

ABSTRACT

CHIZMAR, STEPHANIE JO. A Comparative Economic Assessment of Silvopasture Systems in the Amazonas Region of Peru and in North Carolina, USA. (Under the Direction of Dr. Erin Sills).

Expanding tree cover has become a global priority, e.g. as reflected in the Bonn Challenge. One approach that could deliver ecosystem services and support local livelihoods is the integration of trees into livestock systems, or silvopasture. Utilizing capital budgeting techniques, we compare the financial returns to silvopastures, planted forests, and conventional cattle-forage systems in Amazonas, Peru and the Coastal Plains of North Carolina (NC). Recent literature reports that the components of silvopasture may have complementary relationships at low tree densities such that tree and cattle-forage production are mutually beneficial, e.g. through fertilization and shade. Cost-share and carbon payments can further increase the competitiveness of silvopasture over conventional land uses.

We estimate that forests have a lower land expectation value (LEV) (Amazonas: \$342.00, -\$99.85, -\$251.19 per acre (ac); NC: \$484.63, -\$2.90, -\$124.03 per ac) than the conventional cattle systems in each country at 4%, 8%, and 12% discount rates (Amazonas: \$516.29, \$151.06, \$29.91 per ac; NC: \$1,537.69, \$707.62, \$453.11 per ac). We find that with complementary production in the Coastal Plains, silvopasture is competitive with conventional cattle-forage systems, even before accounting for the benefits of income diversification (\$1,807.08, \$795.91, \$489.71 per ac). If the components of the silvopasture system are competitive, NC landowners are better off investing in traditional cattle-forage systems (\$1,268.89, \$548.25, \$331.13 per ac), unless offered higher carbon prices or stronger governmental support. When the stocking and growth of cattle are independent of tree density, silvopastures earn higher profits than conventional cattle systems at 4% and 8% discount rates (\$1,653.31, \$725.15, \$444.40 per ac).

Silvopastures in Amazonas provide higher returns than conventional land uses in most scenarios, with LEV of \$3,855.94, \$872.63, and -\$112.29 per ac.

Keywords: Agroforestry; Silvopasture; Capital budgeting; Discounted cash flow analysis; Carbon Payments; Peru; North Carolina

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A Comparative Economic Assessment of Silvopasture Systems in the Amazonas Region of Peru
and in North Carolina, USA

by
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I. Introduction

Forest cover, which encompasses 31% of Earth's land area, provides diverse benefits to humans and all living organisms of various scales, from microenvironments to the global economy. Forests and forest cover in agricultural systems supply life essentials such as food, water, and medicine to more than 1.5 billion people as well as habitat for flora and fauna [World Wildlife Fund (WWF), 17b]. Covering 1.4 billion acres of forestland in South America, the Amazon Rainforest, is home to approximately 30 million people who depend on the forest for sustenance (WWF, 2017a). In North America, the Southern timberlands of the United States represent approximately 40% of all forest land in the country. Owning about 70% of timberlands in the region, nonindustrial private forest (NIPF) landowners supply the majority of timber in the Southern United States (Dwivedi, Alavalapati, Susaeta, & Stainback, 2009). Despite its numerous benefits, maintaining and increasing global forest cover has challenges with humans, involving an on-going struggle with development to convert to more profitable land uses.

Amazonas, a political region in Northeastern Peru, is home to many socially-disadvantaged individuals. In localized areas within the region, poverty rates can exceed 50% and malnutrition levels can be 30% or more (Vasquez Perez & Oliva Cruz, 2016). The majority of individuals in Amazonas support themselves through livestock cultivation, agriculture, and silviculture (Vasquez Perez & Oliva Cruz, 2016). Peruvians relying on productive land uses such as cattle production may prosper from incorporating harvests and sales of timber and non-timber products.

Meanwhile, north of the equator, the Southeastern states, also known as the "Wood Basket" of the United States, include mostly privately-owned pine forests, both planted and natural (Greene et al., 2016; Fritts et al., 2016). Loblolly pine, *Pinus taeda*, represents the most

commercially important pine species in the U.S. South making up over 50% of the standing pine volume in the region (Zhao et al., 2014). Historically, the southeastern coastal plains of the United States consisted of open pine woodlands and savannahs with low canopy coverage, variable tree age classes, floristically rich understories, and diverse wildlife (Greene et al., 2016). More recently, the timber market has experienced a loss in profitability due to reduced wood demand, decreases in prices of forest products, and changes in domestic consumption patterns (Dwivedi et al., 2009).

A. Alternative Sources of Revenue

With increased human population and concern about climate change, preventing deforestation and enhancing forest cover have become critical long-term missions among modern conservationists, governmental officials, professionals, and the public alike. Incorporating forest cover on productive lands in Amazonas, Peru and the Southeast United States supplies alternative, environmentally sustainable sources of revenue to local people and communities. Alternative sources of income may include the sale and use of timber and non-timber products harvested in a way that does not lower future forest and land productivity.

One example of non-timber forest products in the Southeast United States is pine straw for its use as mulch in landscaping. Revenues paid to Georgia landowners have increased from \$15.5 million in 1999 to \$81 million in 2009. Starting at canopy closure continuing to the first thinning, pine straw raking may provide gross income ranging from \$300 per acre to over \$1000 per acre to landowners (Dickens et al., 2012). An agricultural intensification study utilizing survey data presented from 185 coffee growers in Peru and 153 coffee growers in Guatemala demonstrate that the consumption and sale of all non-coffee products account for 20% to 33% of the total value realized from the mixed *Inga*-coffee regime with fuelwood and construction

materials representing much of this value (Rice, 2008).

Many individuals and communities rely on timber and non-timber forest products as primary or secondary sources of income. For rural-income families in Brazil, non-timber forest products such as fruit of the acai palm (*Euterpe oleracea* C. Mart), kernels of the babaçu palm (*Attalea speciosa* C. Mart. ex Spreng.), and Brazil nut (*Bertholletia excelsa* Bonpl.), harvested from the Amazon Rainforest constitute significant contributions (Porro et al., 2012).

Natural resource and environmental economists as well as some landowners value land use systems by the services they provide in addition to the products people sell or utilize (Porro et al., 2012). Payments for environmental (or ecosystem) services (PES) are a way to recognize and compensate land owners for these services. PES provide income to landowners for responsibly managing their property to sequester carbon, protect biodiversity, or provide watersheds services. PES systems could provide landowners in Peru and the U.S. with incentives to practice sustainable agriculture and silviculture (International Institute for Environment and Development [IIED], n.d.).

B. Quantification of Public Goods and Services

Including both annual cash flows from ecosystem services and non-timber forest products and periodic income from timber harvests, forest economists use discounted cash flow and capital budgeting methods to quantify the returns to all marketable products and services (Montagnini & Nair, 2004; Cabbage et al., 2016). This requires estimating system productivity, collecting costs of inputs, predicting prices of outputs, and setting parameters such as the discount rate.

Capital budgeting uses discounted cash flow analysis to calculate and summarize the

present values of costs or benefits accrued over time. Costs or benefits accrued in the future are worth less than those accrued in the present due to both impatience and the opportunity cost of alternative investments. In order to summarize and compare investment alternatives, the different time horizons of alternative investments must also be considered.

The economic cycle of forest products range in rotation lengths, from relatively continuous seasons for annual crops to decades for periodic timber harvest. For products harvested on longer time horizons, discounting may make investments less desirable due to the delayed cash flow and higher risk (Sharrow, 2008a). For this reason, encouraging landowners to plant tree species may be difficult when profits from cattle production and agriculture can accrue sooner and more frequently.

Forest ecosystems absorb almost 3 billion tons of carbon annually (Montagnini & Nair, 2004). Ecosystem services such as carbon sequestration and water quality may be characterized as public goods when the landowner assumes the costs of the recommended management practice in exchange for marginally less profits. Public goods are consumed equally by all of a society and are indivisible. Producers of public goods, landowners for the scope of the study, are not able to exclude individuals from consuming the good or service. As a result, landowners typically do not consider environmental services in decision making (Alavalapati, Shrestha, Stainback, & Matta, 2004).

C. Carbon Forestry

Sustainable forest management can reduce atmospheric carbon through increased carbon sequestration, conservation, and/or substitution. Carbon sequestration can be increased by improved silvicultural techniques to increase growth. Carbon conservation aims to protect the

carbon stored in biomass and soil, while carbon substitution involves the conversion of forest biomass into durable wood products or alternative fuels (Montagnini & Nair, 2004). Payments for ecosystem services (PES) for carbon typically promote sustainable forest management by compensating landowners for increased carbon sequestration or conservation. Such PES can diversify and complement a landowners' portfolio of assets through annual payments. PES have the potential to stabilize and increase long term timberland returns (Jenkins & Smith, 2013).

In addition to sustainable forest management, planting trees – through afforestation, reforestation, or agroforestry – can increase carbon removals from the atmosphere. Afforestation, reforestation, and agroforestry may increase forest cover in deforested areas as well as agricultural production systems, thus potentially increasing an area's carbon storage capacity where land has been converted to other uses such as for human development.

D. Payments for Ecosystem Services

The Voluntary Carbon Standard (VCS) and California's carbon trading scheme offer frameworks for estimating the additional carbon stocks from sequestered carbon through either sustainable forest management or expanding the area under tree cover. Incorporating tree cover through afforestation, reforestation, and agroforestry may allow landowners to benefit financially from markets that compensate for ecosystem services such as payments for carbon storage and/or sequestration.

i. Forest Carbon Offsets

Typically, carbon markets utilize CO₂ offset equivalents (CO₂e) for additional carbon stored in planted forests through improved forest management (IFM), afforestation/reforestation (AR), and avoided conversion (AC) of forested lands to a non-forest use. CO₂e are created when

an entity makes a voluntary action which results in the storage or prevention of carbon dioxide, or other greenhouse gas (GHG), from being released into the atmosphere. California's Air Resource Board (CARB), the state's compliance GHG trading scheme, has average offset prices of \$10.50-\$12 per credit. Some projections for CARB offset prices estimate credits to value at \$35-\$70 by 2020 (Jenkins & Smith, 2013).

To calculate above ground forest biomass volume, that stored in aboveground vegetation, researchers multiply the specific gravity of wood by the total biomass volume and subtracting out reserves. Cabbage and Roise analyze the carbon storage potential of the Hofmann Forest, a research and teaching forest managed by North Carolina State University. The study estimates each ton of merchantable wood in a forest yields about 0.9 tons of CO_{2e} (Personal communication, Cabbage, 2017).

