ABSTRACT

GLENN, JAMIE VIOLA. Economic Assessment of Landowner Incentives: Analyses in North Carolina and Malawi. (Under direction of Dr. Frederick Cubbage, Dr. M. Nils Peterson, Dr. Erin Sills).

These analyses present two cases that used economics to understand landowner incentives in differing contexts. The first determined the baseline compensation required to convince private landowners in North Carolina to manage their land as habitat for endangered species, and the second assessed the economic feasibility of an agroforestry system in Malawi.

A key strategy proposed for meeting Endangered Species Act (ESA) mandates for the red-cockaded woodpecker (RCW) on military bases is cooperative conservation between federal military and nonindustrial private agricultural and forest landowners (NIPAFs). Discounted cash flow analysis was used to estimate the opportunity costs to private landowners. Models for land managed in accordance with RCW habitat requirements were analyzed and compared with traditional pine management options and agricultural alternatives, using discounted cash flow measures of net present value (NPV) and soil expectation value (SEV) as criteria at a 4% discount rate. Opportunity costs of conversion of loblolly pine to longleaf pine managed for RCW habitat ranged from \$485 to \$698 per acre with no pine straw income to \$56 to \$255 per acre with moderate income from pine straw. The opportunity cost associated with transitioning average agriculture sites to longleaf ranged from \$1,612 to \$4,655 per acre dependent on the crop, indicating that any future incentives for habitat creating programs should focus on forest land or on poor agriculture lands. The 10 year annual conservation payment that would be required to make longleaf pine financial returns equal to loblolly pine ranged from \$58 to \$83 per acre per year with no pine straw income and \$7 to \$30 per acre per year with moderate income from pine straw. These conservation payment rates are reasonable, and suggest payments for ecosystem services offer potential to establish longleaf pine ecosystems and create additional RCW habitat on nonindustrial private forest lands.

Land scarcity due to rapid population growth no longer allows smallholder farmers in southeastern Africa to use traditional fallowing methods to maintain soil fertility. Consequently, staple food crop yields have considerably diminished in recent decades, exacerbating existing food security concerns. Chemical inorganic fertilizer is perceived as the premiere remedy but concerns remain regarding its environmental impact and affordability. An intercropping system using the indigenous nitrogen-fixing tree species, Faidherbia albida, has reportedly increased crop yields by 280% in experimental settings. An accurate understanding of the benefits and costs of the system in non-experimental settings is crucial in determining its viability. This study assesses the system's impact on yield and its compatibility with farmer resources and preferences. Data were collected during a household survey of 390 farms in Malawi. Two ordinary least squares models were estimated to assess the impact of the species on maize yield. Each showed a statistically significant result, indicating a yield increase of 12% to 14% (169 to 201 kg) per acre. This is much less than in experimental settings but greater than or equivalent to other crop management practices assessed, including chemical inorganic fertilizer. System implementation is expected to increase on-farm labor demand by 11% to 14% in the establishment year and by 1% in maintenance years. The timing of labor demand for the system may conflict with existing maize farming labor demands. However, financial inputs required are minimal, making the F. albida intercropping system a superior alternative in land or credit limited areas, but difficult in areas with limited access to labor. A ranking exercise identified system flexibility and compatibility with existing practices as the two most important decision criteria in new technology adoption. Efforts to expand the use of the system must focus on these two areas rather than the existing focus on economic profitability.

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Economic Assessment of Landowner Incentives: Analyses in North Carolina and Malawi

by
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DEDICATION

To my greatest supporters and the only reason I am here today, both literally and figuratively, my darling parents: Helene and Gary Glenn.

BIOGRAPHY

Jamie Viola Glenn grew up in a small town in Northwest Florida surrounded by sunny memories and longleaf pine trees. She took her first economics course as a high school senior and knew instantly that this complex but flexible field would serve her well no matter what path she ultimately took, and it continues to do just that today. Viola majored in economics as an undergraduate at Stetson University in Deland, Florida and has followed economics through purely environmental work to purely development work and finally found the space where the two converge. Her time at North Carolina State University has helped her crystalize her environmental and social values and goals and she anxiously awaits a lifetime of meaningful research and world travel.

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LIST OF ABBREVIATIONS

AEV	Annual Equivalent Payment
BERDO	Bwanje Valley Environmental Development Organization
CRP	Conservation Reserve Program
DOD	Department of Defense
DOF	Department of Forestry
EPA	Extension Planning Area
EQIP	Environmental Quality Incentive Program
ESA	Endangered Species Act
FISP	Farm Input Subsidy Program
ICRAF	World Agroforestry Centre
IRR	Internal Rate of Return
LPGS	Longleaf Pine Growth Simulator
NATYIELD	Natural Stand Growth and Yield Model
NCFS	North Carolina Forest Service
NCSU	North Carolina State University
NGO	Non-Governmental Organization
NIPAF	Nonindustrial Private Agricultural and Forest
NPV	Net Present Value
NRCS	Natural Resource Conservation Service
RCW	Red-Cockaded Woodpecker
SEV	Site Expectation Value
TIMO	Timber Investment Management Organization
UF	University of Florida
UGA	University of Georgia
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USMC	United States Marine Corps
WHIP	Wildlife Habitat Incentive Program
WTP	Willing-to-Pay

Chapter 1: Private lands to mitigate public Endangered Species Act mandates

1.1 Introduction

The red-cockaded woodpecker (RCW) (*Picoides borealis*) was declared endangered in 1973, upon enactment of the Endangered Species Act (ESA), due to a decline in population and natural range. Recent surveys estimated that slightly more than 14,000 individual birds survive today in nearly 6,000 active clusters (USFWS 2003). The birds inhabit southern pine savannahs and rely on open forage conditions provided by a well-managed understory sustained by regular prescribed burning. Though RCW nesting cavities have been observed in various pine species, the preferred tree species is the longleaf pine. Foraging habitat may be available in younger stands, but nesting habitat is provided only in trees older than 60 years old at which point the woodpeckers can bore nesting holes into trunks that have softened with age and fungal infection (Wood and Kleinhofs 1995).

Endangered species designation is a complex issue with a myriad of potential implications for several landowner types. The ESA makes a strict distinction between the responsibilities of federal versus all other landowners. Private landowners are not mandated to actively participate in endangered species recovery but they are not permitted to undertake any activity that results in a taking "Taking" refers to any action that aims to, "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect." Conservation activities that exceed this basic requirement are encouraged, but not mandatory. Of particular interest for this project were the implications for public lands. Federal properties, on the other hand, are legislatively bound to actively support conservation through, "the use of all methods and procedures necessary to bring an endangered species… to the point at which… [protection] measures… are no longer necessary," (USFWS 2003). This is especially relevant the Department of Defense (DOD) which makes active use of its on base training lands, use that is often inconsistent with habitat requirements.

Central to the recovery plan for RCW are military bases, a subset of the federally held lands in the southern U.S. Of paramount interest is Marine Corps Base Camp Lejeune (Camp Lejeune), a major Marine Corps center located on 156,000 acres in Coastal Plain region of North Carolina (USMC 2011). The base is home to extensive longleaf pine forests and, as of the year 2000, 59 active RCW clusters (USFWS 2003). Leadership within the base is seeking methods to balance their interests in RCW conservation with flexible and sustainable DOD testing and training operations. While RCW requirements currently cause no direct disruption in training maneuvers, base leadership identified this as the number one potential risk factor in the future (Lee et al. 2012). One key strategy that has not been fully investigated is cooperative conservation between federal military and nonindustrial private agricultural and forest (NIPAF) landowners. Ultimately, cooperation at this level may allow DOD to mitigate their own RCW responsibilities mandated under ESA by encouraging habitat on NIPAF lands.

The goal of this project was to generate a robust and realistic economic analysis of land management options consistent with habitat requirements for the endangered RCW. Comparing this analysis to economic valuations of more typical practices provided a baseline estimate of the opportunity cost to NIPAF landowners of managing land for RCW. In this case, the opportunity cost represents the total income and landowner must be willing to forgo, or receive compensation for, when choosing to manage for habitat rather than some other alternative. This opportunity cost can contribute to the development of market-based incentives to supplant Camp Lejeune's administration of RCW clusters on its own base with conservation off base. The implementation mechanism has yet to be specified for such a program, but DOD is experimenting with a reverse bidding process for an unrelated project that also aims to increase cooperation between Camp Lejeune and nearby NIPAF landowners. If such a process is implemented for RCW habitat conservation, the values derived in the report below will serve to ground truth bids submitted in the first iteration.

1.2 Review of Literature

1.2.1 Longleaf Pine: Historical Perspective and Recent Advances

The historical prominence and precipitous decline of the longleaf pine (*Pinus palustris*) forests of the southern U.S. since European colonization is well documented. Pre-settlement inventories estimated that these forests covered as much as 60,000,000 acres (Frost 1993, Wahlenburg 1946), though more recent accounts from the 1980s and 1990s estimated this extent at merely 3,000,000, representing a significant 95% decline (Dennington and Farrar 1983, Outcalt and Sheffield 1996).

Three major issues have contributed to this decline: (1) the severe suppression, and in many cases complete elimination, of a regular fire regime, (2) landowner preferences for short-rotation/high-productivity pine species such as loblolly (*Pinus taeda)* and slash (*Pinus elliotii*) pine (and subsequent natural regeneration of loblolly pine as a pioneer species), and (3) conversion to agricultural land use (van Lear et al. 2005, Alavalapati et al. 2002).

Historically, landowners have chosen alternative pine species in place of longleaf pine due to a variety of concerns: slowed growth due to the uncertain length of longleaf pine's grass stage (Cram 2010), poor seedling quality, shade intolerance (Kush et al. 2006), difficulties in natural regeneration, longer stand rotations and the ecosystem's reliance on prescribed fire (Alavalapati et al. 2006). Advances in silvicultural practices (especially shelterwood regeneration) (Cram 2010), containerized seedlings, and fertilizer use (Alavalapati et al. 2006) in recent decades assuaged many of these concerns, making longleaf pine a more viable option. Herbicides can also expedite early release from the grass stage and control competing hardwood species (Micheal Chestnutt, personal communication, 2011). Further, research conducted in the past 10 years shows longleaf pine may have a competitive advantage on sandy and/or dry sites (Demers et al. 2003), over longer rotations (Cram 2010), and in drought prone areas (Kush et al. 2003).

Longleaf pine stand management regimes can provide important ecological and ecosystem benefits. Most notably, the longleaf pine ecosystem provides essential habitat for a wide range of plant and animal species, nearly 30, which are listed as threatened or endangered (van Lear et al. 2005). Silvicultural advances noted above and recognition of longleaf pine's vital role in the survival of these species has encouraged renewed interest in its restoration in recent decades. Voluntary government-funded planting programs, such as the Conservation Research Program (CRP) Longleaf Pine Initiative, the Wildlife Habitat Incentives Program (WHIP), and the Environmental Quality Incentive Program (EQIP), have further increased the opportunities for successful longleaf pine restoration and the potential to influence landowners' preferences for this species.

1.2.2 The Current State of Longleaf Pine and RCW Economics

Heightened interest in longleaf pine gave rise to a period of renewed interest in longleaf pine economics in the southern U.S. The wide array of economic studies of longleaf pine management regimes can be broadly classified into three groups by their primary focus: (1) optimization of economic returns of longleaf pine, (2) competition with other southern pine species, and (3) environmental and ecosystem services, especially as this applies to RCW.

<u>1.2.2.1 Optimization of Longleaf Pine Stands</u>

The optimization subset of the literature was focused on enhancing the financial return of longleaf pine. Economists analyzed various rotation lengths and stand management regimes to identify the key variables in maximizing financial returns. Work by Cubbage and Hodges (1989) on timber-only returns found that both naturally and artificially regenerated longleaf pine were favored in longer rotations of up to 80 years for natural stands and 50 years for planted stands. Increasing the rotation age, from 45 years in natural regeneration and 40 years in artificial, increases soil expectation value (SEV) by $296 and $130 respectively (in 1998 dollars). This advantage derived from the high value of longleaf pine's superior quality pole timber in later rotations and higher stumpage prices of the late 1980s. The combination of these two factors outweighed discounting's negative impacts on delaying the final harvest (Cubbage and Hodges 1989).

More recent work conducted by the Longleaf Alliance, a non-profit seeking to conserve longleaf pine ecosystems in the southern U.S., explored other methods for optimizing the returns of longleaf pine investments (Johnson 2011). A central tenant of this analysis was the reduced risk of catastrophic loss associated with longleaf pine. Risk aversion benefits are derived from longleaf pine's improved resistance to southern pine bark beetle and smaller incidence of hurricane damage (the latter was shown only in a single post-Hurricane Katrina test site).

In addition to risk-related benefits, Johnson incorporated various levels of pine straw revenue and cost share programs to mitigate early cash outlays. Intensive management for maximum ecosystem services was a uniting feature across the various regimes presented. Each 45year rotation included prescribed burning and pine straw collection occurring in three year intervals, fertilization every fifth year, and three commercial thinnings before a final shelterwood cut to encourage natural regeneration. Net present values (NPVs), contingent on differences in pine straw and cost share assumptions, ranged from $197 per acre to $1,317 per acre using a 4.5% discount rate (Johnson 2011).

1.2.2.2 Competition with Other Pine Species

A second major subset of the literature investigated methods for making longleaf pine financially competitive with other southern pine species, most often loblolly and slash pine. Often this portion of the literature sought to increase revenues by shortening the rotation length and incorporating earlier revenue streams which supplement income at the final harvest. In this tradition, Kessler and Straka (1990) extended the work of Cubbage and Hodges (1989) to assess the impact of eliminating longleaf pine's lengthy grass stage of development and introducing regular pine straw raking (Kessler and Straka 1990).

Unlike other pine species, longleaf pine may spend several early years of development in a grass stage during which growth in height and diameter are nearly stagnant. This is often cited as a major reason for why longleaf pine does not compete with other pine species (Cram 2010). The length of the grass stage is dependent upon environmental and other factors, adding to the uncertainty surrounding the establishment of longleaf pine stands. Kessler and Straka found that eliminating this stage through intensive site preparation and herbicide application increased the NPV of a 40 year rotation by $627 (Kessler and Straka 1990).

Pine straw income is a significant component found in many longleaf pine economics publications. A detailed discussion of this crucial component follows in the succeeding section. Suffice to say, Kessler and Straka found that modest pine straw revenues ($35 per acre per year in 1991 dollars) increased NPV for a 40 year rotation by $300, using a 4% discount rate.

Later work directly compared short rotation longleaf and loblolly pine plantations in North Carolina (Mills and Stiff 2008). The target audience for this work was profit maximizing private landowners including individuals as well as timber investment management organizations (TIMOs). On the high quality sites modeled in this study, longleaf pine was only able to compete with loblolly pine when pine straw revenue was included. Even with this inclusion, loblolly pine SEVs outperform longleaf pine SEVs in all but one scenario, but only by 3-20%, whereas loblolly pine SEVs are 4 to 1.2 times greater than their longleaf pine counterparts without pine straw revenue. The authors used discount rates of 5% and 7% in their analysis (Mills and Stiff 2008).

<u>1.2.2.3 RCW Economics</u>

Of particular interest for this project were economic assessments that fall into the third category where management decisions are primarily targeted to promote and conserve RCW forage and nesting habitat. Two publications from researchers at North Carolina State

University (NCSU) in the late 1980s and early 1990s represent the first attempts at these analyses.

In the first, a hypothetical scenario was created explicitly based on requirements mandated by the U.S. Fish and Wildlife Service's (USFWS) Red-Cockaded Woodpecker Recovery Plan (Lancia et al. 1989). Instead of a uniform property-wide management regime, this paper proposed an alternative, deemed appropriate by the recovery plan. The authors described a plan that left remnant patches of old growth trees (60 years or older) interspersed with younger, more actively managed, areas. This scenario was optimized based on SEV and other USFWS criteria to calculate the opportunity cost of managing remnant patches of longleaf pine, compared to even-aged harvesting of a shorter, economically efficient, rotation age. Economic comparisons between the habitat and economically efficient scenarios, using a 4% discount rate, yielded an opportunity cost of $155 per acre in 1989 dollars. The analysis assumed an opportunity cost of $31,000 per RCW colony and 200 acres of habitat for each colony (Lancia et al. 1989).

The second publication, composed by some of the same authors, returns to the property-wide perspective (Roise et al. 1991). This publication proposed long rotations between 60 and 120 years, intensive site preparation to control hardwoods and minimize brown spot disease, pine straw raking, frequent prescribed burning, minimal commercial thinning, and a shelterwood cut intended to lead to natural regeneration in place of a final harvest. Instead of the static estimates of pine straw yield and revenue employed by other publications, this study used work conducted by C.A. Gresham (1982) to model pine straw yield as an increasing function of stand basal area. This consideration was important because managing for RCW foraging habitat requires that stand basal area be kept at levels lower than those preferred for maximizing timber growth, and may result in reduced pine straw yield in stands managed for RCW habitat (Roise et al. 1991).

Another approach to estimating the value of longleaf pine systems managed for RCW habitat is the capture of environmental benefits. The premise of this process is that, due to incomplete markets, ecosystem services are not assigned their proper monetary values by traditional markets. For example, individual landowners creating habitat for RCW are providing a public good for which they are not being compensated. This discontinuity causes landowners to manage more commercially profitable species in place of longleaf pine, despite the environmental benefits.

In 2002, researchers at the University of Florida (UF) employed this methodology to prepare an economic comparison of private longleaf and slash pine lands in the southern U.S. (Alavalapati et al. 2002). This study attempted to internalize not only the benefits of generating RCW habitat, but also the benefits of carbon sequestration and other environmental amenities such as biodiversity conservation. The RCW values were based on the age of the stand (increasing to age 60 and remaining fixed thereafter) and contingent valuation studies measuring individuals' willingness-to-pay (WTP) for the future survival of RCW. Two studies were conducted on this topic and found that WTP was between $8 and $14 per person (van Kooten and Bulte 2000, Reave et al. 1995). Alavalapati's results showed that even after internalizing both RCW habitat and carbon sequestration values, longleaf pine stands are still unable to compete with their slash pine counterparts. Notably, the authors mentioned that due to the low WTP values associated with RCW survival, this particular portion of the internalized benefits had a very minor impact on stand value (Alavalapati et al. 2002).

Table 1.1 summarizes the methodology and assumptions employed in each of these key studies.

Table 1.1 Key Longleaf Pine and RCW Economics Literature

Author(s)	Pub. Year	Key Point(s)	Management	Harvest
Cubbage et al.	1989	Longer longleaf pine rotations produce higher returns	· Intensive site preparation ·Release at age 1 ·Burning beginning at age 6 every 3 years	·Short: shelterwood at 45, residual at 50 ·Long: shelterwood at 80, residual at 85
Johnson	2011	· Active management for only 45 years · Emphasis on cost sharing programs	· Intensive site preparation · Release at age 1 · Burning beginning at age 3 every 3 years · Fertilization beginning at age 10 every 5 years	Shelterwood cut at age 45
Roise et al.	1991	Focus on RCW and pine straw	·Overstory removal ·Seedbed preparation ·Burns at years 3 and 6 and after thinning	Shelterwood cuts at 60, 80, 100, 120
Kessler et al.	1991	Use of intensive site preparation and herbicide to eliminate grass stage	Intensive site preparation	·Natural: See Cubbage and Hodges ·Plantation: Clearcut at 40 or 50 years
Alavalapati et al.	2002	Capture of environmental benefits (carbon, RCW habitat, others)	Not provided	Rotation length from 40 to 47 years
Mills et al.	2008	Economic comparison of short rotation longleaf and loblolly plantations	·Chemical hardwood control ·Establishment burn ·1 to 2 thinnings	Rotation length from 27 to 52 years

Table 1.2 provides NPVs, IRRs, and financial assumptions of each major study. This will serve as a basis for comparison to the new analyses I conducted. While IRR was not provided

in many cases, it was apparent that the IRR was greater than the discount rate as NPVs were generally positive.

Table 1.2. Financial Returns in Longleaf Pine and RCW Economics Literature

Author(s)	Pub. Year	Interest Rate(s)	NPV/acre	IRR
Cubbage et al.	1989	4%	$86 to $538[1]	5.0% to 6.8%
Johnson	2011	4.5% 6%	$197 to $1,317[2] -$3 to $882[2]	6% to 30%
Roise, et al.	1991	4%	$1,084 to $1,175 dependent on rotation length[3,4]	Not provided
Kessler et al.	1991	4%	$409 to $480[3]	Not provided
Alavalapati et al.	2002	5%	$449[5]	Not provided
Mills et al.	2008	5% 7%	$245 to $968[6] $49 to $502[6]	Not provided

1.2.2.4 Pine Straw Revenue

A key element to the analyses above was the inclusion of income from longleaf pine straw harvest and sale. Starting with some of the earliest literature, pine straw has been recognized as a means to introduce a significant revenue stream that occurs before the final harvest and in between (or in place of) commercial thinning. Pine straw also provides interim income to help pay for management and tax expenses incurred between harvest events. Thus, it is crucial to fully understand how this area was addressed in the literature. Evaluating revenue generated from the harvest of pine straw is reliant on three key factors: (1) span of productive pine straw years, (2) frequency of harvest, and (3) yield and value of each harvest.

[1] Dependent on rotation length, taxation, regeneration.
[2] Dependent on pine straw yield and cost share level.
[3] Dependent on rotation length.
[4] Calculated based on provided SEV, discount rate, and rotation length. Values not directly provided.
[5] Timber only, does not include carbon or other environmental amenities. Calculated from provided SEV, discount rate, and rotation length. Value not directly provided.
[6] Dependent on pine straw yield and rotation length

Typically, pine straw in marketable quantities is not generated in very young longleaf pine stands. While most of the works above assumed that productivity began near age 20, there is no consensus on the terminus. Frequency of harvest is a function of other overall goals rather than stand biology. While raking is biologically feasible each year, plans seeking to create RCW habitat are unlikely to recommend annual harvests as this can have a detrimental effect on RCW forage (Roise et al. 1991). Further, research conducted to determine whether such frequent disturbances have a negative impact on timber and pine straw growth in subsequent years has been inconclusive (Blevins et al. 1996, Haywood 2002). Finally, pine straw market prices in the southern U.S. have been stable for many years, but yield per acre varies significantly by geographic region due to differences in site quality, tree density, and use of fertilizers.

The exact impact of tree density and fertilizer use is difficult to predict. Some researchers have found that pine straw yield is positively correlated with basal area, suggesting that the low tree density needed to promote healthy forage habitat for RCW reduces pine straw yield (Gresham 1982, White et al. 1988). Contrary to this, others have found the wider spacings ideal for wildlife benefits have a positive impact on pine straw yields (South 2006). Fertilizer use is typically expected to increase pine straw yields in the years following application, but experimental research on this topic has provided confounding results (Haywood 2009, Chastain et al. 2007). Table 1.3 summarizes each of these key areas as addressed in the longleaf pine and RCW economics literature.

Table 1.3. Key Pine Straw Assumptions from the Literature

Author(s)	Pub. Year	Productive Age	Raking Frequency	Yield	Annual Revenue per Acre
Roise, et al.	1991	20 – End of rotation	Rake, rest	Yield as function of basal area	$80-$160
Kessler et al.	1991	15 – End of rotation	Annual	70 bales/acre	$35
Mills et al.	2008	12 – 32	4 year enhancement period followed by raking	Not given	$150
Johnson	2011	6 – 45	Rake, rake, rest	Not given	Age 6-9 $50 Age 10-14, $75 Age 15-29, $100 Age 30-45, $125

In 2010, a team of researchers at the University of Georgia (UGA) conducted an experimental assessment of timber and pine straw yields in unfertilized longleaf pine stands located on converted agricultural fields in Georgia (Dickens et al. 2010, 2011). Because these test plots were established on converted agricultural fields, they likely represented sites of higher quality than would typically be observed in the coastal plain of North Carolina. Measurements for this work began when trees were 21 years of age, which represented the beginning of the productive timespan for pine straw production. The yield per acre varied by location and year, but averaged approximately 200 bales per acre per year, implying that the values used in the literature above are realistic (Dickens et al. 2010, 2011).

Regardless of the specific assumptions utilized in each study, the inclusion of income from pine straw production has a significant impact on financial returns. reviews pine straw revenue's contribution to SEV in each of these studies. SEV was used as it captures the difference between various rotation lengths.

Table 1.4. Pine Straw Revenue Impact on SEV

Author(s)	Pub. Year	Interest Rate	SEV, No PS	SEV, PS	Absolute Increase	Percent Increase
Roise, et al.	1991	4%	$209-$386[7]	$1,198-$1,298	$912-$989	236% - 473%
Kessler et al.	1991	4%	$480	$780	$300	63%
Mills et al.	2008	5% 7%	$308-$967[8] $53-$457	$593-$1,109 $178-$597		15%-93% 31%-236%
Johnson	2011	4.5% 6%	$197[9] -$3	$894 $482	$697 $485	354% NA

1.2.3 Longleaf Pine Growth and Yield Models

Central to any economic assessment of possible forest management regimes are the underlying timber growth and yield assumptions. Generally, these assumptions are based on experimental field data and described as either stand and stock tables or equations. Each stand and stock table represents a specific combination of ages and site index and provides the volume and count of trees by diameter class. This method of delivering growth and yield information was more prevalent before the 1980s, when computers became more widely available. Many modern sources now provide equations relating stand or tree volume to various independent variables such as dominant tree height, site index, basal area, or stand density.

Based on the goals of this study, the following review focused on growth and yield equations that predicted stand growth, as opposed to individual tree, volume. Further, each study below is relevant to the southern U.S. and Gulf Coast regions and longleaf pine of at least 20 years of age. A more comprehensive review of other studies predicting growth in longleaf pine stands can be found in Appendix A.

