete a detailed questionnaire about the yield and returns of each specific crop produced (ERS 2009). Prices for hardwood and softwood timber going back as far as 1955 were obtained from the Louisiana Quarterly Timber Price Report (LA DAF 2008).

In order to derive a coherent value of expected returns over time for various crops on various sites, we used all of the above sources of data, as well as a panel of experts we gathered for the task (see section on "Delphi assessment" below). The panelists were asked to consider the available information in order to form their estimates.

III.A.2.1.2 *Somewhat known - General information available*

Little information about hardwood growth and yield is available for the LMAV, particularly for long timber rotations that can often be as long as 50 or 60 years. Most information on LMAV hardwood growth and yield can be traced back to two publications. Cottonwood growth and yield was modeled by Cao and Durand (1991). Baker and Broadfoot (1979) provided guidelines for estimating site indices for numerous hardwood species, depending on soil type.

III.A.2.1.3 *Unknown - No information available*

Agroforestry systems in the LMAV are few and far between. Of the few examples of agroforestry we know of in the LMAV, no data has been published about the growth and yield of the perennials and annuals relative to their production in conventional systems. Because of this lack of empirical data, we relied on the knowledge of a panel of experts with experience in the few known LMAV agroforestry systems, as well as similar bottomland areas in the South, Midwest and Central Great Plains.

III.A.2.1.4 *Unknowable - Future projections*

It is impossible for us to know the future. In most cases, the past is the best guide we have for the future. This is particularly the case for agricultural yields and weather-related risks. On the other hand, information about general economic trends and markets allow us to project price changes in prices in near-term, which are (presumably) more accurate than simply expecting today's prices to continue in the future. We used USDA's published projections of future prices of various commodity crops (IAPC 2009) and future projected timber price indices given by the Subregional Timber Supply (SRTS) model (Abt & Cubbage 2008).

III.A.2.2 *Delphi assessment*

As the various levels of data quality indicate, we needed to obtain opinions of experts in order to provide inputs on key factors such as yields, costs, prices, and management regimes. Expert opinion is also invaluable in distilling and consolidating numerous sources of information for improving the accuracy of parameters. In order to utilize expert opinion, we organized three panels of experts for forestry, agriculture and agroforestry for a Delphi assessment.

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 towards a consensus. Delphi has been used in many fields of social sciences to help in forecasting. Key aspects of the Delphi method are the anonymity of panel members and the iterative nature of the assessments. Anonymity helps to maintain an open dialogue between members by helping them express themselves freely. Repeated facilitated feedback forms help the group to focus discussion and work towards a consensus. We used an iterative Delphi panel approach to obtain the data that was lacking for this analysis.

III.A.2.2.1 *First Assessment Round*

The preliminary round of the Delphi assessment was designed to develop a framework for future assessment rounds by defining the production systems that would be the most likely to have potential for adoption in the LMAV and determine a site classification system to explain the major elements of variability in site productivity for agriculture and forestry in the LMAV. Many panelists suggested regimes that were similar in terms of species, timelines and management. These were consolidated to present regimes that would be “typical”.

When considering whether or not to include a production system for consideration, panelists in the agroforestry panel were asked, “Is there some relatively large (>10% of all farmers) subset of farmers in the LMAV who might be interested in utilizing such a system, or is there some reasonable incentive payment that might be used to convince a relatively large group of farmers to adopt the system?” The 10% limit is arbitrary, but some limit is needed, as there are essentially an infinite number of systems in which some farmer in the LMAV might be interested. The precise limit is not overly important; it is mostly an indicator that we wanted to include only those systems with the most potential for adoption, and those with potential for having an environmental impact in the LMAV. A system that is adopted by only a small number of farmers is not likely to have any measureable impact. Furthermore, the question asked about farmers’ interest in systems, not whether or not the system would actually be adopted, and 10% of farmers/landowners is not the same as 10% of all land, since landowners would have a portfolio of different land types and probably would consider production forestry and agroforestry only on the more marginal lands.

The agroforestry panel in particular was asked to consider the following classes of agroforestry systems, based on the National Agroforestry Center's classification system: alley cropping, windbreaks & shelterbelts, riparian buffers, forest farming and silvopasture.

Panelists were asked to self-report their level of confidence in particular subject areas. This was used to weight their responses to questions in later rounds. Responses from panelists who expressed more certainty and expertise in specific topics were given a greater weight than responses from those who expressed greater uncertainty. This method was demonstrated by Hess and King (2002).

III.A.2.2.2 *Second Assessment Round*

The Delphi second assessment round allowed panelists to read responses from other panelists from the previous round and to revise their responses, as well as to provide information on new topics. First, panelists were asked to reconsider which site classification system they considered most appropriate. Then panelists were asked to review the "typical" management regimes and suggest revisions. Then, panelists were asked about factors that affect returns to agriculture and yield, including general weather events, catastrophic weather events, policy changes, market changes and other long-term changes. The agroforestry panel was asked to rank the agroforestry systems in terms of what they considered the "most feasible, practical and potentially profitable in the LMAV." These combined rankings were compared to the results of the financial models.

Finally, panelists were asked to provide estimates for specific costs and returns of each agricultural, forestry and agroforestry system. In each case, panelists were asked to provide a range of possible values, including a maximum, minimum and most likely value. This allowed panelists to express their uncertainty (Vose 1996).

A BetaPert distribution was created from the range of values for each parameter (Vose 1996) and was weighted according to panelists' self-assessment of expertise in that particular area (from round one). The sum of the distribution was used to calculate a median estimate and a 90% confidence interval. BetaPert distributions were estimated from the Delphi panels for the following parameters:

Agroforestry Panel

- Relative yield of soybeans in alley cropping system at years 1, 5 and 10.
- Relative yield of cottonwood timber, oak timber and pecan nuts in agroforestry situations.

Agriculture Panel

- Costs and revenues for cotton, soybeans and corn on good sites under normal weather conditions
- Cost of converting forestland to agriculture

Forestry Panel

- Establishment costs for hardwoods in the LMAV
- Volume mean annual increment of cottonwood and oaks
- Mixed hardwood pulpwood and sawtimber stumpage prices
- Cottonwood sawtimber stumpage price

III.A.2.2.3 *Third Assessment Round*

Based on results and other panelists' comments from the second round, panelists were asked to revise their estimates of the above parameters in the third Delphi assessment round. In addition, panelists were asked about these parameters:

Agroforestry panel

- Relative yield of cattle in silvopasture situations
- Other potential agroforestry systems

Agriculture panel

- Costs and revenues for rice on good sites under normal weather conditions

Forestry panel

- Cost of converting forestland to agriculture (to be combined with results from agriculture panel)

III.A.2.3 *Soils and site conditions in the LMAV*

The soils and site types in the LMAV are relatively homogeneous. The entire region is relatively flat bottomland, as the region is delimited by the historical floodplain of the Mississippi River. However, the variability that does exist within the soils and site types of the region does play an important role in the productive potential of various crops and trees.

An agroforestry/forestry program that intends to make an impact in increasing forest cover should consider a range of land types. We examined not only whether agroforestry and production forestry systems might be competitive on the *most* marginal land in the LMAV (Amacher et al 1997), but whether some specific systems might also be reasonably profitable on *moderately* marginal lands. An analysis of soil spatial data in the LMAV in Mississippi indicates that frequently flooded land occupies less than 19% of all land, and much of this is already forested and/or on public lands (NRCS 2008a). We did not conduct the analysis on other states, but assume the proportion is similar. 1.1 M hectares of the 2.6 M ha of forest remaining in the LMAV are frequently flooded (Twedt & Loesch 1999). In addition, 72.4% of all public land in the LMAV is maintained in forested wetland, accounting for approximately 0.6 M hectares.

III.A.2.4 *Cash flow assessment*

Cash flow (or "cost/benefit") assessments are typically used to estimate the potential profitability of a particular system in a particular region. Kapp (1998), Ramadhani, et al. (2002) and Franzel (2004) provide examples of various types of cost/benefit financial analyses for agroforestry systems, calculating returns to various types of investments (land, labor or capital) which a landholder might make to implement the system.

The sum of the discounted periodic net revenues over a given time horizon is called Net Present Value or NPV (Klemperer 1996; Pearce & Mourato 2004):

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

where B_t and C_t are benefits and costs per unit of the most constrained input (often per unit of land area) accrued in period t, T is total number of time periods the land use system uses, and r is the discount rate per period. If the NPV is higher for agroforestry or production forestry than for conventional systems, it is potentially adoptable. NPV is commonly calculated on a per hectare basis.

NPV, however, is not appropriate for comparing projects with different time horizons. For these purposes, Soil Expectation Value (SEV) is more appropriate. This is also called the Land Expectation Value or Faustmann Formula approach. SEV is a return on a per hectare basis as if the project, once finished, would be repeated over and over throughout an infinite time horizon (Klemperer 1996):

$$SEV = NPV\left[1 + \frac{1}{(1+r)^{T} - 1}\right] \quad (2).$$

Equation (2) applies to a timber regime with a fixed rotation period, *T*, at the end of which the forest will be clearcut and the regime started again from the beginning with all the same costs. On the other hand, many silvicultural regimes do not involve a fixed rotation that ends with clearcutting. For instance, in uneven-aged management regimes, which are common with shade-tolerant species, a mature stand may have periodic harvest of a small amount of timber, leaving the majority of the trees to continue growing and reproducing. In theory, the amount of timber harvested would be approximately equal to the volume growth over this period. We term this practice "sustainable harvest" because, if practiced correctly, this periodic harvest could be carried out indefinitely into the future.

SEV can be estimated for the sustainable harvest regime, even when starting from bare ground. First, we calculate the NPV of the practices necessary over the time period required to get the stand to maturity, when the sustainable harvest can be started. Then, we approximate the periodic sustainable harvest as a yearly harvest exactly equal to the mean annual increment. An SEV for the yearly sustainable return is calculated and discounted back to the present:

$$SEV_{sust} = \sum_{t=0}^{T-1} \frac{B_t - C_t}{(1+r)^t} + \frac{B_T - C_T}{r} \cdot \frac{1}{(1+r)^T} \qquad (3),$$

where T is the year when the stand reaches maturity and the sustainable annual harvest begins.

Some NPV/SEV calculations have been conducted to measure the profitability of forest management in the LMAV. Stanturf and Portwood (1999) showed that cultivation of eastern cottonwood (*Populus deltoides*) for pulpwood, and similarly Huang, et al. (2004) with cherrybark oak (*Quercus pagoda*) for timber, in the LMAV could produce positive returns. However, they did not compare these returns to those of conventional LMAV agricultural systems. Amacher et al. (1997) and Amacher et al. (1998) showed that Nuttall oak (*Quercus texana*) and cottonwood grown for timber could have positive returns net of the opportunity cost of forfeited soybean production on certain frequently flooded soils.

Anderson and Parkhurst (2004) used NPV to compare forest long-term forest easements under the WRP program with hunting leases to several possible agricultural crops (soybeans, rice and cotton) with payments from commodity programs under the 2002 Farm Bill and found that WRP forest easements could be extremely competitive or even more profitable than crop production with commodity payments, and much less risky for the farmer. Ibendahl (2008), on the other hand, found that commodity crop production was likely to be more profitable than WRP enrollment on average land, but did not include revenue streams such as hunting leases. To our knowledge, NPV estimates of potential agroforestry systems in the LMAV region have not been published, so this research provides new analyses for consideration.

III.A.2.5 *Base case and policy case*

A base case SEV was calculated for each production forestry, agroforestry and the default agriculture scenario, assuming no policy interventions. In principle, this is a relatively simple calculation; however, we must consider the negative impact of occasional flooding, which is considered the main periodic event that affects the returns of forestry and crops. Soil types are classified by the NRCS into 6 categories (NRCS 2007);

- None – Probability of flooding is nearly 0% in any given year; less than once every 500 years
- Very rare – Probability of flooding is less than 1% in any given year
- Rare – Probability of flooding is 1-5% in any given year
- Occasional – Probability of flooding is 5-50% in any given year
- Frequent – Probability of flooding is greater than 50% in any given year, but less than 50% in any month of the year
- Very frequent – Probability of flooding greater than 50% in some months of the year.

For production forestry and agroforestry, flooding causes the most damage due to mortality causing a need to replant when it occurs in the first year of seedling establishment. The base case included a weighted average of NPVs with and without replanting due to flooding. For frequently flooded land, we assumed that flooding would create a need to replant 30% of the time, on rarely flooded land, 5% of the time.

For agriculture, flooding can cause a number of scenarios depending on the severity and timing. Amacher et al. (1997) estimated the relative frequency of these scenarios on frequently flooded (i.e. LCC 5) soils for soybeans, including optimal (15%), prevented planting (5%), initial planting late (40%), replant (10%), replant late (20%) and lose crop (10%). We estimated crop yield and insurance indemnities under these 6 scenarios, then calculated a weighted average of returns per hectare based on the relative frequencies.

On LCC 3 lands, flooding occurs with lower frequency. About 90% of LCC 3 lands fall into the "rarely" flooded category. By definition, on rarely flooded land, "flooding is unlikely but possible under unusual weather conditions. The chance of flooding is 1 to 5 percent in any year." Less than 5% of LCC 3 lands fall into a category that indicates more frequent flooding than rarely, either occasionally or frequently flooded. If production forestry or agroforestry are likely to be adopted on LCC 3 lands, it will be on the most marginal of this category of lands. Therefore, we assumed an 85% chance of no flooding, and 15% chance of flooding causing a lost soybean crop, which is the scenario with the poorest returns.

We included catastrophic insurance coverage (CAT) in both the base case and the policy case, with premiums paid by the federal government. We assumed that other crop insurance coverage would be actuarially fair; that is, purchasing the insurance would have no effect on the expected value of the crop returns.

After calculating the base case with no policy intervention, we calculated a policy case. The policy case assumed ACRE payments and FDPs for the agricultural crops, and payments from markets for ecosystem services for the forestry and agroforestry systems. We also included WRP enrollment as a separate option.

III.A.2.5.1 *ACRE Program with Fixed Direct Payments*

We assume that the farmer/landowner chooses to enroll the agricultural land in the ACRE program. Enrollment and ACRE eliminates eligibility for CCPs, and as explained above, we believe that enrollment in ACRE is likely to make MALs and LDPs minimal in most cases in the LMAV. For this reason we focus on the ACRE payment and FDPs (which are reduced 20% upon enrollment in ACRE).

According to the ERS (2008), "A direct payment is equal to the product of the payment rate for the specific crop, the historical payment acres (85 percent of base acres in CYs 2008 and 2012 and 83.3 percent in CYs 2009-11), and the historical payment yield for the farm. For example, the payment for corn base is:

$DP_{corn} = (\text{Payment rate})_{corn} \times (\text{Payment yield})_{corn} \times (\text{Payment acres})_{corn}$

Where

$(\text{Payment acres})_{corn} = (\text{Base acres})_{corn} \times$ (85% in CY 2008 and CY 2012 and 83.3% in CY 2009-11)".

To facilitate the calculation, we used a value of 84% for all years. The payment rate for various base commodities for 2009-2012 is given in table 1. The last column reflects the 20% reduction in FDPs from enrollment in the ACRE program (ERS 2008).

Table III.A.1. Fixed direct payment (FDP) rates for typical LMAV crops.

Commodity	Unit	Payment rate ($/unit)	Payment rate if enrolled in ACRE
Corn	Bushel	0.28	0.22
Upland Cotton	Pound	0.0667	0.0534
Medium-grain Rice	Hundredweight	2.35	1.88
Sorghum	Bushel	0.35	0.28
Soybeans	Bushel	0.44	0.35
Wheat	Bushel	0.52	0.42

Because the FDPs are decoupled from actual production, a farmer can produce any crop on acreage that is base acreage for one particular crop. Historically, most marginal and moderately marginal cropland in the LMAV has been used for soybeans. Therefore, we utilized the FDP rate for soybean base land. Assuming a historic yield of 86 bushels/hectare (35 bu/acre), the FDP for soybean under the ACRE program would then be approximately $25.42 per base hectare or $10.29 per base acre ($0.35*35*.84).

The ACRE payment is more difficult to estimate. In many years, the farmer may not receive a payment. The farmer will receive an ACRE payment if the statewide revenue per acre for the crop is less than 90% of the 5-year Olympic average, that is, the average revenue during the past five after throwing out the highest and lowest years (first condition), <u>and</u> the farm revenue per acre for the crop is less than 100% of the 5-year Olympic average (second condition).

Using aggregate data for the LMAV from the USDA Agriculture and Resource Management Survey (ARMS) (ERS 2009), we estimated that over the period 1990-2007, the first condition for ACRE payments was met with 25% frequency for cotton, 32% for soybean and 29% for rice. We used 29% as an approximate frequency for the first condition being met. When the first condition is met, there should be a high probability of the second condition being met, because farm-level yields should be correlated with state yields. We estimated that if the first condition is met, then the second will be met 85% of the time. This means that farmers will receive ACRE payments about 25% of the time.

According to the ERS (2008), "ACRE payments, if triggered, equal the product of the following:

- Lesser of: a) ACRE program guarantee - ACRE actual State revenue, OR b) 25 percent of ACRE program guarantee
- 83.3 percent (in 2009-11) or 85 percent (in 2012) of the considered planted acres on the farm
- Farm-specific relative productivity ratio: farm 5-year Olympic average crop yield per planted acre / ACRE benchmark State yield."

We estimated that if an ACRE payment is triggered, then the first factor above may be approximately 20% of ACRE program guarantee, on average. The second factor above was approximated as 84% for all years. The third factor depends on the site. We assumed that the state average yield is equivalent to the yield on average (Land capability class 3) land, and adjustments to this factor were made for other sites.

III.A.2.5.2 *Wetlands Reserve Program enrollment*

The most common WRP enrollment options is a permanent easement which provides a one-time easement payment as well as 100% of the costs of wetland restoration, including drainage, site preparation and planting of bottomland tree species. The value of the easement payment is explained in the Federal Register (NRCS 2009):

> “(3) NRCS shall pay as compensation the lowest of the following: (i) The fair market value of the land using the Uniform Standards for Professional Appraisal Practices, or based on an area-wide market analysis or survey; (ii) The geographic area rate cap determined under paragraph (a)(4) of this section; or (iii) The landowner offer.”

The geographic rate cap for Mississippi and Louisiana in 2008 was $2223 per hectare ($900 per acre), and for Arkansas was $1853 per hectare ($750 per acre).

From 2006 to late 2008, the WRP operated under a different rule. Rather than paying for the full fair market value of the land, section (i) allowed payment of the difference in the land’s estimated market value with and without the easement. In most cases in the LMAV, this estimated difference was in the range of $250-1250 per hectare (approximately $100-500 per acre). In almost every case from 2006-08, the difference between the estimated value with and without the easement was less than the rate cap, and this difference was usually the offer to the landowner. On the other hand, since late 2008, as well as before 2006, the estimated full fair market value of the land has been almost always higher than the geographic rate cap, meaning that almost all landowners were offered the geographic rate cap.

There are two other options for WRP enrollment. One is a 30-year easement that provides 75% of the restoration costs and 75% of the easement payment that would be awarded for a permanent easement. The other is a restoration cost-share agreement that pays 75% of the restoration costs, with no easement on the land.

However, since the vast majority of enrollments in the WRP program have been permanent easements, that is the arrangement we consider in our analysis. According to the NRCS (2009), “Approximately 89.8 percent of the WRP funding has been used for permanent easement projects; about 7.9 percent for 30-year easement projects and about 2.4 percent for restoration cost-share agreement projects." The Wetlands Reserve Program (WRP) permanent easement option is the principal program for reforesting private lands in the LMAV. In our model, we considered the WRP program under the assumption of a payment of $2223 per hectare ($900 per acre), which would generally be the case before 2006 and after mid-2008 as well as a WRP payment of $741 per hectare ($300 per acre), which is an approximate average of the payments offered from 2006-08.

When a landowner agrees to a WRP easement, he maintains the right to access the land for recreational activities such as hunting. In addition, landowners may request a waiver to use the land for activities such as limited timber harvest and livestock grazing, provided such activities "both protect and enhance the wetland functions and values" (NRCS 2008b). In practice, however, there is little experience with these types of waivers, and it is unknown how easy it will be to obtain a waver or what type of restrictions they will contain. For our purposes, we assume that no timber harvest or livestock grazing will occur on WRP lands.

In our model for WRP enrollment, we assumed that the landowner is able to sell a hunting/recreation lease on his/her land for about $15 per hectare per year ($6 per acre per year), which is an approximate average value for hunting leases in the LMAV (Hussain et al. 2007; Murray et al. 2009). We assumed that no timber harvest or other money-making activities were permitted on the site.

III.A.2.5.3 *CCRP CP22 Riparian Buffers*

The Continuous Conservation Reserve Program (CCRP) funds Conservation Practice 22 (CP22) to support establishment and maintenance of riparian buffers in the LMAV. Landowners can enroll in CP22 under a 10-15 year contract. Those landowners are eligible for numerous incentives: a yearly payment equal to 120% of the established land rental rate for similar soils in the county plus $17-25 per hectare ($7-10 per acre) for annual maintenance, a one-time cost-share payment equal to 50% of the cost of establishment plus a practice incentive payment equal to 40% of the cost of establishment and a signing incentive payment equal to $24.70 per hectare ($10 per acre) times the number of years of the contract (e.g. $371 per hectare for a 15 year contract) (Godsey 2005). Minimum buffer widths range from 15 to 30 meters (50 to 100 ft), depending on the stream order, and the maximum buffer width CCRP will fund is 55m (180ft) (Godsey 2005). For our financial calculations, we assumed a soil rental rate of $111 per hectare ($45 per acre) for the most marginal soils and $222 per hectare for moderate soils (Delta Wildlife 2008), and a 15-year contract.

III.A.2.5.4 *Markets for environmental services*

Estimated potential future payments from markets for environmental services were based on values estimated by Murray et al. (2009). Their study estimated that the potential for returns from carbon credits on restored wetland forests could be $59 per hectare assuming only voluntary markets (CO_2 price of $4.20 per ton) or as high as $419 per hectare if a mandatory carbon trading scheme is created in the U.S. (CO_2 price of $30 per ton). The 2010 budget proposal of the Obama administration, released since Murray et al.'s

(2009) findings, assumes the auction of carbon emission rights, which seems to make a regulatory market more likely. We began our analysis by assuming a relatively conservative price of only \$10 per ton of CO_2 (tCO_2), as any such trading scheme is likely to have a relatively long implementation phase, during which prices are likely to be lower. We then conducted the same financial analysis, assuming \$30/tCO_2 in order to estimate the impact of potential higher future carbon prices. The conversion factor used to estimate the amount of CO_2 sequestered is approximately one dry ton of biomass is the equivalent of 1.83 sequestered tons of CO_2. The ratio of green tons to dry tons depends on the density of the wood. We used densities of 400 kg/m^3 for cottonwood, 700 kg/m^3 for hard hardwoods, and 500 kg/m^3 for pine.

Non-permanence of carbon storage would be an issue for some of the forestry and agroforestry systems. That is, when carbon is sequestered from the atmosphere in trees, it may be re-emitted over time at varying rates, depending on the management regime. Kim et al. (2008) suggested a market pricing mechanism for these temporary carbon credits, which we use to provide approximate prices. These markets would discount temporary carbon credits with factors range from 0.07% to 32% as given in Table III.A.2, assuming rising carbon prices (obviated by our selection of a low initial price of \$10 per ton CO_2) and depending on the management. For systems that are never clearcut, non-permanence may not be an issue; however, net growth rates will eventually decline to zero, reducing sequestration rates (and thus carbon payments) to zero. Kim et al. (2008) included a maintenance cost for carbon after the stand reaches saturation, which is why the discount would not be zero.

Table III.A.2. Non-permanence discount factors for temporary carbon credits, assuming increasing future carbon prices. Adapted from Kim et al. (2008).

Rotation length (yrs)	Replant?	Non-permanence discount factor
Permanent	N/A	0.1%
85	No	67%
20	No	93%
20	Yes	32%

Murray et al. (2009) estimated that a market scheme for nitrogen mitigation would pay $634 per hectare to restored wetland forest. We utilized this value as an estimate of what a nitrogen market might pay for hard hardwood riparian buffer systems. We assumed a 25% reduced payment for riparian buffer systems with cottonwood because cottonwood requires more competition control in the early years and therefore may allow more erosion.

III.A.2.6 *System rankings*

Agroforestry system rankings from the Delphi panel were compared to rankings from the SEV calculations. As mentioned, the agroforestry Delphi panel was asked to rank the agroforestry systems in terms of what they considered the "most feasible, practical and potentially profitable in the LMAV." We then ranked the agroforestry systems from most to least profitable according to the calculated SEV. We compared the results to determine similarities or differences between SEV calculation and Delphi expert opinion and considered factors besides simple profit that might cause the Delphi panelists to believe farmers are more or less likely to adopt certain systems.

III.A.3 RESULTS AND DISCUSSION

III.A.3.1 *Site classification*

Panelists voted and were allowed to comment on the site classification system they felt would be the best predictor of yield for both forestry and agriculture. In the second round, they were allowed to change votes based on the comments of other panelists. Panelists' votes were weighted by their self-evaluation of expertise in sites and soils in the LMAV.

By far the two most commonly cited systems were Land Capability Classification (LCC) and Drainage Class (DC). These two classification systems are explained in detail in the National Soil Survey Handbook (NRCS 2007). "Natural drainage class refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed." Classifications range from "excessively drained" to "very poorly drained". "Land capability classification is 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." Classes range from 1 to 8, with LCC 1 soils the most well-suited for agricultural purposes and LCC 8 the least. LCC combines numerous factors, including drainage class, flooding frequency, etc.

Although LCC is designed for agricultural crops, the weighted vote came out in favor of using LCC over DC as the best predictor of both agricultural and forestry yield. Though forestry panelists were more likely to cite DC and agricultural panelists LCC, the weighted vote favored LCC by a score of 38 to 28, despite relatively more forestry experts participating. Therefore, we use LCC as the classification system of choice for our estimates.

Any one classification system is a simplification of reality and, particularly for some of the forestry species. However, there is a high degree of correlation between LCC and other soil classifications, including drainage class. It was therefore possible to estimate typical yields for the most relevant LCC (3 and 5) classes.

We used ArcGIS with soil survey spatial and tabular data from the NRCS Soil Survey Geographic (SSURGO) database from the portion of the LMAV in the state of Mississippi to calculate the area of land in each land capability class (table 3) (NRCS 2008a). LCC 3 and 5 soils account for most of the land area in the MS LMAV, and include moderately to very marginal soils. LCC 1 and 2 include the most productive quarter of the MS LMAV, and are unlikely to be converted to any type of forestry or agroforestry system. LCC 4 soils are usually highly-erodible soils, of which there are few in the LMAV, and LCC 6-8 have little potential for agriculture.

Table III.A.3. Description of Land Capability Classes in the LMAV (NRCS 2007).

Land Capability Class	Proportional Area in LMAV	Description	Typical Drainage Class	Typical Flooding Frequency
1	**4%**	Slight limitations that restrict use. "Best" agricultural land.		None
2	**19%**	Moderate limitations that reduce the choice of plants or require moderate conservation practices.		None
3	**43%**	Severe limitations that reduce the choice of plants or require special conservation practices. "Average" or moderately marginal land.	Poorly drained	Rare
4	**6%**	Very severe limitations (usually erodibility)		
5	**19%**	Little or no hazard of erosion but have other limitations that limit their use mainly to pasture, range, forestland, or wildlife food and cover. "Very marginal" land	Very poorly drained	Frequent
6	**0%**	Severe limitations that limit their use mainly to pasture, range, forestland, or wildlife food and cover.		
7	**1%**	Very severe limitations that restrict their use mainly to grazing, forestland, or wildlife.		
8	**1%**	Limitations that preclude their use for commercial plant production and limit their use to recreation, wildlife, or water supply or for esthetic purposes.		

III.A.3.2 *Systems selected*

Based on the Delphi assessment, we selected the production forestry and agroforestry systems below for financial analysis. Panelists gave their opinions on timelines and management regimes, and the consensus regimes are described below. In many cases, panelists noted details of the management regime that would be important knowledge for land managers, even if they would not have a large impact on the financial calculations. These comments are noted, where applicable, either in the panelists' own words or paraphrased. We present a timeline of typical system management for each case.