In tropical systems, the greatest potential for carbon sequestration is above ground through the establishment of tree-based systems on degraded pastures (Montagnini & Nair, 2004). Since 1996, Costa Rica has had a PES program which promotes forest plantations through incentives for already established plantations and reforestation. In 2003, Costa Rica added agroforestry to the program for its potential to increase forest cover (Montagnini & Nair, 2004). Programs that provide incentives for forest management as well as additional sources of revenue may aid profitability of land use systems in both Amazonas, Peru and the Coastal Plains in Southeastern U.S.A.

Researchers have applied economic and financial approaches to calculate the value of carbon storage within forest systems. Dwivedi, Bailis, Stainback, and Carter (2011) conclude that NIPF landowners' incomes increase more when carbon payments for carbon sequestered in wood products and living biomass are considered. Dwivedi, Alavalapati, Susaeta, and Stainback

(2009) integrate a modified Faustmann model, an equation that estimates economic returns of a land use performed in perpetuity, and a carbon life cycle analysis to assess the relationship between landowner profits and carbon payments in slash pine plantations. Specifically, the study models the impacts of payments for carbon sequestered in live forest biomass on optimum rotation age of stands and profitability of NIPF landowners. The study's results indicate that profitability of an intensively managed slash pine plantation increases with payments for carbon sequestered in live biomass. While profits increase, the researchers observed no significant change in the optimum rotation due to carbon payments, implying carbon payments may be an ecologically sustainable tactic to improve profitability of NIPF landowners in the South.

Cubbage and Davis (2014) examine the income and expenses of the Global Environmental Facility (GEF) forestry programs for carbon storage in Chile as part of the Comisión Nacional Forestal (CONAF). The report, prepared by CONAF, analyzes the biological opportunities for carbon storage. Carbon storage and payments for a variety of tree species were used to estimate the program benefits and costs in trees for each region that received GEF payments (Cubbage & Davis, 2014). The researchers vary the price of carbon from \$5-10 per ton of CO₂e and management practices to determine how changes in productivity from management will affect payments for carbon storage and timber harvest revenue. The results conclude that systems of *Pinus radiata* and *Eucalyptus globulus* were the most profitable and not harvesting on conservation forests leads to negative returns. The study's economic analyses confirm that public support and investments are necessary to improve and sustain Chile's dispersed forests since market prices and timber growth alone are inadequate (Cubbage & Davis, 2014).

D. Agroforestry

Forest systems in Amazonas can provide sustainable sources of income through the

responsible use and sale of timber and non-timber forest products (Porro et al., 2012). For millennia, tropical rainforests have been the source of forest fruits, fibers, grains, medicines, cloths, resins, and pigments to humans (Rainforest Alliance, 2017). European explorers in the 16th century observed mixed land uses in the Amazon incorporating trees into production systems (Porro et al., 2012). In the United States, forest grazing of cattle on National Forests in the western states has been profitable for the Forest Service and cattle ranchers alike (Zee, 2017). Agroforestry systems, such as the scenarios previously mentioned, combine forest or horticultural species and pasture or cropland to make mixed land use systems that produce environmentally sustainable commercial benefits to landowners (Zomer et al., 2016).

i. Agroforestry Defined

Agroforestry is defined by three main characteristics: (1) a combination of agriculture with woody crops; (2) strategic interactions between the woody crops and the agricultural crops; and (3) a systems-approach to management (Sharrow, 2008b). Agroforestry systems (AFS) are also characterized by 4 “I” words: Intentional, intensive, integrated, and interactive (Nair, 2011). Specifically, agroforests are intentionally designed and intensively managed to maintain productivity as a whole system through integrating biological and physical interactions among system components.

Intercropping, structural agroforestry, is a type of polyculture in which two crops are managed together simultaneously on the same parcel of land. Agroforestry can also occur through time in swidden, fallows, or *taungya* where woody crops or agricultural crops are grown following the other to replenish the resource base. Agrosilviculture combines tree production with herbaceous crops. Silvopastoral regimes include trees and livestock management. Agrosilvopastoral systems blend trees, herbaceous crops, and livestock on the same land area

(Sharrow, 2008b).

The United States Department of Agriculture [USDA] defines five land management systems as agroforestry: (1) riparian buffers, (2) forest farming, (3) alley cropping, (4) windbreaks, and (5) silvopasture. Agroforestry systems are commonly believed to provide greater environmental services than monocultures, due to better provision of water supplies, less erosion, more biodiversity, and higher rates of carbon sequestration (Zomer et al., 2016). Agroforestry systems also may be particularly appropriate for reducing monoculture crop failure and price risks, and favor enhanced long-term site productivity and soil protection (United States Department of Agriculture National Agroforestry Center [USDA NAC], 2012). Potential also exists for the use of agroforestry as a vehicle for sustainable agricultural and forestry certifications as well as carbon offset markets. Agroforestry supports organic farming regulations through decreasing fertility inputs, reduced pest management, maintaining reliable sources of clean water, increased resilience to drought, and improved pollination (McEvoy & Haines, 2017).

Agroforestry manages regimes based on the interactions, resource sharing, interference, and facilitation, between system components along with the products created by each component. Agroforestry's philosophy that a successful system is better than the sum of its parts maintains that functional linkages provide increased productivity and ecological sustainability when compared to rates of productivity typical in monoculture forest plantations or agricultural systems. For agroforestry systems to be successful, they must be biologically possible, environmentally sustainable, economically feasible, and socially acceptable (Sharrow, 2008b).

ii. Forms of Agroforestry

In the Southeast United States, Virginia Tech's experimental and extension agroforestry systems include riparian buffer systems, forest farming of shiitake mushrooms, and mixed hardwood silvopasture. Riparian buffers integrate planted rows of trees, shrubs and/or grasses between cropland or pasture and surface waters. Buffers enhance and protect water quality, reduce erosion, and increase flood control. Riparian buffers also provide financial and biophysical opportunities for farmers, ranchers, horticulturists, and livestock producers through periodic harvest of timber or non-timber products (Association for Temperate Agroforestry [AFTA], n.d.).

Forest farming involves the cultivation of high-value crops under the shelter of a forest canopy that is managed to provide the appropriate shade level. Crops such as ginseng, shiitake mushrooms, and decorative ferns are sold annually or seasonally for medicinal, culinary, and ornamental purposes while high-quality trees are grown for timber or non-timber products (USDA NAC, 2017b).

Alley cropping systems include trees and/or shrubs planted in rows with alleys for agricultural crop production. Diversifying farm production and income through alley cropping can also improve soil health. In North America, alley cropping commonly includes high-value hardwood trees along crops that produce annual income while the trees are growing to financial maturity. Tropical regions utilize trees in alley cropping systems to restore and protect soil fertility (USDA NAC, 2017a).

Windbreaks are comprised of strips of trees and/or shrubs planted and managed to control wind flow. In theory, removing some land from crop production for windbreaks results in a net

increase in crop production due to the system's influence on soil health and control of wind erosion (Goodrich, 2017). Rosmann Family Farms in Iowa, U.S.A experience added value from windbreaks through harvested wood products and reduced soil compaction (Straight, 2017).

Within the 38 million acres of jungle in the second largest tropical rainforest in the Americas, the Selva Maya, located in the Yucatan Peninsula of Central America, the Nature Conservancy partners with local communities to prevent deforestation through sustainable intensification of productive lands. Sustainable intensification boosts agricultural yields per unit of land area with a reduced footprint on the environment. Their united goal is to produce better crop, cattle, and logging yields so that they may clear less forest to sustain local livelihoods. Their traditional agroforestry system, La milpa, involves production of corn, beans, squash, and other agricultural crops surrounded by forest for honey and fruit production. Beginning in 2018, Mexico will be 1 of 3 countries to receive carbon payments for carbon emission reductions (Jenkins, 2017).

E. Silvopasture

Silvopasture, the branch of agroforestry of primary interest in this study and the most common in North America, is the strategic and managed agroecosystem in which livestock, forage, and trees or shrubs are integrated to improve individual components (Orefice & Carroll, 2017; USDA National Agroforestry Center, 2012). All components of a silvopasture, when well-designed, interact positively to increase yields and diversify production (Bruck, 2016). Thus, silvopastoral systems diversify earnings to landowners through facilitating the sale of timber and non-timber forest products, such as fuelwood, and agricultural products, such as milk and cheese from livestock production (Cotta, 2017). They also are likely to provide better micro-environments for grazing animals. Providing diverse products of varying harvest rotation

lengths, from seasonal to multiple decades, may increase sources of income while decreasing financial risk for landowners.

i. Benefits of Silvopasture

Silvopasture decreases climatic stress on livestock through providing shade and shelter, helping to increase livestock weight gain, and reduce calving difficulty. The trees from silvopasture regimes slow wind speeds and protect cattle from harsh weather events and climatic conditions such as hot and sunny summer days. Karki and Goodman (2015) measure microclimatic characteristics in a mature loblolly pine silvopasture and an open-pasture in the coastal plains of Florida (Karki & Goodman, 2015). The researchers state that overall average values for all microclimatic parameters, including but not limited to air temperature, wind and gust speed, and photosynthetically active radiation, were lower in the silvopasture.

With less climatic-induced stress, livestock are happier and gain weight at a faster rate than traditional open pasture systems (Orefice & Carroll, 2017). Livestock typically maintain a core body temperature within a 2° to 3° C range. Deviations in excess to this range for many species of livestock negatively impact performance, productivity, and fertility, restricting an animal from generating products such as meat and milk. Cattle that breed during seasons with high temperatures, such as in spring and summer, may experience decreased successful pregnancies. As well as, variations of core body temperature of 5° to 7° C may lead to death (Walthall et al., 2012).

Additionally, while cattle are seeking shade and shelter under trees, they consume understory vegetation, controlling tree to forage competition, and provide nitrogen, phosphorus, potassium, sulphur through nutrient cycling by the means of manure and urine. Faster and

increased weight gain as well as augmented crop growth may lead to higher profits to landowners.

The components of a silvopasture regime, forage, livestock, and trees, complement each other through symbiotic relationships. Silvopasture produces high-quality forage for livestock and increases soil quality causing an expanded grazing season and livestock diets that are higher in protein (Orefice & Carroll, 2017). Livestock provide limited essential elements such as nitrogen, phosphorus, and potassium through nutrient cycling in the form of urine and manure to fertilize forages and trees, reducing dependence on additional fertilizer and chemical inputs (Pent & Fike, 2017; Mercer, Frey, & Cabbage, 2014).