[7] Difference based on differences in rotation length
[8] Difference based on differences in site index
[9] Values are NPV but article advocates only 45 years of management followed by no further activity, rendering NPV and LEV equal

Early work performed by Schumacher and Coile (1960) surveyed 368 longleaf pine sites in the Atlantic Coastal Plain. All plots were evenly-aged natural stands and some had recently been exposed to non-fatal prescribed fires. The data were used to develop an equation relating stand volume to dominant tree height, basal area, and stand age. Further equations were derived to calculate dominant tree height as a function of site index and age and basal area as a function of stocking percentage and age (Schumacher and Coile 1960).

Researchers at NCSU later adapted these equations for use in the computer program, Natural Stand Growth and Yield Model (NATYIELD) (Smith and Hafley 1986). NATYIELD allows users to specify initial density (trees per acre), basal area, site index, age, and thinning specifications and uses these details to produce stock and stand tables. The primary advantages of this program are not only the automation of the equations, but also the built-in responsiveness to thinning (Smith and Hafley 1986).

In 2012, an unfortunate drawback to this program is the lack of general availability and compatibility with modern computers. Running the program requires the installation of a DOS emulator, such as DOSBox, and access is limited outside of NCSU. Once accessed, however, the program is more user-friendly and less prone to bugs and errors than any of its more recently developed counterparts. This ease of use comes at the price of complexity, but for the purposes of these analyses, NATYIELD’s level of complexity was sufficient.

A second study conducted by Farrar (1985) created an alternative set of equations to represent evenly-aged natural longleaf pine stands that had been thinned. Data for his analysis was collected on 209 plots in the East Gulf Coast region, though 312 observations from only 188 plots not displaying excessive mortality were used to develop the final equations. Each sample plot began with a population of at least 80% longleaf pine and all hardwoods present were removed at project start. Plots were burned every 3 to 5 years and thinned twice over their rotations. The resulting equation predicts longleaf timber volume as a function of site index, basal area, and stand age (Farrar 1985).

Each of the studies above was specific to natural stands. While many of the growth characteristics between natural and planted stands are similar after establishment, they are not identical. Separate methods are necessary for estimating growth in plantations. Lohrey and Bailey (1977) developed similar equations for 260 unthinned planted stands located in Texas and Louisiana. As with Schumacher and Coile's earlier work, many of these plots were exposed to non-fatal prescribed fires. The test plots also included a wide range of site indexes (from 29 to 73 feet at age 25), planting densities (from 250 to 2,500 trees per acre), and ages (16 to 38 years). The authors draw on earlier work by Clutter (1963) to determine the form of the resulting volume equation that predicted stand volume as a function of site index, basal area, and stand age (Lohrey and Bailey 1977).

More recent work conducted by Brooks and Jack (2006) developed stand models specific to young longleaf pine plantations (20 years or younger). The authors indicated that the catalyst for this research were the "less than acceptable" results from models designed using measurements from older stands when applied to young stands. Samples were gathered over an 8 year period from 12 intensively-managed stands of between 2 and 19 years of age in southwest Georgia, resulting in 105 individual measurements. Equations projecting survival, basal area, dominant height, and volume based on historical measurements of each characteristic and changes over time in other key characteristics were then developed. A second equation was provided to predict stand volume based on current site characteristics. The prediction equation was more directly comparable to other studies. Details on prescribed fires and thinning are not provided (Brooks and Jack 2006). Table 1.5 summarizes the important growth and yield literature.

Table 1.5. Major Growth and Yield Literature

Author(s)	Pub. Year	Geography	Stand Type	Management	Inputs
Schumacher et al.[10]	1960	Atlantic Coastal Plain	Natural	Past prescribed burns	Dominant height, basal area, age
Farrar	1985	East Gulf Coast	Natural	Prescribed burns, thinned twice	Site index, basal area, age
Lohrey et al.	1977	Texas, Louisiana	Plantation	Past prescribed burns	Site index, basal area, stand age
Brooks et al.	2006	Southwest Georgia	Plantation	Not given	Dominant height, trees per acre, basal area

These four major studies are used to determine growth for the vast majority of the longleaf economics literature outlined in the previous section. When very detailed site characteristics are available, more recent and advanced computer programs are used, but the majority of generalized analysis utilizes one of the models or programs. Table 1.6 summarizes the growth and yield models used in the longleaf economics literature.

Table 1.6. Growth and Yield of Longleaf Economics Literature

Author(s)	Pub. Year	Growth and Yield (Volume) Source
Cubbage et al.	1989	Planted, Lohrey and Bailey (1977) Natural, Farrar (1979)[11]
Roise, et al.	1991	Schumacher and Coile (1960)/ NATYIELD (1986)
Kessler et al.	1991	See Cubbage and Hodges
Alavalapati et al.	2002	Lohrey and Bailey (1977)
Mills et al.	2008	FORSim Longleaf Pine Growth Simulator (LPGS) (FORSight Resources 2007)
Johnson	2011	Not given

[10] Used in the development of NATYIELD
[11] This 1979 publication is a predecessor of the 1985 work directly outlined above

1.3 Methodology

In these analyses, I used the standard capital budgeting approach and criteria as employed in the related literature. Each focused on net present value (NPV), soil expectation value (SEV), annual equivalent value (AEV), and internal rate of return (IRR). These methods are summarized by Klemperer (2003) and Wagner (1995).

For results that are sensitive to a discount rate (NPV, SEV, and AEV), a 4% real discount rate is assumed. This discount rate is standard for the literature assessing longleaf pine returns (Cubbage et al. 1989, Johnson 2011, Roise et al. 1991, Kessler et al. 1991, Row et al. 1981) and consistent with US Forest Service methodology (Wagner 2012). This rate is relatively low, especially compared to financial analysis of other investment options. The justification for this is twofold. First, RCW habitat creation represents a public, rather than private, good. Public goods offer greater benefits to future generations and should thus be best represented with a lower discount rate. Second, recent work indicates that discount rates should be duration dependent with longer term investments analyzed with lower rates (Newell and Pizer 2004). Maintaining this standard also allows for easy comparison to previous work.

IRRs were also calculated and analyzed to provide a useful means for comparing the investments with differing timelines and allow for comparisons without specification of an explicit discount rate. Seventy-six unique land management options were assessed with the goal of producing a range of plausible values reflecting management options for NIPAF landowners in North Carolina. The vast majority of these, 72, were part of a robust analysis of longleaf pine options, with the remaining analyses conducted in the alternative cases to provide a means for comparison.

The analyses fell under three broad categories: longleaf pine managed for various landowner goals, alternative shorter rotation southern pine species, and agriculture. Each case began with recently clear cut or harvested land. New trees or agricultural crops were planted at the beginning of each analysis followed by the described rotation, resulting in the NPV for each scenario. Continuing each rotation infinitely produced the SEVs of each case. Only financial cost and benefits to the private landowner were considered.

SEV was selected as the metric for calculating opportunity costs because it represents the present value of employing a given management regime into perpetuity. Due to its infinite nature, SEV allows for easy comparisons between investments with differing timelines and cash flows. The difference in SEV is equal to the opportunity cost of managing for RCW habitat, which itself represents the forgone income incurred by farmers electing to manage for habitat instead of other goals. Thus, comparing the SEV for longleaf pine managed for RCW habitat to an alternative SEV provides the total income forgone by the landowner.

1.3.1 Capital Budgeting Analysis of Longleaf Pine

A wide array of appropriate longleaf pine scenarios were assessed, representing the full range of potential landowner goals. Each analysis contained 4 key components: management regime, pine straw revenue, timber revenue, and management costs, creating 72 unique combinations. The following sections detail assumptions and data underlying each of these elements.

1.3.1.1 Management Regimes

Longleaf pine management regimes common in the literature and those observed by North Carolina Forest Service (NCFS) experts were reviewed and synthesized into three archetypical options, intended to represent finite points along the continuum of possible regimes (Ron Myers and Fred Cubbage, personal communication, various dates). The proposed continuum moves from scenarios meant to maximize timber profits exclusively to those designed primarily for habitat benefits to RCW. Each manipulated rotation length, prescribed burning, and thinning to achieve the desired goals. Table 1.7 summarizes each regime.

Table 1.7. Longleaf Pine Management Regimes

Management	Max Timber	Multiple Products	Ecosystem Services
Rotation Length	40 years	60 years	80 years of active management, no final harvest
Prescribed burning	With pine straw, at 12 and 29 years Without pine straw, none	With pine straw, at 12 and 41 years Without pine straw, none	With pine straw, every 5^{th} year from 45 to 80 years Without pine straw, every 5^{th} year from 12 to 37 years
Thinning Schedule	1, 28 years to $80ft^2$ per acre basal area	2, 28 and 40 years to $80ft^2$ basal area	2, 40 and 60 years to 60-$80ft^2$ basal area

1.3.1.2 Pine Straw Revenue

Each scenario was assessed both including and excluding additional profits from the interim harvest of pine straw. Conservative and moderate pine straw harvest cases were developed. In each case, pine straw harvest began at age 16 and occurred every third year. Pine straw harvest ends at age 40 in both the maximum timber and ecosystem services regimes, but continues until age 55 for multiple products, when pine straw productivity is expected to cease. As shown in Table 3, this represented a conservative approach as much of the literature reflects annual or biennial pine straw harvests. Allowing the stand to rest for two years between harvests serves the dual purpose of boosting harvest volumes and reducing potential negative habitat and nutrient loss impacts of over-raking (Roise et al. 1991).

The only distinction between the conservative and moderate cases was the value of each harvest. The conservative approach assumed a harvest value of $75 per acre, the lowest literature-supported value. Moderate estimates assumed a value of $125 per acre, which represented a mid-range literature-based value and is quite low when compared to observed values for recent local pine straw sales. Sales at Bladen Lake State Forest in 2011 ranged from $150 to $300 per acre directly to landowners (Ron Myers, personal communication, November, 28, 2011). Both values are within the range used in Roise et al. (1991) which specifically addressed plausible pine straw yields at low basal areas as required by RCW habitat constraints. Costs specifically associated with the harvest and transportation of pine straw were not considered.

1.3.1.3 Timber Revenues

To determine timber yields for each of the proposed scenarios, annual growth in timber volume per acre was estimated using three longleaf pine growth and yield models: NATYIELD (1986), Farrar (1985), and Lohrey and Bailey (1977)[12]. Due to the unavailability of basal area estimates, Lohrey and Bailey's volume estimates were computed using NATYIELD's estimates of basal area. Further, NATYIELD volume estimates are given only in inner bark terms. The Farrar and NATYIELD models were run autonomously. The annual ratio of inner bark to outer bark volumes from Lohrey and Bailey (1977) was used to estimate equivalent outer bark volumes for the NATYIELD model. After this adjustment, all volumes are reported in cubic feet, outer bark.

The first thinning in each scenario(at age 28) contained 25% pulpwood and 75% chip-and-saw, and the second thinning and final harvest, 20% chip-and-saw, 50% sawtimber, and 30% poles. Stumpage prices, by product class, were collected and averaged from 4th Quarter 2011 Forest2Market and Timber Mart-South reports. Prices were as follows: pulpwood for $7.93 per ton, chip-and-saw for $14.88 per ton, sawtimber for $25.41 per ton, and poles for $56.32 per ton (Forest2Market 2011, Timber Mart-South 2011).

1.3.1.4 Management Costs

Costs for site preparation, tree planting, herbicide release application, and prescribed burns were collected for the appropriate regions from NCFS' annual estimates provided through the

[12] Each of these is described in detail in the review of literature and will be discussed in reference to one another in the results section.

Forest Development Program (NCFS 2011). Labor was included as a factor in each of these. Table 1.8 lists each practice and the associated cost.

Table 1.8. Longleaf Pine Management Costs

Activity	**Cost per Acre**
Site Preparation (mechanical chop)	$81
Planting (longleaf in containers)	$135
Herbicide Application (chemical ground machine)	$90
Prescribed Burn	$45

1.3.2 Capital Budgeting Analysis of Rural Alternatives

A simplistic representation of typical performance of applicable rural alternatives was developed for comparison with the longleaf pine for ecosystem services scenario. First, an analysis of loblolly pine managed on a conventional 25-year rotation and as an infinite rotation. Second, the agricultural scenario is represented by typical corn and soybean budgets.

1.3.2.1 Loblolly Pine

Two loblolly pine scenarios were considered: (1) a conventional short rotation regime intended to maximize timber revenue, and (2) an infinite rotation with no final harvest. The infinite rotation scenario is desirable for RCW habitat as there is some evidence that the birds will nest in old loblolly pine equally as well as longleaf pine (Lennartz and Hooper 1979).

The conventional loblolly pine scenario was based on prior research by Siry et al. (2001) and Cubbage et al. (2012a), which both used the TAUYIELD computer program. The planting rate was 600 trees per acre with a site index of 60 feet at age 25[13]. Thinning volume was 475 ft^3 per acre at age 17, comprised of 75% pulpwood and 25% chip-and-saw. The final harvest volume was 2,225 ft^3 per acre at age 25, comprised of 23% chip-and-saw wood, 67% small

[13] Roughly equivalent to a site index of 95 feet at age 50 (Hamilton 1995), this represents a high quality loblolly site in North Carolina where the average SI at 50 for loblolly pine is 75 feet (Bechtold and Ruark 1988).

sawtimber, and 10% large sawtimber. Prices for each product class mirrored those used for the analysis of longleaf pine (Forest2Market 2011, Timber Mart-South 2011). Establishment costs for loblolly pine were lower than those of longleaf pine reflecting a difference in the price of seedlings. A cost of $242 per acre included seedlings, site preparation, planting, and chemical release. As with longleaf, a management and property tax of $8 per acre per year was also included.

There was no final harvest event in the infinite rotation scenario, but instead an infinite series of commercial thinning and natural regeneration. Commercial thinning occurred every 20 years beginning and age 25 and each event was valued at 40% of the final harvest in the conventional scenario (equivalent to 20 tons per acre). Infinite commercial thinning is unlikely; however, this provides a conservative comparison to longleaf pine by allowing for high levels of intermediate income. As with the conventional scenario a thinning of 475 ft^3 per acre occurred at age 17. Costs and prices were also unchanged.

<u>1.3.2.2 Agriculture</u>

The agricultural comparison was derived from NCSU's Agricultural and Resource Economics Extension's enterprise budgets for conventionally tilled corn and soybean row crops located within North Carolina's Coastal Plain region (NCSU 2011a, NCSU 2011b). These represented the average yield per acre of each crop (110 bushels for corn, 35 bushels for soybeans) and current prices. Costs included those for establishment (seed, fertilizer, lime, herbicides), harvest (drying and hauling), and equipment (tractors and machinery). Assuming instantaneous costs and revenues, annual returns for corn were $67.57 per acre and $159.92 for soybeans.

1.4 Results

1.4.1 Longleaf Pine

<u>1.4.1.1 Growth and Yield Models</u>

Three longleaf pine growth and yield models were used to estimate growth from age 20 to the end of rotation in each management regime. Growth was modeled assuming three site indexes to represent the variety of site qualities available in North Carolina. Figures 1.1 to 1.4 show growth for areas with site index (SI) 60 feet at age 50, which is representative of the average site in North Carolina (SI 56 at 50 years) (Bechtold and Ruark 1988). Appendices B and C provide the same graphs for SI 70 at 50 years and SI 80 at 50 years[14].

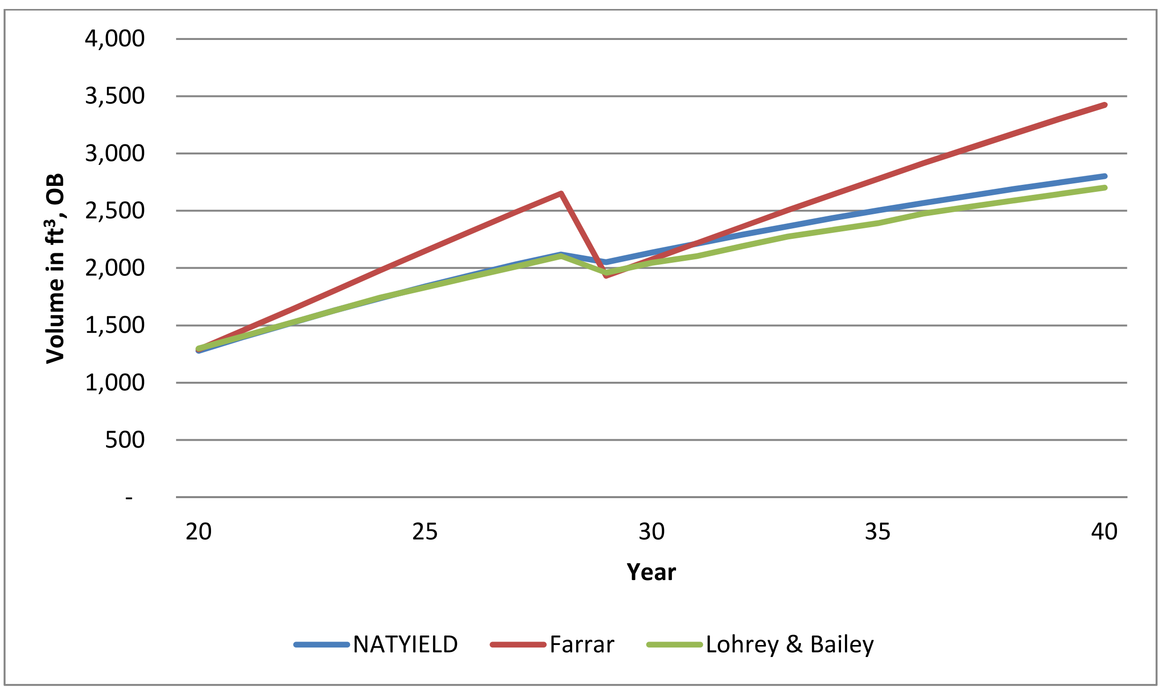

Figure 1.1. Longleaf Outer Bark Volume Over Time, Max Timber, SI 60

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[14] For the Lohrey and Bailey equations, SI at age 50 was adjusted by a ratio of 57/90 to estimate SI at age 25. This conversion factor is derived from multiple graphs and equations representing SI over time found in Schumacher and Coile (1960). Thus, SI 60 becomes SI 38, SI 70 becomes SI 44, and SI 80 becomes SI 51 for these equations.

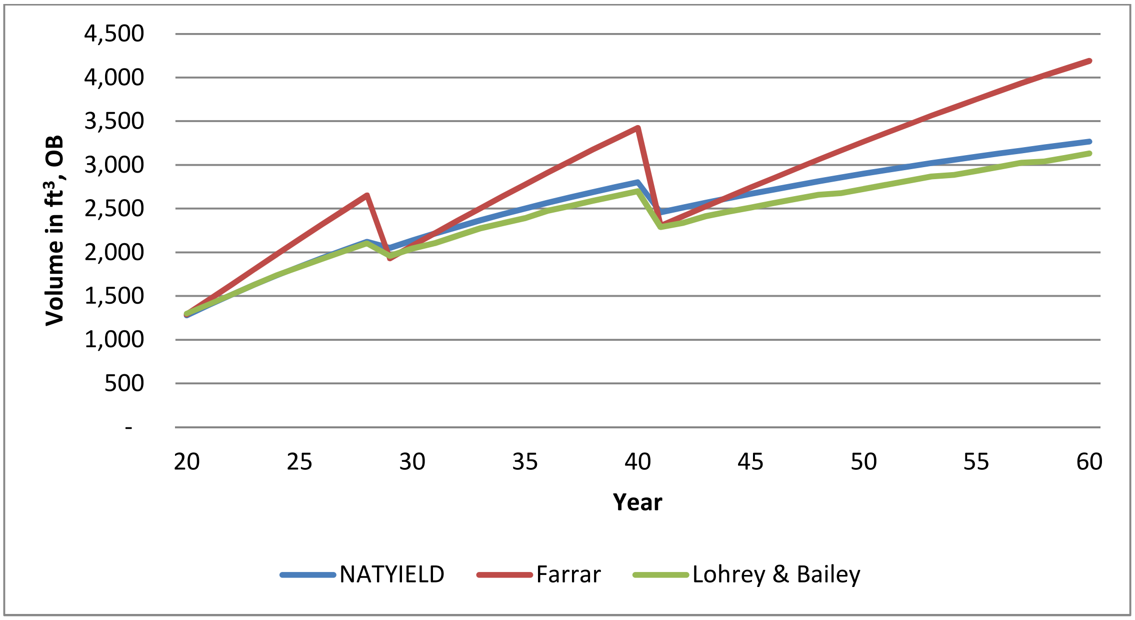

Figure 1.2. Longleaf Outer Bark Volume Over Time, Multiple Products, SI 60

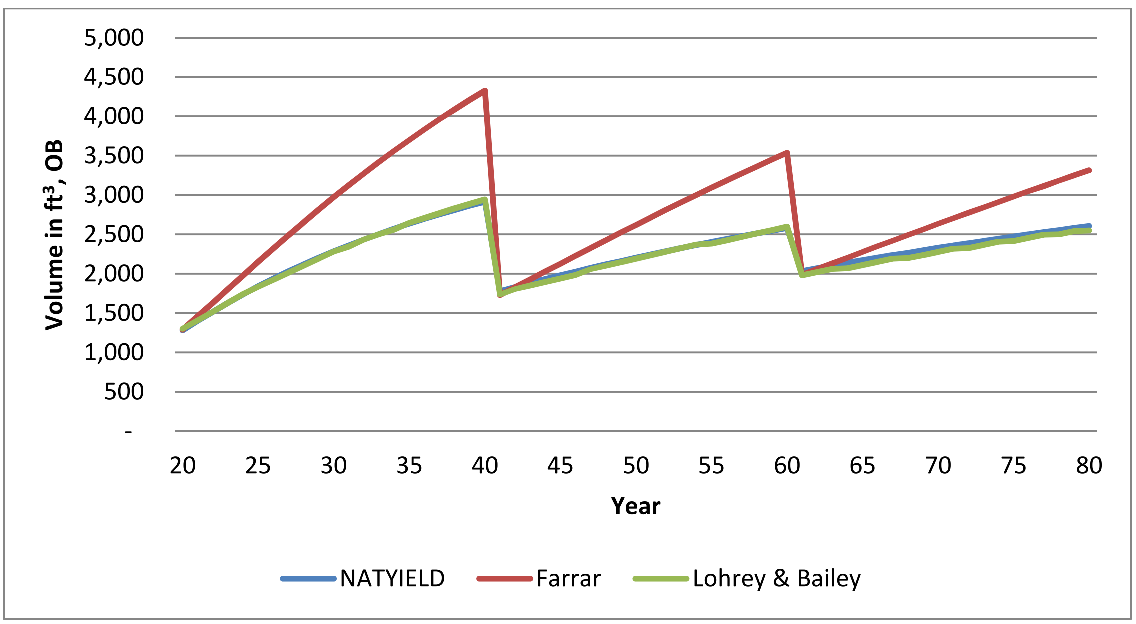

Figure 1.3. Longleaf Outer Bark Volume Over Time, Ecosystem Services Without Pine Straw, SI 60

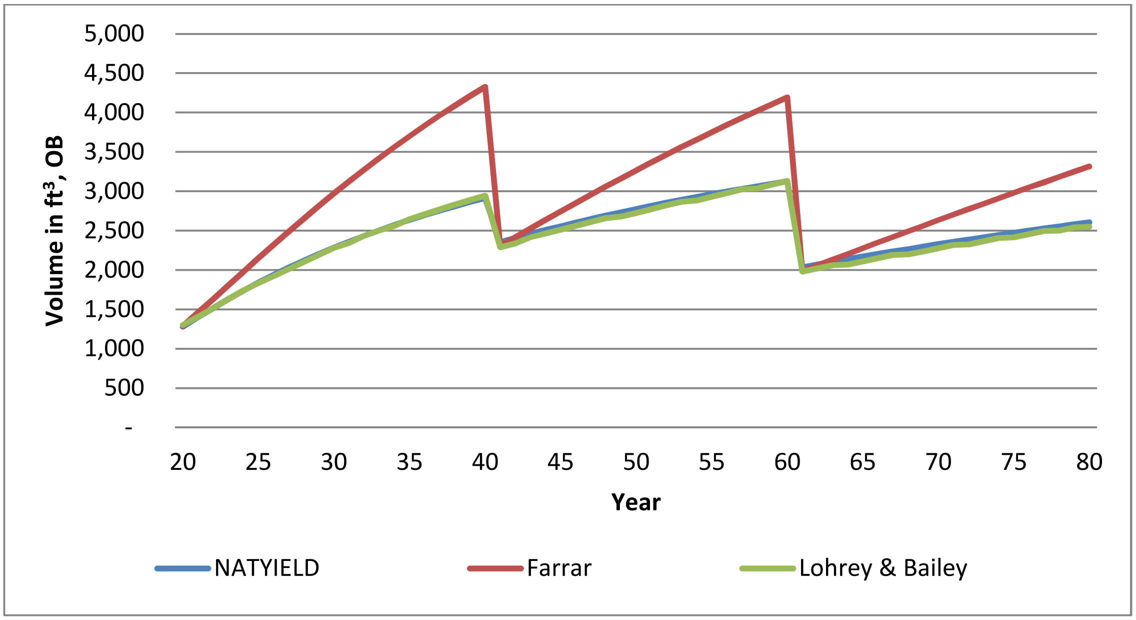

Figure 1.4. Longleaf Outer Bark Volume Over Time, Ecosystem Services With Pine Straw, SI 60

The similarity between the NATYIELD and Lohrey and Bailey models was expected given that the Lohrey and Bailey model relied on basal area projections from NATYIELD. However, basal area is only one variable in the Lohrey and Bailey volume predictions which include coefficients for SI and stand age. The differences in these two models were more prevalent at higher site indexes shown in Appendices B and C, as the NATYIELD model is more sensitive to changes in site quality.

Specifically, NATYIELD's prediction of timber volume increased by 25% and 21% when site quality changed from SI 60 to 70 and 70 to 80, respectively. These differences in Farrar and Lohrey and Bailey's models were less pronounced with Farrar's response to a 10 foot change in SI uniformly 13% and Lohrey and Bailey's ranging from 19 to 20%.