III.A.3.2.1 *Production forestry*

1. Cottonwood for Pulpwood

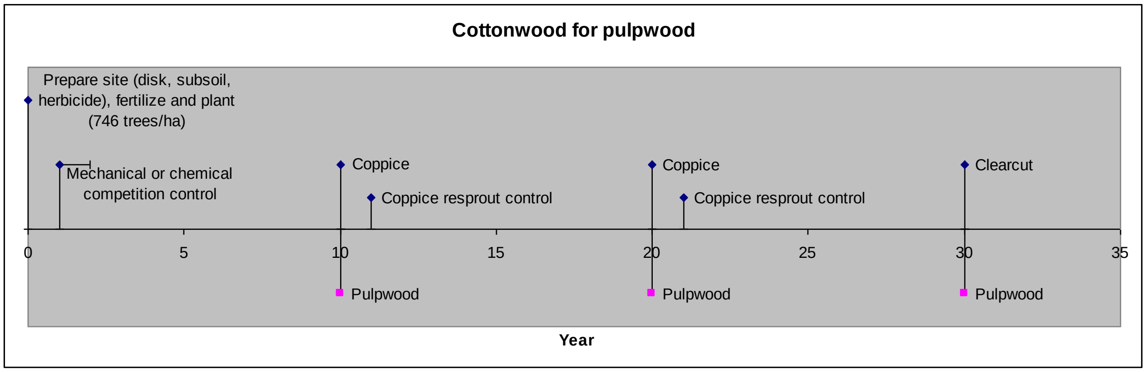

Figure III.A.3. Typical management timeline for a cottonwood for pulpwood system.

Eastern cottonwood (*Populus deltoides*) has been harvested in the LMAV for pulpwood for decades. In most cases, this harvest has come from mixed-hardwood, naturally-regenerated stands. However, cottonwood can be planted, and if planted on agricultural land, additional carbon sequestration and wildlife benefits may accrue (Hamel 2003). Cottonwood establishment in the first two or three years generally require mechanical cultivation and/or chemical weed control, so we expect few benefits for water quality at first; however, in later years runoff may be reduced.

2. Cottonwood for sawtimber

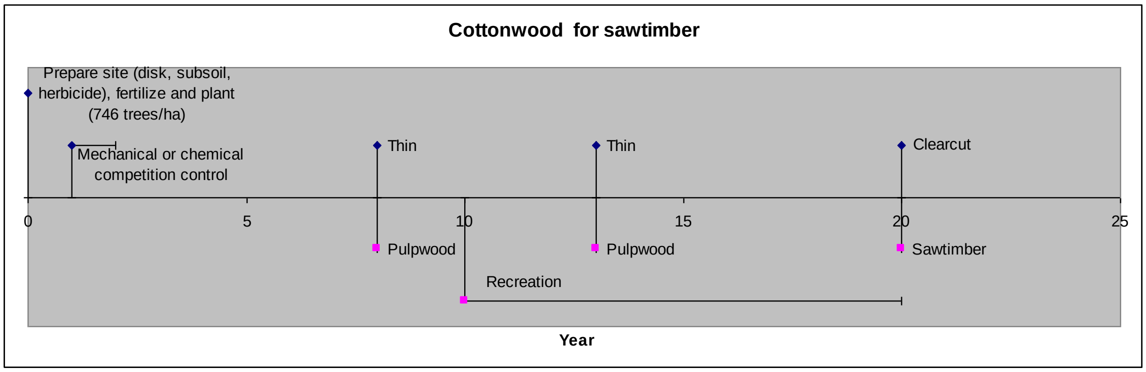

Figure III.A.4. Typical management timeline for a cottonwood for sawtimber system.

This system produces cottonwood for sawtimber, and pulpwood from thinning. While cottonwood plantations are not favored for hunting or other recreational purposes, they do support wildlife (Hamel 2003; Twedt 2006). We estimated that a hunting lease could be sold from year 10-20 at 50% of the hunting lease price for hard hardwood forests.

3. Short Rotation Woody Crop

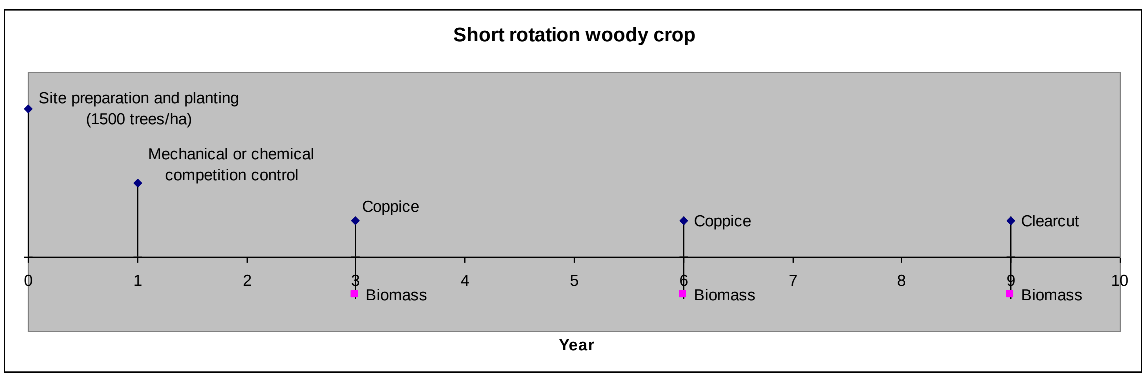

Figure III.A.5. Potential management timeline for a short rotation woody crop system.

Given growing public concern about both climate change and the security of the United State's energy supply, considerable thought has been given to creating sources of energy from biomass. Two possibilities involve the use of woody species: the use of wood chips for direct combustion and the production of cellulosic ethanol. These possible future markets have created interest in growing woody species directly for these purposes. These production systems would use short rotations of 2-5 years, and coppice the trees to allow resprouting, thus avoiding replanting costs. Short rotations may be possible for eastern cottonwood (*Populus deltoides*), black willow (*Salix nigra*) and American sycamore (*Platanus occidentalis*) because no minimum diameter is necessary since the wood will be chipped anyway, and that growth rates in the initial years can be high for soft hardwood trees. We are unaware of any research conducted on the subject of short-rotation woody crops in the LMAV.

Several of the panelists consider short-rotation woody crops to be more akin to agricultural systems than forestry; however, we consider this system among forestry systems because they do utilize woody species and because they represent an alternative to conventional agricultural practices.

The environmental benefits of short-rotation woody crops may be questionable. Certainly, if they can offset the use of fossil fuels, then there is a net reduction in carbon emissions, which is beneficial. However, if there is intensive use of fertilizers or other chemicals it is doubtful whether there would be a benefit for water quality, and it could worsen water quality. The impacts on wildlife are uncertain.

4. Hard hardwood species

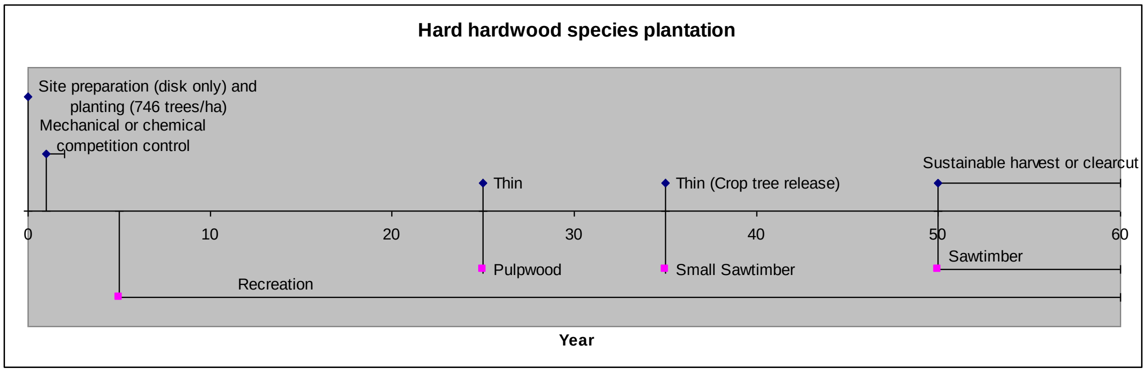

Figure III.A.6. Typical management timeline for a hard hardwood plantation.

Numerous bottomland "hard hardwood" species, mostly oaks, have been planted in the LMAV with varying degrees of success. One of the most common species is Nuttall oak (*Quercus texana* or *Q. nuttallii*), but it is often mixed with other oaks such as cherrybark oak (*Q. pagoda*) and water oak (*Q. nigra*) as well as other hardwood species such as green ash (*Fraxinus pennsylvanica*) and baldcypress (*Taxodium distichum*). Other possibilities include wild cherry (*Prunus serotina*, *P. virginiana*), hawthorns (*Crataegus* spp), or slippery elm (*Ulmus fulva*). In general, specific site conditions should determine the appropriate species or mix of species to plant. However, it is not our intent to create a guide for determining which species should be planted on individual sites. The purpose of our research is to evaluate the conditions under which landowners would adopt various systems, depending on general site conditions.

We include both an option to leave the land under a "sustainable" harvest regime and a clearcutting regime once the stand reaches maturity. This is different than the WRP program, which may be prohibit or render harvest infeasible.

5. Cottonwood and oak interplanting

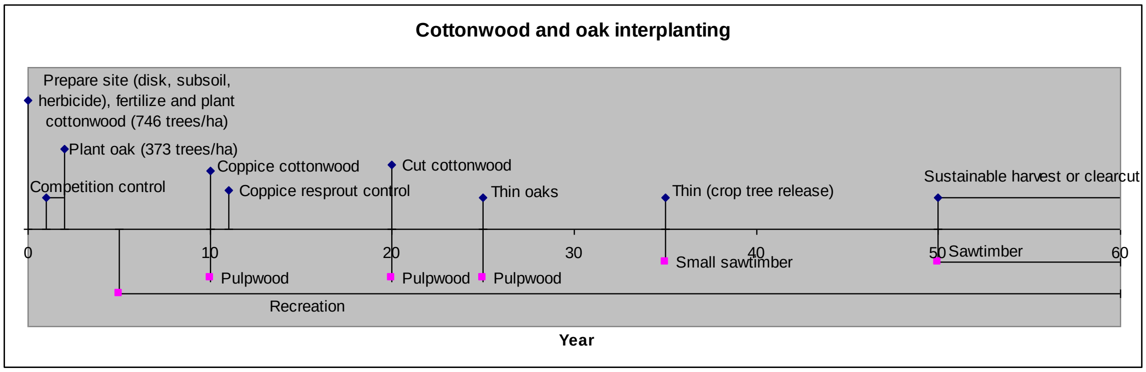

Figure III.A.7. Typical management timeline for a cottonwood and oak interplanting system.

Numerous hardwood experts in the LMAV region have suggested the use of cottonwood or some other relatively fast-growing, shade-intolerant species as a "nurse crop" for the more shade-tolerant oaks (Gardiner et al. 2004). Competition with cottonwood creates conditions under which the oaks are more likely to grow straight and self-prune.

Research has shown that oak growth and yield is decreased none or only slightly per tree, although fewer trees are planted per hectare (Gardiner et al. 2004). It is assumed that growth and yield per hectare would approach the "mixed oaks" system towards the end of the rotation.

III.A.3.2.2 *Agroforestry*

After considering a wide variety of agroforestry systems, the panel of experts agreed that alley cropping, riparian buffers and silvopasture had the best potential for adoption on a large enough level to generate significant environmental impacts. Several panelists noted that riparian buffers probably offered the most environmental value, because they help protect waterways for agricultural runoff. However, social environmental benefits do not necessarily equate to adoption. Since wind is not a major problem in the LMAV, windbreaks are not likely to be widely adopted. Forest farming of some specialty products may be an option for some landowners, to help generate additional income. However, these systems require well-established stands, which would take numerous years, these systems are unlikely to create a large economic incentive in the near term to convert agricultural fields.

Our representative management schemes represent what our panelists thought could be "typical." If these systems were to be widely adopted, we would expect a good deal of experimentation, variations and combinations of these systems. For instance, a plot might start as an alley cropping system when trees are too small to withstand livestock, then be converted to silvopasture once the shade becomes too great for crops. When shade is greater, it might be used for recreation. We have tried to account for the most logical agroforestry combinations.

III.A.3.2.2.1 Silvopasture systems

"Silvopasture systems" are production systems that combine trees, forage and livestock on the same piece of land. Silvopasture systems have been used in other parts of the US Southeast, and their potential economic benefits have been demonstrated (Clason 1999; Grado et al. 2001).

1. Pecan silvopasture

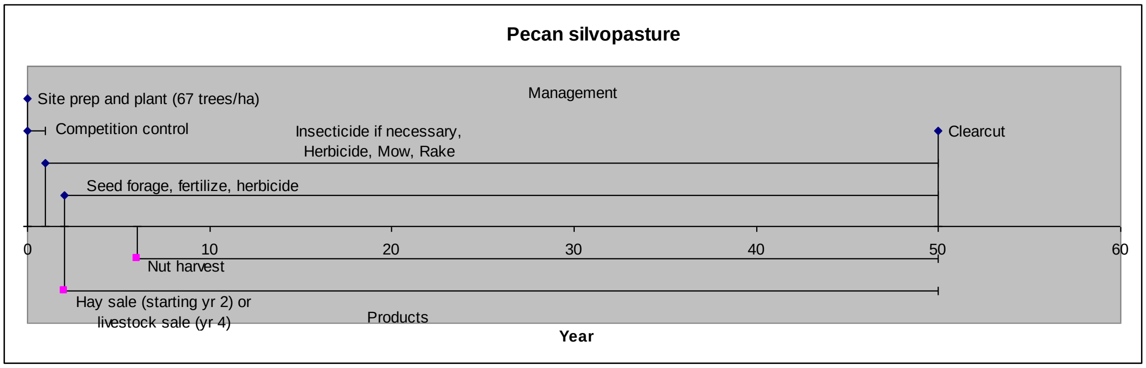

Figure III.A.8. Typical management timeline for a pecan silvopasture system.

The panel of experts concluded that pecan orchards may be a good choice for marginal farmland since pecans commonly grow under wet conditions in the wild. It is a somewhat common practice to graze livestock in pecan orchards, since pecan orchards have wide spacing between trees with about 60 trees per hectare, allowing significant light to pass to the ground. Pecans may be either native or improved varieties. We consider native pecan varieties since they are common in the region, and generally have a less intensive pest management. Still, relative to the other forestry and agroforestry systems, pecan systems are high-input, high-output systems.

The tree is not grown for timber production, but rather for nut production. This is appropriate for agroforestry systems since the lower density of trees for nut production is beneficial for allowing light through. Trees may be offset in order to spread the shade pattern more evenly. Livestock can help keep weeds down, and can be utilized in orchards that are less intensively managed with pesticides. Still, livestock must be removed from the orchards during and after pesticide and fungicide application and when nuts are being harvested. In the more intensively-managed pecan orchards, integrating cattle is probably not an option. Livestock grazing is introduced to the orchard once the trees have reached sufficient size in 3 or 4 years. In the intervening years, hay (or some other alley crop) could be grown between the rows of trees. Nut harvest begins in approximately year 8.

Cattle would graze silvopasture subplots rotationally. Some of the panelists indicated that silvopasture plots could be more productively used in combination with other pasture plots, rotating livestock between pasture and silvopasture. This would allow the landowner to take advantage of the different microclimates to have varied forages and accommodate the livestock's temperature needs (for instance, by placing the livestock in the shade when the temperature is hot).

It is not clear the degree of external environmental services that would be produced by pecan agroforestry. We assume that most conservation payments would not include pecan systems.

2. Hard hardwood silvopasture

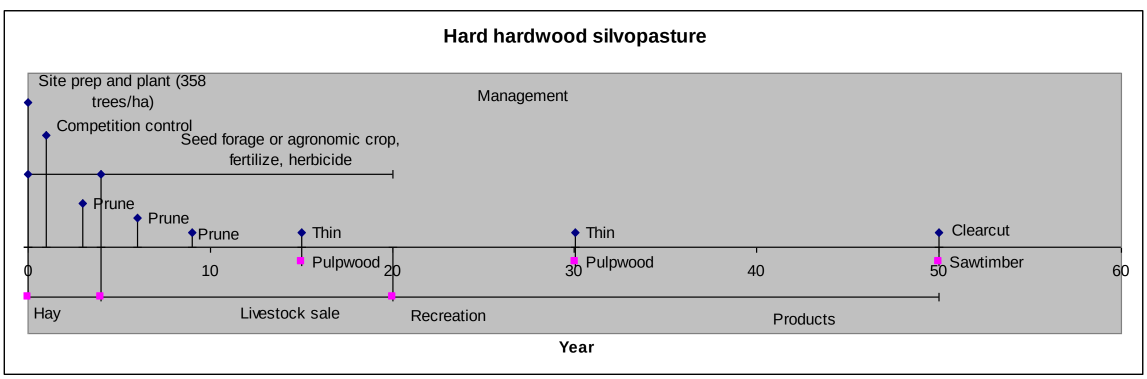

Figure III.A.9. Potential management timeline for a hard hardwood silvopasture system.

As noted above, the particular species or mix of species in hard hardwood systems depends on the particular site conditions. Livestock managers would need to be careful with hard hardwood silvopasture system if oaks are used as the tree species. While acorns and oak foliage can provide good nutrition if consumed on a limited level, high levels of acorn and oak foliage consumption can produce toxicity among cattle, especially nursing calves. For this reason our proposed system only includes livestock until the 20th year. After this point, acorn predominance and limited forage growth would make continuing silvopasture a difficult management decision.

3. Pine Silvopasture

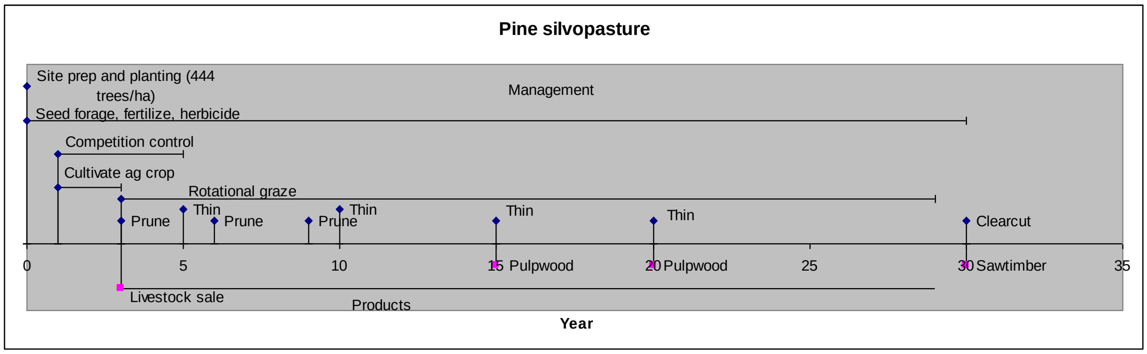

Figure III.A.10. Potential management timeline for a pine silvopasture system.

Cattle grazing under pines (*Pinus taeda*, *P. elliottii* or others) is probably the most typical silvopasture system in the U.S. South. However, softwoods are not a large component of natural forests in the LMAV, nor have they been planted widely. Therefore, an important consideration for pines in the LMAV is the availability of markets. This is discussed below. A typical management scheme for pine silvopastures in other parts of the US South is to plant the seedlings in relatively closely-set rows, allowing for wide alleys of 12-24 m.

III.A.3.2.2.2 Riparian Buffers

Riparian buffers are areas of trees and other vegetation that are planted between agricultural fields and streams and rivers to protect waterways from agricultural runoff containing chemicals, particularly nitrogen and pesticides. Riparian buffers are a form of agroforestry when seen from the landscape level because they are planted in association with agricultural fields, even though management and interspecific interactions may more closely resemble those of a forestry system.

The goal of riparian buffers is first to protect waterways and second to provide income to the landowner. Typically, this is accomplished by dividing the buffer into "zones" (Schultz et al. 2004). The area nearest to the waterway would be an "unmanaged zone", where timber harvest and other activities are prohibited to prevent disturbing the soil. The next zone would be a managed forest zone, where timber extraction is permitted on a limited basis with no machinery, but not clearcutting. Between the managed forest zone and the agricultural field, the riparian buffer would include a native warm season grass filter strip which serves to filter out the largest sediment particles and slow the runoff. We anticipate that no more than 50% of the total area dedicated to riparian buffers would fall within the managed forest zone, limiting the amount of economic benefit the landowner would receive from timber. On the other hand, the addition of grass on the outer edge and the forested stream on the interior makes riparian buffers especially attractive for numerous wildlife species, including quail. We estimated that a hunting lease would be worth 50% more in this type of system than in most forestry systems.

Our panelists indicated that buffers in the LMAV should be at least 10 m wide on each side of the stream, and preferably 25 m or more, in order to provide the desired water quality benefits. To qualify for the CRP CP22 payments, a buffer might be required to be 15m wide or wider, depending on the order of the stream (Godsey 2005). All management decisions should be made with the primary goal of maintaining a healthy ground cover. No bedding or prescribed burns would be allowed, and stream crossings limited. Other important considerations for buffer management are: beaver predation (affecting tree species selection), the types of chemicals sprayed on agricultural fields than might affect the buffer vegetation, and possibly the provision of alternative water sources for cattle.

4. Hard hardwood riparian buffer

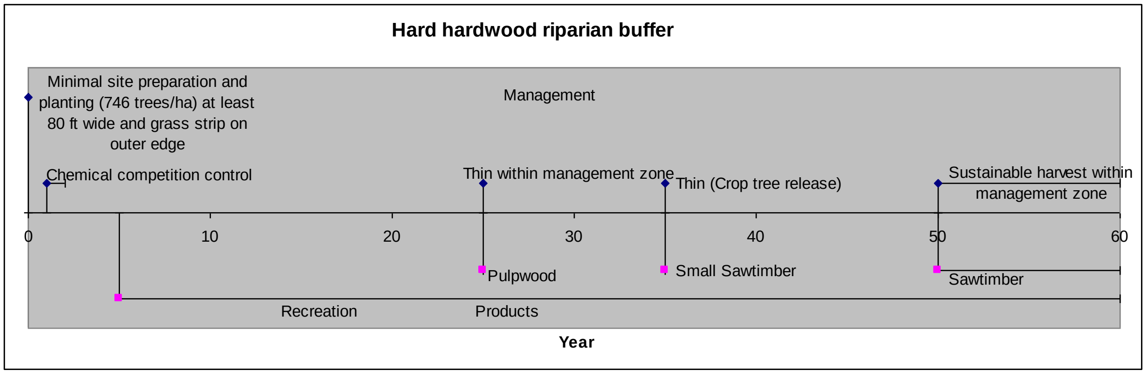

Figure III.A.11. Potential management timeline for a hard hardwood riparian buffer.

5. Cottonwood/Oaks riparian buffer

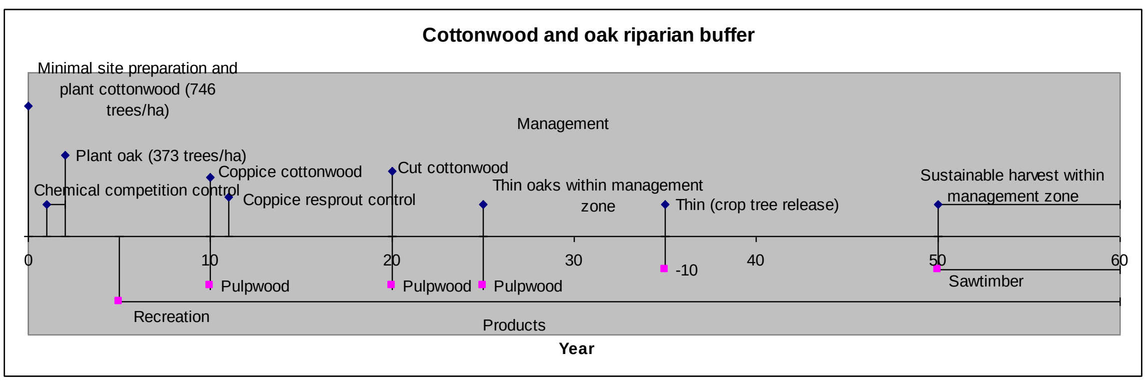

Figure III.A.12. Potential management timeline for a cottonwood and oak interplanted riparian buffer.

Some expert panelists had reservations about using cottonwood in riparian buffers because there is usually a fair amount of mechanical cultivation involved with site preparation, which would encourage erosion. Alternative, limited-impact site preparation techniques would have to be used. The value for nitrogen mitigation would be lower for this type of system because there would be more erosion in the initial years.

III.A.3.2.2.3 Alley Cropping

Alley cropping is the cultivation of annual crops between rows of trees. Many of the panelists were skeptical about the potential adoption of alley cropping systems in the LMAV. One potential barrier is the intensive silvicultural management that would be required to permit enough light to reach the agricultural crop, including pruning and thinning. This would be less of a problem with pecan since trees are planted less densely. A second potential barrier is that farmers must pay special attention to avoid harming trees with farm machinery. All alley cropping systems in the U.S. are designed to permit machinery, but professional farmers may dislike having to work around the trees. This may be especially true if the farmer is not the same as the landowner, if the farmer is not included in the decision-making process.

6. Pecan alley cropping

Alley cropping under pecans may be effective, in much the same way as livestock grazing, since the trees are widely spaced. However, one problem is that crop residue would make nut collection more difficult and costly. Otherwise, the management would essentially be the same as the silvopasture system above.

7. Hard hardwood alley cropping

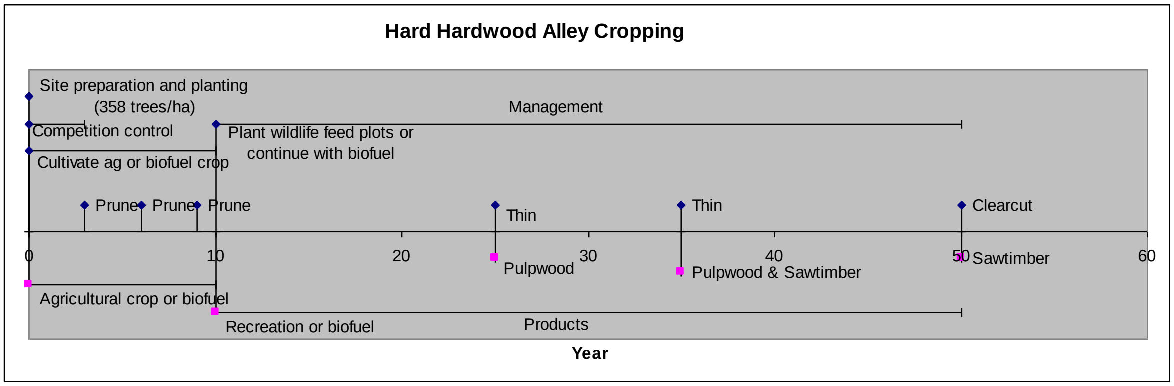

Figure III.A.13. Potential management timeline for a hard hardwood alley cropping system.

Alley cropping with hard hardwoods was considered as an option in the LMAV. Oaks and other hard bottomland hardwoods typically grow dense, thick branches at low stand densities, so costly prunings would be required in oak alley cropping systems.

The width of alleys depends on the specific needs of a farmer's machinery. Several options are available for arranging the trees. Some panelists suggested offsetting the rows of trees, to produce a diagonal arrangement. The rows of trees would be planted in groups of three, within a 6 m (20 ft) strip, leaving a 12 m (40 ft) or wider alley (Figure III.A.14). These panelists felt this design takes the best advantage of space and allows for the trees in the central row to have equal competition on each side, reducing branching.

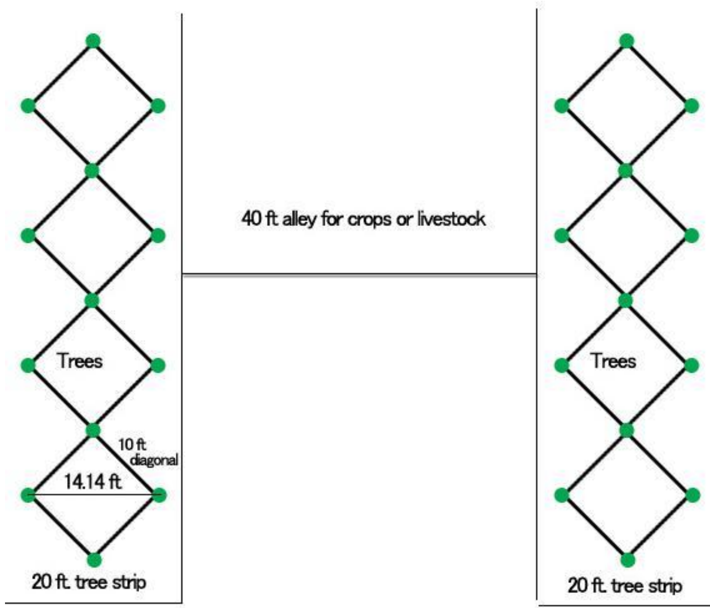

Figure III.A.14. Proposed offset "diagonal" arrangement of trees in alley cropping or silvopasture system. Green dots represent planted trees**.**

On the other hand, an offset pattern might be more costly to maintain. For instance, if machinery were to be used to control weeds amongst the trees, then an offset pattern would not be appropriate. One panelist commented, "With the diamond configuration the area would actually be maintained with machinery driving very short distances on the diagonal perpendicular to the tree diagonal." In this case, a square configuration would be more appropriate. Finally, some panelists suggested that trees might be planted in single rows. In their opinion, since trees will need to be pruned anyway, there is not a great need to create the conditions that reduce branching. There would be fewer trees planted per hectare and potentially wider alleys.