The carbon storage benefit of silvopasture gained international attention when the Kyoto Protocol included AFS in its regulatory carbon market for its potential to increase and expand tree cover as well as supply large volumes of aboveground (ABG) biomass and deep root systems for carbon storage (Shrestha & Alavalapati, 2004; Nair, 2011). In the Southern US, an acre of pine silvopasture on a 20-year rotation has the potential to absorb between 145 to 220 tons of CO₂. Internalizing non-market environmental goods and services such as carbon may incentivize ranchers to adopt silvopasture and generate ecosystem services at optimum levels (Shrestha & Alavalapati, 2004). With ecosystem services and productivity operating at optimum, silvopasture sequesters more carbon than tree monocultures and open pastures (Dube et al., 2011).

Silvopastoral systems may be an environmentally sustainable solution to enhancing forest cover while providing long-term returns to landowners in the Amazonas region of Peru and the Southeastern United States. Mercer, Frey, and Cabbage (2014) identified silvopasture as the most promising agroforestry system in the Southeast United States due to the deep-rooted history

of intensive livestock production and forest management that are characteristic of the region.

ii. Potential Trade-offs of Silvopasture

If silvopastoral systems are not managed to enhance productivity of each individual product and system components compete for resources, then productivity of one and/or multiple good(s) and service(s) may decrease. Therefore, agroforests such as silvopastures require technical ecological knowledge when selecting species in respect to their strategic ecosystem interactions, which may not always be available to landowners in remote locations. In addition, agroforestry systems may not always be able to compete with productivity levels of intensified monocultures where increased yields lead to higher financial returns (Vaast & Somarriba, 2014).

iii. Applications of Silvopasture

Although silvopasture is the most common practice of agroforestry in North America, research on the potential gains of agroforestry systems only recently gained popularity (Orefice & Carroll, 2017). Virginia Tech's Whitethorne Agroforestry Research and Demonstration Project features mixed hardwood silvopastoral studies with cattle and sheep. A Loblolly pine-cattle silvopasture trial at Virginia Tech's Southern Piedmont Agricultural Research and Extension Center highlights the density challenge of agroforestry in practice. The researchers manage the stand pre- and post-harvest tree basal areas at 168 and 46 square feet, respectively, for livestock habitat (North American Agroforestry Conference). The North Carolina State University Center for Environmental Farming System's (CEFS) has a 17-acre (6.9 ha) agroforestry research and extension alley cropping trial in the Coastal Plains. Established in January of 2007, the research trial features a beef cattle silvopasture with 3 species of trees and 4 species of forage.

Silvopasture systems in Amazonas, Peru largely aim to create productive regimes out of improved fallows abandoned during a period of civil unrest during the 1980s and 1990s in which the ruminant populations were decimated (Cotta, 2017; Vera, 2006). In areas of the country where the community is still trying to restore the cattle population, agroforestry systems are primarily dominated by combinations of coffee and cacao with other species, driven by the desire to sequester carbon in agricultural systems (Antle, Stoorvogel, & Valdivia, 2007; Ehrenbergerová, Cienciala, Kucera, Guy, & Habrová, 2016).

iv. Economic Potential of Silvopasture

Antle et al. (2007) examine the economic potential for carbon sequestration in agroforestry and terrace systems. Under favorable conditions for carbon storage and an optimistic carbon price of \$100 per Mg, terrace and agroforestry regimes have the potential to increase per capita income by up to 15% on farms with steeply sloped fields, and reduce poverty by as much as 9% (Antle et al., 2007). Ehrenbergerová et al. (2016) investigate agroforestry coffee plantations in the foothills of the Peruvian Andes and their aboveground and soil carbon sequestration capacity. The study analyzes carbon storage of different combinations of dominant shading trees compared to full-sun cultivation of coffee. The results suggest that ecosystem carbon stocks in the agroforestry regimes were significantly higher than full-sun sites (Ehrenbergerová et al., 2016).

Shrestha and Alavalapati (2004) value the public demand of environmental services produced from silvopastoral systems, phosphorus runoff reduction, carbon sequestration, and improved wildlife habitat, in the Lake Okeechobee watershed of south central Florida. Utilizing survey results from 152 respondents, the researchers estimate households would pay \$30.24-71.17 per year for 5 years for each of the ecosystem services mentioned above, or \$137.87 in

total per household per year for 5 years. With 1.34 million households in the watershed, the study projects residents would be willing-to-pay \$924.4 million for a moderate level of improvement in environmental benefits from silvopasture.

F. Applications of Discounted Cash Flow and Capital Budgeting Analysis in Agroforestry

Researchers have applied DCF and capital budgeting analysis to estimate the value of agroforestry systems. Dube et al. (2011) examine carbon stocks in silvopasture systems in Patagonia, Chile, as well as agroforestry systems in Minas Gerais, Brazil (Dube et al., 2002). Cabbage et al. (2012) review global silvopastoral systems in eight regions, including areas in Argentina, Uruguay, Chile, and Brazil. The authors state that silvopasture offers biophysical and financial diversity and resilience, attributes critical with increased occurrences of extreme weather events due to climate change. They also conclude that silvopasture regimes provide returns comparable to alternative land use systems (Cabbage et al., 2012). As of December 2017, to our knowledge, no major research has been published analyzing the economic returns, including carbon valuation, of silvopastoral systems in the Amazonas Region of Peru and Coastal Plains of North Carolina.

Researchers as well are beginning to study the applications of agroforestry systems in carbon sequestration and GHG trading schemes. Minang et al. (2014), state that sustainable intensification of agroforestry systems in Africa reduces the drivers of deforestation through supplying increased household income and forest products. Franzluebbbers, Chappell, Shi, and Cabbage (2016) estimate carbon dioxide and nitrogen dioxide emission from soils under crop and marginal canopy cover and tree canopy cover. The study results suggest emissions from soils with tree canopy cover are statistically less than emissions from soils with crop and margin canopy cover (Franzluebbbers et al., 2016). Intensifying agroforestry systems produces increased

yields per unit of land, reducing demand for production on additional lands. The resulting reduced dependence of exploited land through agroforestry can be used in Reduced Emissions from Deforestation and forest Degradation (REDD+) programs.

II. Objective

The objective of this thesis project was to analyze the expected financial returns of silvopastoral and conventional systems in Amazonas, Peru and the Coastal Plains of North Carolina utilizing capital budgeting techniques and regional productivity data. Silvopasture is the most promising form of agroforestry due to its history and potential in each region. Silvopasture has been practiced for millennia in both tropical and temperate regions. In the Southeast US, landowners have a long-standing history of intensively managed livestock production and forest management (Bruck, 2016). I also analyze the potential impact of combining traditional forestry and agricultural systems with climate change mitigation activities linked to PES such as carbon storage on landowner income.

The general hypothesis of the research is that silvopasture systems in both North Carolina and Peru can diversify farm income, reduce biophysical and financial risks, and perhaps increase total farm returns. Income diversification with silvopasture is possible through providing timber and non-timber products in addition to forage. The degree of tree and forage competition determines the costs and benefits of silvopasture systems. At some number of trees per unit of land area, trees may complement forage systems; however, at high tree densities, production of forage will decline due to competition for resources. No established literature exists on this relationship, but we examine various scenarios in this study. Additionally, since land use systems

cannot be measured in quantitative terms with 100% precision and accuracy due to the multiplicity of factors and their complex interactions, a need exists to add to the knowledge base (Nair, 2011).

A few authors, such as Pent and Fike (2017), suggest there is a complementary relationship between forage production for livestock and trees. In economics, this relationship can be modeled via a Production Possible Curve. Figure 1 features a theoretical and hypothetical Production Possibilities Frontier (PPF) of cattle and trees.

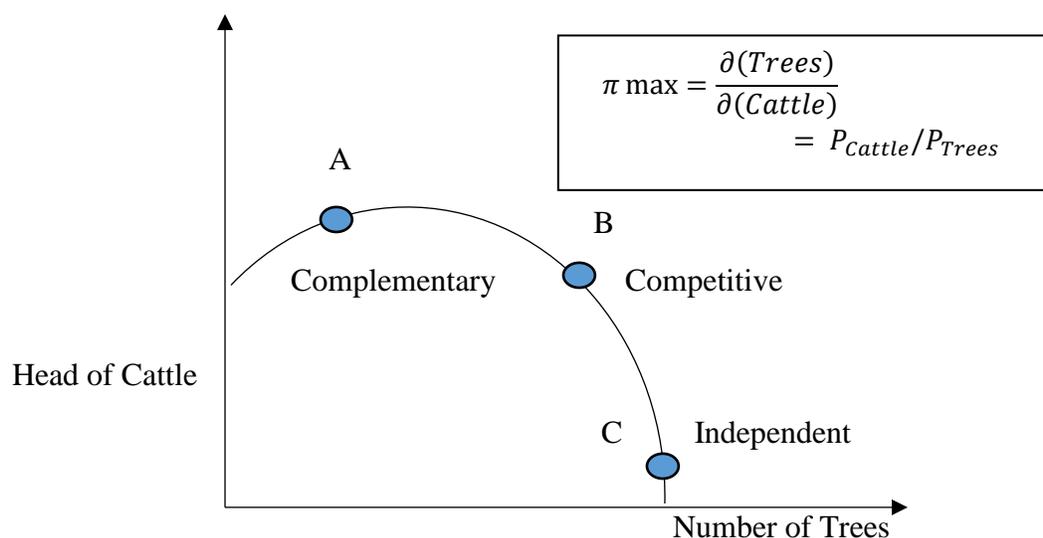


Figure 1: Production Possibilities Frontier of potential theoretical land use combinations of trees and cattle.

The complementary region, up to point A on the figure above, is where our two products benefit one another mutually. Examples of the benefits from the complementary region of adding trees to agricultural lands include reduced weeding, increased available nitrogen, improved microclimate, and reduced erosion control costs (Mercer et al., 2014), as well as better animal health such as increased pregnancy success rates (Pent & Fike, 2017). Possible combinations of

cattle and trees in the independent region, point C in the figure above, are characterized by a lack of change in the number of trees at low cattle stocking rates. An independent relationship between cattle and trees in agroforestry systems translates to a mutually exclusive combination where decreasing cattle stocking rates does not affect the number of trees or volume of wood, or vice versa.

The competitive region, represented by region B, includes higher marginal costs per unit of production for one product over the other, possibly suggesting that monocultures, traditional cattle-forage systems in this case, are more attractive. However, there still may be an “optimal” competitive combination of land practices due to the expected high prices of cattle. The optimal combination when maximizing profit, represented by “ π ” in the figure above, corresponds to the derivative of the price of cattle over the derivative of the price of trees, where “P” refers to each products price. One may add an iso-revenue line representing a landowner’s budget to find the optimal combination of land uses.