It is also evident from the figures that Farrar's model is the most optimistic of those displayed. Farrar's work reflects natural stands in the Eastern Gulf Coast region, where sites are generally of higher quality and thus exhibit faster basal area growth which has a large impact on volume predictions. Lohrey and Bailey's model represents plantations in a similar geographic region, but the comparatively explosive growth is tempered by the use of NATYIELD's basal area estimates within Lohrey and Bailey's equations.

Due to these factors, NATYIELD is the preferred model for the financial analysis that follows. North Carolina exhibits a relatively high level of variation in site quality, indicating that it is best represented by a growth and yield model that is especially sensitive to changes in this variable. Further, Schumacher and Coile (1960), the data which underlies NATYIELD, is based on samples taken within the Atlantic Coastal Plain, a region more geographically representative of Camp Lejeune and the surrounding private lands.

1.4.1.2 Pine Straw and Timber Revenues

Frequency and timing of pine straw harvests vary by management regime as described in the methodology section. Two potential values are considered for each harvest event: $75 per acre in the conservative case and $150 per acre in the moderate case. The present value of each pine straw over each rotation is provided in Table 1.9.

Table 1.9. Present Value, 4%, of Pine Straw Revenue per Acre

Management Regime	**PV of Pine Straw**
Conservative Approach	
Max Timber	$236
Multiple Products	$252
Ecosystem Services	$236
Moderate Approach	
Max Timber	$393
Multiple Products	$420
Ecosystem Services	$393

Timber revenue was based on the volume thinned or harvested, allocations to product classes, and current stumpage prices. The volumes, by management regime, given in the following tables coincide directly with Figures 1.1 through 1.4 and Appendices B and C, but emphasize key years when thinning or harvest occurred.

Table 1.10. Max Timber, Timber Outer Bark Volumes (ft^3)

SI at age 50	Year	NATYIELD	Farrar	Lohrey and Bailey
60	28	155	721	229
	40	2,802	3,425	2,701
70	28	307	825	376
	40	3,418	3,915	3,111
80	28	477	943	522
	40	4,055	4,476	3,575

Table 1.11. Multiple Products, Timber Outer Bark Volumes (ft^3)

SI at age 50	Year	NATYIELD	Farrar	Lohrey and Bailey
60	28	155	721	229
	40	393	1,122	463
	60	3,266	4,192	3,130
70	28	307	825	376
	40	631	1,283	657
	60	4,007	4,792	3,604
80	28	477	943	522
	40	895	1,467	884
	60	4,776	5,478	4,178

The primary management difference between the two ecosystem services management regimes was the level of thinning at age 40. Thinning volume is higher without pine straw because more residual basal area is retained in pine straw cases in order to produce higher pine straw yields later in the rotation.

Table 1.12. Ecosystem Services Without Pine Straw, Timber Outer Bark Volumes (ft^3)

SI at age 50	Year	NATYIELD	Farrar	Lohrey and Bailey
60	40	1,188	2,599	1,256
	60	571	1,550	660
70	40	1,685	2,971	1,645
	60	840	1,771	862
80	40	2,268	3,396	2,130
	60	1,139	2,025	1,133

Table 1.13. Ecosystem Services With Pine Straw, Timber Outer Bark Volumes (ft^3)

SI at age 50	Year	NATYIELD	Farrar	Lohrey and Bailey
60	40	611	2,024	708
	60	1,117	2,204	1,192
70	40	1,017	2,314	1,044
	60	1,510	2,520	1,478
80	40	1,484	2,645	1,471
	60	1,937	2,880	1,846

Average regional stumpage prices and product mixes were applied to each of these volumes to derive the revenue of each event. Product mixes in each case were based on conversation with NCFS experts. Present values were calculated assuming a 4% annual discount rate and summed by scenario, site index, and growth model. The resulting values, the present value of timber revenue, are presented below in Table 1.14.

Table 1.14. Present Value, 4%, of Timber Revenue per Acre

SI at age 50	NATYIELD	Farrar	Lohrey and Bailey
Max Timber			
60	$443	$594	$435
70	$552	$679	$512
80	$666	$776	$597
Multiple Products			
60	$303	$535	$311
70	$406	$611	$389
80	$516	$698	$477
Ecosystem Services, Without Pine Straw			
60	$221	$505	$238
70	$316	$577	$311
80	$426	$659	$404
Ecosystem Services, With Pine Straw			
60	$171	$463	$191
70	$260	$529	$262
80	$361	$605	$353

Again, timber revenue in the ecosystem services regime that excludes pine straw was higher because more timber volume is thinned when future pine straw income is not a consideration. The maximum timber scenario timber revenue benefited from a significantly earlier thinning and final harvest schedule. Harvesting at year 40, rather than 60, significantly decreases the negative impact of discounting.

1.4.1.3 Management Costs

Average costs were collected from geographically representative areas from NCFS' annual estimates provided through the Forest Development Program (NCFS 2011). The majority of costs were incurred in years 0 and 1 for site and stand establishment activities. Maintenance activities, herbicide application, and prescribed burning occur throughout the lifetime of each regime, dependent on the primary management goals. Details on costs and scheduling can be found in the Methodology section. Table 1.15 summarizes the present value, at 4%, of management costs. Differences between with pine straw and without pine straw cases are predominantly explained by differences in prescribed burning frequency and timing.

Table 1.15. Present Value, 4%, of Management Costs per Acre

Management Regime	With Pine Straw	Without Pine Straw
Max Timber	($596)	($554)
Multiple Products	($614)	($577)
Ecosystem Services	($615)	($697)

1.4.1.4 Financial Returns of Base Case

Present values of the pine straw and timber returns and management costs were used to calculate NPV, SEV, AEV, and IRR for each scenario. Tables 1.16 through 1.18 present NPV, SEV, and AEV by site index as these are all measures sensitive to the selection of a discount rate. Values in parentheses represent negative returns.

Table 1.16. Financial Returns per Acre, 4%, Site Index 60ft at age 50

Scenario	**NATYIELD**			**Farrar**			**Lohrey and Bailey**		
No Pine Straw	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	($111)	($6)	($140)	$41	$2	$51	($119)	($6)	($150)
Multiple Products	($274)	($12)	($303)	($43)	($2)	($47)	($266)	($12)	($294)
Ecosystem Services	($476)	($20)	($497)	($192)	($8)	($201)	($459)	($19)	($480)
Conservative	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$83	$4	$104	$234	$12	$295	$74	$4	$94
Multiple Products	($59)	($3)	($65)	$172	$8	$191	($51)	($2)	($56)
Ecosystem Services	($209)	($9)	($218)	$83	$3	$87	($189)	($8)	($197)
Moderate	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$240	$12	$303	$391	$20	$493	$231	$12	$292
Multiple Products	$109	$5	$120	$340	$15	$376	$117	$5	$130
Ecosystem Services	($52)	($2)	($54)	$240	$10	$251	($32)	($1)	($33)

Table 1.17. Financial Returns per Acre, 4%, Site Index 70ft at age 50

Scenario	**NATYIELD**			**Farrar**			**Lohrey and Bailey**		
No Pine Straw	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	($2)	$0	($2)	$126	$6	$159	($42)	($2)	($52)
Multiple Products	($171)	($8)	($189)	$34	$2	$38	($189)	($8)	($208)
Ecosystem Services	($381)	($16)	($399)	($120)	($5)	($126)	($386)	($16)	($403)
Conservative	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$192	$10	$242	$319	$16	$402	$152	$8	$191
Multiple Products	$44	$2	$48	$249	$11	$275	$26	$1	$29
Ecosystem Services	($119)	($5)	($125)	$149	$6	$156	($117)	($5)	($123)
Moderate	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$349	$18	$440	$319	$16	$402	$309	$16	$390
Multiple Products	$212	$9	$234	$249	$11	$275	$194	$9	$215
Ecosystem Services	$38	$2	$39	$149	$6	$156	$40	$2	$41

Table 1.18. Financial Returns per Acre, 4%, Site Index 80ft at age 50

Scenario	**NATYIELD**			**Farrar**			**Lohrey and Bailey**		
No Pine Straw	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$113	$6	$142	$223	$11	$281	$44	$2	$55
Multiple Products	($61)	($3)	($67)	$121	$5	$134	($100)	($4)	($110)
Ecosystem Services	($271)	($11)	($284)	($38)	($2)	($39)	($293)	($12)	($306)
Conservative	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$306	$15	$386	$416	$21	$525	$237	$12	$299
Multiple Products	$154	$7	$170	$336	$15	$372	$115	$5	$127
Ecosystem Services	($18)	($1)	($19)	$225	$9	$235	($27)	($1)	($28)
Moderate	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$463	$23	$584	$573	$29	$724	$394	$20	$498
Multiple Products	$322	$14	$356	$504	$22	$557	$283	$13	$313
Ecosystem Services	$139	$6	$145	$382	$16	$399	$130	$5	$136

The financial analysis underscores the importance of pine straw revenue in producing financially viable longleaf pine investment opportunities. At SI 60 and 70, all scenarios which exclude pine straw income produce negative returns under the preferred NATYIELD model. Even the highest quality site (SI 80) produces an NPV of only$113 per acre, equivalent to $6 in annual returns. Adding moderate pine straw income raised NPV to positive values for all scenarios on higher quality sites leaving only ecosystem services management on site with SI 60 at 50 years with negative returns.

The need for additional income in scenarios where longleaf pine is managed for RCW habitat is also clear in Tables 1.16 to 1.18. Longleaf pine was only able to produce positive returns in the most optimistic cases with above average site quality and moderate pine straw revenue. Though the best case returns are relatively low with an NPV of $139 per acre, equivalent to $6 in annual returns. This level of financial return to investment produces an environment where it is difficult for longleaf pine managed for RCW habitat to compete with other, more profitable, land uses.

Table 1.19 presents IRR as a supplemental means of comparison.

Table 1.19. Longleaf Pine Internal Rates of Return, by Site Index at 50 Years

Scenario	NATYIELD			Farrar			Lohrey and Bailey		
No Pine Straw	*60*	*70*	*80*	*60*	*70*	*80*	*60*	*70*	*80*
Max Timber	3.3%	4.0%	4.6%	4.2%	4.6%	5.0%	3.3%	3.8%	4.2%
Multiple Products	2.6%	3.2%	3.8%	3.8%	4.1%	4.5%	2.6%	3.1%	3.6%
Ecosystem Services	0.0%	1.4%	2.4%	3.0%	3.4%	3.8%	0.3%	1.4%	2.3%
Conservative	*60*	*70*	*80*	*60*	*70*	*80*	*60*	*70*	*80*
Max Timber	4.5%	5.0%	5.4%	5.2%	5.5%	5.8%	4.4%	4.8%	5.2%
Multiple Products	3.7%	4.2%	4.7%	4.7%	5.0%	5.3%	3.7%	3.1%	4.5%
Ecosystem Services	2.3%	3.2%	3.9%	4.4%	4.7%	5.0%	2.5%	4.1%	3.8%
Moderate	*60*	*70*	*80*	*60*	*70*	*80*	*60*	*70*	*80*
Max Timber	5.3%	5.7%	6.1%	5.9%	6.2%	6.5%	5.3%	5.6%	5.9%
Multiple Products	4.6%	5.0%	5.3%	5.4%	5.7%	5.9%	4.6%	4.9%	5.2%
Ecosystem Services	3.6%	4.2%	4.7%	5.2%	5.5%	5.7%	3.8%	4.3%	4.8%

IRR is an attractive result because it allows decision makers to compare financial returns to various investment options without exogenously deciding on the appropriate discount rate, removing some of the inherent uncertainty of doing so. Viewing the data in this fashion presents patterns that may otherwise go undetected. Again, the importance of pine straw revenue, particularly to the ecosystem services management regime, is notable. In the cases without pine straw revenue, ecosystem services' IRR lags far behind the corresponding value for the maximum timber regime, up to 5%, in absolute terms. However, the difference in the moderate pine straw cases never exceeds 2%. Similarly, the greatest relative gains from the addition of pine straw revenue are seen in the ecosystem services regime where the IRR increases from 0% to 3.6% for a site with SI 60 at 50 years compared to the more modest increase from 3.3% to 5.3% in the maximum timber scenario. This underscores both the general importance of pine straw revenue as well as its particular influence on the habitat encouraging regimes.

IRR also allows comparisons with options with dramatically different cash flows. The standard, lowest risk, comparison in these cases is the US treasury bond which posted average range of rates of return between 2 and 4% in 2011 (USDT 2012). This range if often exceeded in Table 1.19 indicating that longleaf pine compares well with other low risk investment opportunities available to NIPAF landowners.

1.4.1.5 Comparison of Longleaf Pine Results to Previous Literature

Longleaf pine returns in this analysis were significantly lower than those cited in the literature, which range from slightly negative values to exceeding $1,000 per acre (Johnson 2011, Mills et al. 2008). The reason for this significant difference was threefold: the current timber prices, emphasis on habitat creation above revenue, and an intentionally conservative modeling approach.

The most prominent driver of the decreased returns is the post-recession timber market. Stumpage prices today are less than 40% of the prices used by Cubbage and Hodges in 1988, adjusted for inflation (Cubbage and Hodges 1988). This has a substantial impact on returns to both loblolly and longleaf pine, as well as the relationship between the two. Prices used in these analyses reflect the fourth quarter of 2011 and prices continue to decline for all product classes except relatively low value pulpwood (Forest2Market 2012).

Another major consideration is the analysis of management regimes, which emphasize management practices and rotation lengths that favor habitat creation over revenue generation. While some previous authors have considered this (Roise et al. 1991, Johnson 2011, Lancia et al. 1989), it has not generally been a predominant focus. Further, this project's methodology is most consistent with Johnson's work which also forgoes a final harvest and posts a wide range of returns including net losses (2011).

The final contributing factor is the intentionally conservative modeling approach used throughout the analysis. This affirms the project goal of providing an upper bound for the opportunity costs between various activities and longleaf pine managed for ecosystem services. Additionally, a conservative approach best represents NIPAF landowners in North Carolina who tend toward less intensive forest management. This approach: used the lowest returning growth and yield models to predict volume thinned and harvested, assumed that timber prices would remain a low post-recession levels forever, selected a pine straw harvest regime that allows ample time for rest, and used pine straw prices from the lower end of the observed spectrum. The site index range considered is at or above the North Carolina state average, though this is more representative of the deep organic soils available in the Coastal Plain area. Further, rural alternatives were cast in the best possible light, with the loblolly site comparison being above the State average (also reflective of higher quality Coastal Plain soil) and the agricultural comparison assuming no adverse climate or weather impacts.

Recent publications indicate that such unsatisfactory returns may be more representative of the actual state of land management in North Carolina. While other analyses found longleaf to be a more attractive investment, landowners continue to favor alternative pine species and agriculture. This divergence indicates that perhaps past analyses have been overly optimistic. Similarly, Cubbage et al. (2010) found that forestry investments were often even less attractive than agricultural investments when using a real optimal approach compared to capital budgeting.

1.4.1.6 Case 1: Longleaf for Ecosystem Services vs. Longleaf for Maximum Timber

This section begins the calculation the first set of opportunity costs. In each case the expected SEV for a longleaf regime managed for RCW habitat is compared to a specific rural alternative. Comparisons were made at varying SIs and pine straw intensities. For reference, the opportunity cost was then converted to an annual payment that would yield an equivalent value if it were paid to private landowners on a one time 10-year contract. A 10-year contract was selected because this was the most popular conservation contract length for this type of contract in a landowner survey conducted in this region in 2011 (Rodriguez et al. 2012). SEVs below were based on results from the preferred NATYIELD model.

Many privately owned forested lands are already comprised of longleaf pine, but emphasize the maximization of timber revenue rather than provision for RCW habitat. Table 1.20 compares the SEVs of (1) maximum timber production versus (2) management for long rotations to develop RCW habitat. Opportunity cost is the difference in the two potential SEVs, for example the first row opportunity cost is -\$357 representing the cost incurred when a landowner currently managing longleaf pine for timber (SEV of -\$140 per acre) transitions to longleaf for habitat (SEV of -\$497 per acre). The hypothetical landowner will lose an additional \$397 per acre.

Higher opportunity costs and payments in each scenario that excludes pine straw may seem counter intuitive, but reflect the complicated interaction of two aspects of the analysis. First, pine straw value increased in both the maximum timber and RCW habitat scenarios; however, the impact on revenue was greater for the maximum timber case[15]. Additionally, the difference in management costs between the two scenarios is more prominent in the case without pine straw.

[15] The impact here is greater due to the shorter rotations in the maximum timber which allow more full rotations to be included in each SEV calculation. This adds increasing revenue because pine straw harvest occurs only in the early years of a rotation.

Table 1.20. Estimated Difference Between Existing Longleaf Pine for Maximum Timber Revenue and Conversion to RCW Habitat Computed as Opportunity Cost and Payments

Site Index	Pine Straw	SEVs Longleaf for RCW Habitat	 Longleaf for Timber	Present Value Opportunity Cost	10-year Contract Annual Payment
60	None	($497)	($140)	($357)	$42
	Conservative	($218)	$104	($322)	$38
	Moderate	($54)	$303	($357)	$42
70	None	($399)	($2)	($397)	$47
	Conservative	($125)	$242	($367)	$44
	Moderate	$39	$440	($401)	$48
80	None	($284)	$142	($426)	$51
	Conservative	($19)	$386	($405)	$48
	Moderate	$145	$584	($439)	$52

1.4.2 Rural Alternatives

1.4.2.1 Loblolly Pine Financial Returns

Table 1.21 provides the results from the conventional loblolly pine financial analysis. Harvest, timber marking, and other costs for sale preparation a not included. Equivalently, this category of costs is excluded from the longleaf pine analysis[16]. Summing the present values below results in a conventional loblolly NPV of $126 per acre, this equates to an SEV, AEV, and IRR of $201, $8, and 5.2%, respectively.

Table 1.21. Conventional Loblolly Pine Analysis Results, 4%

Year	Activity	Cost	Revenue	Value	Present Value
0	Establishment	$242	$0	($242)	($242)
17	Commercial thinning	$0	$103	$103	$53
25	Final harvest	$0	$1,305	$1,305	$490
Annual	Tax and Management	$8			($175)

[16] This exclusion is likely to create a small bias towards longleaf pine given that preparation costs for longleaf are generally higher than those for loblolly pine.

In order to provide for RCW habitat in an alternative species, an infinite rotation loblolly case was also considered. This case used the same underlying values as listed in Table 1.21. However, the final harvest was replaced with a series of infinite commercial thinnings starting at age 25. The present value of these thinnings is $164 per acre. Management costs were increased to $208 due to a longer investment horizon. These adjustments produced an NPV of -$37 per acre, which is equivalent to the SEV due to the infinite rotation length. AEV and IRR are -$1 per acre and 3.7%, respectively.

1.4.2.2 Case 2: Longleaf Pine for Ecosystem Services vs. Loblolly Pine for Maximum Timber

A central focus of this project was identifying the opportunity cost of managing longleaf pine for RCW habitat when compared to faster growing southern pine species. This section uses comparisons to the most common alternative, loblolly pine, to estimate the opportunity cost in these situations. Comparisons were first made directly and then a series of alternative scenarios were assessed: (1) a mixed longleaf model where only portions of a property are managed for habitat, (2) a price recovery analysis, and (3) a longleaf pine cost share analysis.

1.4.2.2.1 Direct Competition with Loblolly Pine

A key component of this research was the financial comparison of RCW habitat creation with longleaf pine to the loblolly pine scenarios. There are few situations where longleaf pine is capable of directly competing financially with loblolly pine. The majority of the longleaf analyses returned negative SEVs at a 4% discount rate, compared to the conventional loblolly pine SEV of $201 per acre. Table 1.22 employs the same methods used in Case 1 to calculate the opportunity cost and payments required to offset conversion from conventional loblolly pine to longleaf pine for ecosystem services.

Table 1.22. Estimated Difference between Loblolly Pine for Maximum Timber Revenue and Conversion to Longleaf RCW Habitat Computed as Opportunity Cost and Payments

Site Index	Pine Straw	Longleaf for RCW Habitat SEV	Present Value Opportunity Cost	10-year Contract Annual Payment
60	None	($497)	($698)	$83
	Conservative	($218)	($419)	$50
	Moderate	($54)	($255)	$30
70	None	($399)	($600)	$71
	Conservative	($125)	($326)	$39
	Moderate	$39	($162)	$19
80	None	($284)	($485)	$58
	Conservative	($19)	($220)	$26
	Moderate	$145	($56)	$7

Further reflecting the importance of pine straw value and management regime over site quality, payments differ far more dramatically across pine straw value within each site index and across pine straw values within each management regime.

The same method was used to estimate the opportunity cost and required payment for converting conventionally managed loblolly pine to an infinite rotation to better provide RCW habitat. Based on the conventional ($201 per acre) and the infinite rotation (-$37 per acre) SEVs, the opportunity cost was $238 per acre, equivalent to annual returns of $28 per acre on a 10-year contract. This is comparable to the lower end of the range in Table 1.22 costs on high quality sites with moderate or conservative pine straw revenue. The long rotation loblolly scenario was simplistic and did not account for potentially costly understory control treatments to enhance RCW forage conditions.

1.4.2.2.2 Mixed Longleaf Pine Models

Key insights regarding USFWS requirements and RCW preferences for habitat allow for a subtle but meaningful change in how opportunity costs can be calculated. USFWS requires that at least one-quarter of a mile of land lies between cavity trees for active clusters (USFWS 2003). Individual clusters should be surrounded by 75 to 100 acres as forage range. Providing adequate forage range requires intensive management of longleaf pine understory but does not require the presence of old growth trees (Bayon 2002). Additionally, while conclusive research is pending, USFWS does not currently consider timber thinning and pine straw harvest activities to be in conflict with habitat provision on private lands (John Hammond, personal communication, April, 20, 2011).

Consistent with methods developed by Lancia et al. (1989), these qualifications reveal that it is possible to provide RCW habitat without managing an entire property at the strict levels required to provide habitat. Instead, a portion of the property can be managed intensively for ecosystem services while the remainder provides income through timber and pine straw harvest. For example, on an average site with site index of 60 at base age 50, managing 29% of a given parcel to maximize habitat benefits (SEV of -$54/acre) and the remaining 71% under a timber maximizing, moderate pine straw, regime (SEV of $303/acre) yields an average property SEV of $201 per acre, equivalent to the conventional loblolly returns with the additional benefit of providing habitat. Increasing the percentage of area managed for timber and pine straw would further increase the average SEV per acre for the mixed longleaf scenarios. In addition, landowners would still have the opportunity to collect payments from DOD for providing habitat in the limited areas managed for this purpose.

Table 1.23 provides a matrix of optimal mixes dependent on pine straw value within the portion of the property managed for ecosystem services. Each is based the NATYIELD model and assumed moderate pine straw raking within the portion of the property managed for maximum timber. A conservation payment is set at an arbitrarily low value ($10 per year per acre for 10 years) for illustration. At this level, pine straw value produces a much larger overall impact on allocation than the inclusion of a payment.

Table 1.23. Hypothetical Management Goal Allocation with and without a Conservation Payment by Pine Straw Value

Ecosystem Services Pine Straw	Payment	Allocation Ecosystem Services	Max Timber
Moderate	Yes	37%	63%
	No	29%	71%
Conservative	Yes	23%	77%
	No	20%	80%
None	Yes	14%	86%
	No	13%	87%

1.4.2.2.3 Post-Recession Stumpage Prices

Stumpage prices in each pine analysis were from the fourth quarter of 2011. These prices highlight the impact of a changing timber market and the uncertainty regarding the future recovery of the market. Use of these prices contributed greatly to longleaf pine's ability to compete with loblolly pine. Loblolly pine's primary financial advantage over longleaf is temporal: a valuable final harvest is available much earlier for loblolly pine. The time value of money decreases the value of the later longleaf pine harvest to a greater extent. Low stumpage values drive the final harvest values for both species down and increase the importance of the pine straw revenue, which has not yet been adversely impacted by the economic downtown.

A sensitivity analysis was performed to assess the magnitude of price impacts the opportunity cost between longleaf pine for ecosystem services on loblolly pine for maximum timber. This analysis assumed stumpage prices 1.5 times current levels. Adjusting prices in this way increased the conventional loblolly SEV to $635 per acre, eliminating longleaf pine's ability to compete directly. Table 1.24 presents updated SEVs for longleaf pine ecosystem services regimes under various site indexes and pine straw values and uses these to calculate opportunity cost and 10-year payments under the higher price assumptions. Complete results from the price sensitivity analysis are provided in Appendix D.

Table 1.24. Estimated Difference between Existing Loblolly Pine for Maximum Timber Revenue and Conversion to RCW Habitat Computed as Opportunity Cost and Payments, High Price Case

Site Index	Pine Straw	Longleaf for RCW Habitat SEV	Present Value Opportunity Cost[17]	10-year Contract Annual Payment
60	None	($382)	($1,017)	$121
	Conservative	($129)	($764)	$91
	Moderate	$36	($599)	$71
70	None	($233)	($868)	$103
	Conservative	$11	($624)	$74
	Moderate	$176	($459)	$54
80	None	($61)	($696)	$83
	Conservative	$170	($465)	$55
	Moderate	$334	($301)	$36

Though the value of each longleaf pine regime increased at the new price levels, this did not offset the more pronounced increases in loblolly pine's SEV, and ultimately left longleaf pine at a disadvantage. The range of annual payments increased from $7 to $83 per acre in the base case to $36 to $121 per acre in the high price analysis.