8. **Cottonwood alley cropping**

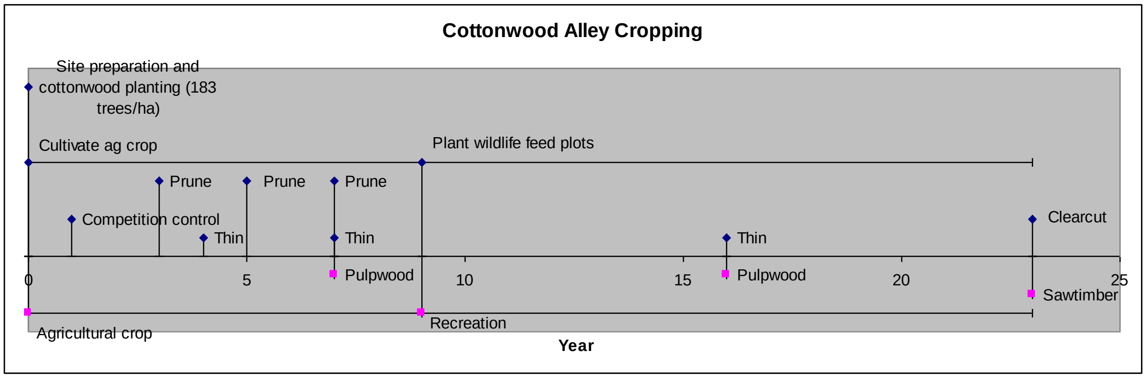

Figure III.A.15. Potential management timeline for a hard hardwood alley cropping system.

There was a wide diversity of opinions about using cottonwood in alley cropping systems. On the one hand, the trees grow quite straight and let a relatively large amount of light through, compared to other species with denser canopies. On the other hand, the trees grow quite fast and obstruct light at a much younger age than hard hardwoods. Also, cottonwood might compete with annual crops for water. The cottonwood is likely to require intensive management through pruning and thinning. Still, most of our panelists agreed that there could be potential for alley cropping under cottonwood under certain conditions, and there is some limited experience in the LMAV with cottonwood alley cropping. Although production in the alley is not likely after 10 years, it still may provide sufficient short-term returns for the landowner.

III.A.3.2.3 ***Suggestions for other components that might be integrated into agroforestry systems on a smaller scale***

In our models, we primarily consider returns to traditional commodity crops within agroforestry (alley cropping) systems. However, there are some other crops that might be cultivated within an agroforestry system, particularly as light decreases. These may provide options for some landowners, but are subject to the availability of markets, as noted below:

1. Vegetables may be used in the alley rows of alley cropping system. Vegetables would perform better in later years, where there is more shade, preventing good production of commodities.
2. Winter wheat may be an excellent option for alley cropping. In the winter, there will be lower competition with the trees (particularly hardwoods) for both light and water.
3. Sweet potatoes
4. Niche products such as coneflower (*Echinacea* spp.) or passionflower (*Passiflora incarnata*)
5. Crops for biofuels, either biomass (switchgrass) or oils (castor oil)

III.A.3.2.4 *Agriculture*

While other crops are cultivated in the LMAV, corn, cotton, rice and soybeans comprise the vast majority of agricultural land. Panelists identified the most typical management systems for each crop, as described below:

Corn

- Roundup Ready variety
- Conservation tillage
- Rotation with cotton, soybeans

Cotton

- BGRR (Bollgard with Roundup Ready) variety

- Conservation tillage
- Solid configuration
- Rotation with corn and soybeans

Rice

- Conventional variety
- Conventional tillage
- Drill seeded
- Rotation with soybeans

Soybeans

- Roundup Ready variety
- Conservation tillage
- Early planting
- Rotation systems can include rice, corn, cotton, others

III.A.3.3 *Costs and Returns*

Panelists were asked to provide typical cost and returns for each crop and for forestry and agroforestry systems in the LMAV. They also provided timber plantation costs, growth rates and management regimes, as previously noted. These were compared to published estimates on the national, regional and state levels. The estimates for agricultural returns for 2009 for the various crops are shown in Table III.A.4. These estimates assume a year with no catastrophic losses for the farmer such as flooding. We also estimated a 90% confidence interval for each crop, based on the range of estimates provided by the panelists.

Estimates without confidence intervals mean that panelists were not directly asked about that specific crop on that land class. Those estimates were derived from relative yield rates for each crop on each land class from soil survey data (NRCS 2008a), based on the land classes that did have estimates for that crop.

Table III.A.4. Estimated agricultural returns ($ per hectare) to land, management and risk* for 2009, assuming no catastrophic events.

Crop	LCC** 1-2	LCC** 3	LCC** 5
Corn	$459 ($91 – 953)	195	-
Cotton	$205 (-$116 – 403)	82	$25
Rice	-	$489 ($333 – 622)	$275
Soybeans	$368 (-$124 – 524)	$336 ($2 – 731)	$326 (-$47 – 731)

Estimates are based on Delphi assessment panel of experts.
90% confidence intervals are in parentheses. Estimates without confidence intervals mean that panelists were not directly asked about that specific crop on that land class. Those estimates were derived from relative yield rates for each crop from soil survey data (NRCS 2008a).
* Returns to land, management and risk equal total revenue minus all costs except the cost of land, management and insurance.
** Land Capability Class

Based on the expected normal-weather crop return estimates for 2009 (Table III.A.1), we determined that of the four major crops, rice and soybeans were the most likely to be planted on LCC 3 and 5 soils. Because the panelists were asked to assume normal weather, that is, no catastrophic weather events, we adjusted the expected returns to rice and soybeans to account for those factors. Furthermore, we adjusted the expected returns to account for projected commodity price changes. Both rice and soybean prices are expected to decrease somewhat over the next ten years, meaning that expected returns for the long term, even with no catastrophic weather events, are somewhat lower than expected returns for 2009 (IAPC 2009). We estimated that soybeans are more profitable than rice on LCC 5 soils, in fact, rice has negative expected returns on those soils. On LCC 3 soils, rice is more profitable in our estimation. It is important that to emphasize that these estimates represent the most typical soils in each class. It is possible that on specific soil types, the crops might perform differently. Also, it is important to recognize that these are expected returns; in any given year, rice might perform better on LCC 5 and soybeans better in LCC 3.

Table III.A.5. Estimated expected agricultural returns ($ per hectare) to land, management and risk* for long-term, including catastrophic weather events.

Crop	LCC** 3	LCC** 5
Rice	388	-38
Soybeans	257	46

* Returns to land, management and risk equal total revenue minus all costs except the cost of land, management and insurance.
** Land Capability Class

We also estimated returns to forestry and agroforestry system using information about costs, growth and yield, and timber price projections. Based on inputs from the Delphi panelists and published cost information, we estimated the establishment costs for forestry and agroforestry systems given in Table III.A.6. Plantations of hard hardwoods, such as oaks, were generally the cheapest because they involve less site preparation than cottonwood or pine. Agroforestry systems such as silvopasture and alley cropping generally had lower establishment costs than production forestry systems of the same tree species because fewer trees are planted per hectare. However, pecan systems, despite including very few trees per hectare, have the highest establishment costs because of an intensive cultivation, insecticide and fungicide regime.

Table III.A.6. Estimated typical establishment costs, including site preparation, planting, competition control, fungicide and pesticide in first three years for trees in production forestry and agroforestry systems ($ per hectare).

System	Establishment cost
Cottonwood for Pulpwood/Sawtimber	$944
Short Rotation Woody Crop	$1319
Hard hardwoods	$763
Cottonwood-Oak intercrop	$1363
Pecan Silvopasture/Alley cropping	$1467
Hardwood Silvopasture/Alley cropping	$530
Pine Silvopasture	$925
Cottonwood Alley Crop	$768

The forestry and agroforestry panels were asked to give their estimates of typical growth rates in LMAV soils, and in various agroforestry and forestry systems (Table III.A.7). For instance, agroforestry panelists were asked how the growth per hectare of trees in alley cropping might compare to growth per hectare in a traditional forestry plantation, given that there are 50% fewer trees in the alley cropping system. The response was that for both cottonwood and hard hardwoods in alley cropping, each tree would grow faster on average than each tree in a plantation forestry system, with a total growth per alley cropping hectare about 58% of a plantation forestry hectare. On the other hand, oaks and cottonwood in an interplanted system would suffer from greater competition between trees lowering growth per tree. The growth of cottonwood would be 90% of the growth in a traditional cottonwood system, despite having the same number of cottonwood trees per hectare. Oak would reach 45% of a traditional oak system despite having 50% of the number of trees per hectare. On the other hand, the total growth per hectare of the two species together would outpace a traditional single-species stand. Despite this lower total growth per hectare for each species during the initial years of agroforestry or interplanting, growth rates would eventually reach the rates in a traditional forestry system.

Table III.A.7. Estimated typical timber growth rates (tons per hectare per year).

System	LCC* 3	LCC* 5
Soft Hardwoods (Eastern cottonwood, American sycamore)	19.5	21.3
Soft Hardwoods – short rotation	21.0	23.2
Cottonwood in cottonwood and oak interplanted system	17.6	19.2
Cottonwood in alley cropping system (years 0-10)	11.1	12.1
Hard Hardwoods (Cherrybark oak, Nuttall oak, Water oak, Green ash)	7.9	7.9
Oak in cottonwood and oak interplanted system (years 0-20)	3.6	3.6
Hard Hardwoods in alley cropping or silvopasture system (years 0-20)	4.6	4.6
Softwoods (Loblolly pine)	17.8	17.8
Softwoods in silvopasture system (years 0-20)	8.9	8.9

Estimates are based on Delphi assessment panel of experts.
* Land Capability Class

Timber prices were based on prices from the Louisiana Quarterly Report of Forest Products (LA DAF 2008) and projections from the Subregional Timber Supply (SRTS) model (Abt & Cubbage 2008). The SRTS model provides indices of relative prices in future years. The 2008-09 prices from the Louisiana Quarterly Report were used to calibrate these indices. The SRTS projects a downward price trend for hardwoods and an upward trend for softwoods.

Agroforestry panelists were asked about the relative productivity of agricultural crops in an agroforestry system. The total relative yield was decomposed into two parts, the portion of each hectare that is planted (because part of the area is taken by tree rows) and the relative yield per planted hectare. It was estimated that relative yield per planted hectare would be 50-75% of a conventional agricultural system, depending on the year of the system.

We were unable to gather a panel on livestock in the LMAV, as it is relatively uncommon and it was not initially a focus of our study. Unfortunately, published estimates are widely variable. Some estimates showed a negative expected return to cattle-raising, and empirical data from ARMS shows negative returns to land, management, operator labor and risk for cow-calf operations in the LMAV for each year from 1996-2007 (ERS 2009). On the other hand, returns to variable expenses (that is, excluding all fixed costs such as the capital recovery cost of machinery and equipment) are very nearly zero on average. With a zero average, many farmers will have a loss in any given year and many will reap a positive return. It is probable that returns therefore depend greatly on the size of the herd, as larger herds would drive down these fixed costs per head, as well as numerous other management decisions. The University of Arkansas gives estimates of returns per head ranging from $23 to $120, depending on management (Brister et al. 2002). Louisiana State University provides estimates ranging from a loss of $434 to a positive return of $101 per head, depending on management (Boucher & Gillespie 2007). This reaffirmed our conclusion that returns for cattle raising depend greatly on the management regime and style of the farmer.

With the highly variable nature of cattle-raising, it made sense to conduct a sensitivity analysis. For the base case, returns to cattle-raising were assumed to be $35 per animal unit (cow-calf pair or equivalent) per year. This may be an optimistic estimate, and we have a relatively low level of confidence, compared to the other systems. Therefore, we also calculated returns for silvopasture assuming returns per animal unit of $0 and -$50.

III.A.3.4 *Factors Affecting Returns*

It is useful to identify those factors that might impact returns to the various land uses. This helps us to know how land uses might change over time. It is important to identify both factors that might influence returns in any particular year, as well as those that might create changes in the markets over the medium or long term. We asked our panelists to identify these factors.

III.A.3.4.1 *Year-to-year factors*

The main biological factors that affect returns to agriculture, forestry and agroforestry systems from year to year are weather related. Our panelists identified flooding as the most important factor that affects production returns on a year-to-year basis. This is consistent with Amacher et al. (1997) for soybean yields in the LMAV. The second most frequent response was drought, followed closely by hurricanes and high winds.

Our panelists were much less likely to believe that extreme heat, ice and hail storms, and frosts and freezing would cause major problems in most years. This may be because these events are less frequent or because they are less difficult to manage when they do occur. Disease and pests were also mentioned with moderate frequency.

III.A.3.4.2 *Medium to long term factors*

The main medium to long term factors that can have an impact on returns are related to the larger economy and also to policy. The most commonly cited was demand for biofuel crops, followed by agricultural subsidies. As the question was posed in early 2008, increased input costs from high energy prices were important factors to consider, as well as the health of the housing market. The housing market drives most of the demand for oak sawtimber. Panelists noted that landowners were very aware of the global interconnectedness of markets and how trade affects their land-use strategies. The panelists also noted that policy can impact returns. Federal and state cost-sharing programs for forest establishment and tax codes for forestry can impact landowners' decisions. Finally, our panelists believed that the emerging markets for carbon could impact returns.

III.A.3.5 *Market Access for System Products*

Since certain products of the systems we analyze do not have viable markets in all parts of the region, there may be barriers to certain systems in large parts of the region. Before deciding to adopt a system, farmers are likely to assess whether or not they will be able to sell their products. If markets appear to be on the decline or on the rise, they may adopt a wait-and-see approach, sticking to familiar systems with familiar products to be sold in familiar markets. Therefore, even in regions where markets are currently available or anticipated to be available, there may be hesitation on the part of some farmers to adopt new systems.

III.A.3.5.1 *Commodity crops*

It is taken as a given that markets for commodities in the LMAV are well-developed. The LMAV has large areas of corn, cotton, rice and soybean production. These markets will be available for the foreseeable future.

III.A.3.5.2 *Vegetables*

The LMAV is not typically a vegetable-producing region, and there are not likely to be many markets for selling vegetables to be shipped to urban areas outside of the region. However, it may be possible for a farmer to sell vegetables at farmers' markets in the local urban areas.

III.A.3.5.3 *Cattle*

Livestock are not common in the LMAV, but they do exist throughout the region. Markets are available.

III.A.3.5.4 *Biofuels and biomass*

Markets for biofuels and biomass clearly do not exist in most parts of the LMAV. Most corn ethanol plants are further to the north. There is a biodiesel plant in Batesville, AR, which might be accessible to the western LMAV. Markets for products like switchgrass or woodchips for biofuel are virtually non-existent at the present time. The future may create more markets and higher prices for biomass.

III.A.3.5.5 *Hardwood pulpwood*

In some parts of the LMAV, it may be difficult to access pulpwood markets. Pulp mills have decreased throughout the region.

III.A.3.5.6 *Hardwood sawtimber*

III.A.3.5.6.1 Soft hardwood sawtimber

Low-value hardwoods for sawtimber principally include the "soft" hardwoods, including eastern cottonwood, American sycamore and sweetgum. Eastern cottonwood, in particular, is a very common species in naturally-regenerated stands in the LMAV region, and has also been used in plantations.

Uses for these species are fairly limited and include crates, pallets and railroad ties. The markets are fairly fluid, and a market that exists in one region one year may disappear the next. In general, markets for low-quality hardwood timber have been in decline. In some areas, these markets would be fairly distant.

The general decline in markets for low-quality timber may be attributed to reduced supply in the region. In the past, the conversion of forestlands to agriculture was sufficient to bring a large supply of timber to market. Now, however, most forests are on land that is either unproductive for agriculture, or are under some sort of conservation scheme, public or private, that prohibits conversion to agriculture. Still, there is timber available from harvest of forests without conversion to agriculture, but the sustainable supply will not be as high as the previous unsustainable supply.

III.A.3.5.6.2 Hard hardwood sawtimber

High value hardwood, including oak sawtimber, is principally used in the housing market. Oak may be used in numerous applications in homes, such as cabinets, paneling, flooring, doors, etc. The 2007-08 collapse of the housing market put a damper on oak prices, which had been relatively high.

III.A.3.5.7 *Softwood*

Pines are not common in natural stands in the bottomlands of the LMAV, and have not traditionally been planted in the region. Therefore, there are no markets developed for pine directly in the LMAV. However, pine stands and markets for the timber are common in the surrounding areas, particularly southern Mississippi. Therefore, a pine-based system is probably only appropriate in the LMAV in these areas bordering pine-producing regions.

III.A.3.6 *Base Case*

Table III.A.1 presents the results from the base case financial calculation. These calculations include no government payments of any form. Without government payments, or ecosystem service markets, very few forestry or agroforestry systems are competitive with agriculture on either type of land under any discount rate we tested. There were exceptions: pine silvopasture and cottonwood for sawtimber on LCC 5 soils under low discount rates. With these systems we should be wary, as previously noted there are limitations to the markets for pine and for cottonwood sawtimber in the LMAV.

On land capability class (LCC) 5, the most marginal land, at the lowest discount rate (5%) three agroforestry and production forestry systems have higher expected returns (measured with soil expectation value, SEV) than agriculture, assuming no policy interventions. These systems are pine silvopasture, cottonwood alley cropping and cottonwood for sawtimber. These systems may be feasible for some landowners in the LMAV who have market access. However, as previously noted, there are problems with markets for both these types of timber. Softwood markets are located outside of the LMAV, so access would be limited for farmers in the LMAV. Soft/low-value hardwood (cottonwood) markets have been in decline in the LMAV. Therefore, even if a landowner has access to a nearby mill for cottonwood today, he may be afraid that that mill may go out of business before he or she can harvest the timber. This may act as a barrier to adoption. On the other hand, a landowner can be fairly certain that commodity crop markets will remain in the LMAV. Other systems with a positive SEV, indicating an internal rate of return higher than 5% were hard hardwood silvopasture and the cottonwood and oak intercropped system.

At higher discount rates of 7-10% on LCC 5, soybean crops have more favorable returns than all of the agroforestry and production forestry systems. The only systems with positive SEVs at 7% discount rate are pine silvopasture, cottonwood alley cropping and cottonwood for sawtimber. All of the agroforestry and production forestry systems have negative SEVs at 10% discount rate. This indicates that landowners with higher discount rates prefer agriculture over forestry. This is a typical result because forestry and agroforestry take longer periods of time to achieve a positive return on investment, and a high discount rate indicates a high degree of impatience.

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, the SEVs for most of these systems, particularly the agroforestry systems, were substantially higher than on LCC 5 soils. In particular, the alley cropping systems, including pecan and cottonwood alley cropping, had SEVs over $2000 per hectare at the lowest discount rate (5%). These systems had significantly higher returns than the comparable production forestry systems, because they take advantage of the higher quality soil to produce some agricultural crops in the early years. This indicates, therefore, that landowners are more likely to adopt agroforestry than pure production forestry systems on moderately marginal land (LCC 3), while on the most marginal land (LCC 5) the results for agroforestry and production forestry are similar. Still, the low SEVs for both agroforestry and production forestry compared to agriculture on LCC 3 lands indicates that landowners/farmers are likely to prefer agriculture on these lands, unless they can receive some sort of incentive payments, as explained in the policy case.

These results are less favorable for forests than those found by Amacher et al. (1997) and Anderson and Parkhurst (2004). First, this reflects that we have accounted for the probability of tree seedling mortality during the first year, requiring replanting. We believe that this is a more realistic framework, and indeed, if one is going to assume loss of agricultural crops because of flooding, it is appropriate to do the same for trees. Second, agricultural crop prices are somewhat higher than they were a few years ago.

Table III.A.8. Soil Expectation Values for various production systems on land types in the LMAV with no policy interventions, varying discount rates ($/ha).

Land Capability Class	**Land Capability Class 3**			**Land Capability Class 5**		
Discount Rate	**5%**	**7%**	**10%**	**5%**	**7%**	**10%**
Soybeans	5150	3679	2575	925	661	463
Rice	7771	5551	3886	-768	-548	-384
Cottonwood for Pulpwood	-257	-499	-689	-338	-625	-844
Cottonwood for Sawtimber	1180	275	-347	1210	205	-479
Short Rotation Woody Crop	-2217	-1839	-1565	-2253	-1941	-1713
Hard hardwoods (clearcut)	52	-495	-758	-129	-667	-922
Hard hardwoods (sustainable harvest)	-179	-613	-794	-357	-783	-957
Cottonwood & Oak intercrop (clearcut)	158	-495	-885	18	-649	-1048
Cottonwood & Oak intercrop (sustainable harvest)	-12	-589	-915	-158	-743	-1077
Pecan Silvopasture	1020	-918	-2255	-28	-1864	-3106
Hard Hardwoods Silvopasture	811	190	-122	321	-246	-513
Pine Silvopasture	2512	951	-12	1861	404	-477
Hard Hardwoods Riparian Buffer	-333	-652	-784	-510	-822	-947
Cottonwood & Oak Riparian Buffer	-590	-956	-1138	-769	-1135	-1317
Pecan Alley Crop	2355	7	-1640	-235	-2000	-3191
Hard Hardwoods Alley Crop	843	275	-13	-8	-467	-656
Cottonwood Alley Crop	2144	1076	362	1367	393	-234
Reference Land Value		6000			4500	

Table III.A.9 shows the results of the sensitivity analysis on the returns per head of cattle on the SEV calculations for silvopasture systems. The silvopasture SEVs are quite sensitive to changes in the returns per head of cattle. The range of values used for returns per head is well within the range of values suggested by the livestock budgets (Brister et al. 2002; Boucher & Gillespie 2007). It is important to note that on LCC 5 lands, with a 5% discount rate, a reduction in the profitability of cattle reduces the SEV of pine silvopasture from being much higher than the reference soybean SEV (from Table III.A.8) to being significantly lower. These results suggest that silvopasture returns are sensitive to numerous management decisions. Therefore, a landowner or farmer without experience in cattle-raising is unlikely to adopt silvopasture because of the risk of incurring significant losses. Since cattle-raising is not common throughout most of the LMAV, silvopasture is also not likely to become common.

Table III.A.9. Sensitivity analysis for the effect of returns per head from cattle-raising on silvopasture. 5% discount rate, $/hectare.

	Land Capability Class 3			**Land Capability Class 5**		
	$35/head	**$0/head**	**-$50 /head**	**$35/head**	**$0/head**	**-$50 /head**
Pecan Silvopasture	1020	323	-673	-28	-596	-1408
Hard Hardwoods Silvopasture	811	373	-251	321	-35	-544
Pine Silvopasture	2512	1838	874	1861	1311	526

III.A.3.7 *Policy Case*

It was estimated that fixed direct payments (FDP) for farmers would have an expected value of $25.42 per soybean base hectare per year ($10.29 per acre) and ACRE payments would have an expected value of $14.60 per soybean hectare per year ($5.91 per acre) on LCC 3 and $2.20 per hectare ($0.89 per acre) on LCC 5, with some years receiving more and some receiving none or less.

Table III.A.10 shows the estimated payments for carbon sequestration and nitrogen uptake per hectare per year. As noted previously, the carbon payments include a discount because of their non-permanence, except in the case of short-rotation woody crops. SRWC systems are assumed directly to produce biofuels, which would offset fossil fuel consumption. Reducing emissions, unlike sequestration in biomass, is a permanent credit. We assumed that only riparian buffers would receive credits for capturing nitrogen from runoff. It is possible that wetland forests in non-streamside areas, particularly non-streamside wetlands, could potentially also help improve water quality, but we did not consider this here.

Table III.A.10. Estimated payments for CO2 sequestration and N capture.

System	Years of CO_2 payment	Non-permanence discount	CO_2 payment ($/ha/yr) ($10/ tCO_2e)	CO_2 payment ($/ha/yr) ($30/ tCO_2e)	N payment ($/ha/yr)
Cottonwood for Pulpwood	10	50%	65	196	
Cottonwood for Sawtimber	20	32%	89	266	
Short Rotation Woody Crop	continuous		154	462	
Hard hardwoods (clearcut)	50	10%	128	385	
Hard hardwoods (sustainable harvest)	50	0%	142	427	
Cottonwood & Oak intercrop (clearcut)	50	10%	166	498	
Cottonwood & Oak intercrop (sustainable harvest)	50	0%	184	552	
Pecan Silvopasture					
Hard Hardwoods Silvopasture	50	10%	68	205	
Pine Silvopasture	30	25%	61	183	
Hard Hardwoods Riparian Buffer	50	0%	107	321	634
Cottonwood & Oak Riparian Buffer	50	0%	138	414	476
Pecan Alley Crop					
Hard Hardwoods Alley Crop	50	10%	68	205	
Cottonwood Alley Crop	23	30%	55	164	

III.A.3.7.1 *Existing Conservation policies*

Table III.A.11 provides SEV calculations including impacts of ACRE and fixed direct payments (FDP) for agriculture, the WRP program and the CRP CP22 practice. Several things are obvious from the table. First, the ACRE and FDP programs together increase the value of agriculture significantly, including a 15% increase in returns for LCC3 land and nearly 60% increase on LCC 5 lands. Second, WRP and CRP enrollment is competitive with agriculture on LCC 5 land. Assuming an easement payment of $2223 per hectare, WRP is quite a bit more profitable than agriculture. It is well known that very few farmers turn down a WRP bid of $2223. On the other hand, assuming a payment of $741 per hectare, the WRP SEV is much lower, and indeed is significantly lower than agriculture including ACRE and FDP. In fact, very few farmers accepted bids this low during the 2006-08 period, which corresponds well to our results. CRP CP22 has an SEV slightly less than WRP, assuming an easement payment of $2223 per hectare, at 5% discount rates. A higher discount rate would make CRP CP22 and agriculture less competitive with WRP because the WRP easement is paid up front, whereas agriculture and CRP CP22 receive annual payments. Therefore, high discount rates might partially explain why WRP has been more popular than CP22, as well as the fact that fewer lands qualify for CP22, because they must be along streams.

On LCC 3 lands, WRP is less competitive with agriculture, mostly because the easement payment is capped at $2223 per hectare. The CRP CP22 program, on the other hand, pays yearly payments based on the typical land rental rate, which is higher for LCC 3 soils. Therefore, CP22 is somewhat more competitive than WRP on these moderate soils.

Table III.A.11. SEVs with existing policies: Agriculture with ACRE[1] and FDP[2], WRP[3], CRP CP22[4] ($/ha). 5% discount rate.

Land Capability Class	System	No Policy	ACRE + FDP	WRP $741 /hectare (no harvest)	WRP $2223 /hectare (no harvest)	CRP CP22
LCC 3	Soybeans	5150	5950			
	Hard Hardwoods (clearcut)	52		751	2233	
	Hard Hardwoods Riparian Buffer	-333				3696
LCC 5	Soybeans	925	1478			
	Hard Hardwoods (clearcut)	-129		751	2233	
	Hard Hardwoods Riparian Buffer	-510				2184

[1] Average Crop Revenue Election
[2] Fixed Direct Payments
[3] Wetlands Reserve Program
[4] Conservation Reserve Program Conservation Practice 22 (Riparian Buffers)

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 easement. These limits may pose additional barriers to extension of WRP and CRP programs in areas with a high proportion of streamside areas and wetland areas.

III.A.3.7.2 *Potential future markets for ecosystem services*

Table III.A.12 and Table III.A.13 demonstrate the impact of markets for ecosystem services. First we note the results from increasing the value of pulpwood or biomass to $20 per green ton (as opposed to $5-6 under the base conditions). Such an increase in price for pulpwood/biomass might result from a carbon policy that requires more energy to be derived from renewable sources. Under higher pulpwood/biomass prices, cottonwood systems designed to produce pulpwood, and short-rotation woody crop systems become the most profitable forestry/agroforestry systems. They surpassed the value of agriculture on LCC 5 lands, but not on LCC 3 lands.

Then, we calculated the SEVs for the forestry/agroforestry systems under markets for carbon dioxide and nitrogen mitigation, assuming CO_2 prices of \$10 and \$30 per ton. The high value of riparian buffers is the most noticeable result. Based on ecosystem markets for nitrogen capture, riparian buffers jump to the range of \$10000 - \$20000 per hectare, much higher than the value of the land under agriculture. This reinforces the opinions of our panelists – that riparian buffers are probably the most important systems from an environmental and societal perspective. Under markets for ecosystem services, riparian buffers could be the principal system to replace agriculture on LCC 3 and LCC 5 land, around waterways.