III. Methodology

Dr. Miguel Castillo, forage specialist in the Crop and Soil Sciences Department at North Carolina State University, along with members of a concurrent study invited Dr. Fred Cabbage and I to participate in research on silvopastoral systems in the Amazonas region of Peru. The study analyzes the predicted economic impacts of forest, silvopastoral, and pastoral systems in the Coastal Plains of North Carolina and the Amazonas Region of Peru. I consulted with landowners and farm managers, foresters, consultants, and agroforestry experts in North Carolina and Peru to develop the scenarios analyzed.

A. Coastal Plains, North Carolina

The coastal plains of the Southeastern United States, more specifically North Carolina, typically experience cool winters and hot humid summers with annual average temperatures surpassing 60 degrees Fahrenheit. The study area in North Carolina receives an average of 53.5 inches of rain annually. The region is characterized primarily by loamy sand, sandy loam, and clay loam soils (Bruck, 2016; Franzluebbers, Chappell, Shi, & Cabbage, 2016).

i. Pine plantation management

Per recommendations from consulting foresters and forest extension publications, I developed hypothetical scenarios to represent typical management regimes for loblolly pine in the Coastal Plains of North Carolina (Maggard & Barlow, 2017). The two typical loblolly pine plantations include varying levels of management intensity and growth rates to represent a range of returns for traditional systems. Table 1 presents the characteristics of each scenario.

Table 1: Loblolly Pine Scenarios, Coastal Plains, NC.

Scenario	Management Activities	Growth (m ³ per ha yr ⁻¹)
Low growth, low costs (LGLC)	Site preparation: Chemical	7
Medium growth, high costs (MGHC)	Site prep. Chemical and Mechanical Stand Establishment: Fertilizer Periodic: Mid-rotation fertilizer	10

I utilized costs published in “2016 Costs and Trends for Southern Forestry Practices” to represent regional average costs for the Southern Coastal region of North Carolina (Maggard &

Barlow, 2017). The “low growth, low costs” (LGLC) scenario characterizes a “plant and leave” management regime with a pre-planting application of herbicide as the only treatment. I used a growth rate of 7 cubic meters per hectare per year as a slightly below-average rate of productivity typical of the Coastal Plains based on Forest Inventory and Analysis (FIA) data (Personal Communication, Abt, 2017).

The “medium growth, high costs” (MGHC) scenario involves more intensive management practices including multiple applications of fertilizer throughout the rotation. Site preparation for the MGHC scenario includes mechanical and chemical treatments standard of the poorly-drained sites of the Coastal Plains of North Carolina. Average-quality loblolly pine plantations experience growth rates of 10 cubic meters per hectare per year in the Coastal Plains (Personal Communication, Abt, 2017).

ii. Pine plantation costs and revenue

Stumpage prices for the North Carolina scenario are based on south-wide averages from TimberMart South’s “U.S. South Annual Review: 2016.” I converted the published stumpage prices from U.S. dollars (USD) per ton to USD per cubic meter by multiplying the harvested amount by 0.84 cubic meters per ton of wood ($2000 \text{ lbs/ton} \div 68 \text{ lbs/ft}^3 \div 35 \text{ ft}^3/\text{m}^3$ or $29 \text{ ft}^3/\text{ton} \div 35 \text{ ft}^3/\text{m}^3$) (Clark, Daniels, & Borders, 2006). TimberMart South’s recommended conversion of 1 short ton of green southern pine, wood, and bark to 0.822 cubic meters of solid wood without bark provides confidence in our calculated conversion factor. Table 2 describes the relative thinning and clearcut harvesting prescription for all scenarios. For analysis purposes, I assumed the management practices and harvest schedule to continue in perpetuity. Table 3 lists the thinning and clearcut harvesting schedule for the forestry scenario in the Coastal Plains.

Table 2: Relative harvesting prescription.

Description	Relative Amount
First Thinning	1/3 rd of cumulative volume
Second Thinning	1/3 rd of remaining volume + accrued growth
Final Clearcut	All remaining volume + accrued growth

Table 3: Harvest schedule by scenario.

Scenario	Year		
	First Thin	Second Thin	Final Clear-cut
LGLC	15	22	30
MGHC	12	18	25

Due to the intensive management of forage production for livestock grazing, we assumed the tree growth is complemented by management practices such as fertilizer application. For this reason, we utilized the costs, growth rate, and activity schedule associated with the LG LC scenario for planted pine monocultures in NC. For silvopastoral systems, we used costs and management practices typical of farmers transitioning to forest management and MG HC's growth rate and harvest schedule due to the complementary growth from forage fertilization.

We assumed landowners prune approximately 20% of tree growth for fuelwood annually, for planted trees from year 3 to 24 in years when thinning or clearcut is not scheduled. We also assumed agroforestry systems were composed of 15-20% planted trees. Traditional plantation forests in the Coastal Plains are planted at 600 trees per acre (TPA) or 1,482 trees per hectare (TPH). In the North Carolina silvopasture regimes, loblolly pine is planted in 2 rows at 10' by 10' spacing, equating to 435 TPA (1,075 TPH). Overall, that allots 30' of trees with an 80' paddock of pasture, repeated once more, to end at a density of 65 to 87 TPA (161 to 215 TPH). Various soils make-up the study area; however, we assumed a site index of approximately 75

feet at 50 years (Hamilton, 2000).

iii. Pasture-fed beef cattle systems

In North Carolina, cool-season forage species flourish when temperatures range from 65° F to 75° F while warm-season species thrive when temperatures are between 80° F and 95° F (Castillo, Mueller, & Green, 2014). Three pasture-fed cattle systems typical of the Coastal Plains are of interest in this study: (1) beef wintering on cold-season (CS) species of pasture and supplemental hay in the summer, (2) beef summer grazing on warm-season (WS) species of pasture and supplemental hay in the winter, and (3) rotational stocking on CS and WS paddocks (Green & Benson, 2013a; 2013b; 2013c; 2013d). Table 4 displays the traditional grazing scenarios in the Coastal Plains of North Carolina along with a summary of the other regimes.

Table 4: Coastal Plains, NC Scenarios.

Scenario	Management Activities	Growth & Species	Number of Cattle & Species
Forest Only: BAU	Site Preparation: Chemical	7 m ³ per ha yr ⁻¹ Pinus taeda	0
Forest Only: SSP	Site Preparation: Chemical	10 m ³ per ha yr ⁻¹ P. taeda	0
Warm-Season Forage Production for hay and pasture	Site Preparation: Chemical Fertilizer	10.5 ton per ha yr ⁻¹ Panicum virgatum L. (Switchgrass)	0
Cold-Season Forage Production for hay and production	Site Preparation: Chemical Fertilizer	7.8 ton per ha yr ⁻¹ Lolium arundinaceum (Schreb.) Darbysh. (Tall fescue)	0
Cattle Only (No land)	Beef cattle operations	0	8 Red and Black Angus
Cows + Pasture: BAU	Site Preparation: Chemical Fertilizer Beef cattle operations	10.5 ton per ha yr ⁻¹ Switchgrass 7.8 ton per ha yr ⁻¹ Tall fescue	8 Red and Black Angus
Silvopasture	Site Preparation: Chemical Fertilizer Beef cattle operations	10 m ³ per ha yr ⁻¹ P. taeda 10.5 ton per ha yr ⁻¹ Switchgrass 7.8 ton per ha yr ⁻¹ Tall fescue	8 Red and Black Angus

To maximize land usage and returns, pastures include paddocks of warm-season grasses and paddocks of cold-season grasses. The costs and benefits associated with each season of pasture are added to create a closed system. I utilized the percent of each pasture season out of the year to estimate a weighted cash-flow of the combined-system. Loblolly pine, switchgrass, a WS forage, and tall fescue, a CS forage, represent typical commercial species employed in the Coastal Plains. Consequently, the range of returns of the scenarios selected for analysis signify typical returns of various land uses.

Switchgrass (*Panicum virgatum* L.) in North Carolina's Coastal Plains produces 8,500 pounds of forage per acre of pasture per year (20,995 lbs/ha/yr), or 699.8 animal unit (AU) days based on 30 pounds of forage consumed daily per cow. Tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.) generates less production relative to Switchgrass in the Coastal Plains of North Carolina at a rate of 6,350 pounds of forage per acre per year (15,684.5 lbs/ha/yr), or 522.8 AU days (Castillo et al., 2015). For the scope of this study, we hold growth rates of forage species constant and assume one AU represents one animal weighing 1,000 pounds (Husak & Grado, 2002).

We introduced crosses of red and beef angus after 6 years, once trees grow beyond browse line (18 inches in height), in silvopastoral systems according to recommendation from silvopasture practitioners and current literature (Bruck, 2016; Husak & Grado, 2002). Costs and revenue for cattle systems were derived from the literature and local experts in each respective region. We utilized North Carolina State University Farm Budgets for winter and summer stockers to determine cattle costs and revenue as well as forage management costs and prices.

B. Amazonas, Peru

The most common land uses in Amazonas, Peru are dual-production systems of cattle and dairy and cultivation of horticultural and forest products such as coffee, guava, citrus fruits, eucalyptus, and cedar (Mejía, 2016). Agroforestry systems in the Amazonas Region of Peru are increasingly incorporating multi-strata systems and improved fallows (Porro et al., 2012). To represent this trend, I varied the Amazonas scenarios by production complexity. Table 5 summarizes the scenarios for Amazonas based on actual farms and observations from local consultants. The first three rows summarize typical systems that were described by our project cooperators – professors and graduate students in Peru. The last four rows describe systems

observed in field visits.

Table 5: Scenarios, Amazonas, Peru.