1.4.2.2.4 Cost Share Options

North Carolina provides several cost share programs that encourage private landowners to replant agricultural and other lands in longleaf pine, due to the species' well-acknowledged ecological significance. These programs were not evaluated in the base case scenario due to the uncertainty of acquiring funds. However, they can have a tremendous impact on the

[17] Opportunity cost is equal to the difference in longleaf and loblolly pine SEVs.

financial returns to longleaf pine, especially when compared to loblolly pine, which does not qualify for all of the same programs or may qualify for a lesser cost share rate. A prominent example of such a program is the U.S. Department of Agriculture's (USDA) Natural Resource Conservation Service's (NRCS) EQIP program that will cost share up to 100% of establishment and maintenance activities for longleaf pine (USDA NRCS 2012a, 2012b). Table 1.25 presents opportunity cost and 10-year payments when a cost share payment of $306 per acre, to cover establishment, is included with the longleaf ecosystem services models. Comparisons are still made to the original loblolly for maximum timber revenue scenario with an SEV of $201 per acre.

Table 1.25. Estimated Difference between Existing Loblolly Pine for Maximum Timber Revenue and Conversion to RCW Habitat Computed as Opportunity Cost and Payments, Cost Share Case

Site Index	Pine Straw	Longleaf for RCW Habitat SEV	Present Value Opportunity Cost	10-year Contract Annual Payment
60	None	($178)	($379)	$45
	Conservative	$102	($99)	$12
	Moderate	$266	NA[18]	NA
70	None	($79)	($280)	$33
	Conservative	$195	($6)	$1
	Moderate	$359	NA	NA
80	None	$36	($165)	$20
	Conservative	$301	NA	NA
	Moderate	$465	NA	NA

Assuming a minimum payment from EQIP, covering only the cost of establishment, the opportunity cost between longleaf and loblolly pine was greatly reduced, and in many cases disappeared. In all cases where moderate pine straw revenue and a minimum cost share payment are included, longleaf was able to outcompete loblolly pine. Even in cases which

[18] In several cases the longleaf pine SEV now exceeds loblolly pine's SEV ($201) and opportunity cost is not applicable.

included only conservative pine straw revenue, longleaf pine is very competitive with longleaf on high quality sites with an SI of 70 or 80 feet at age 50.

1.4.2.3 Financial Returns of Agriculture

The agricultural scenarios assumed average North Carolina Coastal Plain returns to corn and soybean farms for each year into infinity. As with the infinite rotation loblolly scenario, these assumptions were probably optimistic to provide the most conservative comparisons to the longleaf pine results. The analysis assumed that famers would get average yields every year, maintain the current high crop prices, and encounter no weather or climate issues. Rotation of crop was also not considered.

Analyses that better reflect a lower bound of returns from agriculture and account for differences due to poor weather and poor soil quality would produce much lower returns. For poor or marginal agricultural sites, tree growth may be more resilient to adverse weather than crop growth in similar environments. In one experimental setting on a low quality agricultural site in North Carolina, Cubbage et al. (2012a) found that trees outperformed crops in four of the five years from 2007 to 2012— with crops losing $664 per acre in four years. When compared with annual risks and potential losses from agricultural crops, forestry investments can produce competitive investment returns.

Due to differences in the length of agricultural and forestry investments, measures that account for different time frames, such as SEV and IRR, are the most appropriate means for comparison. The SEVs for agricultural crop production of corn and soybeans were $1,757 per acre and $4,158 per acre respectively.

1.4.2.4 Case 3: Longleaf Pine for Ecosystem Services vs. Corn and Soybean Agriculture

Unsurprisingly, comparisons with agricultural production were less favorable. In part, this was due to the simplified agricultural analysis. The comparison was also unfair as it compared high quality agricultural sites with lower quality forestry sites. Further, agriculture is a far more intensive land use incurring higher environmental costs and demanding more time input from landowners. A full analysis of the trade-off between agriculture and forestry would give careful consideration to how time previously spent on agricultural activities could be redirected to generate income elsewhere.

Tables 1.26 and 1.27 provide calculations that mirror those for the previous cases. The SEVs for corn and soybeans were $1,757 per acre and $4,158 per acre respectively. Payments for each of these ranged from $191 to $267 for corn and $476 to $552 for soybeans, dramatically higher than any of the previous forestry analyses.

Table 1.26. Estimated Difference between Existing Corn Agriculture and Conversion to Longleaf RCW Habitat Computed as Opportunity Cost and Payments

Site Index	Pine Straw	Longleaf for RCW Habitat SEV	Present Value Opportunity Cost	10-year Contract Annual Payment
60	None	($497)	($2,254)	$267
	Conservative	($218)	($1,975)	$234
	Moderate	($54)	($1,811)	$215
70	None	($399)	($2,156)	$256
	Conservative	($125)	($1,882)	$223
	Moderate	$39	($1,718)	$204
80	None	($284)	($2,041)	$242
	Conservative	($19)	($1,776)	$211
	Moderate	$145	($1,612)	$191

Table 1.27. Estimated Difference between Existing Soybean Agriculture and Conversion to Longleaf RCW Habitat Computed as Opportunity Cost and Payments

Site Index	Pine Straw	Longleaf for RCW Habitat SEV	Present Value Opportunity Cost	10-year Contract Annual Payment
60	None	($497)	($4,655)	$552
	Conservative	($218)	($4,376)	$519
	Moderate	($54)	($4,212)	$499
70	None	($399)	($4,557)	$540
	Conservative	($125)	($4,283)	$508
	Moderate	$39	($4,119)	$488
80	None	($284)	($4,442)	$527
	Conservative	($19)	($4,177)	$495
	Moderate	$145	($4,013)	$476

1.5 Discussion

Previous research in the area of longleaf economics has focused primarily on the maximization of either timber revenue or RCW habitat, usually through the use of intensive site management (Johnson 2011, Roise et al. 1991). Opportunities for public-private cooperation, however, are likely to occur instead with low input NIPAFs. The analyses above provide the first attempt at quantifying the value of low input management of longleaf for both of these goals (timber or habitat). Comparisons at this level provide a more realistic estimate of opportunity costs to landowners likely targeted for such programs. Past direct comparisons to other rural alternatives have been limited to timber maximizing regimes (Mills and Stiff 2008) rather than attempts to quantify changes if the very goals of landowners. As a result, the opportunity costs above are higher than in previous studies , reflecting the potential for a landowner to shift from timber maximizing management to a more passive habitat creating regime.

The economic recession which began in 2008 has also had a tremendous impact on the estimates of timber revenue and thus opportunity costs for already forested lands. Debate continues regarding the likelihood of a recovery of timber prices and the future of forestry in the Southeast. Timber prices impact no only the returns to longleaf pine managed for its various goals, but also to alternative species (including loblolly pine). Lower timber prices have decreased the present value of all timber investments, but this impact is more profoundly felt in loblolly pine where harvest occurs at an earlier time. The high price sensitivity analysis above shows that should timber prices increase, the opportunity cost of converting existing loblolly stands to longleaf pine for RCW habitat will likewise increase, making the current situation a unique opportunity for increased conservation.

As Camp Lejeune explores its options for mitigating RCW-related ESA mandated habitat responsibilities to private landowners off base, they will be faced with many options. The analysis results identified priority situations where preliminary efforts should begin. It also highlighted key variables that will be essential in developing an overarching longleaf pine conservation strategy.

1.5.1 The Necessity of Payments

Due to the factors above, the longleaf pine scenarios resulted in negative or minimal financial returns. As shown in Tables 1.16 through 1.18, NPV is negative in the majority of cases, except for very high quality sites. Specifically, returns to the RCW scenarios were the lowest. These findings are in line with current practice and serve to explain why rational landowners in North Carolina prefer alternative land uses, despite the environmental benefits of longleaf pine. In order for longleaf pine to be a viable option, NIPAF landowners must have access to pine straw and periodic thinning income as well as some level of outside payment. Past work indicated that pine straw in crucial to longleaf pine's financial successes, increasing the SEV of a given site by as much as $989 per acre (Roise et al. 1991) in the best cases and between $115 and $300 in more conservative scenarios (Mills and Stiff 2008, Kessler and Straka

1990). At current market prices the impact on SEV is estimated at approximately $450 per acre in the above analyses.

Likewise, it is crucial that private landowners be given the opportunity to stack cost share and various incentive payments. As the cost share sensitivity analysis showed, cost share greatly increases longleaf pine's ability to compete with loblolly pine, but unless combined with intermediate income and payments, there are still many cases when loblolly is the more rational option.

The ecological benefits of longleaf pine are many compared to the rural alternatives and private landowners should be appropriately compensated for each service provided as happens in any other market. Further, the high price sensitivity analysis shows that many of the current advantages longleaf pine holds over loblolly pine would disappear if timber prices were to recover even to a fraction of their former levels. If this occurs, intermediate income and payments from various programs will become more necessary and will increase in magnitude.

1.5.2 Prioritization of Rural Alternatives

DOD should expect initial bids to range widely from $7 per acre to nearly $5,000 per acre depending on the current use, though it is unlikely that they will encounter the high end agricultural site bids in practice. Comparing opportunity costs across rural alternatives resulted in a ranking of sites given a finite pool of financial resources.

Specifically, emphasis should first be given to sites which quality for cost share and/or those that can be managed in mixed models with only a portion of the property managed for habitat while remaining tracts are managed for maximum timber revenue. Under the cost share analysis, it is possible for longleaf pine managed for ecosystem services to financially outcompete loblolly pine in all cases where moderate pine straw is considered. Even assuming only conservative or no pine straw revenue, opportunity costs are minimal ranging from $6 to $379 per acre, with maximum annual payments for 10-year contracts at $45 per year per acre.

Mixed models offer similar options for eliminating the opportunity cost between longleaf pine for RCW habitat and loblolly pine. Landowners need only manage 71-87% of their holdings as timber revenue maximizing longleaf pine in order to compete with loblolly pine, leaving the remainder of the property available for management for ecosystem services.

Second priority remains within the loblolly pine category, but focuses on options where cost share is unavailable. Cases where moderate pine straw revenue within the ecosystem services regime is available result in an opportunity cost of $56 to $255 per acre, equivalent to annual payments of $7 and $30 per acre per year.

The next priority should be the conversion of particular existing longleaf pine properties currently managed to maximize timber revenue. Table 1.20 indicates that opportunity costs for Case 1: Longleaf for Ecosystem Services vs. Longleaf for Maximum Timber range from $357 to $439 per acre with one notable exception: average quality sites (SI 60 at age 50) with conservative pine straw revenue. In this scenario the opportunity cost was $322 per acre, within the upper range of the loblolly pine cost share analysis. The remaining longleaf pine for maximum timber to longleaf pine for ecosystem services scenarios are the final priority, followed by conversions from loblolly which exclude both longleaf pine establishment cost share and pine straw income ($485 to $698 per acre).

Finally, average and high quality agricultural sites should be the lowest priority as these continue to be cost prohibitive with opportunity costs an order of magnitude greater than the forestry options, though a more detailed analysis of the full range of potential agricultural returns may have shown otherwise. If agricultural sites were to be considered in the case of Camp Lejeune preference should be given to sites that have been growing crops with lower financial yields or lower rental payments. In this case, payments may serve as a method for retiring unproductive agriculture sites to trees offering mutual benefit to DOD as well as landowners. When compared with annual risks and potential losses from agricultural crops, forestry investments can produce competitive investment returns.

Table 1.28 summarizes the opportunity cost and annual payments for each alternative.

Table 1.28. Ranking of Opportunity Costs per acre and Annual Payments by Current Management Practice

Current Management Practice	Opportunity Cost	10-year Annual Payment
(1) Loblolly pine managed for maximum timber revenue, qualifies for longleaf cost share	$0 to $379	$0 to $45
(2) Loblolly pine managed for maximum timber revenue, does not qualify for longleaf cost share	$56 to $698	$7 to $83
(3) Longleaf pine managed for maximum timber revenue, average quality site with conservative pine straw	$322	$38
(4) All other longleaf sites managed for maximum timber revenue	$357 to $439	$42 to $52
(5) Corn row crops	$1,612 to $2,254	$191 to $267
(6) Soybean row crops	$4,013 to $4,655	$476 to $552

It is noteworthy that because of (1) the complex interactions between rotation length and pine straw income when comparing the two longleaf scenarios (RCW habit vs. maximum timber) and (2) the use of post-recession timber prices, conversion of existing loblolly managed for maximum timber is more economical than conversion of existing longleaf managed for maximum timber. Conditions today present a unique opportunity for longleaf pine to compete more readily with loblolly pine in North Carolina. This presents an important opportunity for the conservation community to make significant changes in longleaf pine's existing range.

The analysis also highlighted that while other southern pine species may generate RCW habitat if given the opportunity to mature to old age, longleaf pine is not only ecologically superior, but also provides higher financial returns on high quality sites. The SEV of loblolly managed on an infinite rotation to promote habitat is -$37 per acre, lower than longleaf pine managed for habitat with conservative and moderate pine straw income on sites with SI 70 at 50 years or greater. Loblolly may only be a superior choice on lower quality sites or in cases where pine straw income is not available. Further, this does not adequately consider the additional ecological benefits derived from longleaf pine when compared to loblolly pine.

1.5.3 Limitations

The results assume that landowners are economically rational investors; use capital budgeting analyses explicitly or implicitly in making decisions; concur that the 4% discount rate represents their alternative rate of return; and would convert from traditional farm and forestry management uses if the price were right. These are of course strong assumptions, but the results are at least indicative of the amount of funds it would take for economically rational landowners to change their land uses. Landowners who were not profit maximizers or who had different discount rates might require different payments to change land use. Furthermore, some evidence suggests that conversion from one land use to another requires a higher than calculated NPV or SEV, because of the long term nature of such a decision, and the relatively higher cost to switch back to agriculture in particular.

Values discussed represent the range of values DOD should expect when engaging in market-based conservation programs targeting RCW in North Carolina. Emphasis should be given to the per acre opportunity cost over the 10-year contract annual payment values. While these are mathematically equivalent, the design of the payment contract and timeframe has yet to be decided. The opportunity costs represent the forgone income from a permanent change in behavior and therefore the bare minimum compensation required. Careful consideration is still be required for identifying the most effective vehicles for implementation, whether that be 10-year contracts, longer contracts, or permanent easements.

1.6 Conclusions

The longleaf pine analyses above quickly show that returns to longleaf pine managed for RCW habitat are seldom positive, and that additional financial incentives are required to induce landowners to change behavior. This is consistent with actual practice and supports the current state of landholdings in North Carolina today, favoring agriculture and more traditionally profitable tree species over longleaf pine. In constructing an overarching approach to RCW habitat mitigation, Camp Lejeune should first consider existing loblolly pine, followed by established longleaf pine currently managed for alternative goals. The economic situation of today offers a unique opportunity to expand the current range of longleaf pine, given its current increased ability to compete with other forestry investments.

Due to a simplistic analysis, opportunity costs associated with agricultural conversion were significantly higher. The stark difference in these findings supports instituting these programs on lands that are already forested or can produce only marginal agricultural returns, rather than average or above average agricultural areas. Further research is needed to fully understand opportunities available on marginal agriculture land. Additional research is also required on the precise approach DOD should utilize when working with landholders. For this analysis, annual payments for 10-year contracts were estimated based on landowner preferences in this region, but final implementation should consider short term contracts as well as permanent easements.

Further, the analysis repeatedly underscores the importance of pine straw and other intermediate income streams, something which should be carefully considered by policy maker, especially those within USFWS. Considerable care should be taken in identifying methods and protocols that allow for habitat-compatible intermediate income sources to offset management costs and delayed or eliminated final harvests. Without this, payments required to offset landowner financial losses will increase dramatically.

Chapter 2: An Econometric and Profitability Assessment of the Faidherbia albida-Based Agroforestry System in Malawi

2.1 Introduction

2.1.1 Background

Malawi is a small country, approximately the size of Pennsylvania, located in Southeastern Africa. Due to its small size and limited endowment of natural resources, the economy is heavily dependent on the agricultural sector, which provides 31% of gross domestic product and 90% of employment (CIA 2010). In addition to the constrained availability of land area and natural resources, the population of Malawi is increasing rapidly. In 2010, the estimated population was 15.9 million, representing an increase of 2.8% from 2009 and making Malawi the 17th fastest growing country in the world (CIA 2010).

Rapid population growth in this undeveloped and land-constrained country has led to critical soil fertility issues as it increases pressure on arable land. In the past, subsistence maize farmers in Southern Africa fallowed land to maintain soil fertility by leaving farmland dormant for intermediate years. Due to increasing population pressure and the decreasing per capita arable land, most farmers are less able to afford to take land out of production, and thus nutrients in the soil have greatly diminished (Ajayi 2009). This lack of fertility has in turn created a dependence on chemical fertilizers, which are unaffordable for most smallholder farmers in Malawi, costing upwards of 5 times the monthly family income. Malawi's Farm Input Subsidy Program (FISP), established in 2006, reduced the cost to farmers by 90%, but due to instability in the government and heavy dependence on uncertain foreign aid there is no guarantee of future availability (Chibwana 2011).

The tension between the need for food security and limited financial resources has prompted research into alternative means of fertilization. One promising solution comes in the form of an indigenous agroforestry tree: *Faidherbia albida*. Research on this species began when scientists noticed farmers in Northern Africa intentionally maintaining it among maize crops. Researchers soon discovered *Faidherbia albida* positively impacts crop yields through four pathways: (1) improved soil physical condition, (2) stabilization of micro-environment, (3) improved fertility through nitrogen fixing, and ($) establishment of healthier microbial populations (Rhoades 1995). Additionally, they found these trees exhibit the unique quality of reverse leaf phenology, where leaves drop at the beginning of the rainy season, adding nitrogen to soils during planting and establishment, but remain dormant throughout the crop growing season, minimizing competition for resources (Barnes and Fagg 2003). Experimental results indicate interplanting *Faidherbia albida* with crops increased maize yields by as much as 280% in areas closest to the fertilizer trees, but no formal analysis has been conducted on effectiveness in non-experimental settings (Garrity et al. 2010). Proving success in these settings is crucial in determining the viability of and securing support for expanding adoption in the future.

2.1.2 Study Goal and Objectives

The project goal was to assess the economics and profitability of *F. albida* and maize intercropping in the Salima and Ntcheu districts of Malawi.

Establishment and maintenance costs, along with intermediate benefits, were estimated for *F. albida*. A second component of the project estimated increases in maize yield attributed to *F. albida*. Comparison of these two values under various scenarios will provide important insight into the question of *F. albida*'s future adoption potential. The specific objectives addressed in this project included:

1) Estimation of costs associated with *F. albida* and maize crops
2) Increased understanding of intermediate non-yield benefits
3) Estimation of the magnitude of yield benefits from presence of *F. albida*
4) Assessment of barriers to adoption and motivation for continued planting/maintenance of *F. albida*, from farmers' perspective

2.2 Methods

2.2.1 Study Area

The study was conducted in 23 villages and 5 extension planning areas (EPA) in the Ntcheu and Salima districts of Malawi, located in the Central region, as depicted below in Figure 2.1 The Ntcheu district is of a relatively higher altitude than Salima which lies within the flatter plains surrounding Lake Malawi. Average temperatures in Ntcheu are also higher than those in Salima.

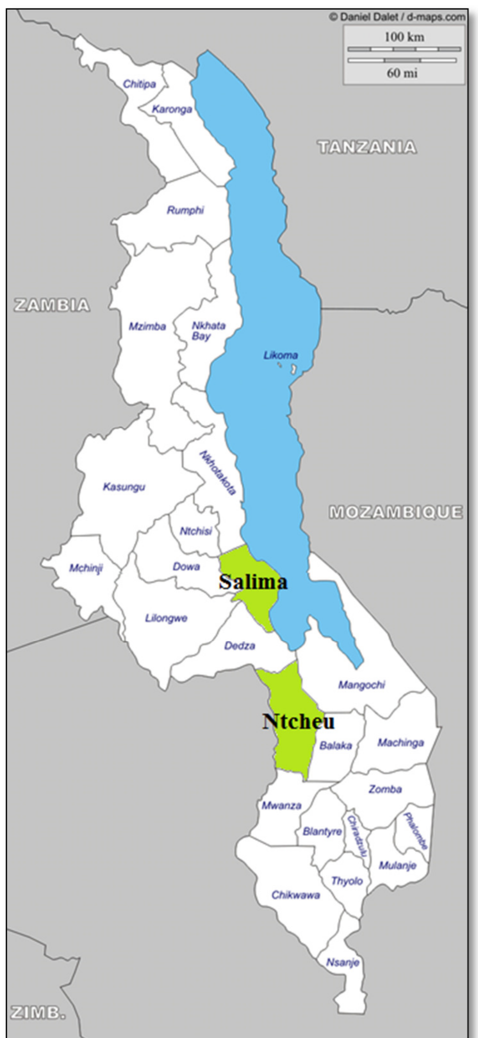

Figure 2.1. Map of Surveyed Districts

2.2.2 Sampling Technique

Data were collected over the summer of 2011 using a semi-formal household survey of 390 farms, under the advisement the World Agroforestry Center (ICRAF), and in conjunction with Malawi's Department of Forestry (DOF) and the Bwanje Valley Environmental Development Organization (BERDO), a well-established environmental non-governmental organization (NGO). The survey elicited information on fields where maize had been cultivated in the most recent crop season resulting in a total sample size of 497 individual fields. Each farmer held between one and four maize fields with an average field size of 0.62 hectares, consistent with previous work in this region (Brummett 2002, Wodon 2006).

Surveys were conducted by five local interviewers with prior experience in either forestry (through completion of a Bachelor of Forestry degree), rural data collection (through previous work with ICRAF), or both. Interviewers were hired specifically for this project based on background, proven ability to communicate in English and the local language of Chichewa, and availability during fieldwork.

The study used a stratified random sampling technique to select farmers. EPAs were selected based on ICRAF's sampling frame for these areas developed in support a carbon study of *F. albida* in the previous year (Beedy et al. 2011). Collaborating extension agents from Malawi's DOF within each EPA provided comprehensive lists of all farmers within their areas during beta testing, in either hard copy or Microsoft Excel spreadsheet. In Salima, random villages were selected from each list and random participants were selected from within each village. In Ntcheu, villages and participants were selected in a similar fashion in conjunction with an extension agent and representatives from BERDO[19]. On each day, surveyors were required to ensure that at least one-third of their surveyed households grew *F. albida* along with maize crops. Forty households were selected in each village given the daily

[19] Only villages within 20 kilometers of the survey team's home base in the town of Balaka were selected for the Ntcheu sample due to an acute fuel shortage. BERDO and extension agents assisted in determining which villages were within this geographic range.

surveying capacity of the team (approximately 25 surveys) and the need for alternates for scheduling conflicts, relocations, deaths, and adequate representation of the intercropping system.

Compared to official government statistics for the Salima and Ntcheu districts, men and individuals with relatively lower levels of education were over-represented in the resulting sample. Whereas the sample contained only 32% and 36% female respondents, for Salima and Ntcheu respectively, Malawi's National Statistical Office estimated rural female populations to be 51% and 52% in these districts. Similarly, the Office estimated primary school completion in rural areas within these regions at 24% in Salima and 40% in Ntcheu compared to 12% and 17% within this sample (Republic of Malawi 2012).

2.2.3 Survey Methods

The questionnaire was initially developed in North Carolina based on similar previous tools (Frey et al. 2012) and faculty consultation. It was then refined significantly in-country based on feedback from country experts and field agents at both ICRAF and Malawi's DOF and local university students. Previous ICRAF surveys conducted to assess the impact of improved fallows in Malawi and Zambia and to establish a baseline food security assessment of Malawi were used to inform soil type, wealth indicator, and production process questions (Akinnifes et al. 2009, Ajayi et al. 2009). Following this process, the tool was beta tested with smallholder maize farmers under the guidance of the researcher, ICRAF field personnel, and DOF extension agents and revised a final time before implementation.

Field work was conducted over a 30 day period with the team visiting one to two villages per day. Two days prior to surveying, representatives from the data collection team and EPA extension office visited with the chief of a new village to review the selected households and ensure availability of participants and adequate sample size given the above criteria. Village chiefs and extension agents also assisted in conducting morning town hall style meetings in each village where the survey goals were communicated.

Each interview began with a review of the informed consent agreement, notifying respondents of the voluntary nature of participation. Only 5 individuals opted out of participation or were unable to complete the full survey due to timing conflicts. Interviews were conducted with each head of household, often with the help of the household member most involved in farming. If the head of household was not available the spouse or main farmer would substitute. Only individuals of at least 18 years of age were interviewed. Questions regarding farmer and household characteristics and maize farming practices were asked within the village in or near an individual's home. Following this, farmers would accompany surveyors to their *F. albida* intercropped fields where physical tree measurements were collected and tree counts were confirmed. The entire process lasted 90 minutes on average.

The following sections briefly describe the data collected to address each of the main objectives stated above. The full household survey tool is attached as Appendix E.

2.2.3.1 Estimation of Costs

Costs for the establishment and maintenance of *F. albida* were collected by planting cohort while costs of establishment, maintenance, and harvest of maize were collected at the farm level and based on initial lists of labor, direct, and indirect costs developed during a similar study of improved fallows in Zambia (Ajayi et al. 2009). Each planting cohort contains all trees established by a single farmer within a given year. This may cover a single or multiple fields. *F. albida* costs were only collected from farmers who established in the 3 years prior to the survey to better ensure accurate recall of activities and inputs. This list was refined and supplemented based on preliminary field testing of the survey tool.

Labor inputs were measured in workdays differentiated by self, friends and family, and hired labor. Information on timing of each activity was also collected. Tables 2.1 and 2.2 below provide the activity lists by major category.