Aside from riparian buffers, the system that is the most competitive with agriculture on LCC 3 soils is the cottonwood-oak intercrop, principally because of the carbon payment. Interestingly, the carbon credit makes the sustainable harvest option more profitable than the clearcut option because of the carbon credit non-permanence discount applied to the clearcut option. At high prices for CO_2 sequestration (\$30 per ton), timber systems with long rotations or permanent plantations become more profitable than agriculture on both LCC 3 and LCC 5 soils. This is quite a different result than the situation of higher biomass prices, which favor short rotations. Therefore, the precise forestry or agroforestry system that would be utilized to help mitigate against atmospheric carbon increases will depend enormously on the policy that is implemented.

Table III.A.12. SEVs for production forestry and agroforestry systems, under potential future markets for conservation. Land Capability Class 3, 5% discount rate.

	No Conservation Policy	High Biomass Price ($15 /green ton)	Carbon/ Nitrogen Markets ($10/ tCO_2e)	Carbon/ Nitrogen Markets ($30/ tCO_2e)
Soybeans with ACRE & FDP	5950			
Cottonwood for Pulpwood	-257	3765	247	1254
Cottonwood for Sawtimber	1180	3383	2285	4495
Short Rotation Woody Crop	-2217	3238	862	7020
Hard hardwoods (clearcut)	52	475	2396	7083
Hard hardwoods (sustainable harvest)	-179	176	2422	7625
Cottonwood & Oak intercrop (clearcut)	158	2884	3186	9243
Cottonwood & Oak intercrop (sustainable harvest)	-12	2476	3349	10072
Pecan Silvopasture	1020	1020	1020	1020
Hard Hardwoods Silvopasture	811	1088	2061	4561
Pine Silvopasture	2512	3007	3452	5332
Hard Hardwoods Riparian Buffer	-333	-156	14298	18200
Cottonwood & Oak Riparian Buffer	-590	654	11441	16483
Pecan Alley Crop	2355	2355	2355	2355
Hardwood Alley Crop	843	1113	2093	4592
Cottonwood Alley Crop	2144	3167	2882	4360

Table III.A.13. SEVs for production forestry and agroforestry systems, under potential future markets for conservation. Land Capability Class 5, 5% discount rate.

	No Conservation Policy	High Biomass Price ($15 /green ton)	Carbon/ Nitrogen Markets ($10/ tCO_2e)	Carbon/ Nitrogen Markets ($30/ tCO_2e)
Soybeans with ACRE & FDP	1478			
Cottonwood for Pulpwood	-338	3987	214	1319
Cottonwood for Sawtimber	1210	3580	2423	4848
Short Rotation Woody Crop	-2253	3707	1152	7963
Hard hardwoods (clearcut)	-129	289	2215	6902
Hard hardwoods (sustainable harvest)	-357	-7	2244	7447
Cottonwood & Oak intercrop (clearcut)	18	2929	3255	9727
Cottonwood & Oak intercrop (sustainable harvest)	-158	2500	3204	9926
Pecan Silvopasture	-28	-28	-28	-28
Hard Hardwoods Silvopasture	321	595	1571	4071
Pine Silvopasture	1861	2349	2801	4680
Hard Hardwoods Riparian Buffer	-510	-334	14122	18024
Cottonwood & Oak Riparian Buffer	-769	560	11262	16304
Pecan Alley Crop	-235	-235	-235	-235
Hardwood Alley Crop	-8	259	1242	3742
Cottonwood Alley Crop	1367	2468	2177	3799

III.A.3.8 *Agroforestry system rankings*

Our panelists ranked agroforestry systems in the LMAV in order of their opinions of feasibility, profitability and potential adoptability. In general, the panelists considered silvopasture systems to have the most potential in the LMAV, followed by riparian buffers, then alley cropping. The final consensus among the panelists was that most farmers would dislike the restrictions imposed by alley cropping on their traditional farming techniques. It is worth noting, however, that in the first iteration of this ranking, some of the panelists did think that cottonwood alley cropping had good potential and ranked it quite high. Within silvopasture and alley cropping, most panelists thought pecan was the species best adapted to agroforestry systems in the LMAV. The trees are planted at very low densities and do not have to be managed with pruning. Furthermore, allowing cattle to graze or cutting hay in pecan orchards is a traditional practice in the South.

The panelists' rankings did not completely agree with the rankings from the SEV calculations, as seen in Table III.A.14. First, we note that the panelists did not rank pine silvopasture as it was added later because pine markets are few in the LMAV. However, in places with access to markets for pine, it may be the most adoptable tree species. Observing the SEV rankings for LCC 5, we see that cottonwood alley cropping was actually ranked higher than the silvopasture systems besides pine, as opposed to the panelists' ranking. Again, this difference may reflect the panelists' understanding of farmers' aversion to having impediments in their fields, even if they do not impose a direct financial cost.

Also, riparian buffers were generally ranked the lowest in SEV, with no policy support. The fact that panelists ranked them somewhat higher may suggest that it is possible to tap into landowners' sense of stewardship to support systems that provide a large amount of environmental services. Still, the SEVs are telling, and indicate that policies such as WRP or payments for ecosystem services to support these systems will be necessary.

Table III.A.14. Rankings of agroforestry systems.

	Expert Ranking	SEV LCC 3 (5%)	SEV LCC 5 (5%)
Pecan Silvopasture	1	4	5
Hard Hardwoods Silvopasture	2	6	3
Pine Silvopasture*		1	1
Hard Hardwoods Riparian Buffer	4	7	7
Cottonwood-oak Riparian Buffer	3	8	8
Pecan Alley Crop	5	2	6
Hardwood Alley Crop	7	5	4
Cottonwood Alley Crop	6	3	2

* Pine silvopasture was not considered in the Expert Ranking, but was added later.

The fact that the Delphi panel's rankings were so different from the SEV rankings suggests that the Delphi results for the ranking are inconsistent with the SEV assumptions. This may mean that Delphi methods, while beneficial for estimating costs and returns, are not well-suited to estimating the more nebulous and intangible characteristic of which systems are more feasible or "adoptable". On the other hand, it is possible that the panelists were considering non-market values that the SEV method does not incorporate, making the panelists' rankings more consistent with farmers' true decisions.

III.A.4 CONCLUSIONS

Our research used financial calculations and expert opinion from three panels to evaluate the potential for production forestry and agroforestry systems in the Lower Mississippi Alluvial Valley, USA. The panelists helped guide and shape the research, and in many cases were able to come to consensus about the factors that drive landowners' decisions. Deterministic estimates of costs and returns were calculated from inputs provided by the panelists and reputable institutions in agriculture and forestry in the region.

We found that, absent policy measures to promote forestry and agroforestry, they are unlikely to be adopted. Only pine silvopasture, cottonwood for sawtimber and cottonwood alley cropping were competitive with agriculture, and only on the most marginal lands (Land Capability Class 5). Pine and cottonwood sawtimber have limited markets in the LMAV, which mean that these systems could only be located in a relatively small geographic area. Agroforestry systems performed better than forestry on lands that were not as marginal (LCC 3), but still did not have returns as high as agriculture.

The major policy promoting forestry in the region is the Wetland Reserve Program. Under the current rules, WRP is very competitive on LCC 5 lands, but is not on the better LCC 3 lands. This is significant because of the large proportion of the LMAV occupied by LCC 3, including many streamside areas. The Conservation Reserve Program Conservation Practice 22 has higher returns for landowners on LCC 3 soils in streamside areas, but still is not as profitable as agriculture.

If carbon sequestration and nitrogen capture markets become viable in the future, we would expect increased interest in forestry and agroforestry. In particular, riparian buffers, which capture agricultural runoff, could become very attractive on the modest area that would qualify for this practice. This is because of the high value of nitrogen capture they would provide. In terms of carbon sequestration, permanent or long-rotation plantation forestry systems seem to be the best systems. On the other hand, if policy drives an increase in the price of biomass, short-rotation woody crops become relatively more profitable.

Deriving the inputs, management regimes, costs, prices, and government programs was complex and comprised much of the research. The subsequent discounted cash flow analysis results are based on relatively simple deterministic models. They do not take into account the variability inherent in agriculture and forestry which causes risk. Risk aversion may play a significant role in landowners' decisions. Also, stochastic variation in the inputs and outputs combined with the costs of switching between agriculture and forestry may create option value for certain systems. These are areas of research we are conducting concurrently.

Furthermore, landowners have a host of preferences that may not be directly tied to financial profitability, some of which may favor or oppose forestry or agroforestry adoption. For instance, farmers may not want to deal with trees in their agricultural fields, even if there is no direct cost to them. Expert panelists suggested that this might be the case with agroforestry systems. On the other hand, some landowners may be motivated by a stewardship ethic.

Our research demonstrates that forestry and agroforestry in the LMAV, aside from the WRP program, are not likely to become common in the near future, absent policy or market changes. Thus in the short run, government programs are needed if agroforestry systems are desired. The range of payments is likely to be modest for the best systems other than streamside buffers, to quite large for the less profitable systems compared to the base farm crop systems. Recent increases in agricultural prices would tend to make forestry and agroforestry systems even less adoptable. Our results suggest that modest payments might be sufficient to encourage pine and hard hardwood silvopasture, and cottonwood alley cropping on LCC 5 lands; and pine silvopasture, and pecan and cottonwood alley cropping on LCC 3 soils.

Markets for carbon and nitrogen are in their nascent stages. As these markets grow, we may see concurrent growth in forestry and agroforestry, particularly riparian buffer systems. Prospective programs such as direct payments to landowners for ecosystem services, or a broad cap-and-trade program for carbon storage could also enhance the financial returns and attractiveness for agroforestry systems. This research can provide a basis for future comparisons and analysis of farm programs and ecosystem service markets.

III.A.5 LITERATURE CITED

Abt, R. C., and F. W. Cubbage. 2008. Subregional Timber Supply Model. Southern Forest Resource Assessment Consortium, Raleigh, NC.

Alavalapati, J. R. R., R. K. Shrestha, G. A. Stainback, and J. R. Matta. 2004. Agroforestry development: An environmental economic perspective. Agroforestry Systems **61/62**:299-310.

Amacher, G. S., J. Sullivan, L. Shabman, L. Zepp, and D. Grebner. 1998. Reforestation of flooded farmland: Policy implications from the Mississippi River Delta. Journal of Forestry **96**(5)**:**10-17.

Amacher, G. S., J. Sullivan, L. Shabman, L. Zepp, and J. W. Groninger. 1997. Restoration of the Lower Mississippi Delta Bottomland Hardwood Forest: Economic and Policy Considerations. Report No. 185. Virginia Water Resources Research Center, Virginia Tech, Blacksburg, VA.

Anderson, J. D., and G. M. Parkhurst. 2004. Economic comparison of commodity and conservation program benefits: An example from the Mississippi Delta. Journal of Agricultural and Applied Economics **36**(2)**:**415.

Angelsen, A., and S. Wunder. 2003. Exploring the forest-poverty link: Key concepts, issues and research implications. Jakarta, Indonesia: Center for International Forestry Research.

Baker, J. B., and W. M. Broadfoot. 1979. A practical field method of site evaluation for commercially important southern hardwoods. General Technical Report, Southern Forest Experiment Station, USDA Forest Service (26).

Blanco-Canqui, H., C. J. Gantzer, S. H. Anderson, E. E. Alberts, and A. L. Thompson. 2004. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen, and phosphorus loss. Soil Science Society of America Journal **68**(5)**:**1670-1678.

Boucher, R. W., and J. M. Gillespie. 2007. Beef Cattle, Dairy and Forage Crop Production in Louisiana: 2007 Projected Commodity Costs And Returns. A.E.A. Information Series No. 241. Louisiana State University - Department of Agricultural Economics & Agribusiness - Farm Management Research & Extension, Baton Rouge, LA.

Brister, S. K., M. Popp, C. West, and K. Coffey. 2002. Feeder cattle production budgets for Arkansas, 2002: Estimated Costs and Returns for Specified Situations. University of Arkansas, Little Rock, AR.

Cao, Q. V., and K. M. Durand. 1991. A growth and yield model for improved eastern cottonwood plantations in the lower Mississippi Delta. Southern Journal of Applied Forestry **15**(4)**:**213-216.

CARD. 2009. Ag Risk Tools. Center for Agricultural and Rural Development, Iowa State University, Ames, IA. Available from http://www.card.iastate.edu/ag_risk_tools/ (accessed 3/15 2009).

Clason, T. R. 1999. Silvopastoral practices sustain timber and forage production in commercial loblolly pine plantations of Northwest Louisiana, USA. Agroforestry Systems **4**4(2/3):293-303.

Dalkey, N., and O. Helmer. 1963. An experimental application of the Delphi method to the use of experts. Management Science 9(3):458-467.

Delta Wildlife. 2008. Resources/Useful Downloads: CRP Soil Rental Rates. Delta Wildlife, Stoneville, MS. Available from http://deltawildlife.org/index.php/resources/downloads (accessed 5/10 2009).

Dixon, R. K. 1995. Agroforestry systems – sources or sinks of greenhouse gases? Agroforestry Systems **31**(2):99-116.

Dixon, R. K., J. K. Winjum, and P. E. Schroeder. 1993. Conservation and sequestration of carbon: The potential of forest and agroforest management practices. Global Environmental Change 3(2):159-173.

EPA. 2007. Hypoxia in the Northern Gulf of Mexico: An update by the EPA Science Advisory Board. EPA-SAB-08-004. US Environmental Protection Agency - Science Advisory Board, Washington, DC.

ERS. 2008. Farm and Commodity Policy. USDA Economic Research Service, Washington, DC. Available from http://www.ers.usda.gov/Briefing/farmpolicy/ (accessed 3/15 2009).

ERS. 2009. Agricultural Resource Management Survey (ARMS). USDA Economic Research Service, Washington, DC. Available from http://www.ers.usda.gov/Briefing/ARMS/ (accessed 1/15 2009).

Franzel, S. 2004. Financial analysis of agroforestry practices: Fodder shrubs in Kenya, woodlots in Tanzania, and improved fallows in Zambia. Pages 9-37 in J. R. R. Alavalapati and D. E. Mercer, editors. Valuing Agroforestry Systems. Kluwer Academic Publishers, Netherlands.

Gardiner, E. S., and J. M. Oliver. 2005. Restoration of bottomland hardwood forests in the Lower Mississippi Alluvial Valley, U.S.A. Pages 235-251 in J. A. Stanturf and P. Madsen, editors. Restoration of boreal and temperate forests. CRC Press, Boca Raton.

Gardiner, E. S., J. A. Stanturf, and C. J. Schweitzer. 2004. An afforestation system for restoring bottomland hardwood forests: Biomass accumulation of Nuttall oak seedlings interplanted beneath eastern cottonwood. Restoration Ecology **12**(4):525-532.

Godsey, L. D. 2005. Funding Incentives for Agroforestry in Missouri. AF1005 - 2005. University of Missouri Center for Agroforestry, Columbia, MO.

Gorte, R. W. 2008. Forestry in the 2008 Farm Bill. Order Code RL33917. Congressional Research Service, Washington, DC.

Grado, S. C., C. H. Hovermale, and D. G. St Louis. 2001. A financial analysis of a silvopasture system in southern Mississippi. Agroforestry Systems **53**(3):313-322.

Groninger, J. W. 2005. Increasing the impact of bottomland hardwood afforestation. Journal of Forestry **103**(4):184-188.

Hamel, P. B. 2003. Winter bird community differences among methods of bottomland hardwood forest restoration: Results after seven growing seasons. Forestry **7**6(2**)**:189-197.

Hess, G. R., and T. J. King. 2002. Planning open spaces for wildlife I. Selecting focal species using a Delphi survey approach. Landscape and Urban Planning **58**(1):25-40.

Huang, C. H., R. Bates, G. D. Kronrad, and S. L. Cheng. 2004. Economic analyses of sequestering carbon in loblolly pine, cherrybark oak, and northern red oak in the United States. Environmental management **33**:187.

Hussain, A., I. A. Munn, S. C. Grado, B. C. West, W. D. Jones, and J. Jones. 2007. Hedonic analysis of hunting lease revenue and landowner willingness to provide fee-access hunting. Forest Science **53**(4):493-506.

IAPC. 2009. USDA Agricultural Projections to 2018. OCE-2009-1. USDA Interagency Agricultural Projections Committee, Washington, DC.

Ibendahl, G. 2008. An Accounting Tradeoff between WRP and Government Payments. Southern Agricultural Economics Association Annual Meeting, February 2-6, 2008. Dallas, TX.

Kapp, G. B. 1998. Financial evaluation tools for smallholder forestry: A methodological comparison of two forms of cost-benefit analysis and optimisation. International Tree Crops Journal **9**(4):233-246.

Kim, M., B. A. McCarl, and B. C. Murray. 2008. Permanence discounting for land-based carbon sequestration. Ecological Economics **64**(4):763-769.

King, S. L., and B. D. Keeland. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology **7**(4):348.

King, S. L., D. J. Twedt, and R. R. Wilson. 2006. The role of the wetland reserve program in conservation efforts in the Mississippi River Alluvial Valley. Wildlife Society Bulletin **34**(4):914-920.

Klemperer, W. D. 1996. Forest resource economics and finance. McGraw Hill, New York.

LA DAF. 2008. Louisiana Quarterly Report of Forest Products. Louisiana Department of Agriculture and Forestry, Baton Rouge, LA. Available from http://www.ldaf.state.la.us/portal/Offices/Forestry/ForestryReports/QuarterlyReportofForestProducts/tabid/451/Default.aspx (accessed 1/15 2009).

Llewellyn, D. W., G. P. Shaffer, N. J. Craig, L. Creasman, D. Pashley, M. Swan, and C. Brown. 1996. A decision-support system for prioritizing restoration sites on the Mississippi River alluvial plain. Conservation Biology **10**(5):1446.

LMVJV. 2002. Mississippi Alluvial Valley Conservation Planning Atlas. Lower Mississippi Valley Joint Venture, Vicksburg, MS. Available from http://www.lmvjv.org/cpa_volume1.htm (accessed 11/30 2007).

MSU. 2008. DELTA 2009 PLANNING BUDGETS. Budget Report 2008-06. Mississippi State University - Department of Agricultural Economics, Starkville, MS.

Mueller, A. J., D. J. Twedt, and C. R. Loesch. 1999. Development of Management Objectives for Breeding Birds in the Mississippi Alluvial Valley. in R. Bonney, D. Pashley, R. Cooper and L. Niles, editors. *Strategies for Bird Conservation: The Partners in Flight Planning Process*. Cape May, New Jersey.

Murray, B., A. Jenkins, R. Kramer, and S. P. Faulkner. 2009. Valuing Ecosystem Services from Wetlands Restoration in the Mississippi Alluvial Valley. NI R 09-02. Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC.

Nair, V. D., P. K. R. Nair, R. S. Kalmbacher, and I. V. Ezenwa. 2007. Reducing nutrient loss from farms through silvopastoral practices in coarse-textured soils of Florida, USA. Ecological Engineering **29**(2):192-199.

NRCS. 2006. USDA-NASS Cropland Data Layer. USDA Natural Resources Conservation Service - National Cartography & Geospatial Center, Washington, DC.

NRCS. 2007. National Soil Survey Handbook, Title 430-VI. USDA Natural Resources Conservation Service, Washington, DC.

NRCS. 2008a. Soil Survey Geographic (SSURGO) database. USDA Natural Resources Conservation Service, Ft. Worth, TX.

NRCS. 2008b. Wetlands Reserve Program. USDA Natural Resources Conservation Service, Washington, DC. Available from http://www.nrcs.usda.gov/Programs/WRP/ (accessed 03/15 2009).

NRCS. 2009. Wetlands reserve program. Federal Register **74**(10):2317-2337.

Oelbermann, M., R. P. Voroney, N. V. Thevathasan, A. M. Gordon, D. C. L. Kass, and A. M. Schlonvoigt. 2006. Soil carbon dynamics and residue stabilization in a Costa Rican and southern Canadian alley cropping system. Agroforestry Systems **68**:27.

Pagiola, S., A. Arcenas, and G. Platais. 2005. Can payments for environmental services help reduce poverty? An exploration of the issues and the evidence to date from Latin America. World Development **33**(2)**:**237-53.

Paxton, K. W. 2009. Cotton, Soybeans, Corn, Grain Sorghum and Wheat Production in Northeast Louisiana: 2009 Projected Commodity Costs And Returns. A.E.A. Information Series No. 261. Louisiana State University - Department of Agricultural Economics & Agribusiness - Farm Management Research & Extension, Baton Rouge, LA.

Pearce, D., and S. Mourato. 2004. The economic valuation of agroforestry's environmental services. Pages 67 in D. Pearce, editor. Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington.

Peterson, C. 2008. H.R. 2419: The Food, Conservation, and Energy Act of 2008; Title II, Section 2709. US Federal Law. Washington, DC.

Pimentel, D., U. Stachow, D. A. Takacs, H. W. Brubaker, A. R. Dumas, J. J. Meaney, J. A. S. O'Neil, D. E. Onsi, and D. B. Corzilius. 1992. Conserving biological diversity in agricultural/forestry systems. Bioscience **42**(5)**:**254-362.

Rabalais, N. N., W. J. Wiseman, R. E. Turner, B. K. SenGupta, and Q. Dortch. 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. Estuaries **19**(2B)**:**386-407.

Ramadhani, T., R. Otsyina, and S. Franzel. 2002. Improving household incomes and reducing deforestation using rotational woodlots in Tabora District, Tanzania. Agriculture, Ecosystems & Environment **89**(3)**:**229-239.

RMA. 2009. Crop Policies. USDA Risk Management Agency, Washington, DC. Available from http://www.rma.usda.gov/policies/index.html (accessed 3/15 2009).

Rodriguez Zuniga, J. M. 2003. Paying for forest environmental services: The Costa Rican experience. Unasylva English ed. **54**(212):31-33.

Schoenholtz, S. H., J. P. James, R. M. Kaminski, B. D. Leopold, and A. W. Ezell. 2001. Afforestation of bottomland hardwoods in the Lower Mississippi Alluvial Valley: Status and trends. Wetlands **2**1(4**)**:602.

Schoonover, J. E., K. W. J. Williard, J. J. Zaczek, J. C. Mangun, and A. D. Carver. 2005. Nutrient attenuation in agricultural surface runoff by riparian buffer zones in southern Illinois, USA. Agroforestry Systems **64**(2):169-180.

Schultz, R. C., T. M. Isenhart, W. W. Simpkins, and J. P. Colletti. 2004. Riparian forest buffers in agroecosystems - lessons learned from the bear creek watershed, central Iowa, USA. Agroforestry Systems **61**(1):35-50.

Stanturf, J. A., E. S. Gardiner, P. B. Hamel, M. S. Devall, T. D. Leininger, and M. E. Warren. 2000. Restoring bottomland hardwood ecosystems in the Lower Mississippi Alluvial Valley. Journal of Forestry **98**(8):10-16.

Stanturf, J. A., and C. J. Portwood. 1999. Economics of afforestation with eastern cottonwood (*Populus deltoides*) on agricultural land in the Lower Mississippi Alluvial Valley. General Technical Report - Southern Research Station, USDA Forest Service: 66.

Stanturf, J. A., S. H. Schoenholtz, C. J. Schweitzer, and J. P. Shepard. 2001. Achieving restoration success: Myths in bottomland hardwood forests. Restoration Ecology **9**(2):189-200.

Stanturf, J. A., C. J. Schweitzer, and E. S. Gardiner. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica **32**(3):281.

Twedt, D. J. 2006. Small clusters of fast-growing trees enhance forest structure on restored bottomland sites. Restoration Ecology **14**(2):316-320.

Twedt, D. J., and C. R. Loesch. 1999. Forest area and distribution in the Mississippi Alluvial Valley: Implications for breeding bird conservation. Journal of Biogeography **26**(6):1215.

Twedt, D. J., W. B. Uihlein, and A. B. Elliott. 2006. A spatially explicit decision support model for restoration of forest bird habitat. Conservation Biology **20**(1):100-110.

U of AR. 2009. Cost of Production. University of Arkansas - Agricultural Economics and Agribusiness - Cooperative Extension Service Departments, Little Rock, AR. Available from http://www.uaex.edu/depts/ag_economics/crop_budgets.htm (accessed 1/31 2009).

UM. 2009. Farm Budgets. University of Missouri - College of Agriculture, Food and Natural Resources, Columbia, MO. Available from http://agebb.missouri.edu/mgt/budget/ (accessed 1/31 2009).

UTK. 2009. Budgets. University of Tennessee - Institute of Agriculture, Knoxville, TN. Available from http://economics.ag.utk.edu/budgets.html (accessed 1/31 2009).

van Noordwijk, M., J. G. Poulsen, and P. J. Ericksen. 2004. Quantifying off-site effects of land use change: Filters, flows and fallacies. Agriculture Ecosystems & Environment **104**(1):19-34.

Vandermeer, J., M. van Noordwijk, J. Anderson, Ong Chin, and I. Perfecto. 1998. Global change and multi-species agroecosystems: Concepts and issues. Agriculture, Ecosystems and Environment **67**(1):1-22.

Vose, D. 1996. Quantitative risk analysis: A guide to Monte Carlo simulation modelling. Wiley, Chichester England; New York.

Walbridge, M. R. 1993. Functions and values of forested wetlands in the southern united-states. Journal of Forestry **91**(5):15-19.

III.B Stochastic models of alternative production forestry and agroforestry systems in the Lower Mississippi Alluvial Valley, USA

Gregory E. Frey[1,2], D. Evan Mercer[3], Frederick W. Cubbage[1], Robert C. Abt[1]

[1] Department of Forestry and Environmental Resources, NC State University, Jordan Hall, Box 8008, Raleigh, NC, 27695
[2] Corresponding author: freyge00@hotmail.com, 703-859-0959
[3] Southern Research Station, USDA Forest Service, RTP, NC

III.B.1 INTRODUCTION

In the previous chapter, we developed a deterministic cash-flow model which compared expected returns per hectare to numerous possible production systems. In general, estimated expected returns can help anticipate which systems are the most profitable and thus the most likely to be adopted by private landowners, who must make money to stay in business. However, expected (mean) returns are only one moment of the distribution of returns; the second moment, variance, may also be important landowner decisions. In addition, the expected return in any given year may be correlated to the returns from the previous year.

In layman's terms, an activity whose returns have high variance is one that is risky. Mitigation of risk may be one of the most important of farmers' preferences aside from expected value maximization. It is probably fair to assume that most farmers are risk-averse, although this inclination may be altered by various subsidized crop insurance programs, other government interventions or off-farm income. Their perception of variability of returns may indeed affect their land-use choices and adoption of new technologies.

The purpose of this paper is to apply two models to land-use problems in the LMAV, one that places a value on risk reduction, the mean-variance model, and one that places a value on flexibility, the real options model. In order to achieve this goal, it was necessary to undertake several preliminary analyses. First, we estimated the variance of revenues to various crops at the farm level. Second, we estimated a mean-reversion model of crop and livestock returns, and timber and pecan prices using aggregate time series data. Third, we conducted a Monte Carlo simulation of multivariate crop returns on a single field to estimate the increase in profitability that a farmer might obtain by switching between various crops rather than always maintaining the same crop.

The outputs of these first three analyses were used as inputs into the two models that we believe are the main contribution of this paper: first, a mean-variance model that demonstrates the trade-off between returns and risk on LMAV land and how risk can be reduced through diversification, and second, a real options model that demonstrates how farmers might value the flexibility inherent in different production systems compared to agriculture.

III.B.2 MATERIALS AND METHODS

III.B.2.1 *Crop variability*

III.B.2.1.1 *Distribution of returns*

Net returns to agriculture can be said to be composed of three parts: costs per unit land area, yield per unit area and price per unit yield. Most agricultural risk research has focused on only one or two of these three parts at a time (Goodwin & Ker 2002). However, in order to model net returns, it is important to consider all three.

The nature of agricultural variability is a matter of much research and controversy. Numerous studies have attempted to provide evidence to support or reject various hypothesized distributions or processes which describe the nature of agricultural variability. A rigorous testing of agricultural and forestry returns variability is not the purpose of our research. Rather, we utilize certain models of agricultural return variability only to estimate parameters that serve as inputs to models of forestry and agroforestry adoption. In some places we make certain simplifying assumptions, principally in order to make the adoption simulation computationally tractable. We discuss how data limitations and need for simplification drives some of the assumptions we make. We also offer some limited evidence to support the plausibility and robustness of these assumptions.

First, we assume that the variability of returns in agriculture is completely due to the variability in revenues (output price times quantity), rather than variability in costs. We recognize that this assumption is clearly not true; costs do vary. Still, agricultural costs in the LMAV (Figure III.B.1) have shown a relatively steady and predictable trend over time compared to net returns (figures 1 and 2). This suggests that most of the variability in agricultural returns comes from the revenues, rather than the costs. Furthermore, farmers probably have more control over costs, as they can decide which crop to produce after receiving information about the costs of each crop in a given year.