Scenario	Management Activities	Tree Growth (m ³ per ha yr ⁻¹) & Species	Number of Cattle (Lactating) & Species
Forest Only	Manual Site Preparation: Mechanical	5 Pinus patula	0 (0)
10-ha Typical System Cows Only	Manual Site Preparation: Mechanical Fertilizer Pasture management Livestock operations Site management	0	16 (5) Brown Swiss, Simmental, Holstein
10-ha Typical Silvopasture System	Manual Site Preparation: Mechanical Fertilizer Livestock operations Site management	5 Alnus acuminata, Eucalyptus globulus, Pinus patula	16 (5) Brown Swiss, Simmental, Holstein
10-ha Cows + Fruit + Trees	Manual Site Preparation: Mechanical Fertilizer Pasture management Pruning and harvesting Livestock operations Fruit cultivation and harvest Site management	5 Eucalyptus globulus	21 (6) Holstein
25-ha Cows + Fruit + Store + Trees	Manual Site Preparation: Mechanical Fertilizer Pasture management Pruning and harvesting Livestock operations Fruit cultivation and harvest Site management	5 Pinus patula, Cypress, Eucalyptus globulus, Aliso	38 (8) Holstein, Simmental, Brown Swiss
30-ha Many Cows + Many Trees	Manual Site Preparation: Mechanical Pasture management Pruning and harvesting Livestock operations Site management	5 Eucalyptus globulus, Alnus acuminata, Pinus patula	49 (24) Brown Swiss
65-ha Many Cows + Many Trees + Store	Manual Site Preparation: Mechanical Pasture management Timber harvest Mid-rotation fertilizer Livestock operations Site management	5 Pinus patula, Cypress	38 (11) Brown Swiss

Molinopampa, located in the northeastern portion of the Chachapoyas Province and in the southern Amazonas Region, experiences an oceanic climate, according to the Koppen Climate Classification System (Climate-Data.org, n.d.). The district is sited about 2,400 meters above sea level and covers 333.86 square kilometers, 8% of which is used for agriculture. The Peruvian National Census of 2007 calculated a poverty rate of 63.2%, an extreme poverty rate of 25.9%, and a malnutrition rate of 30% for the region (Vásquez Pérez & Oliva Cruz, 2016).

At 1,378 to 1,774 meters above sea level, the Huayabamba Valley, in the Rodríguez de Mendoza Province, is characterized as having a tropical savanna climate (Climate-Data.org, n.d.). The region experiences annual average temperature rates of 26° C and precipitation accumulation of 1,600 mm. The field sites are located on small privately-owned farms and were planted and are managed as part of cooperatives with multiple institutions throughout Peru (Mejía, 2016).

B. Data collection

Over the past four years, a coalition of organizations in Peru, La Molina Agrarian Innovation Program, El Porvenir and National University of San Martín de Tarapoto, Research Institute for the Sustainable Development of Ceja de Selva of the National University of Toribio Rodríguez de Mendoza of the Amazonas, and North Carolina State University, have been collaborating with private landowners to better understand the dynamics of applied agroforestry systems (Mejía, 2016).

As part of the project, I gathered production function data for the case studies and typical blended systems. I organized data into a database in order to estimate values from soils, crops, and grazing and economic impacts of inputs and outputs over a 25-year time horizon for regimes

in Peru and NC. I created spreadsheets and performed analysis in Excel outlying discounted cash flows associated with silvopastoral systems and traditional grazing and forestry in NC and Peru. The systems in North Carolina include loblolly pine plantations, open pasture grazing of beef cattle, and an agroforestry system incorporating loblolly pine and beef cattle. As a comparison, I estimated the costs and benefits of the three previously mentioned systems in the North Carolina Coastal Plains and Amazonas, Peru. I adapted and translated my spreadsheets to better correlate with practices in each region based on the literature and consultants.

From July 15 to 22, Dr. Cabbage and I visited the Peruvian collaborators in Chachapoyas: Dante Mauricio Pizarro Paz, Hector Vasquez, Wilmer Bernal. Our research group visited four silvopastoral systems in Pipus, Molinopampa, and Huayabamba, all located in the Amazonas Region of Peru. The Peruvian collaborators recommended I develop a list of questions for the landowners instead of filling-out adapted spreadsheets, from those demonstrating systems in North Carolina's Coastal Plain.

In order to follow NCSU Internal Review Board procedures, I prepared a short-detailed introduction of the project, shown in Appendix A. Additionally, I gave the landowner the choice of not answering and/or not participating in the interview process at any point during the visit. All of the interviewees permitted me to ask about their current and past practices, costs, and incomes associated with their farms. Each landowner also guided my colleagues and myself on a tour of their properties. Appendix B features the questionnaire I read aloud to the landowners.

After meeting with the project's coordinators at La Universidad Nacional Toribio Rodriguez de Mendoza, I learned the cattle systems in Amazonas, Peru are mostly comprised of dairy and dual-purpose cattle. These systems vary from the beef cattle systems in the Coastal Plains of North Carolina. For this reason, I adapted the activity schedule and added tables that I

could complete with the landowners during field visits. The two tables were separated according to whether the practice involved an expenditure or benefit. From the responses of the landowners, I developed cash flow estimations of each individual site. Also, I average the costs and benefits to predict the cash-flow of a “typical” silvopastoral system in Amazonas, Peru.

C. Capital budgeting analysis

Tools in capital budgeting and cash flow analysis such as Net Present Value (NPV), Land Expectation Value (LEV), Annual Equivalent Income (AEI), and Benefit-Cost Ratio (BCR) allow for comparison of different land use systems. Below, drawing from Cubbage et al. (2013; 2016), Wagner (2012), and Mercer et al. (2014), financial analyses are explained in more detail.

Real discount rates of 4%, 8%, and 12% were used in all financial formulas to represent the cost of capital or the opportunity cost of the next best investment option. Pine-based silvopastoral systems have been known to generate a rate of return of 4.5% (Alavalapati, 2004). With less literature on discount rates of land use system in Peru, including but not limited to biophysical and financial risk, we utilized multiple discount rates. Discount rates attempt to represent preferences for incurring costs and benefits now or in the future. Since discount rates are often not known by landowners, most analyses use the rate of return of the next best option such as a bank investment as the discount rate (Cubbage et al., 2016).

NPV measures the amount of capital that an investment returns at a given discount rate through summing the total expenditures and subtracting them from total income (Sharrow, 2008a). Discount rates are utilized to account for the future value of income that would equate to income earned in the present. A NPV equal to \$0 at a 4% discount rate translates to making 4% on the investment. Conversely, the discount rate can also represent the rate of return an

investment must earn to be accepted. Financial theory dictates that one should accept investments with a positive NPV at a given discount rate (Cubbage et al., 2016). Formula 1 demonstrates how NPVs are calculated in terms of farm and forest costs and revenues.

$$\text{Formula 1: } NPV = \sum \frac{(B-C)}{(1+i)^t}$$

Where B and C represent the annual total benefits and costs, respectively, of the land use system, i signifies the interest or discount rate, and t is the year of the cash flow.

LEV is standard in long-term time horizons where rotations are continued indefinitely. Similar to NPV, LEV utilizes expenditures, income, and a specific discount rate to measure the expected cash flow of a land use. By assuming the land use will be continued in perpetuity, LEV allows researchers compare systems of different rotation ages. LEV has four assumptions that should be met to be viable: (1) values of costs and revenues are identical in all rotations; (2) land will be forested in perpetuity; (3) land requires regeneration costs at the beginning of each rotation; (4) the value of land does not enter calculation. LEV represents how much an investor is willing to pay for the land at a given discount rate (Mercer et al., 2014).

$$\text{Formula 2: } LEV = NPV + \frac{NPV}{(1+i)^T - 1}$$

Where NPV equates to the net present value of the system, i again signifies the interest or discount rate, and T is the final year of the system's rotation.

AEI expresses NPV or LEV in annual payments equally distributed over the life of the investment. AEI is essential in comparing agroforestry and agricultural systems which earn annual and periodic returns. AEI allows comparison of long-term timber investments with seasonal returns of agriculture by expressing the income of each alternative in annual payments

(Cubbage et al., 2016). In situations where there is more than one landowner, for instance when a farm is owned and operated by a husband and wife as in the case in some field trials in Amazonas, the AEI was adjusted per person by dividing the value by the number of individuals.

$$\text{Formula 4: } AEI = LEV * i$$

Where LEV represents the system's land expectation value and i signifies the interest or discount rate.

Finally, BCR relates the total discounted benefits to the total discounted costs, as seen in formula 5. The relation describes present-value benefits and costs as a unitless proportion rather than as a difference such as in the case of NPV. The proportion reveals the return landowners receive per dollar invested (Mercer, Frey, & Cubbage, 2014). For example, a BCR of 1 corresponds to earning \$1 in present-value terms per dollar spent on system inputs.

$$\text{Formula 5: } BCR = \frac{\Sigma B_p}{\Sigma C_p}$$

Where B and C represent the benefits or revenues and costs or expenditures, respectively, in present-value terms

D. Spreadsheet Analysis

We designed spreadsheets in Excel for systems in NC and Peru so that we could map the cash flows of each land-use regime. The spreadsheets included necessary measures of productivity, product prices and costs, and management schedules, among other site-specific information, to calculate the net returns of annual activities. The systems in NC were analyzed independently, as monocultures, and combined for mixed-use systems. For instance, conventional forestry includes only the returns of the tree plantation monoculture; however,

conventional cattle-forage systems include a weighted average, corresponding to each land-use option and its proportion to the entire system, of the annual costs and benefits of warm-season forage, cool-season forage, and beef cattle. The Peruvian systems were modeled as whole land-use regimes instead of independent cash flows due to their complexity and the available information. The Excel models and training for the models are available upon request.

E. Carbon Sequestration Benefits of Agroforestry

Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in reservoirs. It involves the transfer of atmospheric CO₂ and its “secure storage in long-lived pools.” Thus, carbon sequestration is a rate process involving a time factor, i.e. per year or per 100 years. Meanwhile, carbon stocks lack a time factor and only measure carbon emission over a set area, i.e. tons of carbon per ha. The total amount of carbon sequestered varies greatly depending on the ecoregion, type of production system, site quality, and previous land uses. Aboveground carbon stocks, the component of carbon storage of interest in this study, include the roots and living biomass and represent approximately one-third of the carbon stored in tree-based land use systems.

Agroforestry systems potentially sequester more carbon than pastures or field crops growing under similar ecological conditions (Nair, 2011). Dube et al. (2011) report silvopasture requires less time than a plantation monoculture to reach similar carbon gains in their above and belowground pools. The researchers accredit the increased carbon sequestration potentially to the positive interactions between cattle, tree, and pasture components and increased tree growth (Dube et al., 2011).

With multiple carbon markets as well as various carbon accounting methods, sequestration rates vary greatly across species and regions. For instance, one study estimates ABG carbon sequestration rates in AFS range from 0.29 to 15.21 Mg carbon per hectare per year. ABG biomass is approximately 50% carbon and often calculated by summing the volume harvested with the standing volume. An erroneous assumption commonly made in carbon modeling is that the carbon in the biomass and soil equate to sequestered carbon. The amount of carbon stored in root biomass is extremely variable. Large-scale global models for carbon accounting are based on extrapolation of field measurements from sample plots. For this reason, carbon modeling studies may result in under- or over-estimations of total carbon stocks (Nair, 2011).

F. Land Management Calculations

Price transformations using TimberMart South publications provide conversions including stumpage prices and free-on-board (FOB) prices, stumpage price \div 2, to account for logging and delivery when not provided. For price transformations of Peruvian wood products, we converted the prices from Nueva Sol per product to USD per cubic meter of wood product. Refer to Appendix C for the price transformations.