Table 2.1. Establishment, Maintenance, and Harvest Inputs for Maize Farming

Cost Category	Activity
Labor	Nursery (planting, weeding, watering)
	Land preparation
	Ridge/mound making
	Transplanting of seedlings
	Planting of seeds
	Digging of holes
	Fertilizer application
	Manure application
	Herbicide application
	Pesticide application before harvest
	Weeding (first round)
	Harvesting
	Stacking within the field
	Transportation to the village
	Transportation to the house
	Shelling of maize
	Pesticide application to shelled maize (actellic)
	Transportation to market
	Selling at market
Non-Labor, Direct	Seeds
	Manure
	Fertilizer
	Pesticide
	Herbicide
	Plastic bags/Hessian sacks

Table 2.2. Establishment and Maintenance Inputs for *F. albida*-Maize Intercropping System

Cost Category	Activity
Labor	Nursery (planting, weeding, watering)
	Land preparation
	Ridge/mound making
	Transplanting of seedlings
	Digging of holes
	Planting of seeds (hand planting)
	Animal propagation
	Manure application
	Fertilizer application
	Herbicide application
	Weeding
	Watering after planting
	Fencing of young tree
	Pruning
Non-Labor, Direct	Seeds
	Seedlings
	Manure
	Fertilizer
	Herbicide
	Plastic bags or tubes

2.2.3.2 Assessment of Non-Yield Benefits from F. albida

F. albida offer a range of benefits beyond increased soil fertility and maize yield. The most common of these are fodder for livestock, fuelwood, charcoal, and medicinal uses (Barnes and Fagg 2003). Because full yield benefits are not realized until trees are at least 15 years old, it is desirable to understand not only the nature of intermediate benefits, but the age times at which they are expected. Each participant in the survey enumerated past benefits incurred along with benefits expected in future years. In addition, for each past benefit, respondents were asked to estimate the age of the tree when benefits began. Only minor benefits are expected in this area given that pod (animal fodder) production does not begin until age 15 (Baumer 1983) and is not substantial until age 25 (De Montgolfier-Kouevi and

Le Houerou 1980). Additionally, *F. albida* is an inferior fuelwood (Lamprecht 1989) and only yields average quality charcoal (Anon 1982).

2.2.3.3 Estimation of Yield Benefits

Given the complex nature of the relationship between *F. albida* and maize yield for a given field, it was very difficult to isolate the effect of the trees themselves. This study utilized multiple regression to predict maize yield per hectare as a function of: (1) *F. albida* characteristics, (2) farmer characteristics, (3) crop management practices, (4) and physical characteristics of the land (Akinnifesi et al. 2009).

Nineteen key variables were identified under the four major dependent variable categories. Tables 2.3 through 2.6 summarize the key variables and expected coefficient signs within each category.

Measurements of tree count and circumference at breast height in centimeters was collected within each field. Surveyors, accompanied by farmers, visited each field containing *F. albida* after conducting the in-home portion of the survey. All trees were counted and circumference at breast height was measured using tailor's tape. If a field contained more than 10 trees, circumference was only measured on a random sample of 10 of the trees. Basal area was estimated using the circumference of each tree at breast height and an equation predicting circumference at the tree's base as a function of the former. The equation was fitted based on measurements of both variables in a sample of 236 randomly selected *F. albida* trees throughout the survey region[20].

Trees per hectare, diameter at breast height (DBH), and basal area (BA) were expected to exhibit quadratic relationships with yield, signifying that at some point the trees will begin to

[20] Specifically, the fitted equation is $baseCIRC=13.23+0.97bhCIRC+0.0004bhCIRC^2$ with both coefficients highlight significant (at less than 1%) and a model R^2 of 0.97. The quadratic relationship captures the increase in the difference between base and breast height circumference as trees grow larger and provides a more robust fit than a linear relationship.

directly compete with maize crops. Various representations and interactions of these key variables were tested.

In order to perform a meaningful analysis, 13 observations (individual fields) were removed. Five of these were removed due to unreasonable yield (4,000 or more kilograms per hectare) and the remainder for incomplete reporting of key variables or irreconcilable inconsistencies within the data. The resulting database contains 484 unique fields.

Table 2.3. Summary of Tree Characteristics, N=484

	Mean/% Yes	Min	Max	Expected Sign
Presence of trees (=1 if yes)	71%			+
Trees per hectare	9.6	0	79.1	+, quadratic
DBH, CM (field average[21])	26.3	0	132.1	+, quadratic
BA, CM (field average)	1,719	0	20,389	+, quadratic

Table 2.4 summarizes farmer characteristics. The coefficient for the indicator variable for single-female-headed households was expected to be negative. Studies of sub-Saharan Africa have shown that when social and access variables are not considered, female-headed households are less productive than households led by a husband and wife (Udry et al. 1995). Age of head of household, agroforestry training and experience, and level of education are all expected to increase maize yield per hectare. When working with subsistence farmers, direct measurements of wealth are often unavailable due to the lack of formal employment. Building on ICRAF's past experience and surveys, two types of potential wealth proxies were collected: home construction material (exterior and roof materials) and the possession of wealth-indicating household items. Theory predicted a positive relationship as wealthier households may be advantaged in other ways such as access to information or underlying ability.

[21] Field average summary statistics provided in the above table but models test various other metrics: field median, high, and low DBH and BA and total BA for fields with 10 or fewer trees. See Results for further discussion.

Table 2.4. Summary of Farmer Characteristics, N=484

	Mean/ % Yes	Min	Max	Expected Sign
Household type	Husband and wife (77%) = 0 Single male (1%) = 0 Single female (22%) = 1			-
Age of head of household	45.6	18	93	+, quadratic
Agroforestry experience (years)	10.8	0	51	+
Agroforestry training, classes or formal (=1 if yes)	43%			+
Education level of head of household	None (13%) = 0 Primary School (not completed) (58%) = 1 Primary School (completed) (16%) = 2 Secondary school (11%) = 3 Post-secondary school (1%) = 4			+
Wealth proxy (individual indicator variables = 1 if yes for each)	Housing construction materials Burn brick (65%) Mud brick (35%) Roofing materials Iron sheet (20.3%) Thatched/leaves (79.7%) Wealth indicating household possessions Bicycle (54.5%) Mobile phone (32.2%) Radio (57.2%) Television (2.7%) Ox cart (2.5%) Wheel barrow (6.2%)			+

The survey also collected field level information on other crop management practices common in Malawi in order to control for their impact on maize yield. The majority of these are alternative soil fertility enhancements, though type of maize seed is also included. It was expected that all of these enhancements, including the use of some or all hybrid seeds, would increase yield, with the exception of residue burning. Burning reduces the positive impact of biomass integration with soils after a harvest. Table 2.5 presents each of these.

Table 2.5. Summary of Crop Management Practices, N=484

	% Yes	Expected Sign
Use of other agroforestry tree species	60.1%	+
Chemical fertilizer	87.6%	+
Farm yard manure	24.0%	+
Organic compost manure	8.9%	+
Residue burning	21.9%	-
Residue incorporation	31.8%	+
Minimum tillage	5.8%	+
Use of hybrid maize	31.2%	+
Use of mixed hybrid and local maize	22.9%	+

The final set of variables described the physical characteristics of the land on which each farm resided. District was included to capture environmental fixed effects between the two geographic regions (e.g. altitude, climate), and as a result the expected sign was uncertain. Soil fertility was self-assessed by each farmer and was expected to return a positive sign as growing conditions for both trees and maize are superior on higher quality sites. The models include only one soil type[22] (Mkanda) with all others serving as the reference group. Mkanda is used because it is dark and clayey and is locally considered as the most fertile (Kamanga 2002). Due to this preferred status, the expected sign was positive. Table 2.6 summarizes the physical characteristic variables.

[22] Soil type classification was based on a previous survey conducted by ICRAF to measure carbon content in *F. albida* soils building on previous work conducted by Kamanga (2002). Detailed work was conducted during this survey to develop the classification system and descriptions of each. Other soil types were: Mchenga (whitish soil/sandy), katondo (red soil/loamy), mtsilo (blackish with fine particles), and nyata (anthill soil).

Table 2.6. Summary of Physical Characteristics of Land, N=484

	Mean/% Yes	Min	Max	Expected Sign
District	Ntcheu = 0 (50.4%) Salima = 1 (49.6%)			?
Farm location	Wetland (22.5%) = 1 Upland/dambo (77.5%) = 0			+
Soil fertility	Poor (21.1%) = 0 Average (47.9%) = 1 Good (31%) = 2			+
Mkanda soil (=1 if soil is dark/clayey)	66%			+

2.2.3.4 Barriers to Adoption and Continued Use

Acceptability is defined in various ways, but this project used Swinkels et al. (2002)'s definition: farmers' perception of advantages and disadvantages of a technology. In addition to an open-ended qualitative exploration of these, data regarding farmer preferences for certain attributes within agroforestry systems was collected using a ranking exercise. In particular, various authors report that smallholders value flexibility and adaptability over increases in soil fertility or even crop yield (Mekuria 2004, Peters 2002, Sirrine 2010, Mercer and Snook 2004). Other potentially important qualities include decreased variability in income, less susceptibility to droughts (Verchot 2007), and helpful impacts to food security (Sirrine 2010). Consistent with the literature and ICRAF's goals, a list of six characteristics was developed:

1. financial performance,
2. reliability of system,
3. consistency of benefits,
4. system's ability to provide multiple products,
5. system flexibility, and
6. system compatibility with existing farm practices.

The above ranking exercise addressed all agroforestry systems and the decision criteria used when making decisions about general adoption. The qualitative assessment of barriers to adoption sought to understand both the rationale for adoption and perceived barriers specific to *F. albida.* Responders were asked a series of open-ended questions to assess attitudes towards adoption that were not captured elsewhere in the survey. The first question assessed why individual farmers adopted *F. albida* themselves. Two additional questions identified personally experienced disadvantages and gathered opinions on why adoption was not greater within in each community.

Specific language was as follows:

- What are some of the reasons for why you initially adopted the trees?
- What are the disadvantages of planting *F. albida* along with your maize crops?
- Why are there not more *F. albida* and maize systems in this area?

Responses to each question were synthesized and tallied by major theme.

2.3. Results

2.3.1 Demographics

Of the 390 farmers interviewed, 197 interviews originated from Ntcheu and 193 from Salima. Geographic spread was more limited in Ntcheu where the team reached 10 villages within 2 EPAs compared to 12 villages within 4 EPAs in Salima. Other basic demographic information is summarized in Table 2.7 by district.

Table 2.7. Demographics Overview

	Ntcheu	Salima	Combined
Respondent Gender	Female 32% Male 68%	Female 36% Male 64%	Female 34% Male 66%
Age Range	21-86	18-93	18-93
Average Age	48	44	45
Average Household Size[23]	4.8	4.6	4.7
Formal Employment	9%	22%	15%

[23] Includes households containing only 1 individual

On average, each maize farm contained only one field or plot, although some farms contained up to three unique plots. The sample contains a total of 497 plots between the two districts with 248 in Ntcheu and 249 in Salima. Overall, 71% of the plots are maize-*faidherbia* while the remaining fields are maize-only with some limited cases of other maize hybrids (for example, *tephrosia*). In Ntcheu, the maize-*faidherbia* plots account for 70% of the sample compared to 75% in Salima.

Of the plots containing *F. albida*, 33% contained trees which had been planted within three years of the survey. This value did not vary significantly between regions: 34% in Salima and 30% in Ntcheu. The most common years for recent establishment were 2008 (64 farms) and 2009 (63 farms). Major methods for establishing the trees include natural regeneration, community nurseries and animal propagation. Other methods and the regional variations are shown in Table 2.8.

Table 2.8. Recent *F. albida* Establishment methods by Region

	Ntcheu	**Salima**	**Combined**
Individual Nursery	3%	6%	4%
Community Nursery	12%	20%	16%
Animal Propagation	39%	13%	24%
Natural Regeneration[24]	43%	48%	46%
Planting Seeds[25]	3%	14%	9%

Size and number of trees per field also varied by district. In Salima, *F. albida* were both fewer in number and smaller in breast height circumference: 8.7 trees per hectare with an average circumference of 101 CM in Salima compared to 10.5 trees per hectare with an average circumference if 139 CM in Ntcheu.

[24] Includes seedlings maintained directly under existing trees and those transplanted to other locations.
[25] Includes seeds purchase, harvested by farmer, and given by 3rd party.

Farmers who had themselves established *F. albida* were asked if they had personally observed an increase in maize yields after establishment. The responses to this question were positive with 94% answering “Yes” in Ntcheu and 91% in Salima.

2.3.2 Estimation of Costs

2.3.2.1 Timing of Activities

Establishing timelines of *F. albida* and maize crop establishment and maintenance activities is essential to understanding the viability of the intercropping system. Tables 2.9 and 2.10 present the annual timing and prevalence of each of the maize and *F. albida* establishment, maintenance, and harvest activities. Percentages below represent the percentage of respondents participating in each activity in a given month. Darker shading indicates activities which were performed by larger portions of the sample. The overall pattern is very similar between the two districts therefore only the combined table is displayed below.

Table 2.9. Timing and Prevalence, as Percentage of Respondents (N=390) Participating in each Maize Activity[26]

Activity	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Land preparation	0%	0%	0%	0%	1%	5%	25%	41%	18%	14%	1%	0%
Ridge/mount making	1%	1%	0%	0%	0%	1%	1%	12%	31%	41%	15%	1%
Planting	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	49%	50%
Digging holes	1%	0%	0%	0%	0%	0%	0%	0%	0%	2%	10%	12%
Fertilization application	53%	5%	0%	0%	0%	0%	0%	0%	0%	0%	1%	29%
Manure application	7%	1%	0%	0%	1%	0%	1%	3%	6%	10%	5%	5%
Herbicide application	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
Weeding	43%	3%	0%	0%	0%	0%	0%	0%	0%	0%	3%	52%
Harvesting	0%	0%	2%	54%	41%	3%	0%	0%	0%	0%	0%	0%
Stacking within the field	0%	0%	5%	25%	14%	1%	0%	0%	0%	0%	0%	0%
Transport to village	0%	0%	2%	42%	32%	2%	0%	0%	0%	0%	0%	0%
Transport to house	0%	0%	1%	10%	9%	1%	0%	0%	0%	0%	0%	0%
Shelling of maize	0%	0%	0%	1%	10%	18%	5%	6%	1%	2%	0%	0%
Pesticide app. to shelled maize (actellic)	0%	0%	0%	1%	3%	7%	5%	4%	1%	1%	0%	0%
Transport to market	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%
Selling at market	1%	2%	0%	0%	1%	2%	1%	1%	0%	0%	1%	1%

[26] No respondents participated in the following activities for maize: nursery, transplant seedlings, pesticide application before harvest, water after planting.

As seen in Table 2.10, tree related establishment and maintenance activities were far less common, even among the smaller pool of only those respondents reporting new seedlings that had been planted within the three years of the survey. This is likely related to the prominence of passive methods of tree establishment with 70% of recent seedlings resulting from sprouts from existing trees or animal propagation rather than active establishment by farmers or community groups.

Active time periods for major activities associated with *F.albida* (land preparation, digging of holes and transplanting seedlings, and weeding) were similar to those observed for maize, presenting the potential for conflict in labor demand during the peak planting and harvesting seasons especially if labor is relatively scarce during these times. However, the activities conducted were similar between the two crops indicating additional effort may be minimal. For example, because each activity will occur in exactly the same physical location, digging of holes and weeding can be conducted simultaneously for maize and *F. albida*[27].

[27] Average *F. albida* density is low in this sample at 8.7 trees per hectare in Salima and 10.5 trees per hectare in Ntcheu.

Table 2.10. Timing and Prevalence, as Percentage of Respondents Establishing Trees within the Last 3 Years (N=119), of *F. albida* Activities[28]

Activity	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Nursery	0%	0%	0%	0%	0%	1%	2%	3%	3%	5%	1%	1%
Land preparation	1%	0%	0%	1%	3%	11%	5%	12%	5%	1%	2%	1%
Ridge/mount making	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	0%
Transplanting seedlings	8%	0%	0%	0%	0%	0%	0%	0%	0%	1%	5%	13%
Digging holes	2%	0%	0%	0%	0%	3%	0%	1%	1%	3%	10%	5%
Planting	2%	1%	0%	0%	0%	1%	1%	1%	0%	1%	3%	6%
Animal propagation	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%
Manure application	1%	1%	0%	0%	0%	0%	0%	0%	0%	2%	2%	1%
Weeding	13%	3%	1%	3%	4%	6%	13%	10%	4%	5%	1%	16%
Watering after planting	3%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	2%
Fencing of young tree	0%	1%	0%	1%	2%	1%	0%	1%	0%	0%	0%	0%
Pruning	1%	0%	0%	3%	2%	11%	11%	15%	7%	3%	2%	3%

[28] No respondents participated in the following activities for *F. albida*: fertilizer application, herbicide application.

2.3.2.2 Labor Requirements for Major Activities

Evidence above suggests that timing alone should not serve as a barrier to the adoption of intercropped *F. albida* in Malawi. Another potential conflict lies in the additional demand for labor. Table 2.11 presents the average person-days per hectare by major activity for maize related activities. Other maize activities were exclusively a second weeding and/or fertilizer application. There were significant differences in labor demanded for each activity between the two districts, with Ntcheu generally requiring more labor.

Table 2.11. Average Person-Days per Hectare by District for Maize Related Activities

Activity	Ntcheu	Salima	Combined
Land preparation*	96.9	71.1	84.2
Ridge/mount making*	120.9	86.2	103.6
Planting*	10	9.7	9.8
Digging holes	12.6	10.8	11.7
Fertilization application*	13.5	10.6	12
Manure application	57.2	36.8	48.4
Herbicide application		2.2	2.2
Weeding*	81.9	61	71.6
Harvesting*	28.4	20.1	24.3
Stacking within the field	20.3	14.7	17.7
Transport to village*	15.3	9.4	12.4
Transport to house	16	11.1	13.6
Shelling of maize	62	80.4	71.8
Pesticide app. to shelled maize (actellic)	4.3	4.2	4.3
Transport to market	2.2	4.6	3.2
Selling at market	2.4	6.4	4.8
Other1	72.7	46.7	64.4
Other2	42.5	26.5	35.1
Other3		8.5	8.5

Note: * indicates activities reported by 50% or more of the responding households.

Values in Table 2.11 do not reflect overlap in labor between activities, for example when planting and hole digging occurred simultaneously, though this was common. Table 2.12

summarizes the major overlapping activities as reported by the respondents, in order from the beginning to end of the planting season. This is not comprehensive and includes only direct overlap where the same activity is performed by the same group of workers during the same time period.

Table 2.12. Maize Activities with Perfect Overlap of Timing and Individuals

Activity	Count of Simultaneous	Percentage of Respondents
Ridge making and manure application	32	8%
Digging holes and planting	78	20%
Planting and first weeding	22	6%
Fertilizer and manure application	27	7%
Fertilizer application and first weeding	61	16%
Harvesting and stacking in field	71	18%
Harvesting and transporting to village or house	214	55%
Second weeding and fertilizer application	36	9%

Summing only those activities which occurred on 50% or more of the surveyed farms (Table 2.11) and removing time spent transporting maize from the field to the village or house due to frequent overlap (Table 2.12), the average number of person-days spent per hectare during a given season is 413 for Ntcheu, 339 for Salima, and 377 for the combined sample. On average, 41% of person-days were assigned to the head of household or main farmer, 51% to friends and family, and only 8% to hired labor. In both districts, use of hired labor was rare. Farmers hired oxcarts to aid in transporting maize from fields to villages or homes but rarely hired labor for other tasks[29].

Table 2.13 presents average person-days per planting cohort for *F. albida*. Because of the smaller sample size variation between districts was notably higher compared to maize activities. Nursery person-day estimates were dominated by a small number of community nurseries established by entire villages of up to 200 individuals. Respondents were given the

[29] The 8% value corresponds to hired labor for all non-transport activities, compared to 31% of transport labor.

opportunity to inform interviewers of overlapping activities but none did so. Again, reported hours are relatively low given that the majority of respondents passively benefit from trees rather than actively planting.

Table 2.13. Average Person-Days per Hectare by District for *F. albida*-Related Activities

Activity	Ntcheu	Salima	Combined
Nursery	789	458	532
Land preparation	10	31.1	17.7
Ridge/mount making		17	17
Transplanting seedlings	3.6	4.7	4.3
Digging holes	2.2	6.8	4.4
Planting	3.6	5.9	4.9
Animal propagation	1		1
Manure application	2	4.9	4.5
Fertilization application			
Herbicide application			
Weeding*	9.5	9.2	9.3
Watering after planting	2.6	23	10.3
Fencing of young tree	2	1	1.8
Pruning*	23.7	13.9	17.9
Other1[30]		8.3	8.3
Other2		7	7

Note: * indicates activities reported by 50% or more of the responding households that had recently established *F. albida* (N=119).

Table 2.14 presents the summed average person-days for establishment of a single *F. albida* planting cohort by method. Due to the small sample size for group nurseries, this method is not included. Natural regeneration was the most popular option for tree establishment, with 46% of respondents using this method in recent cohorts.

[30] Other activities included watering, a second weeding, a second manure application, and fencing the nursery through each of these was reported only once.

Table 2.14. Average Person-Days for Establishment of *F. albida* by Establishment Method

Establishment Method	Ntcheu	Salima	Combined
Animal Propagation[31]	48.8	78.2	58
Natural Regeneration[32]	53.4	87.8	65.8
Planting Seeds[33]	55.6	95.8	59.7

To compare the average person-days for maize-only farms for those with *F. albida* intercropped with maize, a few adjustments were made to the above data. The average number of person-days spent per hectare on maize related activities (413 for Ntcheu, 339 in Salima, and 377 for the combined sample) was adjusted by a factor representing the average farm size by district, in hectares. This value, effectively the average person-days per farm spent on maize activities is then compared to the requirements for establishment of a single *F. albida* cohort to estimate the required increase in labor necessary to implement a new system.

Table 2.15. Required Increase in On-Farm Labor to Implement *F. albida* System with no Adjustment for Overlapping between Maize and *F.albida* Activities

			Percentage Increase to implement new *F. albida*		
District	**Adjustment Factor**	**Adjusted Maize Person-Days**	*Animal Propagation*	*Natural Regeneration*	*Planting Seeds*
Ntcheu	0.75	310	16%	17%	18%
Salima	0.83	281	28%	31%	34%

The aforementioned overlap in both timing and activity conducted between maize and *F. albida* establishment activities, especially in land preparation, digging of holes and transplanting seedlings, and weeding indicates that the above estimates are likely overstated.

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[31] Includes land preparation, animal propagation, manure application, weeding, watering after planting, fencing of young tree, and pruning.
[32] Includes land preparation, transplanting seedlings, manure application, weeding, watering after planting, fencing of young tree, and pruning.
[33] Includes land preparation, digging holes, planting, manure application, weeding, watering after planting, fencing of young tree, and pruning.

Removing the double counting resulting from overlapping activities from the *F. albida* estimates reduced the average labor increase in Ntcheu to 7% and Salima to 12%.

2.3.3 Assessment of Non-Yield Benefits from F. Albida

The survey assessed the non-yield benefits farmers have already received from the trees along with benefits they expect to receive in the future. The expectation category includes only those benefits which were not already being received. There was no significant difference between the two districts. The most common benefit was fuelwood followed by the various benefits to livestock. Contrary to the literature, medicinal use was uncommon in this sample (Rhoades 1995). Table 2.16 summarizes responses to these questions for the combined sample.

Table 2.16. *F. Albida* Benefits, Received and Expected

Benefit[34]	Currently Receive	Expect to Receive
None	15%	38%
Fuelwood	79%	17%
Shade for livestock	47%	1%
Fodder for livestock	43%	1%
Medicinal	2%	0%
Seeds	1%	2%
Timber	6%	17%

The survey tool also attempted to collect data on farmers' recollection of when each benefit began to accrue and the quantity of benefits that could be quantified. Responses to these questions were quite varied given the abstract nature. On average, respondents recalled beginning fuelwood collection at approximately age 6, livestock benefits at age 4, and timber benefits at age 13, however each of these displayed a significant range of values.

[34] Other benefits described by farmers included windbreaks, seedlings for transplanting to other locations, shade for people, and canoes.

2.3.4 Estimation of Yield Benefits

Two ordinary least squares (OLS) models were specified to estimate yield per hectare. As indicated in the model methodology (Section 2.2.3.3), the list of independent variables was derived from ICRAF's previous study of the impact of improved fallows on maize yields in Malawi (Akinnifesi et al. 2009) and specified to the intercropping system through consultation with ICRAF field agents. Standard errors, and therefore significance levels, for each model are adjusted for household clustering. Because the majority of households hold only one (59%) or two (37%) fields, this had a very minor impact on final results.

F. albida are represented differently in the two models, with base model (Model 1) using only an indicator variable for the presence of a single tree and the second using a more nuanced physical representation based on the density and size of a given field's trees (Model 2). Various other physical representations[35] were tested, but median DBH produced the highest $R^2$and there was little variation in the magnitude or significance of other independent variables in the other models. Household wealth was estimated as both a count variable, with each wealth-indicating variable receiving equal weight, and using principle component analysis, where wealth-indicating variables were intentionally weighted to explain the greatest amount of variation. There composite measures produced only marginally significant coefficients and R^2 values lower than those in the model below which included only the presence of an iron roof as an indicator of wealth.

All significant coefficients have the expected signs described in Tables 2.3 through 2.6. The following variables, which were consistently insignificant, were removed: agroforestry experience and training, use of organic compost manure, education level, and use of a mix of hybrid and local maize seeds. Age has a linear effect on yield as opposed to the anticipated quadratic relationship. Though other coefficients were highly insignificant, coefficients on this variable were marginally significant throughout model specification at approximately

[35] High, average, and low DBH and area at the base of each tree (linear and quadratic).

30%. Female head of household maintained a consistent coefficient throughout the various models but in each case it was only marginally significant (less than 30%). The coefficient held a positive value in each case, typically between 70 and 80kg per hectare. This suggests that all else held equal, women in this sample achieved higher average yields. Though this finding in contrary to previous work in this region (Udry et al. 1995), it suggests that wealth and access have been properly controlled.

Table 2.17 summarizes the coefficients and significance of each variable within the models. Quadratic relationships were tested for each of the predicted quadratic variables from Table 2.3 and 2.4, but are only included below as quadratic if significant.