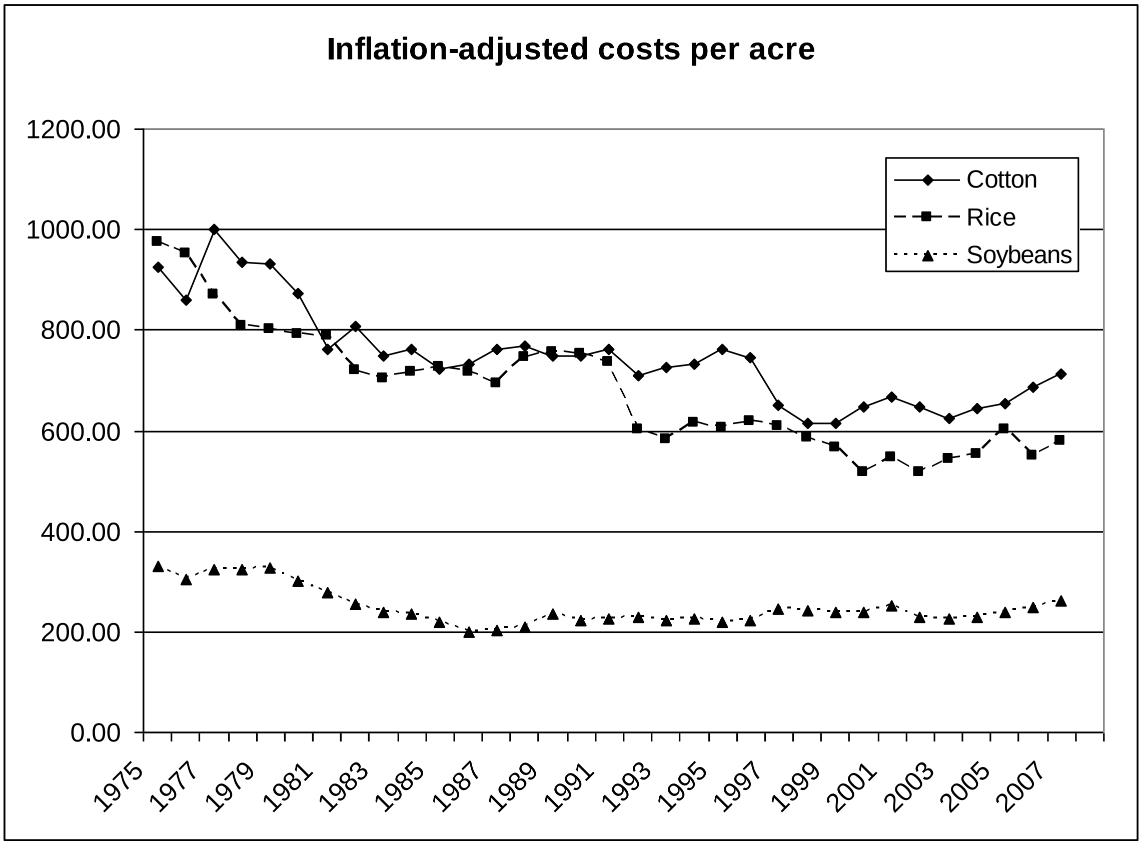

Figure III.B.1. Evolution of aggregate costs per acre of three crops in the Mississippi Portal region, USDA ARMS data (ERS 2009).

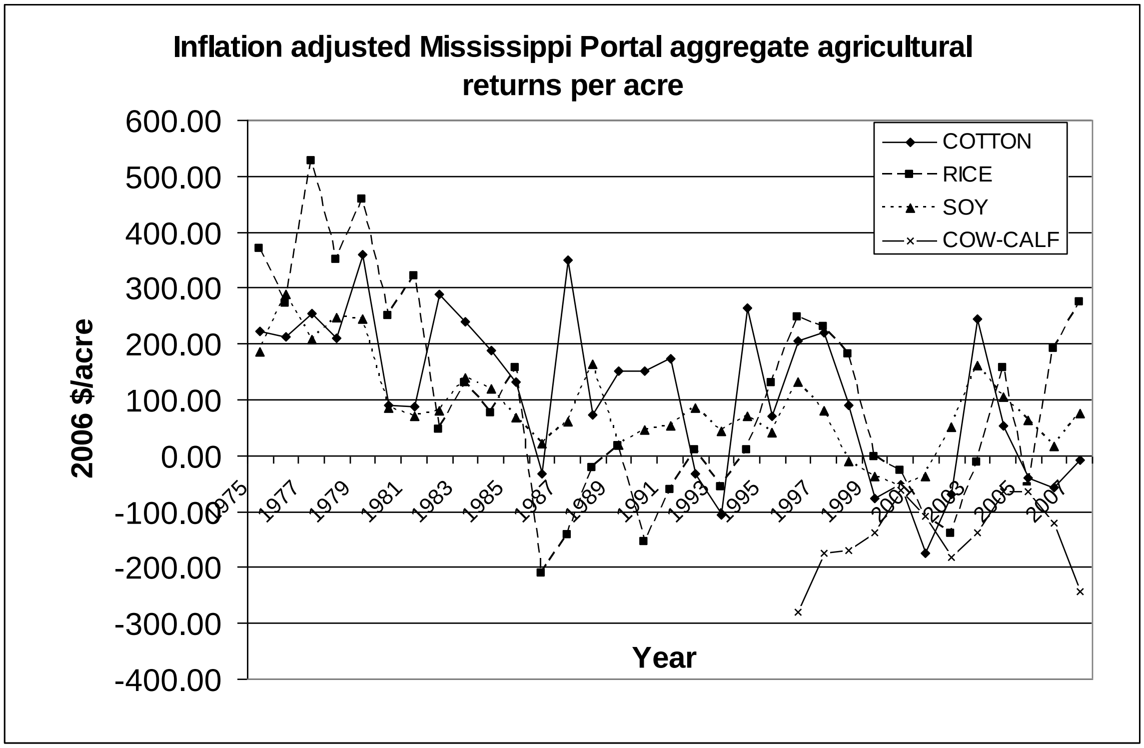

Figure III.B.2. Evolution of aggregate returns per acre of three crops in the Mississippi Portal region and per head for cow-calf enterprises, USDA ARMS data (ERS 2009).

Second, we assume normality of the distribution of agricultural revenues/returns. In order to create a stochastic model of land uses, it is necessary to have at least the first two moments of the returns distribution for each land use: the mean and variance. Ideally, we would like to know higher order moments (skewness, kurtosis, etc.); however, in practice, finding a data set about the land uses we are considering and in the region of interest that is sufficient to estimate these parameters is exceedingly difficult.

The existence of normally-distributed price and yield has been the subject of some debate, with most researchers believing that agricultural yields and prices are not truly normally distributed. Although results are not completely conclusive (Just & Weninger

1999), most research suggests that yields are negatively skewed with a tail that represents occasional catastrophic loss and prices are positively skewed (Goodwin & Ker 2002). Some simple alternatives have been offered for both price and, such as a model of yields that is the sum of two components: a component that represents yields in years when there is no catastrophic loss and is perhaps normally-distributed and a component that represents yields in years of catastrophic loss (Goodwin & Ker 2002), and similar models for price.

Because of the limited nature of agricultural data (Goodwin & Ker 2002), there is little evidence in the literature to support any particular distribution for agricultural revenues (price times yield). However, we believe that it is plausible that the well-known covariate nature of commodity price and yields could act to counteract the hypothesized skewness and/or kurtosis of the price and yield distributions, drawing the revenue to a distribution that is closer to normal. That is, prices are likely to be in the thick upper tail of the price distribution when yields are in the low end of the yield distribution. This would plausibly create a revenue distribution that is closer to normal.

Therefore, while we have no direct empirical evidence to support our assumption of normal returns, we find no compelling reason to reject it as an approximation. Our results should be fairly robust to distributions that are similar to normal. Clearly, if the returns were strongly different from normal, this would have implications on our models, as demonstrated by Goodwin and Ker (2002).

III.B.2.1.2 *Aggregate variability versus farm-level variability*

Finding the mean and variance of returns to each land use can be difficult. The most logical solution is to use some time series dataset of historical revenues, under the assumption that future revenues are likely to be similar to the past; that is, that there will be no major market shifts that impact the way revenues are distributed.

In order to estimate a distribution function, past agricultural risk research has typically used historical data on prices and yield of agricultural crops. In many cases past research has used aggregate data. However, at least in the case of yields, this can lead to biased estimates of yield variability for individual farms, because aggregate data averages out yields over a large area for each year (Just & Weninger 1999; Just 2003). For instance, a researcher may have county-level yield data. However, within a particular county, localized weather variations may cause a particular year to be better for some farmers and worse for others. The next year, different farmers may have a good year and others bad. This variability will be lost when the data is averaged together. Therefore, variability of returns on individual farms or fields in general will be higher than the variability of macro-level average aggregate yields. Since our level of analysis is the farm, it is important to use farm-level microeconomic data to estimate farm-level variability (Just 2003). Few risk studies have used farm-level data in the past.

Just (2003) suggests using a random-effects regression method with farm-level time-series data to decompose the variance estimator into components that are common for all farms in each year and those that are unique to individual farms. In principle, this would be a very effective method. By construction, the two variables would be uncorrelated. Using the property that the variance of the sum of two uncorrelated variables is the sum of the variances, one could add together these two variances to find the variance of yield for a single farm.

The USDA National Agricultural Statistics Service (NASS) in coordination with the Economic Research Service (ERS) conducts an annual survey of farms throughout the United States, the Agricultural Resource Management Survey (ARMS). Of the farms that participate in the general survey each year, a subset of farms are selected to provide more in-depth data about agricultural yields for particular crops and other land uses, which is called the Phase III survey. This is the most complete data set farm-level of agricultural yields that is available for the LMAV region. We were able to obtain data on farm-level yields for the four major LMAV crops (corn, cotton, rice and soybeans) as well as hay production and other economic indicators for the years 1996-2007. We included only farms located in the LMAV counties, as identified in the data set.

Unfortunately for our purposes, the Phase III survey does not track specific farms through time. In fact, NASS designs the sampling method to reduce the burden on individual farmers because of the length of Phase III; that is, NASS purposefully tries to select different farms each year and no farm is selected more than once every three years. With this very sparse data, it is extremely difficult to create reliable panel data that could be used to estimate a random effects model. In addition, even if estimation were feasible with such sparse data, the results would be questionable and highly sensitive to minor changes or small errors in measurement.

Still, the ARMS data does contain data on individual farms, even if they are not the same farms each year, and it makes sense to take advantage of this property. We calculated the mean variance of returns to each agricultural crop among farms for each year from 1996-2007 using the USDA ERS delete-a-group jackknife procedure (Dubman 2000; Kott 2001), as well as the aggregate variance among years.

Since, in general, the variability of yields on a single farm will be higher than the aggregate variability, as explained above, we can use the aggregate variance as a lower bound on the single-farm variance. In addition, we believe that by adding together the between year and between farm variances we estimate an upper bound on the single farm variance. We believe this because the single-year, between farm variance contains the aspect of variability we seek to include, which is the effect of localized weather deviations, as well as aspects of variability that would not apply to individual fields, such as the difference in the inherent productivity of the soils. Soils are constant for individual farmers from year-to-year.

Based on our other research (Chapter III.A) we suspect that the variability that is caused by differences in soils or site classes is quite high. The variability between site classes probably causes much more of variability between farms than does yearly localized weather variations. We estimated that 10% of the yearly between-farm variance (32% of the standard deviation) is caused by localized weather variations. To estimate the within-farm variance for each crop, therefore, we added together the year-to-year aggregate variance and 10% of the average yearly between-farm variance for each crop.

We have no economic justification to believe *a priori* that the within-farm *covariance* between crops would be greater than or less than the covariance that would be estimated by the aggregate data. Therefore, we use the covariance estimate from the aggregate data set.

III.B.2.1.3 *Timber variability*

We modeled variability in timber returns differently than agricultural returns. Because timber grows over numerous years, variability in growth and yield from year to year will tend to average out over time. Therefore, it makes the most sense to model timber volume growth deterministically and price per unit volume stochastically. We used data from the Louisiana Quarterly Report of Forest Products to model variability in the manner explained below.

III.B.2.2 *Risk management through diversification of land uses*

Once we have an estimate of the covariance matrix of returns to the various land uses, we can use a model to estimate the value of alternative products as diversification tools to manage yearly farm risk. Given the numerous federal programs and availability of crop insurance, it has become much less important in the US to consider diversification of farm income as a major risk-management strategy. In addition, most owners of small to medium family farms, which account for the majority of all farms, albeit not a majority of the total land area, receive a large portion of their income from off-farm activities (Mishra et al. 2002). Still, diversification may be an important strategy for some farmers, as long as this diversification does not imply a large loss in the expected value of profits. Most likely, the farmers that utilize this strategy would be those who have less access to other risk-mitigation strategies, such as off-farm income, crop insurance and political connections. These are most likely to be poor, limited-resource farmers.

One way farmers can reduce risk is by diversifying assets (Harwood et al. 1999). Much of the current literature on risk and diversification traces its roots to Markowitz's (1952; 1959) seminal work in the selection of assets for an investment portfolio on the basis of expected returns (mean) and risk (variance). As Markowitz noted, a hypothesis that investors simply attempt to maximize expected discounted returns would not predict any diversification of portfolios.

The guiding objective of risk research based on Markowitz's work is to find a subset of portfolios that are "efficient" in the sense of minimizing risk for any given level of returns, or conversely maximizing returns for any given level of risk. An "inefficient" portfolio would be one for which there exists some alternative "efficient" portfolio that has risk less than the inefficient portfolio and at least the same expected return or expected return greater than the inefficient portfolio and at most the same risk (variance). In general, the analysis will not return one single "optimal" portfolio, but rather some range of efficient portfolios from which an agent might choose a single portfolio according to his particular level of risk aversion. Markowitz hypothesized a rule under which investors would select a portfolio from the set with maximum mean (for any given variance) and minimum variance (for any given mean), and geometrically demonstrated the types of portfolios for which this would be true. Markowitz's (1952) mean-variance hypothesis is theoretically consistent with von Neumann and Morgenstern's (1947) hypothesis of expected utility maximization under risk aversion.

III.B.2.2.1 *Mean variance analysis*

Mean-variance (usually denoted E-V for "expected value-variance") analysis as described by Markowitz can be a very powerful tool in identifying efficient portfolios. It can be shown that the assumptions behind mean-variance analysis limit it to a fairly restricted set of situations. In particular, one must assume that either the agent has a quadratic utility function, the assets have normally-distributed returns, or both (Tobin 1958; Feldstein 1969; Hanoch & Levy 1969). In principal, these restrictive assumptions can cause severe deviations from the outcome of expected utility maximization, depending on the form of the utility function (Collender & Zilberman 1985). However, Kroll, Levy and Markowitz (1984) demonstrated that the E-V method is quite robust in approximating efficient expected utility maximization under a wide variety of utility functions under commonly-used levels of risk-aversion.

A non-parametric approach with weaker assumptions is the stochastic dominance approach, which still relies on the assumption of expected utility maximization. However, the stochastic dominance approach requires more data than E-V to approximate a distribution of returns.

Using either of these frameworks should be able to help analyze the relative properties of different land-use systems and which portfolios of land uses maintain high expected return and lower risk. Because of our limited data, we have chosen to utilize the E-V framework. We believe that the E-V framework is robust enough to be a reasonable approximation for optimal farm diversification under returns distributions that similar to normal (Kroll et al. 1984). As we previously noted, we do not attempt to prove or disprove the normality of the distribution of returns.

III.B.2.2.2 *Quadratic program for mean-variance*

Steinbach (2001) demonstrated various methods for operationalizing the mean-variance criteria. Notably, E-V can be evaluated in a quadratic programming framework (Young 1998; Steinbach 2001). This quadratic program minimizes variance for a given level of expected returns, by allowing the amount invested in each asset to vary:

$$\begin{aligned} &\min_{\lambda \in \Lambda} \lambda' \cdot s \cdot \lambda \\ &s.t. \\ &\lambda' \cdot y \geq G \\ &\lambda' \cdot \bar{1} = 1 \\ &\lambda_j \geq 0 \forall j = 1, \ldots, N \end{aligned} \qquad (1),$$

where λ_j is the proportion of the portfolio invested in asset j and Λ is the set of possible weights, N is the number of assets being evaluated, s is the N x N covariance matrix, y is the N x 1 vector of mean returns of the assets, and the LHS 1 in the second constraint represents an N x 1 vector of ones. G is the minimum level of expected returns. By repeating the quadratic program (1) for numerous levels of G, one can find the frontier of efficient portfolios.

III.B.2.2.3 *Mean-variance agroforestry literature*

While most of the research in diversification of portfolios for risk has been conducted in settings with assets such as stocks, bonds and other securities, there is a relatively small, but relevant literature about mean-variance and stochastic dominance in land-use decisions. In essence, the problem is the same: the amount of land available is an initial endowment, land-use (agricultural or forestry) systems are potential assets and the proportions of land in each system are the weights on the assets.

Lilieholm and Reeves (1991) and Babu & Rajasekaran (1991) both addressed the question of efficient allocation of agroforestry system within the whole farm. Both of these studies used aggregate data, either at the national or state level. These studies showed that inclusion of agroforestry systems can be optimal for certain levels of risk-aversion.

III.B.2.2.4 *LMAV mean-variance model*

We utilized the mean-variance framework to determine whether or not farm diversification into products that are not agricultural crops could be optimal for some risk-averse farmers. We view this from the point of view of mitigating risk within a single year assuming the farmer has no prior information about how the current year's crop might be different than previous years, rather than considering change in returns through time (which is considered in some the models explained below). Also, this approach does not tell us about the mixing of crops and perennials on the same field in the sense of agroforestry, but can give us a sense of whether farmers might be willing to diversify into non-annual products.

We selected for our analysis six of the principal products that come from conventional LMAV agriculture and from the alternative systems highlighted in chapter IIA: cotton, rice, soybeans, cattle, pecan nuts and hardwood timber. The hardwood timber return is based on a cottonwood-oak intercropping system (see chap. III.A) and is used as a representative of other timber-producing systems in the LMAV.

The inclusion of pecan nuts and, in particular, timber in the model does create something of a conceptual and operational problem in the model, because these two products are not necessarily produced every year. Conceptually, pecan nuts may be produced every year once the trees are mature, but some time (5-10 years) must pass before nuts are produced at all. Furthermore, in a timber stand, not only is timber not produced in the first years, but would only be produced periodically after that.

Is it reasonable therefore, to create a model that uses pecans and/or timber as a hedge to manage yearly risk from crops? A farmer cannot manage the current year's risk by planting trees today. He or she can, however, plant trees with forethought towards balancing risk in the future. In this scenario, a farmer might maintain a timber plot, and harvest a portion of timber to make up for income lost if annual crops do poorly in any particular year. It is in this sense that a farmer might balance yearly crop risks by diversification with perennials.

Still, there is an operational problem created by the periodic nature of timber harvest. We cannot utilize the revenue generated by a timber rotation as a comparison with annual crops, because the revenue generated by a timber rotation (in this case, 50 years long) will be much greater than the annual returns from agriculture (for a single year). Therefore we utilize the Annual Equivalent Value (AEV) measure for timber, based on the Soil Expectation Value from chapter III.A:

$$AEV = SEV \cdot \rho \qquad (2),$$

where ρ is the discount rate. We then divided the AEV by the timber price utilized in chapter IIA and multiplied by each of the timber prices from the Louisiana Quarterly Report of Forest Products from 1991-2007 to create a time series of AEVs adjusted to the price of timber in each year.

We utilized the MATLAB function quadprog.m in a script to solve the quadratic program (1) and find the mean-variance efficient frontier of portfolios in four different land class endowment scenarios. The first scenario assumed that 100% of the farmer's land is of land capability class (LCC) 5 (see Chapter III.A for an explanation of land capability classification). The second scenario was 100% LCC 3 and the third scenario was 50% LCC 5 and 50% LCC 3. The final scenario was 25% LCC 1-2, 50% LCC 3 and 25% LCC 5. This final scenario approximates the true distribution of arable land in the LMAV (Chapter III.A).

Within each land class in each land endowment scenario, the farmer is permitted to produce any of six different products in any proportion. In the quadratic program (1), constraints are added in order to restrict the total allocation of land in each land class to the amount specified in each of the four scenarios.

We should be clear that our E-V model only assesses the potential for risk reduction by diversification of products; it does not deal specifically with the 11 forestry and agroforestry systems we analyze in the real options (RO) model below. Furthermore, we do not consider directly in the E-V model any complementarities that might arise through the mixing of two components in the same field, as would be the case with agroforestry. This model is only as an indicator of the potential for risk reduction from diversification in a general sense.

III.B.2.3 *Mean reversion*

In order to model potential for adoption of alternative production systems while taking into account stochastic returns through time, which is the goal of the real options model described below, it was necessary to first create a credible model of how returns evolve over time.

Typically, real options models have utilized the underlying models of either geometric Brownian motion (GBM) or mean-reversion. Both GBM and mean-reversion are stochastic processes based on Weiner processes (Brownian motion). The principal difference is that GBM is non-stationary while mean-reverting processes are stationary. That is to say, GBM variables may increase without bound, depending on the parameters of the process, while a mean-reverting process would stay, in the long run, centered around a mean, or “equilibrium”, value.

We believe that a mean-reverting process is more theoretically plausible alternative for modeling agricultural and timber product returns. When returns to a particular commodity are higher, more suppliers are likely to enter the market, putting downward pressure on prices and returns, and the opposite when returns are low (Schwartz 1997; Insley & Rollins 2005; Isik 2006). This theoretical intuition about commodities has received empirical validation (Bessembinder et al. 1995).

As previously noted, we modeled agricultural returns per hectare and timber and pecan prices per unit output. Annual average timber and pulpwood prices were obtained from the Louisiana Quarterly Report of Forest Products for the years 1955 to 2007 (LA DAF 2008). In some cases, localized weather conditions could cause prices in the LMAV to vary somewhat from the state average; however, the state averages should provide a good indicator of variability in prices and trends through time. National prices for pecan were obtained from the USDA National Agricultural Statistics Service's Noncitrus Fruits and Nuts Summary (NASS 2008). Agricultural and livestock returns were obtained from the USDA ARMS aggregate data (ERS 2009). Prices and returns were converted to real 2007 dollars using the US Bureau of Labor Statistics average annual Consumer Price Index (CPI). Timber and nut prices, and agricultural returns were tested for mean-reversion under an Ornstein-Uhlenbeck process, using the statistical model:

$$P_t = P_{t-1} + \alpha\left[P_{t-1} - \mu\right] + \sigma \cdot \varepsilon_t \qquad (3),$$

where P_t is the price or returns in time t, μ is the mean or equilibrium of the mean-reverting process, $-\alpha$ is the mean-reversion rate, ε is a random standard normal shock variable and σ

is the square root of the variance of the shock. The mean of the process, μ, is generally thought of as an expected value or an equilibrium price to which the process is driven and will return in the absence of shocks. Equation (3) can be rewritten as:

$$\Delta P = -\alpha \cdot \mu + \alpha \cdot P_{t-1} + \sigma \cdot \varepsilon_t \qquad (4),$$

where $\Delta P = P_t - P_{t-1}$, and modeled using OLS. A value of α that is negative and significantly different than zero is an indication of mean reversion, whereas a value of α that is non-negative may indicate some other process, such as Brownian motion or geometric Brownian motion (GBM).

While the mean-reversion theory is plausible for agricultural commodities, it may be less so for timber prices. This is because it takes a number of years for new timber producer to enter the market. Timber prices may follow an increasing trend in real terms, that is, that timber prices increase faster than the rate of inflation. It would be necessary to add one (or two) terms to the Ornstein-Uhlenbeck model in order to model reversion to a linear (or quadratic) trend:

$$P_t = P_{t-1} + \alpha\left[P_{t-1} - \left(\mu_0 + \beta \cdot t\right)\right] + \sigma \cdot \varepsilon_t \qquad (5), \text{ or}$$

$$P_t = P_{t-1} + \alpha\left[P_{t-1} - \left(\mu_0 + \beta \cdot t + \gamma \cdot t^2\right)\right] + \sigma \cdot \varepsilon_t \qquad (6),$$

which can be rewritten and modeled in a manner similar to (4). Here, μ_0 represents the intercept, or the expected value of price or returns in the first year of the time series.

Indeed, a simple review of the timber price data leads one to believe that there is strong evidence for increasing real prices over time. For instance, inflation-adjusted prices for mixed hardwood sawtimber in the late 1950s and early 60s range from \$7 to \$8 per ton in 2007 dollars, while prices in the late 1990s and 2000s range from $25 to $40. However, there is an alternate hypothesis, forwarded by Yin and Caulfield (2002), suggesting that southern US timber markets changed drastically somewhere around the late 1980s or early 90s. After that shift, timber prices increased not only in average, but also in volatility. Yin and Caulfield (2002) suggest that the growing global market for timber, as well as other global and national factors, caused this upward shift in prices.

If we assume that prices operate under a different market process now than before the early 1990s, then data from before that time become irrelevant for our analysis. We conducted the same analysis of mean reversion and trend reversion using only data starting in 1991.

III.B.2.4 *Switching crops through time to improve returns*

For our real options simulation, it is important to reduce the number of variables as much as possible because of the amount of memory required to run the simulation. For this reason, we chose to combine returns to all the agricultural crops into a single variable representing overall agricultural returns. This is representative of the idea that a farmer will generally only plant one crop on a field at a time, but might change crops from year to year depending on what crop he feels will be the most profitable in a given year.

We feel that combining the yearly returns from a number of alternative crops into a single variable can be an important factor in modeling farmers' valuations of their land for agricultural purposes, as opposed to models that utilize only single crops at a time. Consider, for instance, a farmer who has perfect knowledge of which crop out of a number of alternatives will perform the best in a given year. This farmer will certainly receive higher returns from his land by switching between crops than by producing any one specific crop.

Even with imperfect knowledge, a farmer might be able to improve returns over what he would expect from consistently farming a single crop. We utilized a decision rule under which a farmer would produce in the current year the crop that performed the best during the previous year.

We used a Monte Carlo simulation with this simple decision rule to imitate the returns a farmer might receive from agriculture over a 100-year period. Yearly estimated returns *r* to crop *i* in year *t* was modeled as

$$r_{i,t} = r_{i,t-1} + \alpha\left[r_{i,t-1} - \mu\right] + \varepsilon_{i,t} \quad (7),$$

where α is the mean reversion rate and μ is the mean or equilibrium return. The error terms ε for each crop are correlated using the covariance matrix derive from the ARMS data to generate a multivariate normal distribution.

We generated 20,000 time paths of 100 years each to estimate a returns distribution for agricultural returns under the flexible decision rule.

III.B.2.5 *Real options*

In land management, there is variability in costs, yields and output prices. A good land manager will value practices that give him/her the option to change or postpone decisions in order to adapt to changing conditions. Real options (RO) techniques place value on flexibility, as opposed to traditional cash-flow (NPV, SEV) methods which assume a deterministic return and a "locked-in" decision. Sensitivity analyses do help cash flow methods address this limitation, but real options, where applicable, can be an important key to understanding land managers' decisions.

RO analyses are generally based upon the Bellman equation, which states that decision-makers choose a management regime to maximize the sum of the present value (profit, utility, etc.) and discounted expected future rewards:

$$V_t(s) = \max_{x \in X} \{ f(s,x) + \delta \cdot E_{\varepsilon}[V_{t+1}(g(s,x,\varepsilon))] \} \quad (8)$$

Where V_t is the value function at time t, $f(s,x)$ is the reward given by making decision x under state s, $\delta = \frac{1}{1+\rho}$ (or $e^{-\rho}$ for continuous discounting) is the discount factor, and $E[\cdot]$ is the expectation operator. $g(\cdot)$ is the transition function from states and actions in year t and some shock epsilon (variability, risk) to conditions in year t+1. The key difference between the Bellman equation and cash-flow counterparts is the recursive nature of the decision-making process. It assumes that decisions made in year t can also be put off until year t+1. This is the flexibility we seek to model.

RO modeling has become an important part of forest economics in the past decade. Most importantly, RO has been used to estimate optimal timber harvest rotations and thinning regimes under stochastic prices (Haight & Holmes 1991; Plantinga 1998). RO provides insight into the optimal timber rotation because harvesting is a decision that can generally be put off until the future if conditions are not ideal; it is a flexible decision.