Derived residual prices were calculated to account for logging and transportation when not given labor amounts for pruning, transport, and/or sale. We assumed the delivered price equates to the stumpage value divided by 2 for the properties that did not employ a worker to harvest and deliver wood products. As a result, we are able to capture the income generated by the manager or landowner as well as hired laborers. For this reason, we do not include landowner labor in the analysis; therefore, land-values calculated through capital budgeting methods include landowner income. For larger farms in Peru, greater than 15 head of cattle, additional laborers

are needed. Utilizing average income data from the Peruvian co-investigators, we proportionately increased income to outside laborers and/or land managers in the absentee landowner case study. Likewise, small silvopasture systems in Amazonas required less inputs for outside labor.

IV. Results

Net revenue from timber harvests as well as self-consumption of timber from mixed-systems increases overall landowner income if forage, cattle, and timber production complement one another. In fact, the silvopasture regimes with complementary product relationships in Southeastern U.S.A supply greater returns than any other system at all discount rates. Silvopastures, both hypothetical and actual, provided the greatest returns out of all the systems in Peru at low discount rates.

Table 6 demonstrates the relative quantity of the three types of wood products for each harvesting activity throughout the 25-year time horizon evaluated in the study based on the growth rates utilized. The following tables and figures depict the capital budgeting results of each scenario in both regions.

Table 6: Wood products harvested by removal.

Removal	Product
First Thin	All Pulpwood
Second Thin	$\frac{1}{2}$ Pulpwood & $\frac{1}{2}$ Chip-and-saw
Final Clearcut	$\frac{4}{5}$ Sawtimber & $\frac{1}{5}$ Pulpwood

A. Southeastern U.S.A Capital Budgeting Results

Table 7 and figure 2 summarize the capital budgeting results of the land use scenarios located in the Coastal Plains of North Carolina. Pure low-intensity forest investments such as the scenario Forest BAU analyzed in the study provides the lowest returns in present value terms at all discount rates used in the study (LEV: 4% = \$484.63 per acre (ac); 8% = -\$2.90 per ac; 12% = -\$124.03 per ac). Traditional cattle and pasture regimes in Southeastern U.S.A earn higher net returns than plant-and-leave loblolly plantations generate (LEV: 4% = \$1,537.69 per ac; 8% = \$707.62 per ac; 12% = \$453.11 per ac).

Since the cash flow models for agroforestry systems were calculated based on the proportion of land each industry uses out of the total productive area, the results closely follow the cattle-grazing scenario which constitutes 110% of the complementary regime, 100% of the independent silvopasture, and 75% of the competitive system. Agroforestry systems such as SPS Complement offer landowners the highest returns out of the systems evaluated in the study at all discount rates (LEV 4% = \$1,807.08 per ac; 8% = \$795.91 per ac; 12% = \$489.71 per ac). Agroforestry systems that include products that must compete for resources such as growing space, light, and water generate lower returns than conventional cattle grazing regimes (SPS Competitive – LEV: 4% = \$1,268.89 per ac; 8% = \$548.25 per ac; 12% = \$331.13 per ac). Independent silvopasture systems earn higher returns, compared to conventional cattle-forage systems, at low discount rates (LEV: 4% = \$1,653.31 per ac; 8% = \$725.15 per ac; 12% = \$444.40 per ac). At a 12% discount rate, the ranking order changes and conventional cattle-forage systems generate greater net returns than silvopasture systems with independent product relationships.

Table 7: North Carolina Capital Budgeting Results: Net Present Value and Land Expectation Value.

Scenario	NPV (\$/ha)			LEV (\$/ha)		
	4%	8%	12%	4%	8%	12%
Forest Only BAU	\$748.00	-\$7.17	-\$306.35	\$1,197.03	-\$8.40	-\$325.50
Forest Only SPS ¹	\$1,427.68	\$295.85	-\$161.89	\$2,284.72	\$346.44	-\$172.00
WS Only ¹	-\$453.64	\$262.22	\$589.74	-\$725.97	\$307.06	\$626.60
CS Only ¹	-\$4,176.74	-\$2,404.97	-\$1,441.27	-\$6,684.04	-\$2,816.18	-\$1,531.35
Cattle Only ¹	\$9,377.11	\$5,127.96	\$2,958.22	\$15,006.18	\$6,004.76	\$3,143.10
Cattle + Pasture BAU	\$2,373.36	\$1,492.61	\$1,053.34	\$3,798.09	\$1,747.82	\$1,119.18
SPS Independent ²	\$2,551.82	\$1,529.59	\$1,033.11	\$4,083.68	\$1,791.13	\$1,097.68
SPS Competitive ³	\$1,958.48	\$1,156.44	\$769.77	\$3,134.16	\$1,354.17	\$817.88
SPS Complement ⁴	\$2,789.16	\$1,678.85	\$1,138.44	\$4,463.49	\$1,965.91	\$1,209.59

¹Systems cannot stand alone (SPS complementary relationships)

²SPS shares: Forest 25%; WS, CS, Cattle 100%

³SPS shares: Forest 25%; WS, CS, Cattle 75%

⁴SPS shares: Forest 25%; WS, CS, Cattle 110%

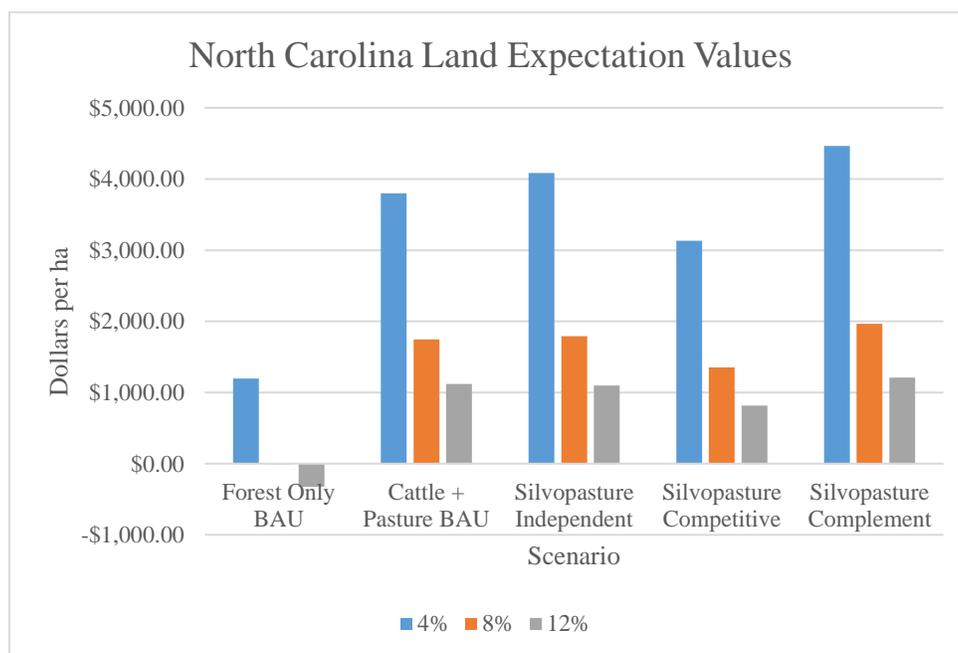


Figure 2: North Carolina Land Expectation Values at 4, 8, and 12% discount rates.

B. Amazonas, Peru Capital Budgeting Results

Table 8 displays the capital budgeting results for the hypothetical and actual regimes centralized in Amazonas, Peru. The three typical systems were regimes as described by the project co-authors during the visits in Peru.

Table 8: Peru Net Present Values and Land Expectation Values.

Amazonas, Peru Capital Budgeting Results	NPV (\$/ha)			LEV (\$/ha)		
	4%	8%	12%	4%	8%	12%
Typical Forest	\$527.87	-\$210.61	-\$583.94	\$844.74	-\$246.62	-\$620.44
Typical Cattle-Forage	\$796.88	\$318.64	\$69.53	\$1,275.25	\$373.12	\$73.87
Typical SPS	\$992.52	\$321.91	\$2.52	\$1,588.33	\$376.96	\$2.68
10-ha C + T + F	\$5,794.18	\$4,045.62	\$3,040.01	\$9,272.43	\$4,737.36	\$3,230.01
25-ha C + T + F + S	\$3,626.78	\$1,433.91	\$276.45	\$5,803.93	\$1,679.08	\$293.73
30-ha C + T	\$5,951.49	\$1,840.67	-\$261.03	\$9,524.17	\$2,155.39	-\$277.35
65-ha C + T + S	\$4,603.27	\$2,615.55	\$1,555.65	\$7,366.60	\$3,062.77	\$1,652.88

Figure 3 features the land expectation values for the conventional land-uses analyzed in Amazonas. Similar to pine plantations in the Southeastern U.S.A., pure timber investments in Amazonas provide the lowest returns of the land uses evaluated for landowners (LEV: 4% = \$342.00 per ac; 8% = -\$99.85 per ac; 12% = -\$251.19 per ac). Dual-purpose, dairy and beef, cattle grazing systems earn about 50% more than the returns of plantation forests at the lowest discount rate (LEV: 4% = \$516.29 per ac; 8% = \$151.06 per ac; 12% = \$29.91 per ac). The silvopasture scenario, based on local expert knowledge, generates the highest landowner profitability of the hypothetical regimes (LEV: 4% = \$643.05 per ac; 8% = \$152.61; 12% = \$1.09 per ac). These were “typical” systems consisting of costs and returns as estimated by the co-investigators in Peru. Similar to in the Coastal Plains, at a 12% discount rate the ranking of systems in respect to landowner profitability changes and conventional cattle-forage regimes

earn more net income than conventional SPS.