Table 2.17. Regression Results, Dep. Var.: Maize yield per hectare, mean value is 1,418kg		
Model	**1**	**2**
Tree Characteristics		
Presence of trees (=1 if there is at least 1 tree in field)	168.5+	
Trees per hectare		17.1+
Trees per hectare, squared		-0.2**
Median DBH (CM)		2*
Farmer Characteristics		
Age of head of household	-6.9+	-7+
Single female head of household	75^	77.8^
Iron roof (=1 if home has iron roof)	200+	190+
Crop Management Practices		
Other agroforestry tree (=1 if any other agroforestry tree is used in field) [36]	96.8***	116.1**
Chemical fertilizer (=1 if field uses chemical fertilizer)	172.8*	205.4*
Farmyard manure(=1 if field uses farm yard manure)	91.4***	92.9***
Residue burning (=1 if farmer burns residuals in field)	-158.2*	-165.9*
Residue incorporation (=1 if farmer incorporates residuals in field)	-328.6+	-317.4+
Hybrid maize (=1 if field uses only hybrid maize seeds)	143.4*	120.1**
Physical Land Characteristics		
District (=1 if farm is located in Salima district)	Insig.	88.4***
Location (=1 if farm is located in wetland)	228.3+	230.8+
Soil Fertility (scale from 0-2)	138.8+	124.1+
Mkanda Soil (=1 if soil is dark/clayey)	109.1**	101.1**
Constant	1,183	1,095
Observations (N)	484	484
Adjusted R^2	0.1880	0.2233

Notes: + indicates significance at 1%, * indicates significance at the 5% level, ** at the 10% level, *** at the 20% level, ^ marginally significant at 30%

Irrespective of the metric used to represent *F.albida* within a given field, the impact on maize yield per hectare is positive and meaningful. Magnitude of impact was similar between

[36] Includes the use of any alternative agroforestry tree species. Specific species were tested, but none yielded significant results, likely due to limited sample size in these species. The alternative species included *Tephrosia, Gliricidia, Lucaeuna, Cajanus cajan, Cassia, Senna,* and *Sesbania*.

models with the impact at the average being a 12% increase for Model 1 and 14% for Models 2 and 3 (211kg and 206kg, respectively). This is significantly lower than experimental findings (Garrity et al. 2010) which have shown these intercropping systems to increase yield nearly threefold from unfertilized maize plots. Comparing the average impact of each set of tree coefficients to unfertilized maize plots alone, where the average yield was slightly lower at 1,314 kilograms per hectare, made little difference.

However, as borne out in the establishment methods and establishment and maintenance timelines, this sample population maintains a passive relationship with *F.albida.* Active management could have a profound impact on effectiveness. Further, only 43% of respondents received any training in agroforestry and this was not as a significant variable once age was controlled. This may highlight significant room for more training activities.

Despite its moderate impact compared to previous experimental studies, the impact of *F. albida* is significant. When evaluated as an indicator variable, *F. albida* produced a larger impact than other agroforestry tree species and farm yard manure application. Increases associated with *F. albida* compared well to those seen from the use of chemical fertilizers, which themselves performed far below other observed values (Chibwana 2011). Further, coefficients assigned to *F. albida* tree use are more significant and robust than other crop management practices. Other key variables location on a wetland and soil fertility status. Wetland location likely offers better access to water within soils for maize crops, critically important in this rainfed agricultural setting where only 25 fields were irrigated and no farmers reported watering maize crops.

Controlling for soil fertility, in particular, was crucial to reducing potential endogeneity. Because these data were collected outside of an experimental setting, it is impossible to explicitly prove cause and effect. Without some attempt to control for underlying soil fertility, it is not possible to determine if the trees were planted in more fertile soils or if the trees resulted in more fertile soils (Giller and Cadish 1995, Geiger et al.1992). There is one crucial relationship evident within the data that supports the latter. Soil fertility level is strongly related to both soil type and count of trees; however, soil type is not related to count of trees. This implies that we would not expect to see more trees within soil types recognized as more fertile, a result which is inconsistent with the belief that trees are simply thriving on higher quality, fertile sites.

One unexplainable element is the highly significant and economically meaningful coefficient on residue incorporation. Not only is the magnitude and significance suspect, but also the negative sign accompanying the coefficient. Previous studies (Akinnifesi et al. 2009) have shown residue incorporation to have a positive impact in maize yields in Southeastern Africa. In fact, the data showed a positive correlation between residual incorporation and soil fertility though this did not carry through to the relationship to yield per hectare. The likelihood of residual incorporation was tested against various other variables including presence of livestock and field size but no significant relationships were uncovered. This likely represents an omitted variable bias to be further investigated in future work.

2.3.5 Barriers to Adoption and Continued Use

2.3.5.1 Ranking Exercise

Respondents were asked to rank six characteristics in regards to how they make decisions between different agroforestry systems: compatibility, flexibility, provision of multiple products, reliability, consistency of benefits, and financial benefits. Considerable effort was used in developing the appropriate language for the subtle differences between each of these attributes. While the rest of the survey was written in English and translated to the local language by surveyors after significant training, the ranking question was translated and tested by multiple independent local groups. Initial translations were then revised by an ICRAF intern particularly fluent in English and Chichewa based on extensive conversation with the researcher.

Respondents in both districts assigned the same relative ranking to the system attributes, as depicted in Table 2.18. All differences in rankings are statistically significant at at least the 10% level. Details on significance level are included below. Compatibility with existing practices and flexibility stand out as the defining attributes for these decision makers, followed by availability of multiple products, system reliability, and consistency of benefits. The final attribute, financial performance, is consistently and significantly ranked last.

Table 2.18. Relative Ranking of Agroforestry System Attributes

Attribute	Average Rank[37]
How well the systems combine with existing farm practices – *Compatibility*	4.9+
Flexibility of the systems	4.5+
The systems' ability to *provide multiple products* such as food or fuelwood	3.2*
Your confidence in the systems' ability to provide the promised benefits – *Reliability*	3.1**
Consistency of benefits each year	2.9+
Financial benefits compared to cost of planting trees	2.3

Notes: + indicates significance at 1% between the average rank of this attribute and the next attribute, * indicates significance at the 5% level, ** at the 10% level

2.3.5.2 Qualitative Assessment of Barriers

Whereas the ranking exercise above assessed decision criteria applicable to all agroforestry systems, farmers were also asked open-ended questions to assess their experience with and opinion of *F. albida* in particular.

Two questions were asked to gather firsthand accounts of motivations behind initial adoption of *F.albida* and disadvantages encountered after adoption. Three-hundred-and-two individuals responded to the question regarding motivations for initial adoption, highlighting the tree's positive impact on soil fertility as the primary driver for adoption decisions (89%

[37] Maximum possible rank is 6.

of respondents provided this response). This is noteworthy because it suggests farmers are well-aware of the benefits provided by the trees. Table 2.19 lists the remaining responses.

Table 2.19. Qualitative Responses to Motivation for Initial Adoption of *F. albida*

Motivation	**Count**	**Percentage[38]**
Witnessed friends and/or neighbors experiencing higher yields with *F.albida*	20	7%
Future fuelwood and timber harvest	16	5%
To minimize soil erosion	15	5%
Insufficient access and/or funds for purchase of fertilizer	13	4%

Respondents also listed training by extension agents (6), retention of soil moisture (5), windbreak for maize crops (5), improved soil structure (4), provision of shade (3), and interest in owning a tree (1) as reasons for adoption.

Three hundred farmers answered the question regarding the disadvantages of *F. albida.* Unfortunately, the primary disadvantage farmers encountered after planting the trees is not something easily addressed with outreach. Ninety-five percent of individuals responding to the question listed the thorny branches of *F. albida* as a major disadvantage to maintaining the trees within maize fields. This is a particular issue with younger trees as they are lower to the ground. Thorns both injure farmers during their work and make field work such as weeding and harvest more time consuming as farmers take extra time and care to avoid them. The second major disadvantage, mentioned by 13%, of respondents, is damage to maize crops resulting from branches which break during high winds. Farmers noted that *F. albida* is a relatively weak tree and prone to breaking in windy conditions. Other disadvantages included providing habitat for monkeys which damage maize (8), shading out maize crops (7), difficulty controlling sprouts from existing trees (7), and attraction of livestock for grazing which disturbs maize (3).

The final question asked respondents to describe why adoption was not greater within their community. The goal of this question was to better understand the attitudes of non-adopters

[38] N=302 respondents for this question.

and external factors impacting the use and maintenance of *F. albida*. Responses to this question were varied, but insightful, and highlight some important issues to consider for future outreach activities. Table 2.20 summarizes response to this question within broad categories. This is not a comprehensive list. Sample size for this question was 370.

Table 2.20. Qualitative Responses to Why More Trees not Present in Community

Description	Count	Percentage
The benefits of the tree are not known	116	31%
Lack of seeds or seedlings	58	16%
Farmers unwilling to commit time and effort to establishment and maintenance	44	12%
Unwilling to work with thorns	38	10%
Trees harvested for fuelwood, timber, or charcoal	32	9%
Farmers expect natural, unassisted regeneration (through sprouts) or animal dispersal and do not plant	24	7%
Young trees eaten by livestock	23	6%
Trees are cut down but not replaced	19	5%
Inappropriate soil type or moisture level	19	5%

Many of the issues above could be addressed with increased outreach and extension efforts, especially the lack of knowledge of tree benefits which likely contributes to other issues of farmer unwillingness to invest in trees and harvest for fuelwood and other products without replacement. A smaller number of respondents (less than 10) noted that limited extension activities specific to agroforestry and access to agroforestry clubs and training programs contributed to the lack of adoption. Farmers also suggested technical difficulties that could be ameliorated with additional training including difficult establishing nurseries, low survival rates, and uncertainty over planting methods. Of similar importance are factors not mentioned including land tenure, interference with current maize activities, and delay between establishment and beginning of benefits. While each of these was mentioned, each was only included by 1% or less of the respondents.

2.4. Discussion

2.4.1 System Profitability: Labor vs. Cash

The regression analysis showed that yield increases comparable to those achieved with the use of chemical fertilizer are possible with *F. albida* intercropping. What is more meaningful is comparing the inputs for each system. The establishment of an *F. albida* system requires a lower financial investment though it is more labor intensive. However, this initial investment will continue to deliver yield benefits without significant investment after establishment with very limited further labor input. This is an important differentiation from chemical fertilizer application alone which requires the purchase of expensive inputs each year, often at ever increasing levels (Chirwa et al. 2008). In the year of this survey, the cost of fertilizer for a typical 0.6 hectare field would have been higher than the cost of all other maize inputs (seeds, manure, pesticides, herbicides, and bags[39]); specifically, unsubsidized 50kg bags of chemical fertilizer cost farmers an average of $32.72 (5,000 MK).

Although the establishment of *F. albida* requires only a 7% to 16% increase in labor during the establishment year, the necessary activities directly conflict with the peak labor demand during planting season. While much of Malawi's rural population is not fully employed within a given year, evidence suggests that seasonal labor shortages, aligned with the planting and harvest of maize crops, are acutely felt by smallholder farmers. These shortages lead farmers to make suboptimal decisions such as planting late or cultivating smaller portions of land (Woden 2006, Brummett 2002). Indeed, in a survey conducted in 2003, 45% of Malawian farmers listed labor shortage as a limiting factor in the maximum amount of land available for cultivation, although a much larger portion, 67%, listed lack of access to inputs (predominantly fertilizer and pesticides) as the primary constraint. The same farmers were then asked to identify factors which limit their access to adequate amounts of food. In this exercise, lack of inputs was listed as the primary concern with labor shortage only the fourth most popular response (Tango International 2003). Experimental linear programming

[39] Farmers generally purchased a single bag, and average farm size was 0.6 hectare.

specific to smallholder maize farmers in Malawi reaffirmed these findings, showing that both land and access to credit (and therefore expensive chemical fertilizer) produced higher shadow prices than labor (Alwang 1999).

For this particular sample, household size was tested as a potential independent variable in the yield regression analyses to determine if access to family labor, far more prevalent than hired labor[40], had any impact on yield. Three correlations were tested: total household size, number of male members, and number of female members. In each case, household size coefficient was highly insignificant indicating that labor availability may not be a crucial issue in these communities.

Given the comparable yield impacts between the two technologies, the real question becomes one of applicability to smallholders in this region. In regions where labor is a more limiting factor, fertilizer may be a more desirable option, but in regions where soil fertility and access to credit are more substantial issues, the agroforestry system offers a sustainable and appealing alternative.

2.4.2 Eliminating Barriers to Adoption

The qualitative assessment revealed physical flaws (thorny and weak branches) as primary concerns for existing adopters, though respondents did not consider these major reasons for the lack of further adoption in their communities. Instead, most barriers are directly related to a misunderstanding or limited appreciation of the benefits derived from *F. albida*. Genetic alterations are possible, but it is likely far more cost effective and realistic to focus on outreach activities to better educate farmers on the benefits of this agroforestry system. Additional outreach efforts should be directed towards establishment methods given the relatively frequent mention of nursery issues and dependence on passive establishment methods (sprouting and animal dispersal).

[40] 34% of household reported hiring no labor, while an additional 30% hired labor for only one activity almost always related to transportation of maize from field to the village, home, or market.

As seen in Table 2.20, availability of seeds and seedlings is also a considerable barrier to adoption in these communities. In this context, ICRAF should see to both expand the commercial sale of seeds[41], distribute more seeds through training programs, and expand farmer knowledge of harvesting both seeds and seedlings from their existing trees.

The ranking exercise highlights a crucial next step in increasing the adoption potential of this technology. Recent research touches on this topic in other geographic regions and the same trends were borne out here as well (Mercer and Snook 2004). Smallholder farmer decision makers are not primarily concerned with the economic returns available from a given system. Although it is crucial to fully understand the economics of any system, especially when encouraging adoption, this alone is not the correct path to take when developing outreach and extension materials.

Instead emphasis should be given to *F.albida's* compatibility with existing farming practices and flexibility. Many of the activities required to establish and maintain *F.albida* within fields are compatible with activities already performed for maize crops. Working with trees will, however, require acquisition of new knowledge about tree nurseries and seedling growth and care. Requiring that farmers work additional hours during peak seasons causes direct conflict with the compatibility criteria. Field research should be conducted on the level of conflict this presents based on accepted practices in this region. With only 8 to 10 trees per hectare this would be minor, but in areas with a fuller canopy this may present a substantial barrier.

Similarly, the system only partially meets the flexibility criteria. Once the seeds or seedlings have been established within a field farmers have little capacity to change the system based on their own evolving needs. Fortunately, in experimental settings, *F.albida* has been shown to exhibit a positive impact on cotton yield as well (Garrity et al. 2010). This will at least

[41] Currently, there is only one commercial *F. albida* seed seller in Malawi (Personal communication, Tracy Beedy, July 12, 2011).

maintain the farmer's ability to switch between food and cash crops while maintaining fertilization benefits. Further, farmers may harvest *F. albida* after 3 to 5 years for fuelwood and convert the field to purely agricultural use.

F. albida also works well with the multiple productions, reliability, and consistency attributes. Farmers are very familiar with this species and well aware of the potential for non-yield benefits, especially fuelwood. They are also well aware of its reliable and consistent nature, something particularly evident in a hearty tree species.

2.4.3 Limitations of Study and Potential Future Work.

Due to the development context and time and budget constraints of this study, some limitations exist. Limitations include the incomplete measurement of key variables such as household wealth and physical characteristics of the trees and reliance on farmer recall rather than actual measurements for yield and field size.

Both yield and field size data were based on farmer recall. Although the survey was conducted 3 weeks after harvest to promote accurate recall and time availability, formal recordkeeping is uncommon in these communities and measurement error in yield is probable. Similarly, due to the lack of technology resources, such as Global Positioning Systems (GPS), the field size was based on the farmers' own estimation, further introducing the potential for error. Ideally, collecting physical measurements as the maize is being harvested as well as investigating other methods to determine a more accurate field size should be included in future work. As it is not currently possible to remedy these errors through additional data collection, their impact on the above models must be considered.

Measurement error in the dependent variable (yield) represents classical error, which will produce higher standard errors and therefore smaller t-statistics thus decreasing the likelihood of false positive, or type I, errors. Conversely, this also increases the likelihood of rejecting a significant relationship, which may partially explain the lack of significance in important variables such as agroforestry experience and household type. Measurement error in field size, which is used to calculate trees per acre, represents nonclassical error. Nonclassical error may bias the coefficient on trees per acre towards zero, through attenuation bias which effectively dilutes the impact of the imperfectly measured variable. Acknowledging this error, then, indicates that the coefficient in Table 2.17 represents a minimum estimate of the impact of an additional tree per acre. It is also essential to acknowledge that bias in one coefficient will result in bias in other coefficients.

These factors should be carefully considered, but a closer look at the dependent variable indicates that sample size was great enough to counteract some of the inherent bias of farmer recall. Figure 2 shows the distribution of yield, in kilograms, per hectare from the sample. The blue line represents a normal distribution. Most evident are the artificial peaks at round numbers where respondents clearly round real values near these round values up or down to the nearest ox cart. However, the distribution exhibits a normal pattern overall. Additionally, the official government estimates of maize yield per hectare in Malawi are 1.3 tons per hectare, compared to sample's average of 1.4 tons per hectare, supporting sample validity (Republic of Malawi 2006). Average field size, 0.62 hectares, is also comparable to previous studies in this region: 0.6 hectares (Brummett 2002) and 0.8 hectares (Wodon 2006).

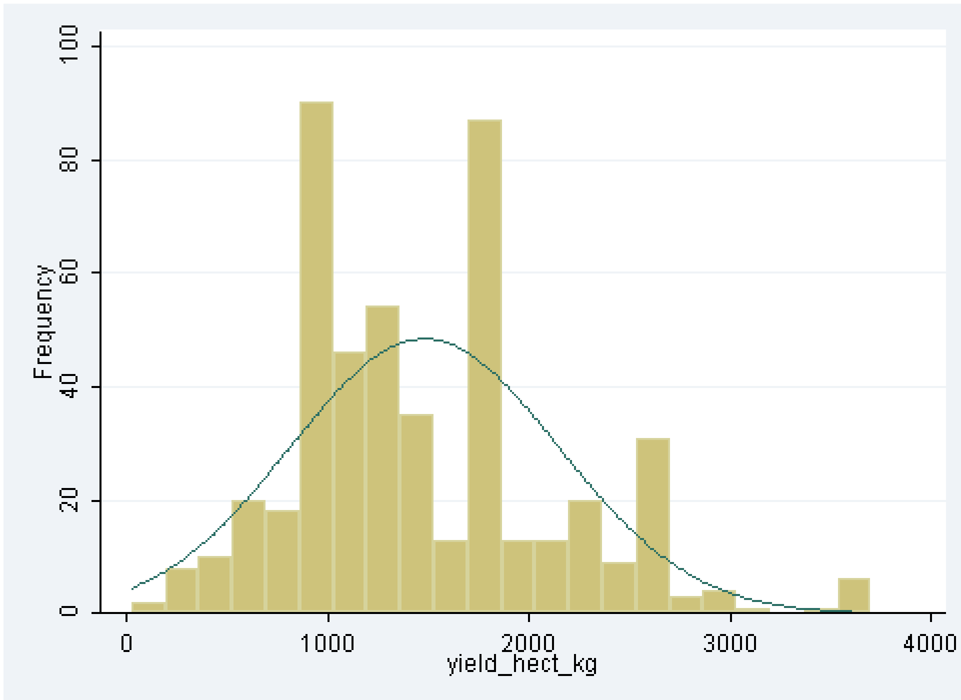

Figure 2.2. Yield per Hectare, in Kilograms, Histogram

2.5 Conclusions

Within this sample, intercropping of *F.albida* among maize crops in Malawi requires only modest, between 7 and 12%, increases in farm labor. Further, these increases are temporally well aligned with existing maize activities which could allow farmers to more efficiently establish and maintain the trees within existing fields.

The econometric analysis consistently linked meaningful increases in maize yield to the presence, density, and size of *F. albida* trees within a field. Maize yield improved related to the trees ranged from 169 to 211kg per hectare depending on the metric used to evaluate the trees. This is comparable with increases related to the use of chemical fertilizers and exceeds those related to other farm management practices including other fertilizer tree species, use of hybrid maize seed, and application of farmyard manure.

While the improvements related to both *F. albida* and chemical fertilizer are substantially lower than what has been observed in experimental settings. This is related to several factors. First, the vast majority of farmers with trees within their maize fields benefit from them passively rather than actively seeking to increase tree population or maximize non-yield benefits (fuelwood, livestock fodder, etc.). Additionally, less than half of the respondents have participated in formal agroforestry training. Improved management and training could substantially contribute to the effectiveness of both *F. albida* and chemical fertilizer.

Though increases of 169 to 211kg per hectare fall short of experimental settings, both are considerable for these communities According to official Malawi government estimates, farmers should allocate 150kg per year to feed a single child and 300kg per year to feed a single adult (Zodiac Radio, July 2011). Yield increases from *F. albida* alone, then, provide enough additional food to feed a single child for a full year, or an adult for more than 6 months.

The key difference between the demands of the *F. albida* intercropping system and chemical fertilizer application is the type of input required. While *F. albida* requires a larger increase in labor requirements, the financial obligation is minimal. Chemical fertilizers involve the inverse: large financial expenditures and relatively small labor adjustments. The *F.albida* system is more applicable to this population where financial constraints are far more substantial than labor constraints. The models also indicate that chemical fertilizer and *F. albida* may be used in conjunction for even greater benefits than each can provide alone.

The survey also worked to better understand farmer identified barriers to increased adoption, first with a series of open-ended questions. In these questions farmers clearly articulated to need for increased outreach and education, citing that the primary reason trees are not more prevalent in their communities is lack of awareness of the trees' various benefits. There is also substantial room for training, especially as it relates to establishment and care and protection of young trees.

Understanding the decision criteria farmers use to make decisions about agroforestry systems will allow ICRAF to better tailor future programs and outreach materials. The ranking exercise clearly showed that farmers value system flexibility and compatibility with existing practices above other considerations. *F. albida* is well suited on the compatibility criteria though outreach materials should directly address ways in which it is flexible, as this is more nuanced.

REFERENCES

Alavalapati, J., Stainback, G. & Carter, D. (2002). Restoration of the longleaf pine ecosystem on private lands in the U.S. South: an ecological economic analysis. *Ecological Economics*, *40*(3), 411-419.

Alavalapati, J., Stainback, G. & Matta, J. (2006). Longleaf pine restoration: economics and policy. *The Longleaf Pine Ecosystem: Ecology, Silviculture, and Restoration* (pp. 403-412). Springer.

Alwang, J., & Siegel, P.B. (1999). Labor shortages on small landholdings in Malawi: Implications for policy reforms. *World Development 27* (8), 1461-1475.

Ajayi, O., Akinnifesi, F, Sileshi, G & Kanjipite, W. (2009). Labour inputs and financial profitability of conventional and agroforestry-based soil fertility management practices in Zambia. *Agrekon 48*(3), 276-292.

Akinnifesi F., Sileshi, G., Franzel, F., Ajayi, O.,Harawa, R., Makumba, W., Chakeredza, S., Mngomba, S., de Wolf, J., Chianu, J. (2009). On-farm assessment of legume fallows and other soil fertility management options used by smallholder farmers in southern Malawi. *Agricultural Journal 4*(6), 260-271.

ANON, (1982). Short monograph on *Acacia albida* del., troisieme comite recherche forestitiere, Institut de Recherche en Biolgie et Ecologie Tropicale, Ouagadougou, Republique de Haute Volta, 30-31 Novembre.

Baldwin, V. & Saucier, R. (1983). *Aboveground weight and volume of unthinned, planted longleaf pine on West Gulf forest sites.* U.S. Forest Service Research Paper SO-RP-191. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Barnes, R. & Fagg, C. (2003). *Faidherbia albida*: *Monograph and annotated bibliography.* Tropical Forestry Papers No 41, Oxford Forestry Institute, Oxford, UK.

Bartlett, J., Kotrlik, J., Higgins, C.C. (2001). Organizational research: Determining appropriate sample size in survey research. information . *Technology, Learning, and Performance Journal 19*(1):43-50.

Baumer, M. (1983). *Faidherbia albida.* In *Notes on trees and shrubs in arid and semi-arid regions.* Rome, Italy: EMASAR Phase II/FAO, Plant Production and Protection Division 165-181.

Bayon, R. (2002) A Bull Market In…. *The Milken Institute Review (1)*: 30-39.

Bechtold, W.A., & Ruarck G.A. (1988). Structure of pine stands in the southeast. U.S. Forest Service Research Paper SE-274. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Blevins, D., Allen, H., Colbett, S., & Gardner, W. (1996). Nutrition management of longleaf pine straw. North Carolina State University. Woodland Owner Notes WON-30, NC Cooperative Extension Service.

Beedy, T., Place, F., Bayala, J., Kalinganire, A. (2011). Targeted food security and carbon benefits from soil fertility replenishment agroforestry technologies. In *Increasing Agricultural Productivity & Enhancing Food Security in Africa*, Addis Ababa, Ethiopia.

Brooks, J.R. & Jack, S.B. (2006). A whole stand growth and yield system for young longleaf pine plantations in Southwest Georgia. P. 317-318 in *Proceedings of the 13th Biennial Southern Silvicultural Research Conference*, Conner, Kristina F.(ed.). U.S. Forest Service General Technical Report SRS-92.

Brummett, R.E. (2002.) Seasonality, labor and integration of aquaculture into Southern African smallholder farming systems. *Naga - The ICLARM Quarterly, 25*(1).

Central Intelligence Agency (2010) *The World Factbook 2010: Malawi*. Washington, DC. https://www.cia.gov/library/publications/the-world-factbook/index.html.

Chastain, J.P., Rollins, P.A., & Riek, M. (2007). Using poultry litter to fertilize longleaf pine plantations for enhanced straw production. *American Society of Agricultural and Biological Engineers Annual Meeting*, St. Joseph, Michigan.