III.B.2.5.1 *Dichotomous choice: Afforestation/deforestation*

Another flexible decision relating to forestry that has received somewhat less attention in the literature is the decision to afforest or reforest. Assuming that land is currently used for agriculture, a landowner may easily put off the decision to afforest and continue farming until the following year. Behan, McQuinn, and Roche (2006) and Wiemer and Behan (2004) showed that showed that it is optimal for a farmer to wait longer to afforest under a RO framework than under a standard discounted cash-flow framework. This is because of the barrier to entering forestry in terms of establishment costs, and also because of the irreversibility of the decision to switch to forestry.

Although the decision to switch to forestry has been modeled as irreversible, we know that this is not necessarily the case. In fact, we know that forests are deforested all the time in many parts of the world for conversion to agriculture. Land conversion to agriculture does involve numerous up-front costs, such as stump removal, that create a barrier to shifting to agriculture, but not an insurmountable one. We therefore view the decisions to switch from agriculture to forestry (or agroforestry) and from forestry (or agroforestry) to conventional agriculture as a dichotomy of choices that allows switching from one land use to another, and switching back as well; it includes the adoption and disadoption choices. Land decisions have not been modeled in this way previously in the published literature.

By including the possibility of switching back to agriculture after afforestation, we include both forms of flexibility that have been modeled in the previous models: the flexibility to stay in agriculture depending on agriculture and timber prices, and the flexibility to wait to harvest timber depending on agriculture and timber prices. We include the flexible decision to switch from agriculture to forestry and forestry to agriculture. However, in order to fully describe the possible decisions, it is necessary to add one more possibility: to harvest the timber but remain in forestry by replanting the trees. In this case, the landowner incurs the cost of tree establishment, but not the cost of stump removal, etc. These are the three decisions we allow throughout our models.

III.B.2.5.2 *Methods for solving the Bellman equation*

Most forest harvesting RO models have used a Markov-chain Monte Carlo approach to the Bellman equation. However, recently partial differential methods have come into favor because of improved precision and other factors (Insley & Rollins 2005). In our case, a partial differential method was used because the Markov chain would not accommodate our model. This is because the backward-moving dynamic program utilized to solve the Markov-chain process would require one to know the stand age at the final year of the model. Since, in our model, the stand age will vary depending on what year the landowner switches to forestry, it would be impossible to model in a Markov-chain dynamic program.

For an infinite-horizon model, all points in time become equivalent and the Bellman equation simplifies to (Miranda & Fackler 2002):

$$V(s) = \max_{x \in X} \{ f(s,x) + \delta \cdot E_{\varepsilon}[V(g(s,x,\varepsilon))] \} \qquad (9).$$

One way to solve for the value function $V(s)$, and thus determine the optimal regime for each state, $x(s)$, is to use a **partial differential collocation method** (Miranda & Fackler 2002). $V(s)$ is approximated by a set of known basis functions ϕ such that

$$V(s) \approx \sum_{j=1}^{n} c_j \phi_j(s) \qquad (10),$$

where c_j is the unknown coefficient for basis function ϕ_j. Using (10) in (9),

$$\sum_{j=1}^{n} c_j \phi_j(s) \approx \max_{x \in X(s)} \left\{ f(s,x) + \delta \cdot E_\varepsilon \left[\sum_{j=1}^{n} c_j \phi_j \big(g(s,x,\varepsilon) \big) \right] \right\} \qquad (11).$$

The ϕ_j's can belong to one of a number of families determined by the analyst, including linear functions, polynomial spline functions, and others. We have chosen to use linear basis functions, as they are the simplest. The c_j coefficients are estimated to solve the Bellman equation at n nodes in the state space S. Let i=1,…,n index the nodes and j=1,…,n index the basis functions and their respective coefficients. By having n nodes and n basis function coefficients, we create a system with n equations and n unknowns (Miranda & Fackler 2002):

$$\sum_{j=1}^{n} c_j \phi_j(s_i) = \max_{x \in X(s_i)} \left\{ f(s_i,x) + \delta \cdot E_\varepsilon \left[\sum_{j=1}^{n} c_j \phi_j \big(g(s_i,x,\varepsilon) \big) \right] \right\} \forall i \qquad (12).$$

If we define $\Phi_i c$ as the left-hand side and $v_i(c)$ as the right-hand-side of (12), then the above can be expressed in matrix notation as

$$\Phi c = v(c) \qquad (13),$$

which can be solved by using, for instance, Newton's method iterative update rule:

$$c \leftarrow c - [\Phi - v'(c)]^{-1} [\Phi c - v(c)] \qquad (14),$$

where $v'(c)$ is the derivative matrix of $v(c)$.

In order to estimate the value of the expectation within $v_i(c)$, the distribution of the stochastic shock ε is discretized into K shocks ε_k, each with weight $w_{k.}$ so that

$$v_i(c) = \max_{x \in X(s_i)} \left\{ f(s_i, x) + \delta \cdot \sum_{k=1}^{K} \sum_{j=1}^{n} \left(w_k \cdot c_j \cdot \phi_j \left(g(s_i, x, \varepsilon_k) \right) \right) \right\} \qquad (15)$$

(Miranda & Fackler 2002). Also, because the c_j coefficients are estimated over a finite set of x actions, the max operator is simply calculated by finding the node with the maximum value within that set (no differentiation used).

III.B.2.5.3 *Operationalizing the PDE collocation method*

In order to solve this PDE collocation problem for the agriculture versus forestry optimal switching problem, we must define the state variables, S, the action set, X, the state transition function, $g(\cdot)$ and the reward function, $f(\cdot)$, among other practical decisions. Although we know that agricultural and forestry management activities can take place year round, it is common to approximate them with discrete, yearly costs and benefits. In this case, agriculture would be modeled as yearly net returns (gross revenues minus costs excluding land rental and management) per acre. Forestry would be modeled as net returns for a given year in the rotation.

We utilized the discrete-time dynamic programming solver for MATLAB dpsolve.m, designed by Miranda and Fackler (1997), which is software in the CompEcon Toolbox, to solve the Bellman equation in the manner explained above. However, it was necessary for us to program the state variables, S, the action set, X, the state transition function, $g(\cdot)$ and the reward function, $f(\cdot)$ for each land use we tested as an option to agriculture.

III.B.2.5.4 *State variables*

There are three state variables in the model. In theory, it would be ideal to model very many state variables, but in practice the analyst must condense these into as few as reasonably possible to allow computational tractability, even with today's computing power. First, the yearly net returns to agriculture per hectare is a state variable, represented by s^{AG}. s^{AG} is defined by the model, previously discussed, of switching crops over time to improve expected returns. In this way we combine all agricultural crops into a single state variable.

Second, timber stumpage price is a state variable, represented by s^{TIMB}. In this situation, costs such as site preparation, competition control, etc. would be considered constants. The amount of variability in these costs is small enough relative to the eventual payoff that it is unlikely that variability in forestry costs would have a large effect on decision-making. Growth and yield of timber were modeled deterministically. Even though growth in any given year may vary because of weather variability, over a number of years yield should even out to a relatively predictable value for a given site. In order to limit the number of state variables, pulpwood and sawtimber price are modeled together. s^{TIMB} represents pulpwood price per ton. To estimate sawtimber price, then, we multiply by the ratio of the mean sawtimber price to the mean pulpwood price from the mean reversion model. In the case of species that might have sawtimber prices that tend to be lower or higher than the mixed hardwood sawtimber price, we include an adjustment factor.

The final state variable is land condition/stand age. This is a discrete variable, s^{SA}, ranging from 0 to the maximum allowable stand age. If s^{SA} is 0, the land is in agriculture. If s^{SA} is 1, this represents the beginning of the first year of a stand of trees, whether it is forestry or agroforestry.

III.B.2.5.5 ***Decision variable***

The decision variable is x, which can be 0 for continued agriculture (if s^{SA}=0) or a timber harvest with subsequent change to agriculture (if $s^{SA}\neq 0$), 1 for switching from agriculture to forestry or maintain the forest stand for one more year, or 2 for a timber harvest with subsequent return to forestry. As long as x=1, s^{SA} will continue increasing until it the maximum allowed stand age.

The model is allowed to choose x= 0, 1 or 2 at any state. That is, there are no pre-determined years for switching from agriculture to forestry or back. This is precisely the flexibility we seek to model. Optimal timber harvest or forest plantation can be determined on the basis of all the state variables: agricultural returns, timber value and stand age. This differs from traditional deterministic models (chapter IIA) that define a single optimal timber harvest age based on single values for returns.

It is important to note that, while the model allows for switching between forestry and agriculture at any time, there are monetary barriers to going back and forth. To switch from agriculture to forestry involves site preparation and plantation. To switch back involves digging up the stumps and roots of the trees. These barriers make a farmer more likely to stay in the same regime that he is in currently rather than switching back and forth with every minor shift in prices.

III.B.2.5.6 *Value function*

For a relatively simple forestry management regime, such as cultivation of cottonwood for pulpwood with no intermediate thinning, the reward function is

$$f(s,x)=\begin{cases} s^{AG} \mid s^{SA}=0 \\ SPREP \mid s^{SA}=1 \\ CC \mid s^{SA}=2 or 3 \\ GY(s^{SA})*s^{TIMB} \mid x=2 \\ GY(s^{SA})*s^{TIMB}+LCLEAR \mid s^{SA}\neq 0 \,\&\, x=0 \\ 0 \mid otherwise \end{cases} \tag{16}$$

Where *SPREP* is the cost of site preparation, *CC* is the cost of competition control in years 2 and 3, $GY(s^{SA})$ is the growth and yield which is a function of stand age and *LCLEAR* is the cost of land clearing for agriculture (stump removal), all on a per hectare basis.

III.B.2.5.7 *State transition function*

The state transition function assumes that agricultural net returns and timber prices follow a mean-reverting random walk, as previously discussed. This assumption means that agricultural net returns per acre per year and timber returns are serially correlated, but tend to move back to a long-run equilibrium value over time. The randomness of the walk is driven by a shock, ε. The εs for agriculture returns and timber price can be modeled independently or with covariance. Assumptions other than mean-reversion (geometric Brownian motion, standard Brownian motion with drift) are possible, but we believe the mean-reversion assumption is the most plausible, as noted above. The state transition function is as follows:

$$
\begin{aligned}
s_{t+1}^{AG} &= s_t^{AG} + \alpha^{AG}(AGeq - s_t^{AG}) + \varepsilon^{AG} \\
s_{t+1}^{TIMB} &= s_t^{TIMB} + \alpha^{TIMB}(TIMBeq - s_t^{TIMB}) + \varepsilon^{TIMB} \\
s_{t+1}^{SA} &= \begin{cases} 0 \mid x = 0 \\ s_t^{SA} + 1 \mid x = 1 \\ 1 \mid x = 2 \end{cases}
\end{aligned}
\qquad (17).
$$

In total, then this RO approach allows us to model the ability of landowners to utilize the most profitable land use, and switch between those land uses based on their returns from previous years and expectations for future returns based on past data as well. This new approach provides a powerful and realistic reflection of the actual decisions that landowners do make, and significantly extends previous analyses of farm, forest, and agroforestry decision-making.

III.B.3 RESULTS AND DISCUSSION

III.B.3.1 *Crop variability*

Using USDA Agricultural Resource Management Survey (ARMS) Phase III data from 1996-2007, we estimated farm-level variability for revenue from the four main crops in the LMAV, corn, cotton, rice and soybeans. Unfortunately, ARMS Phase III data does not include information about revenues per unit land area (or per head in the case of cattle) for pecan nuts, timber or cattle.

The between-year covariance matrix of revenue from the four major crops from the ARMS Phase III aggregate data, and the within-year, between farm variance for each crop is presented in Table III.B.1. To estimate the within-farm variance for each crop, we added the between-year aggregate variance to 10% of the average yearly between-farm variance. The resulting covariance matrix is found in Table III.B.2.

Table III.B.1. Between-year covariance matrix of average revenues to four crops in the LMAV, and average yearly between-farm variances ($\$^2/ha^2$).

	Between-year covariance matrix of average revenues in LMAV				Average yearly between-farm variance
	Corn	Cotton	Rice	Soybean	
Corn	38662	23787	26158	16710	754679
Cotton	23787	53948	60252	21640	416014
Rice	26158	60252	101052	19816	377333
Soybean	16710	21640	19816	13483	258679

Table III.B.2. Estimated within-farm covariance matrix of revenues to four crops in the LMAV ($2/ha2)

	Corn	Cotton	Rice	Soybean
Corn	114130	23787	26158	16710
Cotton	23787	95550	60252	21640
Rice	26158	60252	138786	19816
Soybean	16710	21640	19816	39351

III.B.3.2 *Farm diversification mean-variance model*

Table III.B.3 through Table III.B.6 show the results of the mean-variance (E-V) model under the four different land class endowment scenarios. We have calculated a set of points approximating the efficient E-V frontier by minimizing the variance for each level of expected returns, from the point of minimum variance to the point of maximum expected returns. These tables show the expected value of returns and standard deviation of returns in $ per hectare, and the allocation of land to each of the products for numerous points along the efficient E-V frontier.

It is clear from the E-V frontiers that diversification into the products of cottonwood, pecan and cattle can reduce the risk from farming agricultural crops. What these models cannot show is whether farmers would be willing to accept the reduction in expected value of returns in order to achieve the reduction in variance that would come from this.

If a farmer owns 100% LCC 5 land (Table III.B.3), he can achieve a large decrease in risk for only a relatively small decrease in expected profit by diversifying into pecan and timber production. While the highest expected value of return comes from producing only soybeans, a 10% decrease in expected returns from about $41/ha to about $37/ha can reduce standard deviation from over $100/ha to under $20/ha. This reduction in risk could be achieved by diversifying some of the land into pecan production. To reduce risk further, a farmer could include timber production.

Table III.B.3. Mean-variance efficient frontier for a farm with only Land Capability Class (LCC) 5 land.

Expected Value of Returns ($/ha)	Standard Deviation of Returns ($/ha)	Proportion of land allocated Land Capability Class 5					
		Cotton	Rice	Soybeans	Cow	Pecan	Timber
25.92	2.97	0	0	0	0	0.10	0.90
26.00	2.98	0	0	0	0	0.11	0.89
26.17	2.99	0	0	0	0	0.12	0.88
26.41	3.05	0	0	0	0	0.14	0.86
26.73	3.17	0	0	0	0	0.16	0.84
27.13	3.40	0	0	0	0	0.20	0.80
27.59	3.74	0	0	0	0	0.23	0.77
28.12	4.21	0	0	0	0	0.28	0.72
28.71	4.80	0	0	0	0	0.32	0.68
29.35	5.50	0	0	0	0	0.38	0.62
30.03	6.30	0	0	0	0	0.43	0.57
30.75	7.17	0	0	0	0	0.49	0.51
31.50	8.11	0	0	0	0	0.55	0.45
32.28	9.08	0	0	0	0	0.61	0.39
33.06	10.09	0	0	0	0	0.68	0.32
33.85	11.11	0	0	0	0	0.74	0.26
34.64	12.13	0	0	0	0	0.80	0.20
35.41	13.15	0	0	0	0	0.87	0.13
36.16	14.13	0	0	0	0	0.93	0.07
36.88	15.09	0	0	0	0	0.99	0.01
37.57	20.57	0	0	0.13	0	0.87	0
38.20	33.49	0	0	0.29	0	0.71	0
38.79	47.06	0	0	0.44	0	0.56	0
39.32	59.75	0	0	0.57	0	0.43	0
39.78	71.07	0	0	0.69	0	0.31	0
40.18	80.77	0	0	0.79	0	0.21	0
40.50	88.69	0	0	0.87	0	0.13	0
40.74	94.72	0	0	0.93	0	0.07	0
40.91	98.79	0	0	0.98	0	0.02	0
40.99	100.84	0	0	1.00	0	0	0

On the other hand, if a farmer owns 100% LCC 3 land (Table III.B.4), which comprises about 40-50% of all LMAV land, there is less incentive to diversify into pecan or timber production. A great deal of risk, up to about 50% of the standard deviation, can be reduced by simply balancing soybean and rice production.

Table III.B.4. Mean-variance efficient frontier for a farm with only Land Capability Class (LCC) 3 land.

Expected Value of Returns ($/ha)	Standard Deviation of Returns ($/ha)	Proportion of land allocated Land Capability Class 3					
		Cotton	Rice	Soybeans	Cow	Pecan	Timber
26	3	0	0	0	0	0.11	0.89
29	3	0	0	0.00	0	0.15	0.85
34	4	0	0	0.01	0	0.19	0.79
41	6	0	0.00	0.03	0	0.25	0.72
51	8	0	0.01	0.04	0	0.33	0.62
63	11	0	0.01	0.06	0	0.42	0.50
78	15	0	0.02	0.08	0	0.54	0.36
94	19	0	0.02	0.11	0	0.66	0.20
112	23	0	0.03	0.14	0	0.80	0.03
131	29	0	0.04	0.19	0	0.77	0.00
152	35	0	0.05	0.25	0	0.70	0
175	41	0	0.07	0.31	0	0.63	0
198	49	0	0.08	0.37	0	0.55	0
221	56	0	0.10	0.43	0	0.47	0
245	64	0	0.11	0.50	0	0.39	0
270	72	0	0.12	0.56	0	0.31	0
294	80	0	0.14	0.63	0	0.23	0
317	87	0	0.15	0.69	0	0.15	0
341	95	0	0.17	0.76	0	0.08	0
363	102	0	0.18	0.82	0	0.00	0
384	113	0	0.31	0.69	0	0	0
403	128	0	0.44	0.56	0	0	0
421	146	0	0.56	0.44	0	0	0
437	164	0	0.66	0.34	0	0	0
452	180	0	0.76	0.24	0	0	0
464	195	0	0.84	0.16	0	0	0
474	208	0	0.90	0.10	0	0	0
481	217	0	0.95	0.05	0	0	0
486	224	0	0.98	0.02	0	0	0
489	227	0	1.00	0.00	0	0	0

When a farmer owns multiple land types, for instance 50% LCC 3 and 50% LCC 5 (Table III.B.5), some diversification comes automatically by simply planting what does the best on each land class. Here, a farmer might plant only rice on LCC 3 land and soybeans on LCC 5 land to maximize expected return, yet still realize benefits in terms of a relatively low risk. To reduce risk further, however, he might include pecans on his LCC 5 land.

Table III.B.5. Mean-variance efficient frontier for a farm with 50% Land Capability Class (LCC) 3 and 50% LCC 5 land.

Expected Value of Returns ($/ha)	Standard Deviation of Returns ($/ha)	Proportion of land allocated: Land Capability Class 3						Land Capability Class 5					
		Cotton	Rice	Soy	Cow	Pecan	Timber	Cotton	Rice	Soy	Cow	Pecan	Timber
25	3	0	0	0	0	0.01	0.49	0	0	0	0	0.09	0.41
26	3	0	0	0	0	0.05	0.45	0	0	0	0	0.04	0.46
29	3	0	0	0	0	0.13	0.37	0	0	0	0	0	0.50
33	4	0	0	0.01	0	0.17	0.32	0	0	0	0	0	0.50
38	4	0	0	0.02	0	0.21	0.27	0	0	0	0	0	0.50
44	6	0	0.00	0.03	0	0.26	0.20	0	0	0	0	0	0.50
51	8	0	0.01	0.04	0	0.32	0.13	0	0	0	0	0	0.50
60	10	0	0.01	0.05	0	0.39	0.05	0	0	0	0	0	0.50
69	12	0	0.01	0.07	0	0.41	0	0	0	0	0	0	0.50
79	15	0	0.02	0.10	0	0.38	0	0	0	0	0	0	0.50
90	18	0	0.03	0.13	0	0.34	0	0	0	0	0	0	0.50
102	22	0	0.03	0.16	0	0.30	0	0	0	0	0	0	0.50
114	26	0	0.04	0.20	0	0.27	0	0	0	0	0	0	0.50
126	30	0	0.05	0.23	0	0.23	0	0	0	0	0	0.05	0.45
139	34	0	0.05	0.26	0	0.19	0	0	0	0	0	0.11	0.39
151	38	0	0.06	0.29	0	0.15	0	0	0	0	0	0.18	0.32
164	42	0	0.07	0.32	0	0.11	0	0	0	0	0	0.24	0.26
176	46	0	0.08	0.35	0	0.07	0	0	0	0	0	0.30	0.20
188	49	0	0.08	0.38	0	0.04	0	0	0	0	0	0.36	0.14
199	53	0	0.09	0.41	0	0	0	0	0	0	0	0.42	0.08
210	58	0	0.16	0.34	0	0	0	0	0	0	0	0.50	0
220	66	0	0.22	0.28	0	0	0	0	0	0	0	0.50	0
230	75	0	0.28	0.22	0	0	0	0	0	0	0	0.50	0
238	84	0	0.34	0.16	0	0	0	0	0	0	0	0.50	0
246	93	0	0.39	0.11	0	0	0	0	0	0	0	0.50	0
252	101	0	0.43	0.07	0	0	0	0	0	0	0	0.50	0
257	107	0	0.46	0.04	0	0	0	0	0	0	0	0.50	0
261	112	0	0.49	0.01	0	0	0	0	0	0	0	0.50	0
264	119	0	0.50	0	0	0	0	0	0	0.13	0	0.37	0
265	135	0	0.50	0	0	0	0	0	0	0.46	0	0.04	0

For land that is spread between LCC 1-2, LCC 3 and LCC 5 (Table III.B.6), in approximately the proportions of all land in the LMAV, it is possible to have relatively high expected returns ($347/ha) with relatively low standard deviation ($134/ha), without very much diversification. Still, if a farmer wanted to reduce risk further, he might include pecans on LCC 5 land, or cattle on LCC 1-2 land.

Table III.B.6. Mean-variance efficient frontier for a farm with 25% Land Capability Class (LCC) 1-2, 50% LCC 3 and 25% LCC 5 land.

Ex val ($/ha)	St. dev ($/ha)	Proportion of land allocated																	
		Land Capability Class 1-2						Land Capability Class 3						Land Capability Class 5					
		Cot	Rice	Soy	Cow	Pcn	Timber	Cot	Rice	Soy	Cow	Pcn	Timber	Cot	Rice	Soy	Cow	Pcn	Timber
24	3	0	0	0	0	0.00	0.25	0	0	0	0	0	0.50	0	0	0	0	0.09	0.16
25	3	0	0	0	0	0.10	0.15	0	0	0	0	0	0.50	0	0	0	0	0	0.25
29	3	0	0	0	0	0.10	0.15	0	0	0	0	0	0.50	0	0	0	0	0	0.25
34	3	0	0	0.00	0	0.17	0.08	0	0	0	0	0	0.50	0	0	0	0	0	0.25
41	4	0	0	0.01	0	0.23	0.01	0	0	0	0	0.00	0.50	0	0	0	0	0	0.25
50	6	0	0	0.03	0.00	0.22	0	0	0.00	0	0	0.04	0.46	0	0	0	0	0	0.25
59	8	0	0	0.05	0.00	0.20	0	0	0.01	0	0	0.13	0.37	0	0	0	0	0	0.25
71	11	0	0	0.07	0.01	0.17	0	0	0.01	0	0	0.20	0.29	0	0	0	0	0	0.25
83	14	0	0	0.09	0.02	0.13	0	0	0.02	0	0	0.28	0.20	0	0	0	0	0	0.25
97	17	0	0	0.12	0.04	0.09	0	0	0.03	0.00	0	0.36	0.11	0	0	0	0	0	0.25
112	21	0	0	0.15	0.05	0.05	0	0	0.04	0.00	0	0.46	0.01	0	0	0	0	0	0.25
127	25	0	0	0.17	0.08	0	0	0	0.05	0.02	0	0.43	0.00	0	0	0	0	0	0.25
143	29	0	0	0.14	0.11	0	0	0	0.07	0.10	0	0.34	0	0	0	0	0	0	0.25
160	34	0	0	0.10	0.15	0	0	0	0.08	0.18	0	0.24	0	0	0	0	0	0	0.25
177	38	0	0	0.07	0.18	0	0	0	0.10	0.26	0	0.14	0	0	0	0	0	0	0.25
194	43	0	0	0.03	0.22	0	0	0	0.12	0.34	0	0.04	0	0	0	0	0	0	0.25
210	48	0	0	0.05	0.20	0	0	0	0.13	0.37	0	0	0	0	0	0	0	0	0.25
227	53	0	0	0.09	0.16	0	0	0	0.13	0.37	0	0	0	0	0	0	0	0.00	0.25
243	59	0	0	0.12	0.13	0	0	0	0.14	0.36	0	0	0	0	0	0	0	0.15	0.10
258	65	0	0	0.16	0.09	0	0	0	0.15	0.35	0	0	0	0	0	0	0	0.25	0.00
273	71	0	0	0.20	0.05	0	0	0	0.15	0.35	0	0	0	0	0	0	0	0.25	0
287	76	0	0	0.23	0.02	0	0	0	0.16	0.34	0	0	0	0	0	0	0	0.25	0
299	82	0	0	0.25	0.00	0	0	0	0.20	0.30	0	0	0	0	0	0	0	0.25	0
311	89	0	0	0.25	0	0	0	0	0.27	0.23	0	0	0	0	0	0	0	0.25	0
321	98	0	0	0.25	0	0	0	0	0.34	0.16	0	0	0	0	0	0	0	0.25	0
329	106	0	0	0.25	0	0	0	0	0.39	0.11	0	0	0	0	0	0	0	0.25	0
336	113	0	0	0.25	0	0	0	0	0.44	0.06	0	0	0	0	0	0	0	0.25	0
341	119	0	0	0.25	0	0	0	0	0.47	0.03	0	0	0	0	0	0	0	0.25	0
345	123	0	0	0.25	0	0	0	0	0.49	0.01	0	0	0	0	0	0.00	0	0.25	0
347	134	0	0	0.25	0	0	0	0	0.50	0	0	0	0	0	0	0.19	0	0.06	0

These results offer qualified support for diversification to reduce risk. Particularly on marginal land (LCC 5), pecans or timber can help reduce whole-farm risk substantially.

III.B.3.3 *Mean reversion model*

Results for the timber price mean-reversion and trend-reversion models for the entire data set (1955-2007) are presented in Table III.B.7. All the estimated models have a negative sign on the α coefficient, suggesting that a mean-reverting or trend-reverting model is more appropriate than an explosive model such as geometric Brownian motion, which would be indicated by a positive sign on α.

The mean-reverting model for sawtimber prices for 1955-2007 does not seem to be a good fit. The mean reversion rate, - α, is not statistically significantly different than zero. Also worrisome is the fact that the mean, μ, is \$58.99 per ton, which is significantly higher than any of the observed data points. The model is essentially saying that the price in 1955 was so far below the mean or equilibrium price that it has slowly reverting to that mean ever since. This is not plausible. The linear trend reversion and quadratic trend reversion models also do not provide a good fit. The p-value of the F-statistic for the model is greater than 0.2 for both models.

For pecan prices, all the models provide a good fit, but adding a linear or quadratic trend does not appear to improve the fit much. We note the high value for α in the mean-reversion model, 0.90. This is indicative of the fact that pecan prices tend to oscillate back and forth between low and high values (Ares et al. 2006). In fact, we might have expected this value to be greater than one.

Table III.B.7. Mean-reversion and trend-reversion models for the full (1955-2007) mixed hardwood timber price data set*, and pecan prices**.

	Model	μ or μ_0 ($/ton for timber or $/pound for nuts)	α	β ($/ton/yr or $/pound /yr)	γ ($/ton/yr^2 or $/pound /yr^2)	σ ($/ton or $/pound)	F
Saw-timber	Mean-reversion	61.76 (0.29)	-0.01 (0.74)			2.19	0.11 (0.74)
	Linear	3.67 (0.57)	-0.10 (0.10)	0.67 (0.09)		2.15	1.58 (0.21)
	Quadratic	9.53 (0.26)	-0.16 (0.07)	-0.09 (0.87)	0.01 (0.33)	2.15	1.38 (0.26)
Pulp-wood	Mean-reversion	4.37 (0.09)	-0.12 (0.09)			0.65	3.06 (0.09)
	Linear	2.57 (0.08)	-0.21 (0.02)	0.06 (0.08)		0.64	3.20 (0.05)
	Quadratic	3.97 (0.05)	-0.31 (0.01)	-0.08 (0.44)	0.00 (0.22)	0.63	2.68 (0.06)
Pecan	Mean-reversion	0.88 (0.00)	-0.90 (0.00)			0.33	15.91 (0.00)
	Linear	1.02 (0.00)	-0.94 (0.00)	-0.01 (0.29)		0.32	8.59 (0.00)
	Quadratic	0.88 (0.03)	-0.90 (0.00)	0.02 (0.65)	0.00 (0.47)	0.33	5.80 (0.00)

p-values in parentheses
* Louisiana Quarterly Report of Forest Products (LA DAF 2008)
** USDA National Agricultural Statistics Service's Noncitrus Fruits and Nuts Summary (NASS 2008)

On the other hand, if we estimate a model only from the data after 1990 (Table III.B.8), as suggested by Yin and Caulfield (2002), we obtain a much better fit for the data. The mean reversion rate is significantly different than zero, and the mean or equilibrium sawtimber price is estimated as $34.48 per ton in 2007 dollars, which is reasonable, given average prices over the past 18 years. The linear and quadratic trend reversion models do not improve the fit.