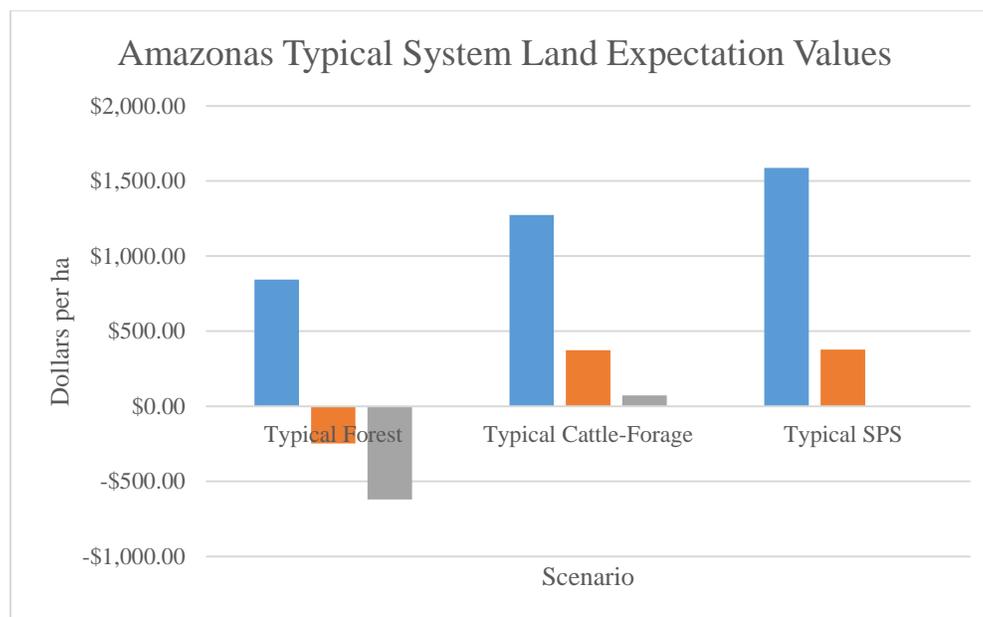


Figure 3: Peruvian Typical Systems, Net Present Values and Land Expectation Values.

The four complex agroforestry systems surveyed in Amazonas provided actual landowners much higher returns, seen in figure 4, than those based on local market expert opinions. These farms were purposefully selected by the project co-investigators, and probably are local leaders in their farm practices. The 10-ha farm including planted trees for fruit and timber production and cattle grazing earns relatively high net returns (LEV: 4% = \$3754.02 per ac; 8% = \$1,917.96 per ac; 12% = \$1,307.70 per ac). The second smallest farm visited, a 25-ha system with planted timber and fruit trees, cattle grazing, and a store on-site for sale of final products to the public, provide the lowest returns of the case studies at low discount rates (LEV: 4% = \$2,349.77 per ac; 8% = \$679.79 per ac; 12% = \$118.92 per ac). While, the second largest agroforestry system, a management-intensive 30-ha cattle grazing regime with a “living-fence” of planted trees, generates the highest returns seen in the study at 4% but profitability of the system is quite sensitive to higher discount rates (LEV 4% = \$3,855.94 per ac; 8% = \$872.63 per

ac; 12% = -\$112.29 per ac). Lastly, the largest property analyzed, a 65-ha farm with multiple cattle grazing paddocks and tree plantations produce relatively low returns at 4% but is more competitive with other land uses at higher discount rates (LEV: 4% = \$2,982.43 per ac; 8% = \$1,239.99 per ac; 12% = \$669.18 per ac).

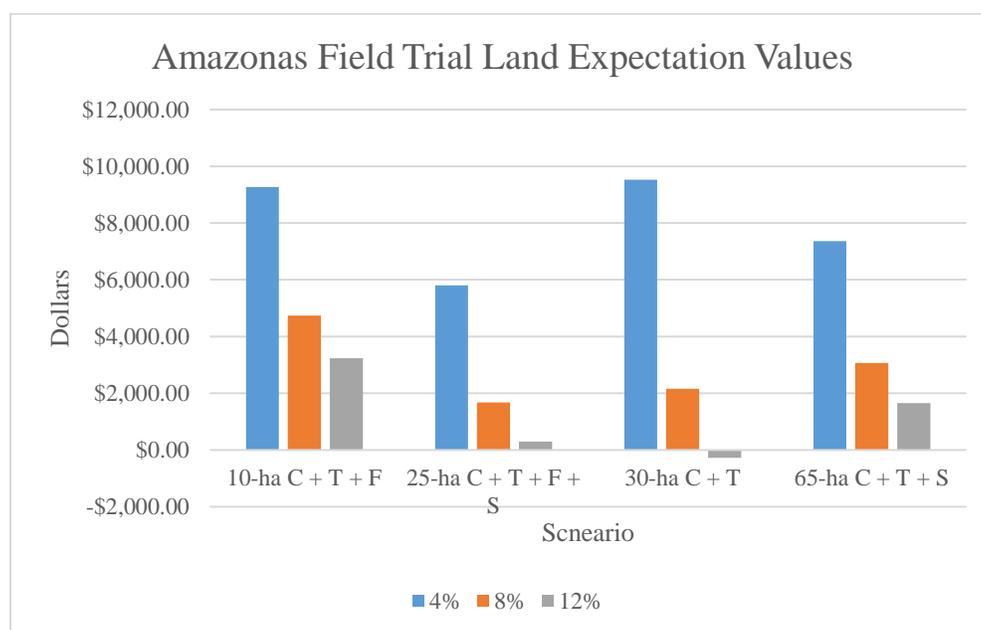


Figure 4: Peruvian Case Studies, Net Present Values and Land Expectation Values.

At a 4% discount rate, the 30-ha intensive cattle system earns the highest returns followed by the 10-ha family-operated farm, the 65-ha farm-restaurant, and the 25-ha farm-store. Increasing the discount rate to 8% changes this ranking, making the 10-ha farm the most profitable system, followed by the 65-ha intensive cattle and tree system, the 30-ha absentee landowner farm, and the 25-ha farm-store regime. At the highest discount rate used in the study, 12%, the ranking changes for the third and fourth most profitable systems: the 25-ha system earns more income in present-value terms than the 30-ha intensive cattle farm.

C. Other Measures of Landowner Profitability

i. Annual Equivalent Income (AEI) of Land Use Systems

When comparing land uses of varying harvest time-horizons, it is often useful to compare the AEI of the alternatives to estimate what the landowner would expect to receive annually from their productive systems. This annual value provides a useful metric that landowners and analysts can relate to better. Since AEI is calculated by multiplying the LEV by the respective discount rate, the profitability ranking of the systems at each discount rate follows the same trend as LEV.

Figure 5 demonstrates the AEI of the conventional monoculture regimes for both regions of the study area. At 4%, the values of all conventional systems in Peru and traditional forests in NC range from \$33.79 per ac per year to \$51.01 per ac per year. While, conventional cattle-forage systems in NC return \$151.92 at the lowest discount rate. In fact, conventional cattle-forage regimes at all discount rates in NC and 12% in Peru earn the highest annual returns. Forest monocultures in both regions experience negative returns at higher discount rates.

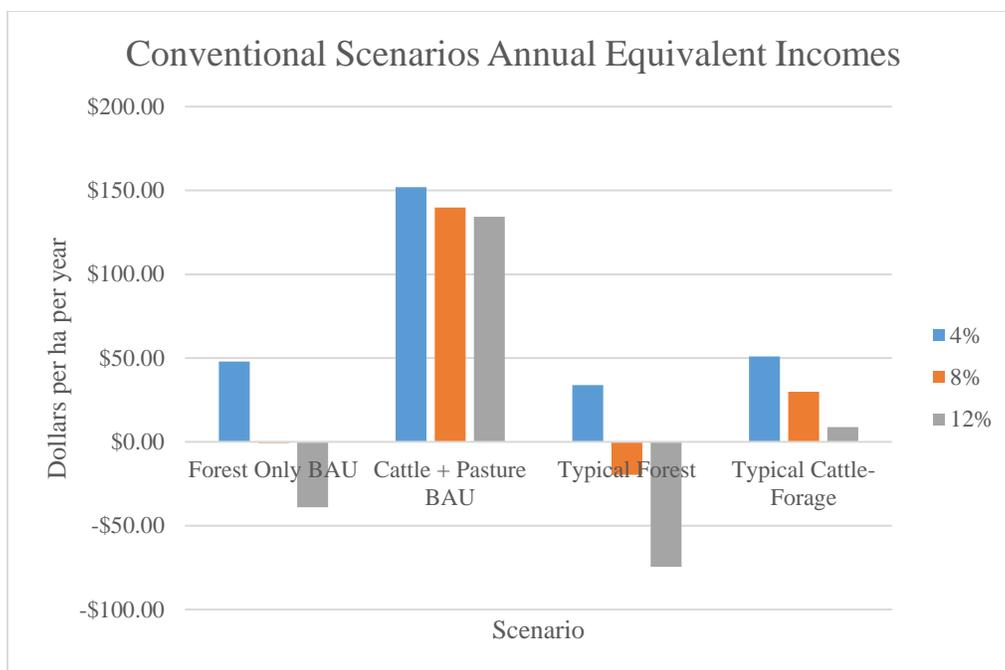


Figure 5: Annual Equivalent Income of traditional forest and cattle systems.

Figure 6 displays the AEI values for mixed land-use regimes. The actual dual-purpose silvopastoral systems in Amazonas, Peru increased returns considerably compared to the typical systems. The agroforests analyzed in NC and the typical silvopastures in Peru experience positive annual returns at all discount rates. The calculated annual net revenue of actual systems, adjusted by the number of owners of each respective field trial, range between \$116.08 per ac per year to \$185.45 per ac per year when using a 4% discount rate. With higher discount rates, the returns of the 25-ha and 30-ha regimes decrease dramatically. The 10-ha and 65-ha are less sensitive to higher discount rates and maintain relatively consistent high annual net revenues.

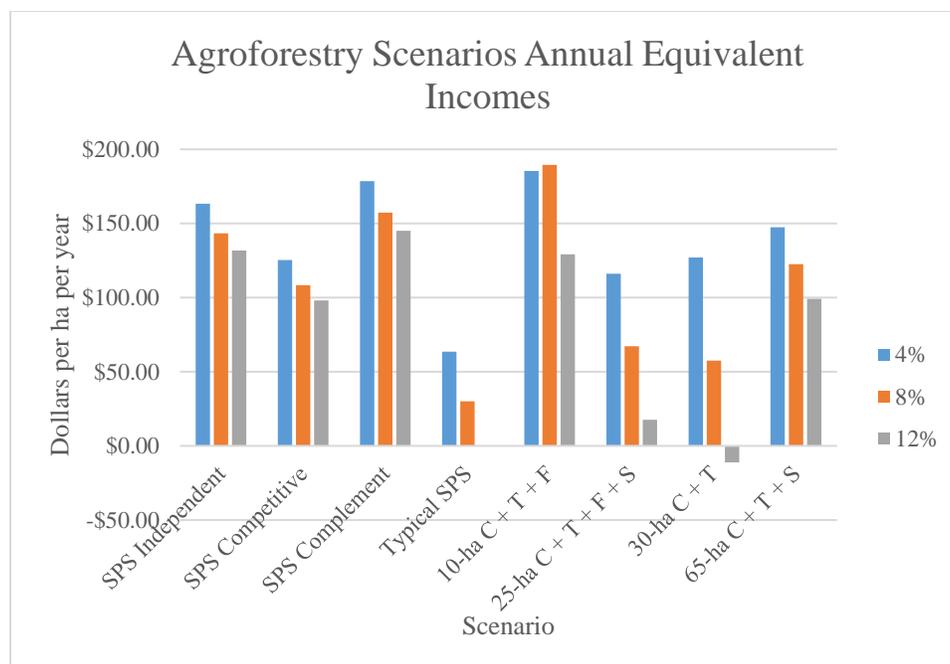


Figure 6: Annual Equivalent Income of agroforestry systems.

ii. Benefit-Cost Ratios (BCR) of Land Use Alternatives

Table 9 and figure 7 display the BCRs, a measure of the financial returns received per dollar spent in an investment, of all systems analyzed in the study. Tree plantations in the Coastal Plains of North Carolina and in Amazonas, offer relatively high returns per dollar invested at the lowest discount rate, as observed in their BCRs (NC Forest BAU – 1.89; Amazonas Typical Forest – 1.27). At 8% and 12%, the BCR of forest monocultures in both regions is less than 1, signifying a loss per dollar invested (NC: 0.99, 0.52; Amazonas: 0.87, 0.61). In the Southeastern U.S.A., silvopasture landowners receive the same return per dollar invested as experienced in cattle-forage production regimes at all discount rates (BCR - 1.09). Competitive silvopasture regimes at a 4% discount rate, however, earn slightly more per dollar invested (BCR – 1.1).