Chibwana, C., Fisher, M., & Shively, G. (2012). Cropland allocation effects of agricultural input subsidies in Malawi. *World Development*. *40*, 124-133.

Chirwa, P.,Akinnifesi, F., Sileshi, G., Syampugani, S., Kalaba, F. & Ajayi, O (2008). Opportunity for conserving and utilizing agrobiodiversity through agroforestry in Southern Africa. *Biodiversity & Agriculture, 9*(2); 45-48.

Clutter, J.L. (1963). Compatible growth and yield models for loblolly pine. *Forest Science*. *9*, 354:371.

Cram, M.M., Outcalt, K.W., & Zarnock S.J. (2010). Growth of longleaf and loblolly pine planted on South Carolina Sandhill sites. *Southern Journal of Applied Forestry*, *34*(2), 79-83.

Cubbage, F.W. & Hodges, D. (1990). The economics of managing longleaf pine. P. 215-229 in *Proceedings of the Symposium on the Management of Longleaf Pine*, Farrar, R.M. (ed.) U.S. Forest Service Technical Report SO-75.

Cubbage, F.W., Glenn, J.V., Mueller, J.P., Robison, D., Myers, R., Luginbuhl, J., Meyers, R. (2012a). Early tree growth, crop yields, and estimated returns for an agroforestry trial in Goldsboro, North Carolina. *Agroforestry Systems.*

Demers, C., Long, A. & Minogue P. (2004). Longleaf pine regeneration. University of Florida SS-FOR-13, IFAS Extension.

Dennington, R.W., & Farrar, R.M. (1991). Longleaf pine management. Forestry Rep. R8-FR 3. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region.

Dickens, D.E., Moorhead, D., Bargeron, C., & McElvany, B. (2011). Pine straw yields and economic benefits when added to traditional wood products in loblolly, longleaf and slash pine stands. University of Georgia.

Dickens, D.E., Moorhead,, D., Hicks, R., & McElvany, B. (2010). Longleaf pine growth and economics on old-field planted sites in Georgia – results through age 21years in *SOFEW Proceedings*, Mississippi State University, Starkville, MS.

Farrar, R. (1985). Volume and Growth Predictions for Thinned Even-Aged Natural Longleaf Pine Stands in the East Gulf Area. U.S. Forest Service Research Paper SO-220. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Forest2Market (2011). North Carolina Timber Report, Southeast North Carolina Stumpage Prices, 4th Quarter.

Forest2Market (2012). North Carolina Timber Report, Southeast North Carolina Stumpage Prices, 2nd Quarter.

Frey, G.E., Fassola, H.E., Pachas, A.N., Colcombet, L, Lacorte S.M., Perez O., Renkow M., Warren S., Cubbage, F. (2012). Perceptions of silvopasture systems among adopters in northeast Argentina. *Agricultural Systems 105*, 21-32.

Frost, C.C. (1993). Four centuries of changing landscape patterns in the longleaf pine ecosystem. P. 17-43 in *Proceedings of the Tall Timbers Fire Ecology Conference, No. 18, The longleaf pine ecosystem: ecology, restoration and management*. Tallahassee, Fl.

Garrity, D., Akinnifesi F., Ajayi, O., Sileshi, W., Mowo, J., Kalinganire, A., Larwanou, M., and Bayala, J. (2010). Evergreen agriculture: A robust approach to sustainable food security in Africa. *Food Security 2* (3), 197-214.

Geiger, S.C., Vandenbeldt, R.1. & Mann, A. (1992). Pre-existing soil fertility and the variable growth of Faidherbia albida. In: Faidherbia albida in the West African Semi-arid Tropics: Proceedings of a Workshop, 22-26 April 1991, Niamey, Niger.

Giller, K.E. and Cadisch, G. (1995). Future benefits from biological nitrogen fixation: An ecological approach to agriculture. Kluwer academic publishers. Netherlands. 21pp.

Gresham, C.A. (1982). Litterfall patterns in mature loblolly and longleaf pine stands in coastal South Carolina. *Forest Science 28*(2): 223-231.

Gresham, C.A. (1982). Litterfall patterns in mature loblolly and longleaf pine stands in coastal South Carolina. *Forest Science 28*(2): 223-231.

Hamilton, R. (1995). Forest Soils and Site Index. Woodland Owner Notes WON-07, NC Cooperative Extension Service.

Haywood, J.D. (2002). Delayed prescribed burning in a seedling and sapling longleaf pine plantation in Louisiana. 103-108 in *Proceedings of the 11th Biennial Southern Silvicultural Research Conference*, Outcalt, K.W (ed.). U.S. Forest Service General Technical Report SRS-GTR-48.

Haywood, J.D. (2009). Influence of pine straw harvesting, prescribed fire, and fertilization on a Louisiana longleaf pine stand. *Southern Journal of Applied Forestry 33*(3), 115-121.

Hepp, T.E. (1994). WINYIELD 1.0, a Windows-based forest growth, yield, and financial analysis tool for southern forests. Tennessee Valley Authority, Norris, TN.

Johnson, R. (2011). The economics of longleaf pine management: a road to making dollars and sense. Accessed at: http://ncforestservice.gov/publications/LongleafLeaflets/LL07.pdf.

Kamanga, B.C.G. (2002). Understanding the Farmer's Agricultural Environment in Malawi. Risk Management Projects Working Paper Series 02-01, International Maize and Wheat Improvement Center, Mexico.

Kessler, G. & Straka, T. (1991). Economics of longleaf management. Presented at *Establishing and Managing Longleaf Pine Workshop*. Sumter, South Carolina.

Klemperer, W.D. (2003). *Forest resource economics and finance.* McGraw-Hill, USA.

van Kooten, G.C. & Bulte, E.H. (2000). *The economics of nature*. Blackwell Publishers, Massachusetts.

Kush, J.S., Goelz, J.C.G.,Williams, R.A., Carter, D.R., & Linehan, P. (2006). Longleaf pine growth and yield. *The Longleaf Pine Ecosystem: Ecology, Silviculture, and Restoration* (pp. 403-412).

Lamprecht, H. (1989). *Acacia albida.* In *Silviculture in the Tropics.* Eschborn, Germany; Deutsche gesellshaft fur technische zusammenarbeit (GTZ) (1989) 216-217.
Lancia, R.A., Roise, J.P., Adams, D.A. & Lennartz, M. (1989). Opportunity cost of red-cockaded woodpecker management. *Southern Journal of Applied Forestry 13*(2), 81-85.

Lander, J.L., Van, L., David, H. & Boyer, W.D. (1995). The longleaf pine forest of the southeast: requiem or renaissance? *Journal of Forestry 93*, 39-43.

van Lear, D.H, Carroll, W.D., Kapelpuck, P.R. & Johnson, R. (2005). History and restoration of the longleaf pine-grassland ecosystem: Implications for a species at risk. *Forest Ecology and Management 211*, 150-165.

Lee Jenni, G.D., Peterson, M.N., Cubbage, F. W., and Jameson, J. K.. (2012). Assessing biodiversity conservation conflict on military installations. *Biological Conservation 153*, 127-133.

Lennartz, M.R., Hooper, R. (1979). Tree age and cavity initiation by red-cockaded woodpeckers. *Journal of Forestry 77*, 102-103.

Lohrey, R.E. & Bailey, R. (1977). Yield tables and stand structure for unthinned longleaf pine plantations in Louisiana and Texas. U.S. Forest Service Research Paper. SO-130, New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Mills, S.D. & Stiff, C.T. (2008). Financial performance of loblolly and longleaf pine plantations. FORSight Resources, Inc., North Charleston, SC.

North Carolina Forest Service (NCFS) (2011). Prevailing rates for sub-practices: NC forest development program FY 2011-2012. Accessed from http://ncforestservice.gov/Managing_your_forest/pdf/FDP+Prevailing+Rates.pdf.

NC State University (2011a). Corn-Conventional Till-NC, Coastal Plain, 2010. Department of Agricultural and Resource Economics, NC State University. http://www.ag-econ.ncsu.edu/extension/budgets/corn/2010/Corn100-CT-CoastalPlain2010.pdf; http://www.ag-econ.ncsu.edu/extension/Ag_budgets.html. Accessed 2 February 2011.

NC State University (2011b). Soybeans-Full Season, Conventional Tillage 2010. Department of Agricultural and Resource Economics, NC State University. http://www.ag-econ.ncsu.edu/extension/budgets/wheat/SoybeanFullConv2010.pdf ; http://www.ag-econ.ncsu.edu/extension/Ag_budgets.html. Accessed 2 February 2011.

Newell, R.G. & Pizer, W.A. (2004). Uncertain discount rates in climate policy analysis. *Energy Policy 32*:519-529.

Outcalt, K.W. & Sheffield, R.M. (1996). The longleaf pine forest: Trends and current conditions. U.S. Forest Service Resource Bulletin. SRS-RB-9.
Phombeya, H.S.K., Simmons, E. and Giller, K.E. (2005). Farmers' perception of the value of *Faidherbia albida* trees in the farming system of Central Malawi. *African Crop Science Conference Proceedings* 7, 1459-1463.

Reave, D.W., Randall, K.A. & Holmes, T.P. (1995). Economic valuation of the red-cockaded woodpecker and its habitat. P. 219-224. *Red-cockaded woodpecker: recovery, ecology and management,* Kulhave, D., R.G. Hooper & R. Costa (eds.). A Center for Applied Studies in Forestry, Texas.

Rodriguez, S. L., Peterson, M. N., Cubbage, F. W., Sills, E. O., Bondell, H.D. (2012). Private landowner interest in market based conservation incentive programs for endangered species. *Wildlife Society Bulletin*: In Press.

Roise, J.P., Chung, J. & Lancia, R. (1991). Red-cockaded woodpecker habitat management and longleaf pine straw production: An economic analysis. *Southern Journal of Applied Forestry*, *15*(2), 88-92.

Row, C., Sessions, J., & Kaiser, F. (1981). Discount rate for long-term Forest Service investments. *Journal of Forestry 79*(6), 367-376.

Schumacher, F.X. & Coile, T.S. (1960). Growth and Yields of Natural Stands of the Southern Pines. Durham, NC: School of Forestry and Environmental Sciences, Duke University.

Siry J., Cubbage, F.W., & Malmquist, A. (2001). Growth, yield and returns for southern pine forestry investments. *Forest Products Journal 51*(3), 42-48.

Smith, W. & Hafley, W. (1986). North Carolina State University, Natural stand growth and yield model (NATYIELD).

South, D.B. (2006). Planting longleaf pine at wide spacings. *Native Plants Journal, 7*(1), 79-88.

Tango International. 2003. *Malawi Baseline Survey: Report of Findings*. C-Safe.
Timber Mart-South (2011). North Carolina Timber Report, Southeast North Carolina Stumpage Prices, 4th Quarter.

Udry C, J. Hoddinott, H. Alderman & Haddad, L. (1995). Gender differentials in farm productivity: implications for household efficiency and agricultural policy. *Food Policy*, 20(5), 407-423.

U.S. Fish and Wildlife Service (2003). Recovery plan for the red-cockaded woodpecker (*Picoides borealis*): second revision. U.S. Fish and Wildlife Service, Atlanta, GA. 296 p.

USDA NRCS (2012a). North Carolina Longleaf Pine. Accessed from http://www.nc.nrcs.usda.gov/programs/EQIP/Longleaf_Pine_North_Caorlina.html.

USDA NRCS (2012b). 2012 Payment Schedule, Longleaf Pine. Accessed from http://www.nc.nrcs.usda.gov/programs/EQIP/2012_LLP_Payment_Schedule.pdf.

USDT (2012). U.S. Department of Treasury historic treasury rates chart, January 2011 to December 2011. Retrieved August 15, 2012 from http://www.treasury.gov/resource-center/data-chart-center/interest-rates/pages/textview.aspx?data=yield

USMC Base Camp Lejeune, "About the Base." (n.d.). Retrieved December 21, 2011, from http://www.lejeune.usmc.mil/about/

Wahlenberg, W.G. (1946). *Longleaf pine: Its use, ecology, regeneration, protection, growth, and management*. Charles Lathrop Pack Forestry Foundation and U.S. Forest Service, Washington DC.

Wagner, J.E. (2012). *Forestry economics: A managerial approach*. Routledge. New York.

Wagner J.E., Cubbage F.W., & Redmond C.H. (1995). Comparing the capital asset pricing model and capital budgeting techniques to analyze timber investments. *Forest Products Journal 45*(7/8), 69–77.

White, F.M. (1988). *Establishment and growth of longleaf pine on droughty sites in North Carolina.* North Carolina Forest Service Note No. 61.

Wodon, Q., & Beegle, K. (2006). Labor shortages despite underemployment? Seasonality in time use in Malawi. *Gender, Time Use, and Poverty in sub-Saharan Africa* (edited by Mark Blackden and Quentin Wodon, World Bank Working Paper) (January 2006): pp. 97-116.

Wood, G.W. & Kleinhofs J. (1995). Integrating timber management and red-cockaded woodpecker conservation: the George-Pacific Plan. *Red-cockaded woodpecker: recovery, ecology and management,* Kulhave, D., R.G. Hooper & R. Costa (eds.). A Center for Applied Studies in Forestry, Texas.

APPENDICES

Appendix A: Expanded Longleaf Pine Growth and Yield Review

Author(s)	Pub. Year	Title	Detail	Management	Geography	Thin	Input Parameters
USFS	1976	Volume, yield, and stand tables for second-growth southern pines	Stand	Natural	US South	No	Age, Site index
Lohrey	1979	Predicted growth of longleaf pine planted on cutover forest sites in the West Gulf	Stand	Planted	West Gulf	Yes	
Saucier et al.	1981	Green weight, volume, board-foot, and cord tables for the major southern pine species	Tree				Individual tree
Farrar	1981	Cubic-foot volume, surface area, and merchantable height functions for longleaf pine trees	Tree				Individual tree
Baldwin et al.	1981	Taper functions for unthinned longleaf pine plantations on cutover West Gulf sites	Tree	Planted	West Gulf	No	Individual tree
Baldwin et al.	1983	Above ground weight and volume of unthinned, planted longleaf pine on West Gulf forest sites	Tree	Planted	West Gulf	No	Individual tree
Lohrey	1983	Stem volume prediction and crown characteristics of thinned longleaf pine plantations	Tree	Planted		Yes	Individual tree
Thomas, et al.	1995	Biomass and taper for trees in thinned and unthinned longleaf pine plantations	Tree	Planted	LA, TX	Both	Individual tree
Shaw et al.	2007	A density management diagram for longleaf pine stands with application to red-cockaded woodpecker habitat	Stand	Natural and planted	US South	Some	Quad. mean diameter, TPA
Brooks et al.	2007	Compatible stem taper, volume, and weight equations for young longleaf pine plantations in SW GA	Tree	Planted	Southwest GA	No	Individual tree

Appendix B: Longleaf Pine Growth and Yield Figures, SI 70

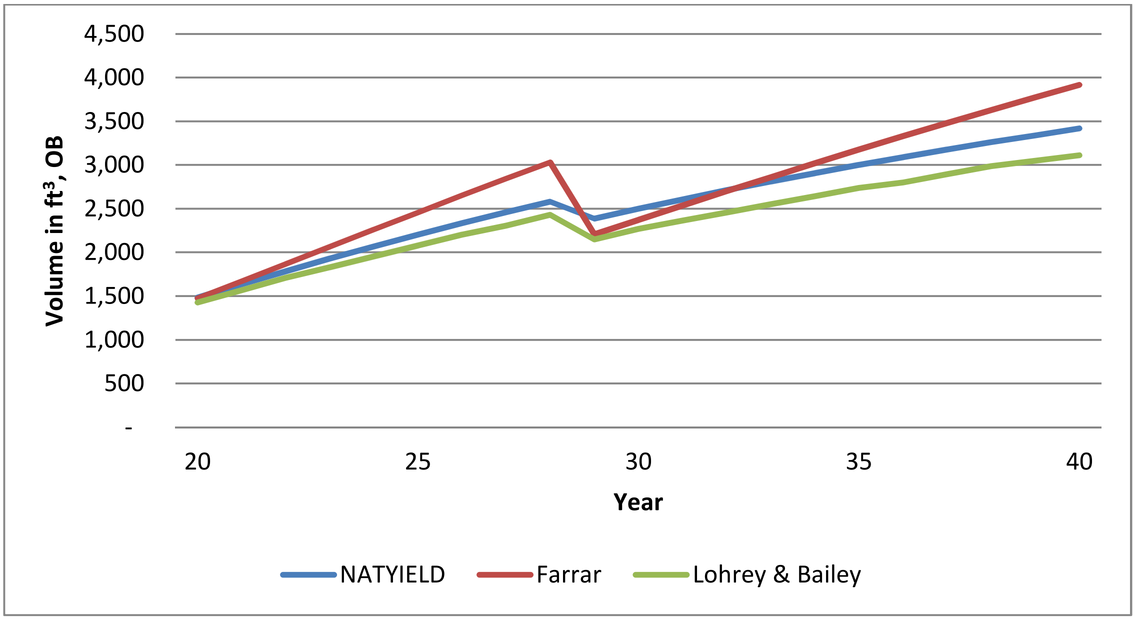

Figure B1. Longleaf outer bark volume over time, max timber, SI 70

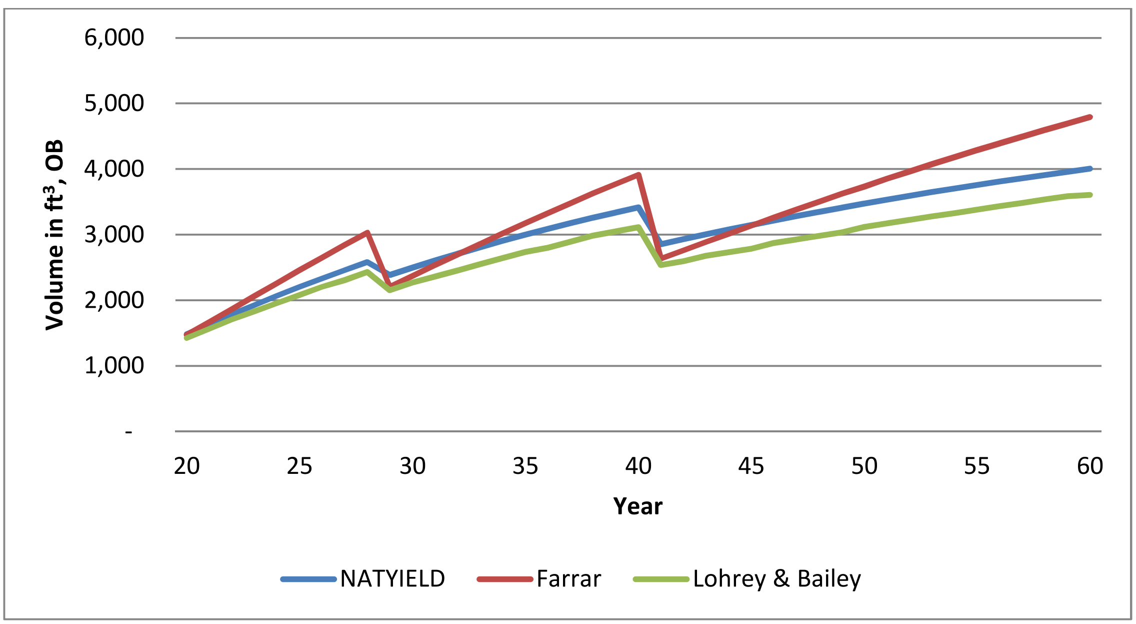

Figure B2. Longleaf outer bark volume over time, multiple products, SI 70

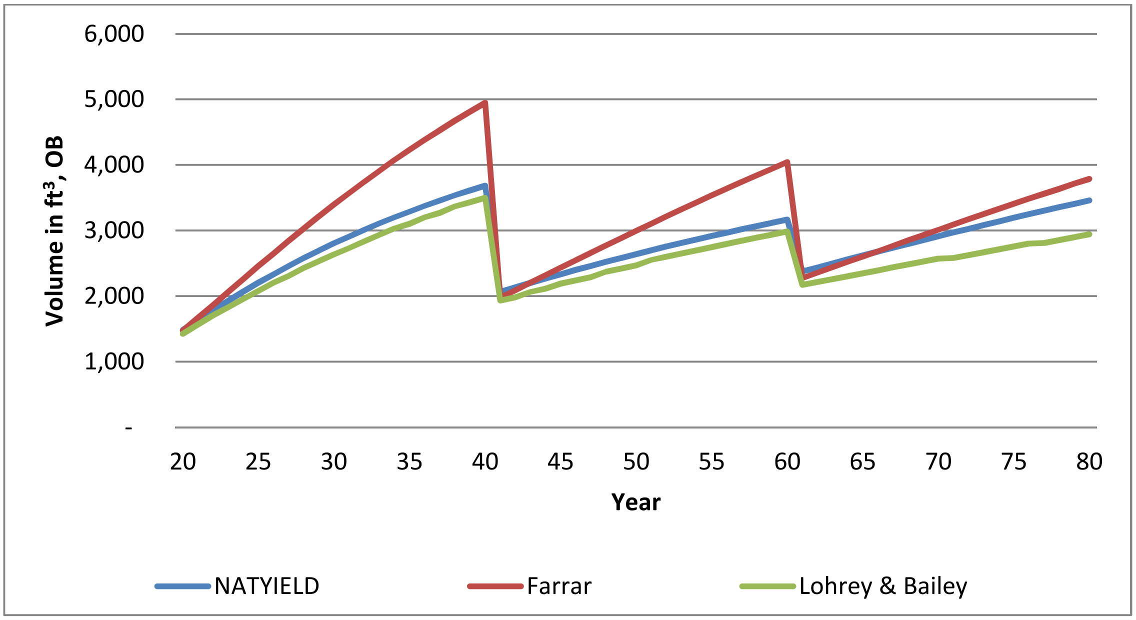

Figure B3. Longleaf outer bark volume, ecosystem services without pine straw, SI 70