The results for pulpwood prices are not as clearly in favor of breaking the data at around 1990, although it appears plausible. Of the models with the entire data set, the linear trend model has the F-statistic with the lowest p-value (0.05). Using hardwood pulpwood price data since 1990, the simple mean-reversion model produces a slightly better fit with an F-statistic p-value of 0.04.

Table III.B.8. Mean-reversion and trend-reversion models for the restricted (1991-2007) mixed hardwood timber price data set.

	Model	μ or μ_0 ($/ton)	α	β ($/ton/yr)	γ ($/ton/yr^2)	σ ($/ton)	F
Saw-timber	Mean-reversion	33.47 (0.01)	-0.29 (0.01)			2.97	8.54 (0.01)
	Linear	2.87 (0.91)	-0.46 (0.07)	0.65 (0.44)		3.01	4.48 (0.03)
	Quadratic	-219.40 (0.12)	-0.76 (0.02)	10.38 (0.10)	-0.11 (0.11)	2.81	4.39 (0.03)
Pulp-wood	Mean-reversion	5.90 (0.04)	-0.50 (0.04)			1.01	5.37 (0.04)
	Linear	6.46 (0.24)	-0.49 (0.06)	-0.01 (0.92)		1.04	2.50 (0.12)
	Quadratic	-46.63 (0.36)	-0.63 (0.04)	2.38 (0.31)	-0.03 (0.31)	1.04	2.07 (0.16)

p-values in parentheses
LA DAF (2008)

Because we had no farm-level time series data, we utilized ARMS aggregate data on agricultural returns per hectare for the Mississippi Portal region (approximately the same as the LMAV) from 1975-2007 for cotton, rice and soybeans, and from 1996-2007 for returns to cow-calf enterprise per head. No data was available for corn in the region, as it has only become a major crop in the region recently.

The results of the regressions for agriculture are supportive of mean reversion (table 9), and consistent with Bessembinder et al. (1995). Rice and soybeans had α values that were very similar and close to 0.35. Cotton and cattle had a higher level of mean-reversion, close to 0.69.

Table III.B.9. Mean-reversion and trend-reversion models for agricultural returns (1975-2007) and cow-calf enterprise returns (1996-2007).

	Model	μ or μ_0 ($/ha for agriculture or $/head for cattle)	α	β ($/ha/yr or $/head/yr)	γ ($/ha/yr^2 or $/head/yr^2)	σ ($/ha or $/head)	F
Cotton	Mean-reversion	259.72	-0.69			338.12	15.84
		(0.03)	(0.00)				(0.00)
	Linear	621.58	-1.03	-21.41		295.39	15.53
		(0.00)	(0.00)	(0.00)			(0.00)
	Quadratic	616.91	-1.03	-20.60	-0.02	300.62	10.00
		(0.00)	(0.00)	(0.38)	(0.97)		(0.00)
Rice	Mean-reversion	219.24	-0.34			340.86	6.63
		(0.28)	(0.02)				(0.02)
	Linear	339.58	-0.37	-71.93		345.97	3.28
		(0.45)	(0.03)	(0.73)			(0.05)
	Quadratic	1130.79	-0.60	-132.24	1.45	320.73	4.46
		(0.02)	(0.00)	(0.02)	(0.02)		(0.01)
Soybean	Mean-reversion	192.44	-0.35			152.84	6.85
		(0.10)	(0.01)				(0.01)
	Linear	383.20	-0.51	-11.09		149.48	4.76
		(0.04)	(0.00)	(0.14)			(0.02)
	Quadratic	632.62	-0.72	-52.76	0.50	138.62	5.60
		(0.00)	(0.00)	(0.01)	(0.02)		(0.00)
Cow-Calf	Mean-reversion	-203.31	-0.69			57.99	5.66
		(0.05)	(0.04)				(0.04)
	Linear	-120.01	-0.46	-13.61		59.22	3.03
		(0.66)	(0.30)	(0.45)			(0.11)
	Quadratic	-290.24	-0.76	45.30	-4.03	55.97	2.91
		(0.23)	(0.13)	(0.29)	(0.20)		(0.11)

p-values in parentheses
USDA ARMS aggregate Mississippi Portal data (ERS 2009).

III.B.3.4 *Switching crops through time model*

By using a Monte Carlo simulation under the assumption of mean reversion of crop returns and correlation of the error terms in the mean reversion models of the various crops, we were able to show how a farmer might be able to take advantage of returns that vary through tune. By utilizing a flexible decision rule whereby the farmer chooses for the current year whichever crop performed the best in the previous year, a farmer would be able to increase his expected returns significantly over choosing a single crop and never varying from the choice.

Because the variance of the error term in a mean-reverting process is not the same as the variance of the mean-reverting variable (Oksendal 1985; Garcia Franco n.d.), the covariance input for the error terms of the process is not the same as the resulting covariance of the annual returns. We wanted the output returns covariance to match the covariance matrix from the ARMS data, rather than the input error term covariance. Therefore, we used an iterative process by which we adjusted the error term input covariance matrix, ran the Monte Carlo simulation, observed how the returns output covariance compared to the ARMS covariance, and repeated the process until the output covariance approximated the ARMS covariance. The resulting input and output covariance matrices are in Table III.B.10 and Table III.B.11.

Table III.B.10. Input mean-reversion error term covariance matrix ($\$^2/ha^2$).

	Corn	Cotton	Rice	Soybean
Corn	67100	19500	15000	9500
Cotton	19500	87000	48000	17000
Rice	15000	48000	79000	10800
Soybean	9500	17000	10800	22500

Table III.B.11. Output returns covariance matrix from Monte Carlo model (compare to covariance matrix from ARMS data Table III.B.2) ($\$^2/ha^2$)

	Corn	Cotton	Rice	Soybean
Corn	114261	23974	25705	16144
Cotton	23974	95164	59578	20926
Rice	25705	59578	137466	18434
Soybean	16144	20926	18434	38285

Figure III.B.1 shows the cumulative distribution functions (CDFs) from the Monte Carlo simulation of the various crops, and the CDF of the returns under the flexible decision rule. Table III.B.12 shows the summary statistics of the various crop returns. In particular, a farmer could increase expected returns on LCC 3 sites from $267/ha for rice to $382/ha. In the case of LCC 5 sites, expected returns increased from $43/ha to $110/ha. The use of this rule to choose crops also affected the variance of returns.

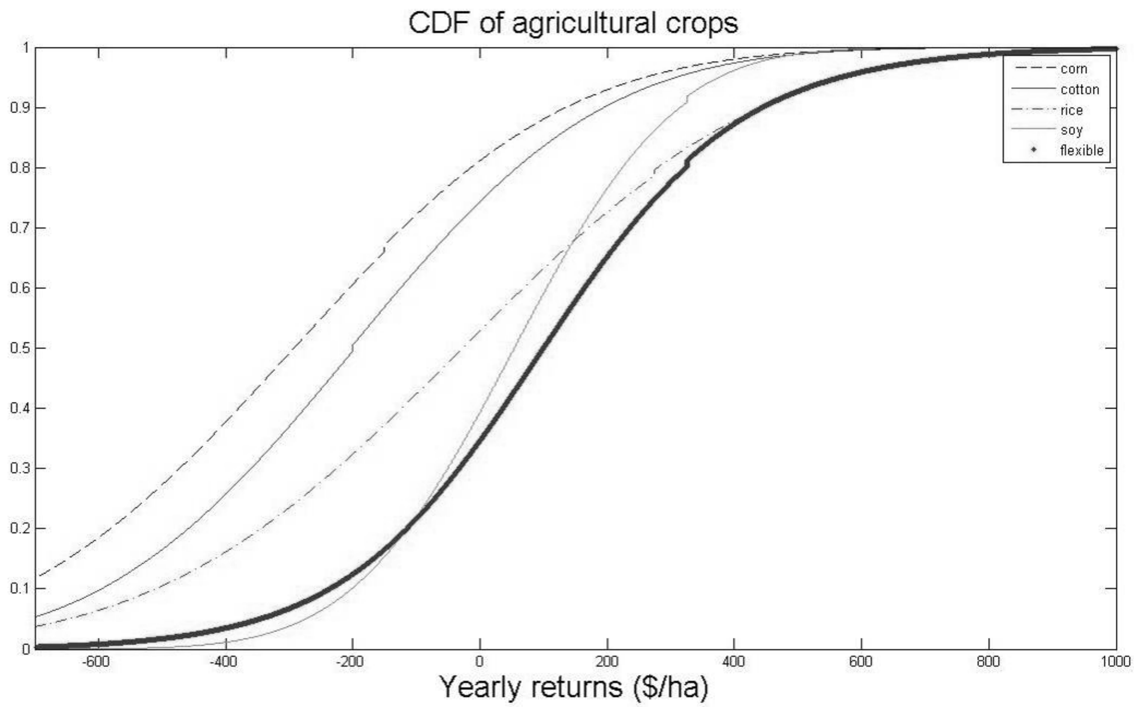

Figure III.B.3. Cumulative distribution functions of returns to various crops and the flexible crop decision rule, on land capability class (LCC) 5 land, from Monte Carlo simulation.

Table III.B.12. Summary statistics of the Monte Carlo simulation. "Flexible" represents returns under a decision rule allowing different crops each year ($/ha).

		Corn	Cotton	Rice	Soybean	Flexible
LCC 3	Expected returns	165	212	267	221	382
	Standard deviation of returns	338	309	373	197	302
	100-year net present value	3270	4204	5293	4378	7579
LCC 5	Expected annual returns	-294	-210	6	43	110
	Standard deviation of returns	338	308	371	196	286
	100-year net present value	-5836	-4162	128	852	2177

Once we estimated the standard deviation of agricultural returns under the flexible decision rule, it was necessary to adjust this to be the equivalent of the standard deviation of error term in a mean reverting process, for use in the RO model. It can be shown that for a long time series (greater than 10 years) this value is equal to

$$\sigma^2 = Var(x) \cdot 2\alpha \qquad (18)$$

where α is the mean reversion parameter (Oksendal 1985; Garcia Franco n.d.). We therefore found the value of the standard deviation of the error term for the mean reverting flexible agricultural returns to be $252/ha for LCC 3 land, and $238/ha for LCC 5.

III.B.3.5 *Real options model*

The real options (RO) model was used to compare agriculture to each of the various forestry and agroforestry systems proposed as having potential in the LMAV. The output of the RO models can be quite massive in terms of the amount of data, so we have attempted to provide only the output data that provides the most understanding of the systems' attributes and adoptability.

An important input into the RO model is the cost of clearing land that is in forestry. This value affects the ease of which farmers can switch back and forth. This value was estimated by a panel of experts (Chapter IIA) to have a median of approximately $1356/ha (90% confidence interval $430-10072/ha), which is the value we used in our model.

A few figures of the types of data that can be provided by the RO analysis will help the reader understand the models and their outputs. In Figure III.B.4 one observes a comparison of agriculture and a hard hardwood alley cropping system. This figure assumes that the land that is being considered for conversion to alley cropping is currently being used for agriculture. On the x-axis is the price per ton of timber, and on the y-axis is the return to agriculture per hectare. The black-colored cells represent the points at which the optimal decision is to remain in agriculture, while the white colored cells represent the points at which it is optimal to switch to alley cropping. That is to say, if the pulpwood price in the current year was $10/ton and the agricultural returns in the current year were $100 per hectare, it is optimal for a farmer to continue agriculture. If, however, the agricultural returns this year were a loss of $800 per hectare, then it would be optimal to switch to alley cropping.

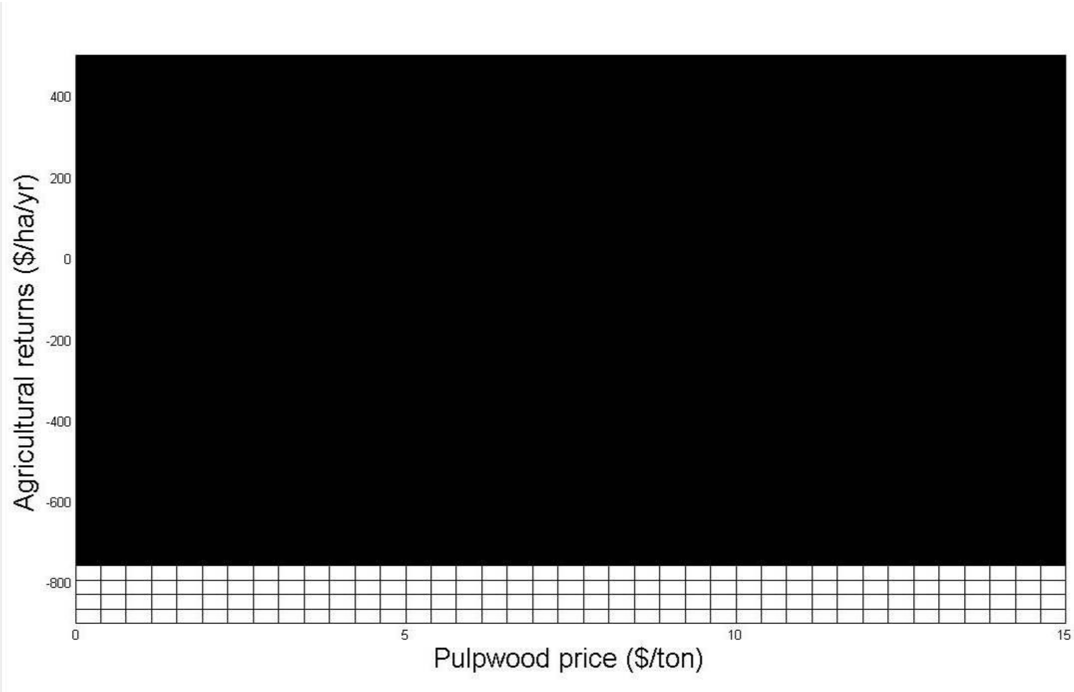

Figure III.B.4. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land currently in agriculture.

White cells represent switching to alley cropping, black cells represent staying in agriculture.

One thing that is clear from the graph is that the pulpwood price plays very little role in the decision to switch or not. The decision is driven almost entirely by agricultural returns. This is seen by the fact that the division between the white and black cells is horizontal. The reason for this is the assumption of mean-reversion and the relatively long time period until timber harvest, compared to agriculture. That is to say, regardless of today's timber price, given the assumption of mean reversion, the expected value of timber prices far in the future (greater than say, 10 year) is very close to the equilibrium or mean timber price.

The level at which a farmer crosses from non-adoption of alley cropping to adoption (moving downwards on the graph) is what we call the "RO adoption threshold". Because the level of this threshold is largely unaffected by timber prices, it is convenient to summarize this as the level of agricultural returns per hectare below which a farmer/landowner would find it optimal to switch to alley cropping, at the equilibrium timber price.

The following Figure III.B.5 shows the same decision, but on land that has recently been planted to an oak alley cropping system. In this graph, the white represents maintaining the alley cropping system at least until next year, while the black represents clearing the planted trees and returning to agriculture. In this case, the agricultural returns level above which a landowner returns from the alley cropping system to agriculture would be the "RO disadoption threshold". This disadoption threshold will vary depending on the age of the stand, as we describe below. We can see that, while the decision is still mostly driven by agricultural returns rather than timber prices, the agricultural returns level at which one reverts to agriculture is much higher than the level at which one remains in agriculture.

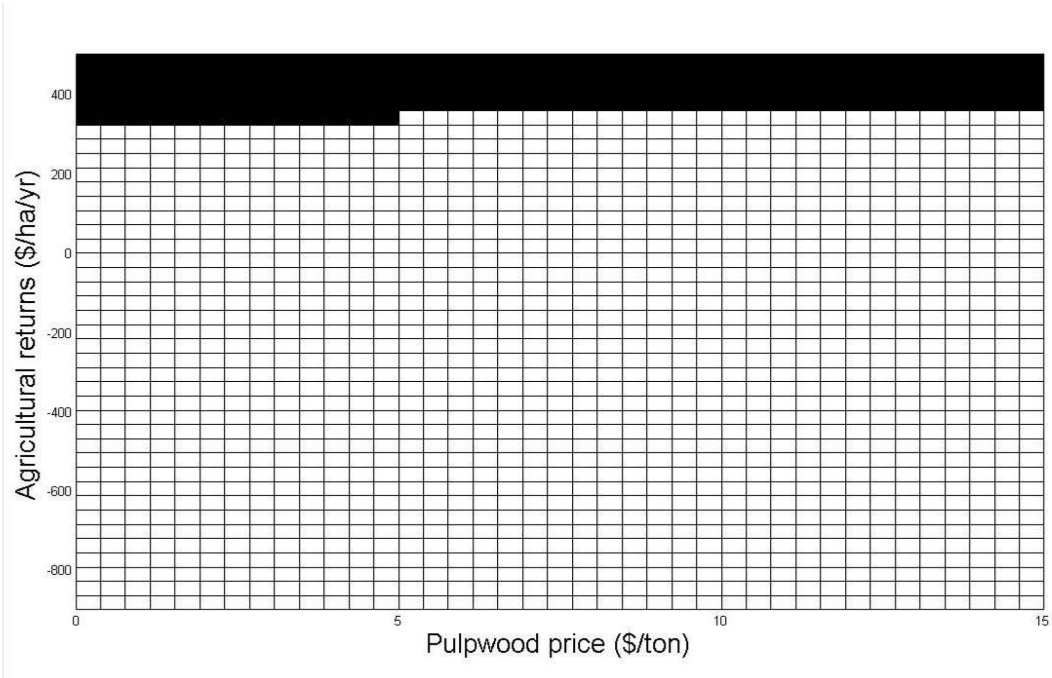

Figure III.B.5. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land recently planted to alley cropping.

White cells represent staying in alley cropping, black cells represent switching to agriculture.

Our research is primarily concerned with the adoption threshold, rather than the disadoption threshold. However, it is useful to continue with this example to see how the RO model works.

The following two figures (Figure III.B.6 and Figure III.B.7) represent land that is used as an oak alley cropping system at stand ages 5 and 10 years, respectively. As the stand ages, the landowner becomes less likely to clear because he is getting closer to the age at which the trees will be of value for sawtimber, a more valuable product. If he/she were to harvest immediately, he/she would receive pulpwood prices, but by waiting can achieve more value.

Figure III.B.6. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land with 5-year-old alley cropping stand.

White cells represent staying in alley cropping, black cells represent switching to agriculture.

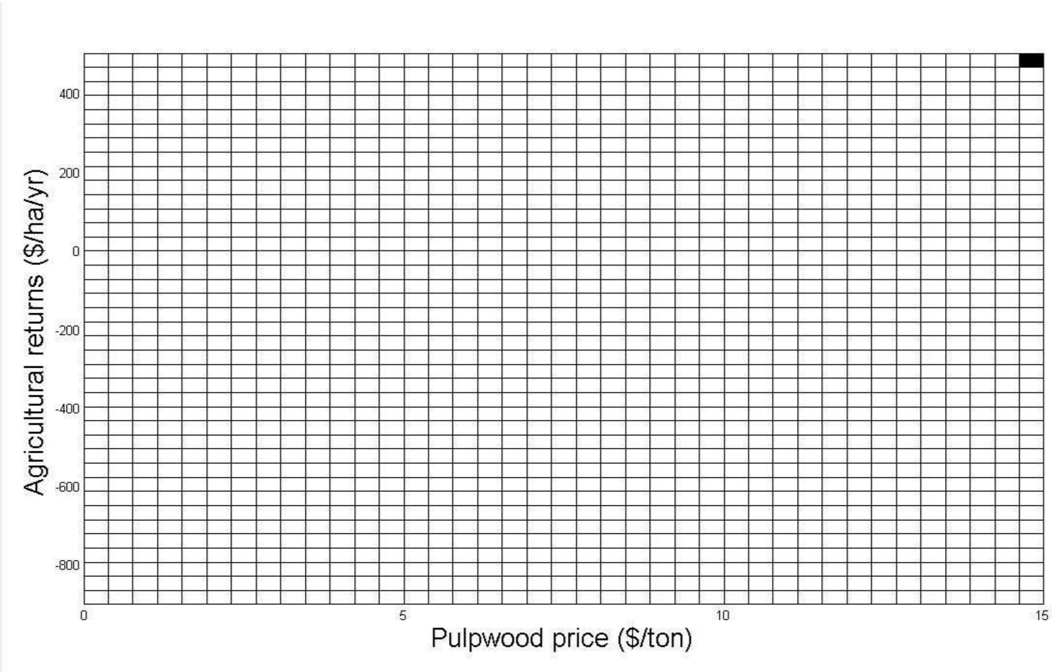

Figure III.B.7. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land with 10-year-old alley cropping stand.

White cells represent staying in alley cropping, black cells represent switching to agriculture.

The following Figure III.B.8 skips several years during which, over the range of agricultural returns and pulpwood price values we have used, it is optimal for the landowner to wait. There are still silvicultural activities in those years, such as thinning. However, this figure presents the stand at age 40, when the landowner is considering harvest. Here the figure includes a third color, grey, to represent the third possible action: to harvest the timber and replant the alley cropping system. That is, black represents harvesting the timber and clearing the stumps to return to agriculture, white represents keeping the forest stand at least one more year and grey represents harvesting the timber and restarting the alley cropping rotation. At low levels of timber prices, it is optimal to wait, to see if the price will increase in the future.

Figure III.B.8. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land with 40-year-old stand.

White cells represent staying with hardwood, black cells represent clearcutting and switching to agriculture, grey cells represent clearcutting and replanting alley cropping system.

The following Figure III.B.9 represents optimal decisions for the same stand at age 49. At this point, the landowner is allowed to maintain the stand and conduct a small, steady-state, sustainable harvest equal to the mean annual increment each year; or clearcut the forest to either return to agriculture or replant the alley cropping system. It is worth noting that at age 49, the landowner is willing to accept a slightly lower timber price to clearcut than at age 40.

Figure III.B.9. Optimal decisions for RO model comparing agriculture to hardwood alley cropping, land with 49-year-old stand.

White cells represent staying with hardwood, black cells represent clearcutting and switching to agriculture, grey cells represent clearcutting and replanting alley cropping system.

As noted, our research is primarily interested in the adoption threshold of various production forestry and agroforestry systems for land that is currently in agriculture. We summarize the adoption thresholds for LCC 5 and LCC 3 in Table III.B.13 and Table III.B.14.

At first glance, the outlook for most forestry and agroforestry activities in the LMAV looks bleak because the graph indicates that agricultural returns must become significantly negative for pulpwood to become optimal. However, we should consider that this does not mean that agricultural returns must be negative over a long period; they only have to be that low one year for the farmer to decide it is worthwhile to plant trees. It seems reasonable that net returns on marginal land will occasionally be negative.

In the tables, we also include the probability of agricultural returns reaching the threshold level, based on the mean agricultural returns, standard deviation and assumed distributional form of agricultural returns. One can observe that, on LCC 5 sites, several forestry and agroforestry systems have greater than a 10% chance of being adopted on any given plot in any given year.

The real options value is the numerical value estimated for the value function, $V(s)$, assuming forestry/agroforestry at the year of site planting, at equilibrium mean reversion prices. This is comparable to the SEV in some cases, but allows for increased value from numerous options, including the option to switch back to agriculture. In fact, in many cases on LCC 3 land, on recently planted forestry or agroforestry land, at equilibrium prices, it is optimal to switch back to agriculture immediately. In these cases, which are noted in the table, it is not necessarily appropriate to compare to the SEV.

For comparison, we include values for the soil expectation value (SEV) from Chapter IIA and the Annual Equivalent Value (AEV) for the SEV. The AEV can be viewed as the "SEV adoption threshold", that is, the level of agricultural returns below which it is optimal to switch to the forestry or agroforestry system, utilizing SEV assumptions. The SEV does not allow for either the option value of waiting a year to convert agricultural land to forestry or the option value of selecting the optimal year to harvest timber because of changing timber prices.

In most cases, the RO analysis shows a more negative threshold of agricultural returns for switching to forestry or agroforestry than the SEV analysis. This means that, if farmers value the flexibility provided by different production systems, in most cases they will be less likely to adopt forestry or agroforestry than a SEV analysis might suggest. This fairly pessimistic finding for forestry prospects does at least provide more insight why so little conversion to forestry or agroforestry has occurred. It is useful to have models that do generally conform to farmers' decisions. Despite their pessimism, however, it is useful to help identify the level of government interventions that actually would be needed to encourage these practices if deemed socially desirable.

To be specific, on LCC 5 sites, the RO adoption threshold was significantly more negative (i.e. more difficult to reach) than the SEV adoption threshold (the AEV) for Wetlands Reserve Program enrollment, cottonwood timber plantation, short-rotation woody crops, hard hardwood timber plantation, cottonwood-oak intercrop plantation, pecan silvopasture, pecan alley cropping and hardwood alley cropping. The RO adoption threshold was slightly lower than the SEV adoption threshold for cottonwood alley cropping. The RO adoption threshold was higher than the SEV adoption threshold for hard hardwood silvopasture and pine silvopasture.

The reason why the real options threshold is lower than the SEV threshold for WRP enrollment is the clearest. In our model, we have assumed that once a plot of land is enrolled in WRP, it can never return to agriculture. Also, no timber harvest is permitted. The only income after the easement payment is income from a hunting lease. This means that WRP has essentially no flexibility. Still, it is important to note, that even with this lack of flexibility, the returns to WRP enrollment on LCC 5 land are high enough that it is a more attractive option in the RO model than many of the other forestry and agroforestry regimes.

Of the forestry and agroforestry production systems, the most attractive in the RO model are pine silvopasture, hard hardwood silvopasture, cottonwood alley cropping and cottonwood plantation. It is important to reiterate that pine markets are extremely limited in the LMAV (see chapter III.A), so that particular system may be limited to a few regions in the LMAV. Also, as discussed in chapter III.A, returns per head of cattle may depend significantly on management decisions, and may not have returns this high for all farmers, particularly those with small herds or who do not have experience with livestock.

Of the forestry and agroforestry systems on LCC 5 soils, the three most adoptable systems from the real options perspective are agroforestry systems. This depends principally on the profitability of livestock. Alley cropping systems appear to be about the same in terms of adoptability as conventional forestry systems. For instance, there is a 39% in any given year of agricultural returns crossing the threshold for cottonwood alley cropping compared to 31% for conventional cottonwood. For hard hardwoods, there is a 0.1% chance of crossing the threshold for alley cropping and 0.3% for the conventional system.

Table III.B.13. RO and SEV adoption thresholds in terms of agricultural returns per hectare, and RO value and SEV for production forestry and agroforestry systems on land capability class (LCC) 5 land ($/ha).

	Real options adoption threshold	Prob. of crossing threshold	Annual Equivalent Value (SEV threshold)	Real options value	SEV
Wetlands Reserve Program	-247	11%	112	2236	2233
Cottonwood	-29	31%	61	3804	1210
Short Rotation Woody Crop	-429	3%	-113	1841	-2253
Hard hardwoods	-667	0.3%	-6	1136	-129
Cottonwood-Oak intercrop	-415	3%	1	1571	18
Pecan Silvopasture	-779	0.1%	-1	1513	-28
Hard Hardwoods Silvopasture	186	61%	16	5246	321
Pine Silvopasture	>500	>91%	93	10023	1861
Pecan Alley Crop	-451	2%	-12	1834	-235
Hard Hardwoods Alley Crop	-774	0.1%	0	1405	-8
Cottonwood Alley Crop	29	39%	68	3583	1367

On sites of LCC 3, the real options analysis paints a much bleaker picture of the adoptability of production forestry and agroforestry systems. This is an important finding, as approximately 40-50% of the LMAV land is on LCC 3 soils, and any large-scale effort at reforestation would need to include these soils. Most of the systems analyzed have less than a 0.1% chance of agricultural returns in any given year reaching a level low enough that adoption of the forestry or agroforestry system is optimal. Of the two systems that stand a greater chance of adoption, both are agroforestry systems. Still, hard hardwoods silvopasture stands only a 1% chance of reaching the RO adoption threshold in any year. Again, pine silvopasture far out-performs the rest, but with the normal caveats about the lack of pine markets in the region.

Table III.B.14. RO and SEV adoption thresholds in terms of agricultural returns per hectare, and RO value and SEV for production forestry and agroforestry systems on land capability class (LCC) 3 land ($/ha).

	Real options threshold	Prob. of crossing threshold	SEV threshold	Real options value	SEV
Wetlands Reserve Program	<-900	<0.1%	112	2236	2233
Cottonwood	<-900	<0.1%	59	5548*	1180
Short Rotation Woody Crop	<-900	<0.1%	-111	6645*	-2217
Hard hardwoods	<-900	<0.1%	3	5553*	52
Cottonwood-Oak intercrop	<-900	<0.1%	8	5553*	158
Pecan Silvopasture	<-900	<0.1%	51	5422*	1020
Hard Hardwoods Silvopasture	-586	1%	41	7383*	811
Pine Silvopasture	>500	>70%	126	10622	2512
Pecan Alley Crop	<-900	<0.1%	118	5414*	2355
Hard Hardwoods Alley Crop	<-900	<0.1%	42	6641*	843
Cottonwood Alley Crop	<-900	<0.1%	107	6226*	2144

III.B.3.6 *System rankings*

We used the threshold levels for LCC 5 land to compare the adoptability of the various agroforestry systems and ranked them on this basis. We compared this ranking to the ranking from the expert panel and SEV analysis from Chapter III.A (table 15). The results differed moderately, but not completely, from the expert rankings. The principal difference was for pecan silvopasture, which experts ranked as the most likely to be adopted, but our RO analysis found to be the least likely. The RO analysis appeared to look unfavorably on pecans because there is such as large investment in the initial years. Even though there are few trees per hectare, they require intensive pest and fungus control, etc. These types of large investments typically create a large barrier to adoption in RO models. On the other hand, we have seen in the mean-variance analysis that pecan can be a very effective risk mitigator for farmers. This might drive farmers to adopt pecans in a way not measured in the RO analysis.

Cottonwood alley cropping performed somewhat better in our analysis than in the expert opinion. Several experts tended to believe that alley cropping would not be favored by farmers because they are bothersome, which is a non-market value that would not be picked up in the RO or SEV models.

Table III.B.15. Rankings of agroforestry systems in terms of potential for adoption.

	Expert Ranking	SEV LCC 3	SEV LCC 5	RO LCC 5
Pecan Silvopasture	1	4	5	8
Hard Hardwoods Silvopasture	2	6	3	2
Pine Silvopasture*		1	1	1
Hard Hardwoods Riparian Buffer	4	7	7	6
Cottonwood-oak Riparian Buffer	3	8	8	4
Pecan Alley Crop	5	2	6	5
Hardwood Alley Crop	7	5	4	7
Cottonwood Alley Crop	6	3	2	3

III.B.4 CONCLUSIONS

We utilized two models, a mean-variance (E-V) and real options (RO) model, to further illuminate whether agroforestry and production forestry activities have potential for adoption in the LMAV. These models take into account the stochasticity, or variability, of returns to agriculture, forestry and agroforestry. These results may be viewed in conjunction with our research in Chapter IIA, which considers only the deterministic expected returns, to provide a more holistic economic picture of these production systems.

In order to utilize the E-V and RO models, it was first necessary to estimate a few other models to provide the inputs. First, we utilized USDA ARMS data to estimate the covariance of agricultural returns on the farm-level. We estimated the variance for individual crops on individual farms to be higher than that of aggregate data. Second, we estimated mean-reversion parameters of a statistical model for an Ornstein-Uhlenbeck process for agriculture returns and timber prices. Third, we used a Monte Carlo simulation to determine the increase in returns a farmer might achieve by being flexible about which crop to plant. This combined agricultural returns into a single variable.

With this data in hand, we were able to calculate the E-V and RO models. The E-V model showed that, although to achieve maximum expected returns a landowner might utilize only agriculture, he or she can reduce the risk involved by including pecan or timber plantations on his/her land. E-V does not define exactly how individual landowners will allocate their land; it only provides a set of efficient portfolios, from which a landowner might choose, depending on his/her level of risk aversion. In most of the scenarios considered, a landowner would be able to mitigate risk substantially for only a small decrease in expected return, generally by including pecan plantations. Further risk reduction might be achieved by including timber production in the portfolio. However, our results indicate that this is most likely to be restricted to the most marginal land, and since significant risk reduction can be achieved with only a small area of pecan or timber, risk will only drive diversification on small areas of land. This is consistent with the findings of Lilieholm & Reeves (1991).

We found the mean-variance (E-V) approach relatively simple to use, and it provides a good overall framework for understanding how landowners can benefit from diversification. E-V does rely on assumptions that are fairly strong. The stochastic dominance approach is an alternative method to determine the set of portfolios that minimize risk with much weaker assumptions; however, stochastic dominance is very data intensive and large amounts of data are not normally available for agricultural returns.

The RO model produced some interesting results. On the most marginal land, several systems, including pine and hardwood silvopasture, and cottonwood alley cropping and timber plantation, were more likely to be adopted than the WRP program. Since we know that the WRP has been adopted by many landowners, this may be an indicator of potential for adoption of those other systems. On the other hand, many landowners may adopt WRP because it is a good way to get out of farming altogether, which is a non-market value that cannot be modeled in RO, and could make WRP more favorable than agroforestry. Also, pine silvopasture, which receives the most favorable rankings, suffers from limited markets in the LMAV. On average-quality LMAV land, almost none of the forestry or agroforestry systems showed much potential.

Real options methods based on dynamic programs using the Bellman equation are the principal methods utilized to place a value on flexibility ("option value") under stochastic conditions. Previous literature has found that option value can play an important role in land use decisions including forestry. This previous research can be split in two parts: those that use real options to model the timber harvesting decision (Haight & Holmes

1991; Plantinga 1998) and those that use real options to model the afforestation decision (Weimers & Behan 2004; Behan et al. 2006). The timber harvesting literature has shown that flexibility in deciding when to harvest can add significant value to timberlands. The afforestation literature, on the other hand, has shown that the option value of agriculture is likely to cause farmers to delay afforestation; however, that literature did not take into account the option value of timber from the harvesting decision. It makes sense to combine both decisions into one model to include both the option value of agriculture and forestry. Our results confirmed that, in most cases, option value favors agriculture, meaning that farmers will be more hesitant to adopt forestry and agroforestry than is suggested by the purely deterministic model. This is consistent with previous real options afforestation models.

We urge the reader to consider our results with some caution. Because of the quality of data and the computational necessity of simplification to be able to undertake the real options model, we have make some assumptions about variability of agricultural or forestry costs, normality of the distribution of agricultural returns and timber prices, and mean reversion. Still, the methods are robust enough that they should provide a good approximation of reality.

All in all, agroforestry and other production forestry systems may have some potential for adoption on marginal lands for farmers or landowners who feel they want to reduce risk or are not inhibited by trying non-traditional systems. These are most likely to be limited-resource farmers and landowners for whom farming is more of a lifestyle than an occupation, and plots are likely to be small. We do not see much potential for adoption of agroforestry in large areas or on land that is not marginal. Even on marginal private land, WRP is likely to continue to be the principal reforestation program.

III.B.5 LITERATURE CITED

Ares, A., W. Reid, and D. Brauer. 2006. Production and economics of native pecan silvopastures in Central United States. Agroforestry Systems **66**(3)**:**205-215.

Babu, S. C., and B. Rajasekaran. 1991. Agroforestry, attitude towards risk and nutrient availability - a case-study of South Indian farming systems. Agroforestry Systems **15**(1)**:**1-15.

Behan, J., K. McQuinn, and M. J. Roche. 2006. Rural land use: Traditional agriculture or forestry? Land Economics **82**(1)**:**112-123.

Bessembinder, H., J. F. Coughenour, P. J. Seguin, and M. M. Smoller. 1995. Mean reversion in equilibrium asset prices - evidence from the futures term structure. Journal of Finance **50**(1)**:**361-375.

Collender, R. N., and D. Zilberman. 1985. Land allocation under uncertainty for alternative specifications of return distributions. American Journal of Agricultural Economics **67**(4)**:**779-786.

Dubman, R. W. 2000. Variance Estimation With USDA's Farm Costs and Returns Surveys and Agricultural Resource Management Study Surveys. AGES 00-01. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, Washington, DC.

ERS. 2009. Agricultural Resource Management Survey (ARMS). USDA Economic Research Service, Washington, DC. Available from http://www.ers.usda.gov/Briefing/ARMS/ (accessed 1/15 2009).

Feldstein, M. S. 1969. Mean-variance analysis in theory of liquidity preference and portfolio selection. Review of Economic Studies **36**(1):5-12.

Garcia Franco, J. C. n.d. Maximum likelihood estimation of mean reverting processes. Unpublished paper. Onward Inc.

Goodwin, B. K., and A. P. Ker. 2002. Modeling Price and Yield Risk. Pages 289-323 in R. E. Just and R. D. Pope, editors. Kluwer Academic Publishers, Boston.

Haight, R. G., and T. P. Holmes. 1991. Stochastic price models and optimal tree cutting: Results for loblolly pine. Natural Resource Modeling **5**(4):423-443.

Hanoch, G., and H. Levy. 1969. Efficiency analysis of choices involving risk. Review of Economic Studies **36**(3):335-346.

Harwood, J., R. Heifner, K. Coble, J. Perry, and A. Somwaru. 1999. Managing risk in farming: Concepts, research, and analysis. Agricultural Economic Report - Economic Research Service, US Department of Agriculture (774):125.

Insley, M., and K. Rollins. 2005. On solving the multirotational timber harvesting problem with stochastic prices: A linear complementarity formulation. American Journal of Agricultural Economics **87**(3):735-755.

Isik, M. 2006. Implications of alternative stochastic processes for investment in agricultural technologies. Applied Economics Letters **13**(1):21-27.

Just, R. E. 2003. Risk research in agricultural economics: Opportunities and challenges for the next twenty-five years. Agricultural Systems **75**(2-3):123-159.

Just, R. E., and Q. Weninger. 1999. Are crop yields normally distributed? American Journal of Agricultural Economics **81**(2):287-304.

Kott, P. S. 2001. Using the delete-a-group jackknife variance estimator in NASS surveys. RD-98-01. Research Division, National Agricultural Statistics Service, U.S. Department of Agriculture, Washington, DC.

Kroll, Y., H. Levy, and H. M. Markowitz. 1984. Mean-variance versus direct utility maximization. Journal of Finance **39**(1***)***:47-61.

LA DAF. 2008. Louisiana Quarterly Report of Forest Products. Louisiana Department of Agriculture and Forestry, Baton Rouge, LA. Available from http://www.ldaf.state.la.us/portal/Offices/Forestry/ForestryReports/QuarterlyReportofForestProducts/tabid/451/Default.aspx (accessed 1/15 2009).

Lilieholm, R. J., and L. H. Reeves. 1991. Incorporating economic risk aversion in agroforestry planning. Agroforestry Systems **13**(1):63.

Markowitz, H. 1959. Portfolio selection; efficient diversification of investments. Wiley, New York.

Markowitz, H. 1952. Portfolio selection. Journal of Finance **7**(1):77-91.

Miranda, M. J., and P. L. Fackler. 1997. CompEcon Toolbox for MATLAB. Available from http://www4.ncsu.edu/~pfackler/compecon/toolbox.html.

Miranda, M. J., and P. L. Fackler. 2002. Applied computational economics and finance. NetLibrary, Inc edition. MIT Press, Cambridge, Mass.

Mishra, A., H. El-Osta, M. Morehart, J. Hopkins, and J. Johnson. 2002. Assessing the economic well-being of farm households. Agricultural Outlook (293):31.

NASS. 2008. Noncitrus Fruits and Nuts 2007 Summary. Report No. Fr Nt 1-3 (08) a. USDA National Agricultural Statistics Service, Washington, DC.

Oksendal, B. K. 1985. Stochastic differential equations : an introduction with applications. Springer-Verlag, Berlin; New York.

Plantinga, A. J. 1998. The optimal timber rotation: An option value approach. Forest Science **44**(2):192-202.

Schwartz, E. S. 1997. The stochastic behavior of commodity prices: Implications for valuation and hedging. Journal of Finance **52**(3):923-973.

Steinbach, M. C. 2001. Markowitz revisited: Mean-variance models in financial portfolio analysis. SIAM Review **43**(1):31-85.

Tobin, J. 1958. Liquidity preference as behavior towards risk. Review of Economic Studies **25**(2):65-86.

Von Neumann, J., and O. Morgenstern. 1947. Theory of games and economic behavior. 2nd edition. Princeton Univ. Press, Princeton.

Weimers, E., and J. Behan. 2004. Farm forestry investment in Ireland under uncertainty. The Economic and Social Review **35**(3):305-320.

Yin, R. S., and J. P. Caulfield. 2002. A profile of timber markets in the U.S. southeast. Forest Products Journal **52**(3):25-34.

Young, M. R. 1998. A minimax portfolio selection rule with linear programming solution. Management Science **44**(5):673-683.

IV CONCLUSIONS

The studies presented in this dissertation serve to further our understanding of the economic benefits and challenges of agroforestry systems for private landowners. Each chapter has utilized a different methodology to measure the potential of these systems for adoption and/or disadoption. While none of the basic theory behind these methodologies was new, they were utilized and combined in novel ways to adapt them to unique situations and overcome theoretical and practical complications.

The first section used *ex-post* analyses of silvopasture systems in northeastern Argentina. In the first chapter of the section statistical analyses were conducted on indices of farmers' subjective positive and negative perceptions of the systems. Most adopters have a positive view of the system and indicate that they will likely continue in the future. Unfortunately, the data did not prove sufficient to gain a good understanding of the factors that influence many of the farmers' perceptions, including perceptions of costs and returns of silvopasture. However, it was determined that small and medium farmers tended to have a more positive view of the cash flow and risk characteristics of silvopasture, while annual crop farmers and had a more negative view of cash flow and less educated farmers had a more negative view of its risk. It was also found that farmers' perceptions of the costs and returns of the system were the most important factors in determining the likelihood of continuance.

The second chapter of the first section utilized a non-parametric linear programming technique, data envelopment analysis, to estimate the relative technical efficiency of real silvopasture, pasture and forestry plots based on a survey of farmers. The efficiencies of the plots were compared pairwise by farm with non-parametric statistics test if one group of systems was systematically more efficient, that is, produced more outputs per unit of inputs, than the other systems. This was a novel approach to comparing land-use systems and took advantage of the fact that many farms have plots of two of the three, or of all three types of systems to control for differences between farms. This comparison showed that silvopasture systems were more efficient than pasture systems.

The second section is comprised of *ex-ante* financial and economic analyses of various potential agroforestry systems in the Lower Mississippi Alluvial Valley, in the US South. Those systems were compared to production forestry systems and conventional agriculture in the region. In the first chapter of this section, a panel of experts helped define the most appropriate systems and delineate market conditions in the LMAV. A deterministic model of profits was used to identify the most profitable systems and experts assessed other factors not directly tied to profitability. Some agroforestry and production forestry systems were shown to have potential for adoption on the most marginal land, but cannot compete with agriculture on average land unless incentives are paid to landowners. The panelists considered silvopasture systems and pecan-based agroforestry to be the most likely to be adopted in the region.

The second chapter of the second section used stochastic models to compare those same systems in the LMAV to agriculture. These stochastic models used measures of the variability of returns to different systems to understand how farmers' decisions may be affected. A mean-variance model is employed to understand whether risk aversion might drive farmers to diversify their farms to produce agroforestry outputs. The model showed that diversification into forestry or agroforestry may help reduce the risk inherent in agriculture. A real options model utilized measures of variability and the costs of switching between agriculture and forestry or agroforestry to estimate how farmers might value flexibility. The real options analysis showed that farmers will be unlikely to adopt most forestry or agroforestry systems on anything but the most marginal land.

The overarching result of this dissertation is that agroforestry systems can provide net economic benefits to private landowners in some cases, but not in all cases. Policies that can help promote agroforestry include easements such as the Conservation Reserve Program Conservations Practice 22 (CRP CP22) for riparian buffers in the United States, and markets for environmental services. The results of this research also show that the Wetlands Reserve Program (WRP) and CRP CP22 have potential to induce reforestation on marginal farmland but not average farmland, which is consistent with observations in the region.

Even though silvopasture was shown to be more economically efficient than pasture, and most adopters have an overall positive view of the system, adoption has proceeded fairly slowly. It is estimated that 20,000 hectares of formal silvopasture systems had been adopted by 2007 in Misiones and Corrientes provinces. Therefore, even when finances favor an agroforestry system, adoption can be slow. Likely, farmers are fairly risk averse and avoid experimentation with new systems if they are unsure of outcomes, especially in the cases where up-front costs are high, or the time period of the investment is long. The impact of these up-front costs was demonstrated by the real options models in the LMAV, which showed that they can be a barrier to adoption. In these cases, incentive and cost-sharing payments like those that have been used in Argentina to promote forestry and silvopasture, and the WRP and CRP programs in the USA, can help landowners overcome initial costs of the system.

APPENDICES

Appendix 1: MATLAB function crsdea.m to conduct a constant returns to scale data envelopment analysis

```
% crsdea is a function which conducts a constant returns to scale (CRS)
%   output-oriented data envelopment analysis (DEA) of a matrix of
%   economic inputs and outputs for various decision making units (DMUs)
%   based on the CCR dual model, using slacks.  Optionally, includes
assurance
%   region analysis.
% USAGE
%   [TE,P,S,R] = crsdea(B,n,m,CL,CU)
% INPUTS OF FUNCTION
%   n  : number of economic inputs
%   m  : number of economic outputs
%   B  : an (n + m) x d matrix of economic inputs and outputs for the d
%        DMUs.  Columns must represent the DMUs.  The first n rows must
%        represent the economic inputs and the remaining m rows must
%        represent the ecomonic outputs.
%   CL : [optional] Assurance region.  an (n x (n-1))/2 + (m x (m-1))/2
vector of lower bounds of the ratios of
%        shadow prices.  should be in order c12, c13,..., c1n, c23,...,
%        c2n,..., cn-1n for inputs, then similarly for outputs.
%   CU : [optional] similarly for upper bounds
% OUTPUT OF FUNCTION
%   TE : a d x 2 matrix, with the first column showing the DMU number and
%       the second column with the technical efficiency of that DMU.
%   P : a matrix showing the efficient peers for each DMU and the linear
%       combination of each peer for that DMU to reach efficiency
%   S :
%   R : nature of returns to scale

function [TE,P,S,R] = crsdea(B,n,m,CL,CU)

% error check
if n+m ~= size(B,1), error('total number of rows must equal number of
inputs plus outputs') ; end ;

% make matrices of AR
if nargin==5;
    ARIL = zeros(n,(n*(n-1))/2);
    ARIU = zeros(n,(n*(n-1))/2);
    AROL = zeros(m,(m*(m-1))/2);
    AROU = zeros(m,(m*(m-1))/2);
    for j=1:n-1 ;
        ARIL(j,n*(j-1)-j*(j-1)/2+1:n*j-(j+1)*j/2) = CL(n*(j-1)-j*(j-
1)/2+1:n*j-(j+1)*j/2)';
        ARIL(j+1:n,n*(j-1)-j*(j-1)/2+1:n*j-(j+1)*j/2) = -eye(n-j);
        ARIU(j,n*(j-1)-j*(j-1)/2+1:n*j-(j+1)*j/2) = -CU(n*(j-1)-j*(j-
1)/2+1:n*j-(j+1)*j/2)';
        ARIU(j+1:n,n*(j-1)-j*(j-1)/2+1:n*j-(j+1)*j/2) = eye(n-j);
    end ;
```

```
    ARI = [ARIL ARIU];
    for k=1:m ;
        AROL(k,m*(k-1)-k*(k-1)/2+1:m*k-(k+1)*k/2) = CL(n+m*(k-1)-k*(k-
1)/2+1:n+m*k-(k+1)*k/2)';
        AROL(k+1:m,m*(k-1)-k*(k-1)/2+1:m*k-(k+1)*k/2) = -eye(m-k);
        AROU(k,m*(k-1)-k*(k-1)/2+1:m*k-(k+1)*k/2) = -CU(n+m*(k-1)-k*(k-
1)/2+1:n+m*k-(k+1)*k/2)';
        AROU(k+1:m,m*(k-1)-k*(k-1)/2+1:m*k-(k+1)*k/2) = eye(m-k);
    end ;
    ARO = [AROL AROU];
end;

if nargin==3; ARO = []; ARI = []; CL=[]; CU=[]; end;

d = size(B,2) ;

% make matrices of inputs and of outputs
inputs = zeros(n,d) ;
outputs = zeros(m,d) ;
for j=1:n ;
    inputs(j,:) = B(j,:) ;
end;
for k=1:m ;
    outputs(k,:) = B(k+n,:) ;
end;

epsilon = 10^(-7) ; % infinitesimally small epsilon for slacks
ep = epsilon*ones(n+m,1) ;

f = [-1 ; ep ; zeros(d,1) ; zeros(size([CL ; CU]))] ; % Objective
function vector
A = [zeros(d+n+m+length([CL ; CU]),1) -eye(d+n+m+length([CL ; CU]))] ; %
Non-negativity constraints
b = zeros(d+n+m+length([CL ; CU]),1) ;

% Linear Program loop for DEA model - solved for each DMU
options = optimset('MaxIter',2000) ; % Maximum number of iterations
results = zeros(d+n+m+length([CL ; CU])+1,d) ;
for i=1:d ;
    x0(:,1) = inputs(:,i) ; %inputs for DMU being evaluated
    y0(:,1) = outputs(:,i) ; %inputs for DMU being evaluated
    phi_vector = [zeros(n,1) ; y0] ;
    Aeq = [phi_vector eye(n+m) [inputs -ARI
zeros(size(ARI,1),size(ARO,2)); -outputs zeros(size(ARO,1),size(ARI,2)) -
ARO]] ;
    beq = [x0 ; zeros(m,1)] ; %constraint
    results(:,i) = linprog(f,A,b,Aeq,beq,[],[],[],options) ; % DEA LP for
DMU i
end ;
```

```
% inefficiency score is >= 1, take inverse for 0<=score<=1
phis = results(1,:) ;
TE = zeros(d,1) ;
for p=1:d ;
    TE(p,1) = 1/(phis(1,p)) ;
end ;

S = results(2:1+n+m,:)' ;

mus = zeros(d,d) ;
for s=1:d ;
    mus(s,:) = results(s+n+m+1,:) ; %weights
end ;

R = sum(mus) ; %Returns to scale

[r,c] = find(mus>.000001) ;
peer = zeros(length(r),1) ;
for t = 1:length(r) ;
    peer(t,1) =  mus((r(t,1)),(c(t,1))) ;
end ;

P = [c r peer] ; %matrix showing efficient peers
```

Appendix 2: MATLAB function EV.m to conduct mean-variance analysis

```
% EV conducts a mean variance analysis on a portfolio of risky assets to
%   determine the set of portfolios with minimum variance for any given
%   feasible return.  Allows restrictions to be placed on groups of
%   assets to limit what percent of the total portfolio can be in that
%   group
% USAGE
%   [S,E,V] = EV(m,cov,n,w,q,fspace)
% INPUTS
%   m : n x 1 matrix of means (expected value) of the assets
%   cov : n x n covariance matrix
%   n : number of assets
%   w : restriction on groups of assets
%   q : number of chebychev nodes
% OUTPUTS
%   S : n x (q+1) matrix of  efficient set of portfolios, showing
%       allocation to each asset
%   E : expected value of portfolios
%   V : variance of portfolios

function [S,E,V] = EV(m,cov,n,w,q,fspace)

options = optimset('MaxIter',200) ;

N = size(m,1) ; %number of assets x number of groups
c = N/n ; % number of land classes

S = zeros(q,N) ;
V = zeros(q,1) ;
E = zeros(q,1) ;

% find minimum variance allocation for any level of profit
H = cov ;
Aeq = zeros(c,N);
for i=1:c
    Aeq(i,(i-1)*n+1:i*n) = ones(1,n) ;
end
beq = w ;
x0 = ones(N,1)*1/N ;
A = [-m' ; -eye(N)] ;

x = funnode(fspace) ;

for i=1:q ;
    e = x(i) ;
    b = [-e ; zeros(N,1)] ; %constraint
    [s,v] = quadprog(H,[],A,b,Aeq,beq,[],[],x0,options) ;
    S(i,:) = s' ;
    V(i,:) = v ;
```

```
    E(i,:) = e ;
end ;
```

Appendix 3: Sample Real Options model for hard hardwood alley cropping system

Appendix 3a: MATLAB function oakalley.m to input parameters and run real options model

Note that the parameters given in the first line must be input from a separate script file.

```
function
[s,x,v]=oakalley(tons,tonsadj,ageq,timbeq,pulpsaw,oakmixed,a1,a2,mu,varia
nce,sprep,cc,lclear,admin,lease,delta,agmin,agmax,timbmin,timbmax,pa,ry,p
rune)

% ENTER MODEL PARAMETERS

  MAXSA   = 50;                                         % maximum stand
age

% COMPUTE SHOCK DISTRIBUTION
  m = [5 5];                                            % number of nodes
  [e,w] = qnwnorm(m,mu,variance);                       % normal nodes and
weights

% CONSTRUCT ACTION SPACE
  x = [0;1;2];

% PACK MODEL STRUCTURE
  clear model
  model.func = 'oakalleymodel';                         % model functions
  model.discount = delta;                               % discount factor
  model.e = e;                                          % shocks
  model.w = w;                                          % probabilities
  model.actions = x;                                    % model actions
  model.discretestates = 3;                             % index of
discrete states
  model.params =
{sprep,cc,lclear,MAXSA,tons,tonsadj,lease,admin,pa,ry,prune,ageq,timbeq,a
1,a2,pulpsaw,oakmixed};                                 % other parameters

% DEFINE APPROXIMATION SPACE
  n = [4 4];                                            % number of nodes
  fspace = fundefn('lin',n,[agmin timbmin],[agmax
timbmax],[],(0:MAXSA)');    % approximation space
  snodes = funnode(fspace);                             % state
collocation grid coordinates
  s = gridmake(snodes);                                 % state
collocation grid points

clear agmu agsigma cosigma timbmu timbsigma ;
```

```
% CALL SOLVER

[c,s,v,x,resid] = dpsolve(model,fspace,s);              % dpsolve.m is a
copyrighted product in the CompEcon toolbox (Miranda & Fackler 1997)
```

Appendix 3b: MATLAB function oakalleymodel.m to define reward function and state transition function

```
% model
function out =
oakalleymodel(flag,s,x,e,SPREP,CC,LCLEAR,MAXSA,TONS,tonsadj,LEASE,ADMIN,P
A,RY,PRUNE,AGEQ,TIMBEQ,a1,a2,pulpsaw,oakmixed)
AG = s(:,1); TIMB = s(:,2); SA = s(:,3);
oaktons=TONS;
oakadj=tonsadj;
THIN25=(oaktons*oakadj*20+oaktons*5)/3;
THIN35=(oaktons*oakadj*20+oaktons*15-THIN25)/3;
switch flag
case 'f';                           % REWARD FUNCTION
  out=AG.*(SA==0)+SPREP.*(SA==1)+ADMIN.*(SA>0)+CC.*(SA==2)+PRUNE.*(SA==4
| SA==7 |
SA==10)+AG*PA.*(RY(1).*(SA==2)+RY(2).*(SA==3)+RY(3).*(SA==4)+RY(4).*(SA==
5)+RY(5).*(SA==6)+RY(6).*(SA>6 &
SA<12))+LEASE.*(SA>11)+(THIN25*TIMB).*(SA==26)+(THIN35*TIMB*.5*(1+pulpsaw
*oakmixed)).*(SA==36)+(TONS*TIMB*pulpsaw*oakmixed).*(SA==50 &
x==1)+((oaktons*oakadj).*TIMB.*(SA-1)).*(SA>3 & SA<21 & (x==2 |
x==0))+(oaktons*oakadj*20+oaktons.*(SA-21)).*TIMB.*(SA>20 & SA<26 & (x==2
| x==0))+((oaktons*oakadj*20+oaktons.*(SA-21))-THIN25).*TIMB.*(SA>25 &
SA<36 & (x==2 | x==0))+((oaktons*oakadj*20+oaktons.*(SA-21))-THIN35-
THIN25).*TIMB*(.9*pulpsaw*oakmixed+.1).*(SA>35 & SA<50 & (x==2 |
x==0))+(oaktons*oakadj*20+oaktons*30-THIN25-
THIN35)*(pulpsaw*oakmixed).*TIMB.*(SA==50 & (x==0 | x==2))+LCLEAR.*(x==0
& SA>3);
  out(SA>MAXSA)=-inf;
case 'g';                           % STATE TRANSITION FUNCTION
  out(:,1) = AG+a1*(AGEQ-AG)+e(:,1);
  out(:,2) = TIMB+a2*(TIMBEQ-TIMB)+e(:,2);
  out(:,3) = (SA+1).*(x==1 & SA<MAXSA)+MAXSA.*(x==1 & SA==MAXSA)+(x==2);
% x=0 represents farming or cutting timber to change to agriculture, x=1
forestry (keep stand until next year, if SA>0), x=2 harvest and replant
end;
```