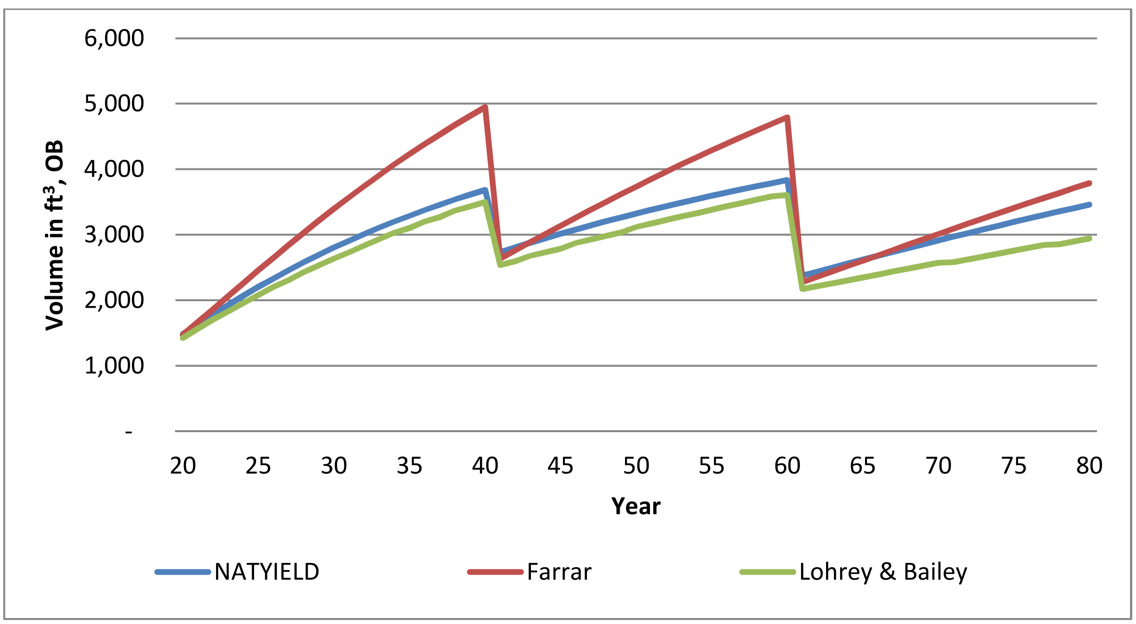

Figure B4. Longleaf outer bark volume, ecosystem services with pine straw, SI 70

Appendix C: Longleaf Pine Growth and Yield Figures, SI 80

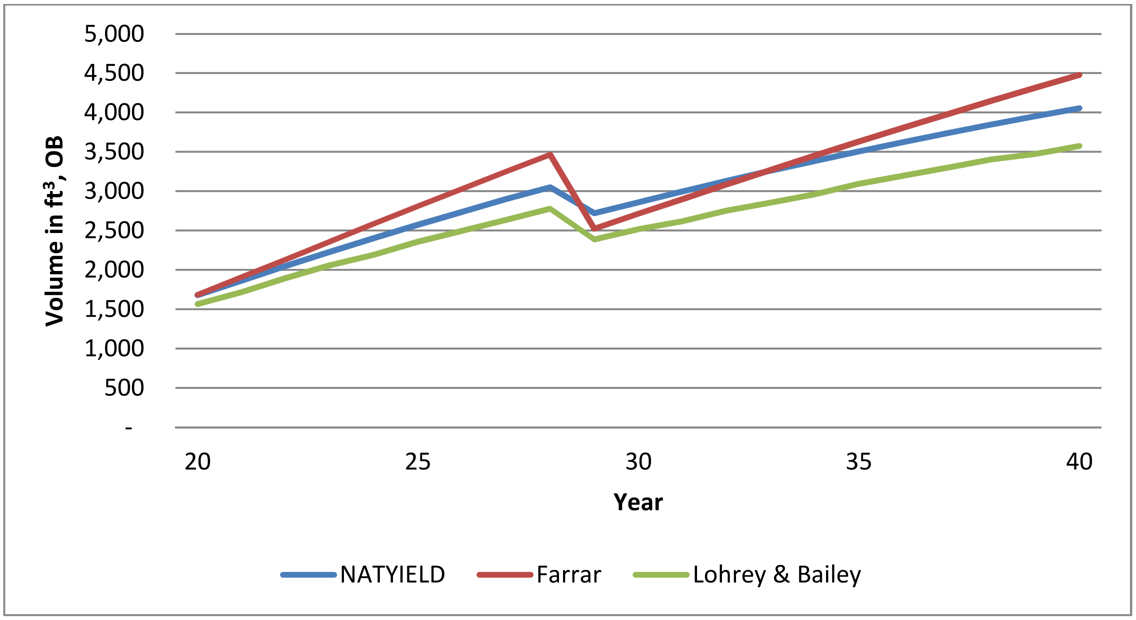

Figure C1. Longleaf outer bark volume over time, max timber, SI 80

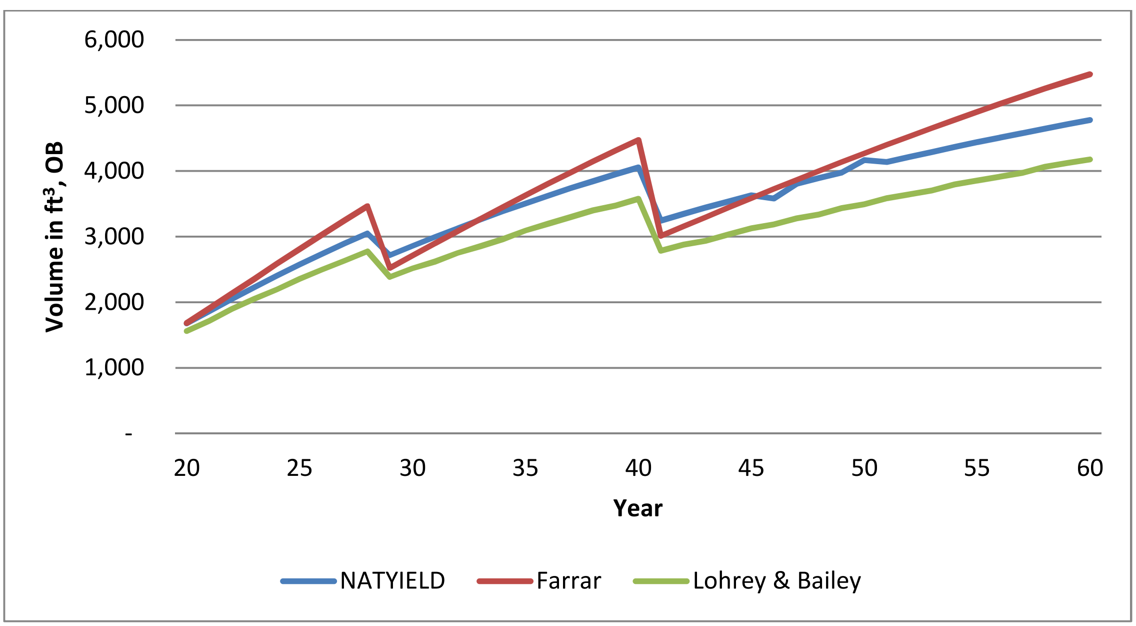

Figure C2. Longleaf outer bark volume over time, multiple products, SI 80

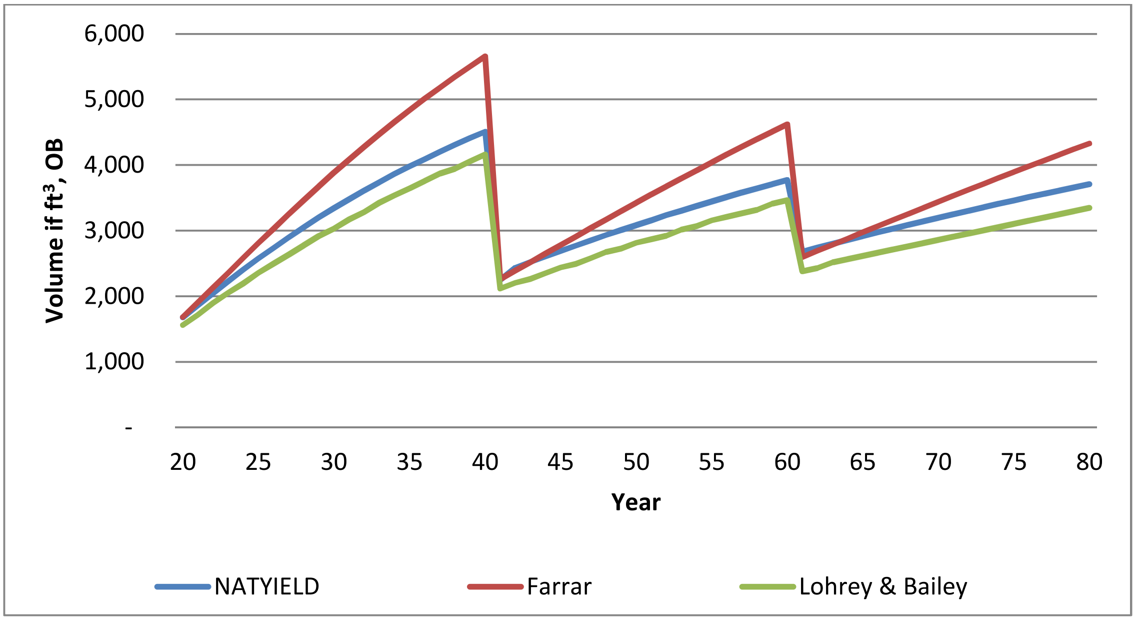

Figure C3. Longleaf outer bark volume, ecosystem services without pine straw, SI 80

Figure C4. Longleaf outer bark volume, ecosystem services with pine straw, SI 80

Appendix D: Full High Price Longleaf Pine Sensitivity Analysis Results

Table DI. High Price Financial Returns per Acre, 4%, Site Index 60

Scenario	NATYIELD			Farrar			Lohrey and Bailey		
No Pine Straw	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$111	$6	$140	$338	$17	$426	$99	$5	$125
Multiple Products	($123)	($5)	($136)	$225	$10	$248	($110)	($5)	($122)
Ecosystem Services	($365)	($15)	($382)	$60	$3	$63	($340)	($14)	($356)
Conservative	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$304	$15	$384	$531	$27	$670	$292	$15	$369
Multiple Products	$92	$4	$102	$440	$19	$486	$105	$5	$116
Ecosystem Services	($123)	($5)	($129)	$314	$13	$328	($93)	($4)	($97)
Moderate	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$461	$23	$582	$688	$35	$869	$449	$23	$567
Multiple Products	$260	$12	$288	$608	$27	$672	$273	$12	$302
Ecosystem Services	$34	$1	$36	$471	$20	$493	$64	$3	$67

Table D2. High Price Financial Returns per Acre, 4%, Site Index 70

Scenario	NATYIELD			Farrar			Lohrey and Bailey		
No Pine Straw	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$274	$14	$347	$465	$23	$587	$214	$11	$271
Multiple Products	$31	$1	$35	$339	$15	$375	$6	$0	$6
Ecosystem Services	($223)	($9)	($233)	$168	$7	$176	($230)	($10)	($241)
Conservative	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$467	$24	$590	$658	$33	$831	$408	$21	$515
Multiple Products	$246	$11	$272	$554	$25	$613	$221	$10	$244
Ecosystem Services	$11	$0	$11	$413	$17	$432	$14	$1	$14
Moderate	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$625	$32	$789	$815	$41	$1,030	$565	$29	$713
Multiple Products	$414	$18	$458	$722	$32	$798	$389	$17	$430
Ecosystem Services	$168	$7	$176	$571	$24	$596	$171	$7	$179

Table D3. High Price Financial Returns per Acre, 4%, Site Index 80

Scenario	NATYIELD			Farrar			Lohrey and Bailey		
No Pine Straw	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$446	$23	$563	$611	$31	$772	$342	$17	$432
Multiple Products	$198	$9	$218	$471	$21	$520	$139	$6	$154
Ecosystem Services	($59)	($2)	($61)	$292	$12	$305	($91)	($4)	($95)
Conservative	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$639	$32	$807	$804	$41	$1,015	$535	$27	$676
Multiple Products	$412	$18	$456	$686	$30	$758	$354	$16	$391
Ecosystem Services	$162	$7	$170	$527	$22	$551	$150	$6	$157
Moderate	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*	*NPV*	*AEV*	*SEV*
Max Timber	$796	$40	$1,005	$961	$49	$1,214	$693	$35	$875
Multiple Products	$581	$26	$642	$854	$38	$943	$522	$23	$577
Ecosystem Services	$320	$13	$334	$684	$29	$715	$307	$13	$321

Appendix E: *F. Albida* Economics Household Survey Tool

Informed Consent

We are asking that you participate in a study regarding the profitability of *Faidherbia albida (nsangu)* trees led by the World Agroforestry Centre (ICRAF) and North Carolina State University (NCSU).

If you agree to participate in this study, we request that you answer some questions regarding the characteristics of your household, business, rents and costs, use of the *nsangu* and maize. In addition, we request to observe your farm and agroforestry system. The complete process will take approximately 2 hours.

The information in the files of the study will be kept confidential. All the data will be reported in an anonymous form, and there will be no reference to oral or written information that could be used to associate you directly with the study.

If you have any questions regarding the study or the procedures, you may contact the main investigator, Viola Glenn, telephone number 001-919-599-1773. If you feel you have not been appropriately treated during the course of this project, you may contact Deb Paxton, telephone number 001-919-515-4515.

Participation in this study is voluntary; you can decide not participate without penalty. If you decide to participate, you can end your participation at any time without penalty. If you end participation in the study before the collection of data is finished, your data will become yours and you may discard it.

"I, (participant) have read the paragraphs above. I affirm that I am of legal age and I give my informed consent to participate in the study."

Or

"I, the interviewer, have read the paragraphs above to the subject. I affirm that (participant) is of legal age and has given their informed permission to participate in the study."

Full name of the subject: ______________________ Of legal age? □ Yes □ No

Community: _______________ Name of the interviewer: ________________________

Subject or Interviewer Signature: ___________ ______________ _______________

I. Introduction

Good day. My name is ____________________. I am working with the World Agroforestry Centre. We work at trying to find ways to increase food crop productivity using trees. I am here to speak with you today because we want to learn more about the nsangu and other agroforestry trees you have planted. Knowing this information will help us better understand why farmers do and don't adopt these trees and gives us the chance to design better systems to meet the needs of farmers. Thanks again for helping us with this interview. ***Your specific responses will remain confidential.***

1. Name of interviewee: _____________________

2. Date: _____________

3. Start time: _______________

4. Finish time: _____________________

5. Village: ___________________________

6. EPA: ____________________________________

7. District: __________________________

8. Interviewer: __________________________ QA:________________ (Leave blank)

9. How many individual maize-only plots are located at this farm? _______________

10. How many individual maize-*nsangu* plots are located at your farm? ____________

II. Maize Input Costs

<u>Interviewer</u>: Input costs for maize should be collected at the **household level,** including only maize or maize-*nsangu* fields, for the last harvest only.

11. In which month did you plant maize in the current season? ___________________

12. Please list each activity you use to plant and harvest maize on your property. (<u>Interviewer</u>: Tick each activity or its equivalent in the "□" column of the table below. **Do not read out the list**, but instead allow farmer to provide answers)

13. I will read back each activity to you. Please tell me when (month) each occurred, how many and what type workers (yourself, family members or friends (FF), or hired), and how many days it took (round to nearest half day).

Labor Inputs – Maize

Activity	□	When	Workers (count)			Days (by type)			
			Self	FF	Hired	Total	Self	FF	Hired
Nursery									
Land preparation									
Ridge/mount making									
Transplant seedlings									
Planting									
Digging holes									
Fertilization application									
Manure application									
Herbicide application									
Pesticide application before harvest									
Weeding									
Watering after planting									
Harvesting									
Stacking within the field									
Transport to village									
Transport to house									
Shelling of maize									
Pesticide app. to shelled maize (actellic)									
Transport to market									
Selling at market									

14. If there are activities listed other than those above specify them below.

Activity	□	When	Workers (count)			Days (by type)			
			Self	FF	Hired	Total	Self	FF	Hired
Other: _______________									
Other: _______________									
Other: _______________									

15. Which of these activities occurred at the same time? For example, digging holes and planting may occur over the same 5 day period using the same 4 workers. Please list all groups of activities belowa.

16. Were family members or hired workers paid with things like food or drink instead of cash? □ Yes □ No

17. The next table is for <u>non-labor</u> inputs, estimate the total quantity used and the cost per unit.

Input	□	Unit of Measure	Quantity	Unit Cost	Total Cost
Seeds (including given and bought)					
Materials to begin community nursery					
Manure					
Fertilizer					
Pesticide					
Herbicide					
Plastic bags/Hessian sacks					

18. Were any seeds given to you by a government organization, NGO or other farmer? □ Yes □ No
19. If Yes, estimate quantity _______________ and unit of measure _______________.
20. If Yes, name the organization which gave the seeds: ______________________

21. Are there any other inputs I've forgotten? □ Yes □ No
(Interviewer: If Yes, continue to question 22, if No, skip to 23)

22. Specify the other inputs and attempt to estimate the quantity and unit cost of each.

Input	**Unit of Measure**	**Quantity**	**Unit Cost**	**Total Cost**
Other (Specify: ________________)				
Other (Specify: ________________)				
Other (Specify: ________________)				

Interviewer: Review costs and quantities with the respondent and make corrections.

Nsangu Establishment and Maintenance Costs

Interviewer: *Nsangu* cost qs are answered **only for the most recent planting since 2008.**

23. Have you planted any *nsangu* since 2008? □ Yes □ No
(Interviewer: If Yes, continue to question 24, if No, skip to FIELD DATA sheet)

24. In which years did plantings occur? □ 2008 □ 2009 □ 2010 □ 2011

III. *NSANGU* COSTS

25. Year planted (Interviewer: Most recent year from question 24.):
□ 2008 □ 2009 □ 2010 □ 2011

26. Were the *nsangu* planted as part of ICRAF's programmes?
□ Yes □ No □ Don't Know

27. How were the trees in this planting established? (Tick all that apply)
- ☐ Individual/personal nursery
- ☐ Community nursery
- ☐ Animal/livestock dispersed
- ☐ Volunteers/seedlings starting near existing tree
- ☐ Transplanting seedlings starting near existing tree
- ☐ Seeds bought from third party
- ☐ Seeds given by government organization or NGO
- ☐ Seeds harvested by farmer

28. How many trees or seeds were planted this year? ________________________
29. How many trees or seeds from above are still surviving today? ________________

30. List each activity you use to establish and maintain *nsangu* on your property. (Interviewer: Tick each activity in the "□" column. **Do not read out the list.)**
31. Now tell me when (month and year) each occurred, how many and what type workers (yourself, family members or friends (FF), or hired), and how many days it took (nearest half day).

Labor Inputs – *Nsangu*

Activity	□	**When**	**Workers (count)**			**Days (by type)**			
			Self	**FF**	**Hired**	**Total**	**Self**	**FF**	**Hired**
Nursery									
Land preparation									
Ridge/mount making									
Transplanting seedlings									
Digging holes									
Planting									
Animal propagation									
Manure application									
Fertilization application									
Herbicide application									
Weeding									
Watering after planting									
Fencing of young tree									
Pruning									

32. If there are activities listed other than those above specify them below.

Activity	□	**When**	**Workers (count)**			**Days (by type)**			
			Self	**FF**	**Hired**	**Total**	**Self**	**FF**	**Hired**
Other: ________________									
Other: ________________									

33. Which of these activities occurred at the same time? For example, digging holes and planting may occur over the same 5 day period using the same 4 workers. Please list all groups of activities below.

34. Were family members or hired workers paid with things like food or drink instead of cash? □ Yes □ No

Interviewer: This table is for **non-labor** cost information.

35. For each of the inputs below, estimate the total quantity used and the cost per unit.

Input	□	**Units**	**Quantity**	**Unit Cost**	**Total Cost**
Seeds					
Seedlings					
Manure					
Fertilizer					
Pesticide					
Herbicide					
Plastic bags or tubes					

36. Were any seeds or seedlings given to you by a government organization, NGO or other farmer? □Yes □ No

37. If Yes, estimate quantity _______________ and unit of measure _______________.

38. If Yes, name the organization which gave the seeds: ______________________

39. Are there any other inputs I've forgotten? □ Yes □ No
(Interviewer: If Yes, continue to question 40, if No skip to question 41.)

40. Specify the other inputs and attempt to estimate the quantity and unit cost of each.

Input	**Units**	**Quantity**	**Unit Cost**	**Total Cost**
Other (Specify: __________________)				
Other (Specify: __________________)				

Interviewer: Review costs and quantities with the respondent and make corrections.

41. We will be able to use your input cost information no matter what, but are interested in how confident you feel about remember these numbers years after planting. How confident are you in this final number? (Tick one)
    - ☐ I am sure this is almost all correct
    - ☐ I am mostly sure, but have some doubts
    - ☐ I am not very confident of this number

42. How would you assess the amount of weeding under *nsangu* compared with maize field?
□ More weeding in *Nsangu* □ Less weeding in *Nsangu* □ Same

IV. FIELD DATA **Field _________ of _____________**

Interviewer: These questions will be answered at the **field level** for maize and maize-*nsangu* fields. Fill up to 4 "Field Data" sections. Focus on getting equal representation of maize-only and maize-nsangu fields.

Physical Characteristics

43. Area of field:
    Quantity: ______________________ Unit of measure:___________________

44. What is the dominant soil type in this field? (Tick two)
    - □ Whitish soil/sandy (mchenga)
    - □ Red soil/loamy (katondo)
    - □ Dark/clayey soil (mkanda)
    - □ Blackish/fine particles (mtsilo)
    - □ Anthill soil (nyata)
    - □ Other (Specify: _______________)

45. How would you describe the soil fertility status of this field presently?
    □ Poor □ Average □ Good

46. Is this field upland (garden) or wetland (dambo)? □ Upland □ Wetland

47. Are other trees than *nsangu* located on this field? □ Yes □ No
(Interviewer: If Yes, continue to question 48, if No skip to 49.)

48. If you are currently using any of the following agroforestry technologies on this field, please let me know and provide approximate counts where possible.

Type	**Count**	**Comment**
Tephrosia (*mthuthu/katupe*)		
Gliricidia		
Lucaenea (*lukina*)		
Cajanus cajan (*nandolo*)		
Cassia		
Senna (*keshya*)		
Sesbania (*jelejele, binu*)		
Other (Specify: ______________________)		
Other (Specify: ______________________)		
Other (Specify: ______________________)		

49. Are you using any of these technologies within this field? (Tick all that apply)

Technology	□	**Comment**
Chemical fertilizer		
Farm yard manure		
Organic compost manure		
Irrigation		
Residue burning		
Residue incorporation		
Minimum tillage		
Other (Specify: ______________________)		
Other (Specify: ______________________)		
Other (Specify: ______________________)		

Maize Yield

50. What type of maize is planted here? □ local □ hybrid □ mix/both

51. What is the maize yield you received from this field in the current year?
    Quantity: ________________ Unit of measurement: _______________

52. Of this total, can you remember approximately how much you sold either at farmgate or the market:
    Quantity: ________________ Unit of measurement: _______________

53. Of this total, can you remember approximately how much you consumed at home:
    Quantity: ________________ Unit of measurement: _______________

54. <u>Interviewer</u>: If the total from above does not add up to total yield: What did you use the remaining maize for?

55. We will be able to use your maize yield information no matter what, but are interested in how confident you feel about remembering the number now that harvest is finished. How confident are you in this final number? (Tick one)
    - ☐ I am sure this is almost all correct
    - ☐ I am mostly sure, but have some doubts
    - ☐ I am not very confident of this number

56. Is this field: □ maize-only, □ maize-*nsangu*, □ other (specify: _____________)
    (<u>Interviewer</u>: if maize-*nsangu* continue to question 57, otherwise skip to BARRIERS AND MOTIVATIONS)

Nsangu Characteristics

57. Were the *nsangu* established in this field at nearly the same time? □ Yes □ No
(Interviewer: If Yes continue to 58, otherwise skip to 59.)

58. Estimate the age of the trees in this field _______________

59. How many *nsangu* are located within this field? _________

60. Interviewer: Use provided tape measure to measure the breast height diameter (DBH) of 10 trees in each field. If there are not 10 trees in the plot, measure all that are present.

Tree No.	**DBH (in)**
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

61. Estimate the total area used to plant *nsangu* in this field:
Quantity: ________________ Unit of measure: ____________________
62. Did you forgo planting maize in the entire are mentioned in question 40?
□ Yes □ No
63. If Yes, what was the area of maize forgone in order to plant trees?
Quantity: ________________ Unit of measure: ____________________
64. Trees located (Tick one): □ Strictly on boundaries □ Only within rows □ Both
65. Do livestock graze here? □ Yes □ No
(Interviewer: If Yes continue to question 66, if No skip to question 67)
66. Which types of livestock graze in this field?
____
67. If you planted the trees, have you noticed a change in yield in maize in this field after planting the trees? □ Yes □ No □ Did not plant

V. NSANGU BENEFITS

68. What are the outputs **<u>you have already received in the past</u>**? □ None

Product	□	**Consumed at home (□)**	**Age when product began**	**Current year's yield**	
				Quantity	**Unit**
Fuelwood					
Shade for livestock					
Fodder for livestock					
Medicinal					
Sale of seeds					
Poles/timber					
Other: ____________					
Other: ____________					

69. What are the outputs **<u>you expect to receive in the future</u>**? □ None

Product	□	**Consumed at home (□)**	**Age product expected to begin**	**Future year's yield**	
				Quantity	**Unit**
Fuelwood					
Shade for livestock					
Fodder for livestock					
Medicinal					
Sale of seeds					
Poles/timber					
Other: ____________					
Other: ____________					

VI. Barriers and Motivations

In this section I will ask a few general questions about why you think nsangu are valuable. This will help us better understand how to develop the best possibly agroforestry systems for your area. Remember, the following exercise deals with ***any type of agroforestry system,*** *not just systems using nsangu. Imagine that you are considering adopting a new agroforestry system.*

70. How would you rank the following characteristics, from most important to least important, when making a decision **between different agroforestry** systems? (Interviewer: 1=Most important, 6=Least important)

Attribute	**Rank**	**Rank**
Financial benefits compared to cost of planting trees	Ndalama zimene timapindula zimaposa ndalama zimene timalowetsa	
Your confidence in the systems' ability to provide the promised benefits – Reliability	Malimidwe ake alindimapindu odalirika	
Consistency of benefits each year	Malimidwe amapindu achaka ndi chaka	
The systems' ability to provide multiple products such as food or fuelwood	Malimidwe amapindu osiyanasiyana	
Flexibility of the systems	Malimidwe akasithasitha	
How well the systems combine with existing farm practices	Malimidwe osasitha malimidwe athu akalen'kale.	

(Interviewer: The following questions are only for farms where *nsangu* are planted with maize. If no *nsangu* is at this farm tick here □ and skip to question 74)

71. What are the advantages of planting *nsangu* along with your maize crops?
72. What are some of the reasons for why you initially adopted the trees?
73. What are some of the reasons that you have continued to maintain them?
74. In your opinion, what are the disadvantages of planting *nsangu* along with your maize crops?
75. In your opinion, why are there not more *nsangu* and maize systems in this area?

V. Demographics

76. Gender of head of household: □ Male □ Female

77. Age of head of household: ____________________

78. Level of education of head of household (Tick one):
    - ☐ None
    - ☐ Primary school (not completed)
    - ☐ Primary school (completed)
    - ☐ Secondary school
    - ☐ Post-secondary school
    - ☐ Other (Specify: ___________________)

79. Household type:
    □ Husband and wife both present □ Single female □ Single male

80. Number of household members: ________________________

81. Females in household: __________________________-

82. Males in household: __________________________
    (Interviewer: Confirm that these totals match)

83. Formal employment outside of the home: □ Yes □ No

84. Type of ownership: □ Own □ Lease □ Other (Specify: __________________)

Background

85. Which of the following items does your household possess? (Tick all that apply)
    - ☐ Ox cart
    - ☐ Wheel barrow
    - ☐ Bicycle
    - ☐ Radio
    - ☐ Television
    - ☐ Mobile phone

86. Description of dwelling (Tick one):
    - ☐ Poles/thatched
    - ☐ Mud
    - ☐ Burn brick
    - ☐ Cement block

87. Type of roof (Tick one): □ Thatched/leaves □ Iron sheet □ Asbestos

88. How much of your household cash is obtained from the farm?
    □Almost all □ About one-half □ A small amount □ Almost none

89. How much of your household food needs are obtained from the farm?
    □Almost all □ About one-half □ A small amount □ Almost none

90. What are the objectives of your farm? (Tick all that apply)
    - ☐ Produce food for family
    - ☐ Produce food for barter
    - ☐ Produce food for sale to external market
    - ☐ Improve soil and site conditions
    - ☐ Improve the yield of maize (or other crops)
    - ☐ Improve income diversification
    - ☐ Reduce risk of crop loss
    - ☐ Provide shelter to livestock
    - ☐ Provide wood for fuel or timber
    - ☐ Other, specify: ________________________________

91. How many years of experience do you have with mixed crop systems (agroforestry)? This should refer to how long you've been planting trees within your crops.

    ____

92. Have you had formal training or attended classes to learn more about agroforestry? □ Yes □ No
    (Interviewer: If Yes continue to question 93, if No skip to conclusion)

93. Which organizations provided the training? (Tick all that apply)
    - ☐ ICRAF
    - ☐ Forest Service
    - ☐ Agriculture department
    - ☐ BERDO
    - ☐ Other (Specify: ___________________)

V. Conclusion

We have now completed the survey. Thank you for sparing time to answer my many questions. Before I leave, could you tell me if you have any questions, comments or any other observations about agroforestry systems or this interview?