Table 9: Benefit-Cost Ratios for all systems.

Region	Scenario	BCR		
		4%	8%	12%
NC	Forest Only BAU	1.89	0.99	0.52
	Cattle + Pasture BAU	1.09	1.09	1.09
	SPS Independent	1.09	1.09	1.09
	SPS Competitive	1.10	1.09	1.09
	SPS Complement	1.09	1.09	1.09
Peru	Typical Forest	1.27	0.87	0.61
	Typical Cattle-Forage	1.11	1.07	1.02
	Typical SPS	1.16	1.08	1.00
	10-ha C + T + F	1.62	1.66	1.71
	25-ha C + T + F + S	1.27	1.15	1.04
	30-ha C + T	1.24	1.11	0.98
	65-ha C + T + S	2.54	2.33	2.12

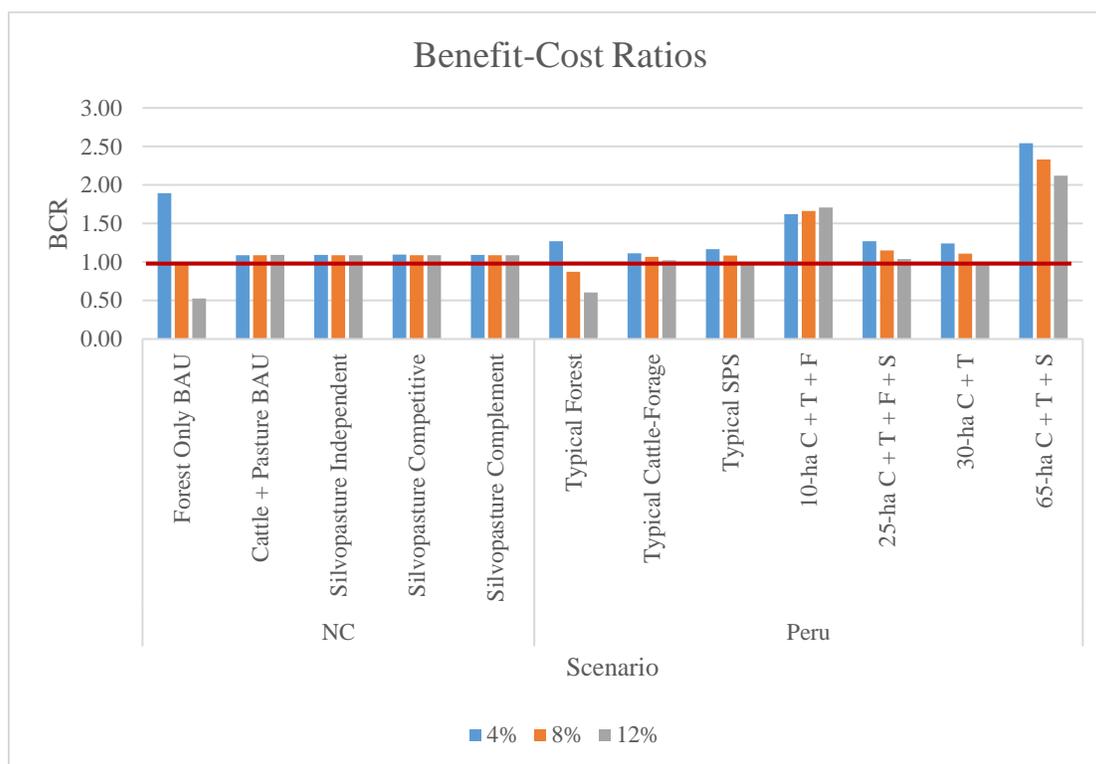


Figure 7: Benefit-Cost Ratios for all systems.

Dual-purpose cattle-forage regimes in Amazonas are highly cost-intensive, compared to planted tree monocultures, and generate less returns per dollar invested at the lowest discount rate (BCR - 1.11). At higher discount rates, cattle-forage systems earn more per dollar invested than forests (Amazonas BCR: 8% = 1.07, 12% = 1.02). The returns per dollar invested in silvopastures in Amazonas include a combination of costs and benefits from each individual industry and thus, the BCR is located between each respective value (4% = 1.16, 8% = 1.08, 12% = 1.00).

The 10-ha case study had the second highest returns per dollar invested of the actual farming systems at all discount rates (BCR: 4% = 1.62, 8% = 1.66, 12% = 1.71). In fact, the BCRs of the 10-ha farming system increased as the discount rate increased. The less profitable 25-ha mixed-use farm required slightly higher management intensity and generate less returns per dollar spent (BCR: 4% = 1.27, 8% = 1.15, 12% = 1.04). The system with the most management inputs, a 30-ha silvopasture with an absentee landowner, earned the lowest returns per dollar invested of the case studies analyzed in the project (BCR: 4% = 1.24, 8% = 1.11, 12% = 0.98). The largest actual farm evaluated, a 65-ha silvopastoral system with a restaurant and timber sale on site, generated the greatest returns per dollar invested of the entire study at all discount rates (BCR: 4% = 2.54, 8% = 2.33, 12% = 2.12).

iii. Establishment Costs and Payback Periods

The production systems analyzed in the project require varying degrees of intensity of establishment practices as seen in table 10. Of the hypothetical scenarios, pure forest investments in North Carolina and Amazonas demand the least in establishment inputs (Forest BAU - \$181.12 per acre; Forest Only - \$457.69 per acre). However, due to the longer turn-around time before generating a positive net income, forest monocultures also include the longest payback

period, in non-present value terms (Forest BAU – 18 years; Forest only – 8 years). While traditional cattle-grazing regimes in both regions required higher-cost inputs for establishment (NC Cattle + Pasture BAU - \$1,189.07 per acre; Amazonas Cattle + Pasture Only - \$484.83 per acre), they produced positive net returns sooner than planted forests (Cattle + Pasture BAU – 4 years; Cattle + Pasture Only – 3 years).

Silvopastoral regimes include relatively high establishment costs ranging from \$915.70 per acre to \$1,341.84 per acre and require 4 years to pay off upfront costs, similar to cattle systems in the region. The establishment costs of hypothetical and actual silvopastures range from as low as \$252.63 per acre to as high as \$1,212.97 per acre and require as soon as 1 year and as long as 5 years to pay back establishment costs, in non-present value terms.

Table 10: Establishment costs per hectare and payback periods for all systems.

Region	Scenario	Establishment Cost (\$/ha)	Payback Prd (yrs)
NC	Forest Only BAU	\$447.36	18
	Cattle + Pasture BAU	\$2,937.00	4
	Silvopasture Independent	\$2,996.04	4
	Silvopasture Competitive	\$2,261.79	4
	Silvopasture Complement	\$3,314.34	4
Amazonas	Forest Only	\$1,130.50	8
	Cattle + Pasture Only	\$1,197.53	3
	Typical Silvopasture System	\$1,203.35	4
	Cattle + Trees + Fruit Case Study	\$915.56	1
	Cattle + Trees + Fruit + Store Case Study	\$1,183.10	1
	Cattle Intensive + Trees Case Study	\$1,082.35	5
	Cattle Intensive + Trees Intensive Case Study	\$623.99	5

D. Incentive Policy Analysis

In order to alleviate the pressure of high establishment costs and long pay back periods, governmental intervention through cost-share payments and payments for ecosystem (or environmental) services may aid landowners in Amazonas and the coastal Plains of North Carolina.

i. Cost-share Payments

Landowners may receive various cost-share payments for conservation practices from the federal government or other entities. Typical 50% cost-share payments, which pay landowners half the establishment costs necessary to develop a tree plantation, or other conservation practice, may shorten the time needed to generate positive net earnings, in non-present value terms. Table 11 summarizes planted forest establishment costs, 50% cost-share payments, the new LEV of each scenario with reduced costs, and the payback periods required to cover establishment costs.

Table 11: 50% Cost-Share Payment for Establishment of Tree Plantations.

Scenario	Establishment Cost (\$/ha)	Payback Prd (Yrs)	50% Cost Share (\$/ha)	New LEV (\$/ha)			New Payback Prd (Yrs)
				4%	8%	12%	
NC SPS Independent	\$111.84	4	\$55.92			\$1,153.60	3
NC SPS Competitive		4		\$3,190.08	\$1,410.09	\$873.80	4
Peru Typical SPS	\$175.23	4	\$87.61			\$90.29	4

The cost-share payments in the initial years increase the NPV or LEV by the amount of the payment, *ceteris paribus*. More significantly, the payments reduce the payback period in independent silvopastoral regimes, which would make adoption more attractive for small landowners.

ii. Payments for Ecosystem Services

Payments for ecosystem services such as carbon sequestration and water quality can help increase returns of agroforestry systems such as silvopastures. In the case of silvopastures that include competitive, and independent at high discount rates, product-product relationships and

produce less returns to landowners than traditional cattle-forage systems, payments for ecosystems can provide landowners an equal choice between land uses. Table 12 demonstrates the payments needed over a 10-year time horizon to break-even with cattle-grazing regimes common to each region, not including an initial cost-share payment.

Table 12: Breakeven Payment for Ecosystem Services.

Region	Scenario	LEV Difference: Cattle-Forage – SPS (\$/ha)			10-yr Annuity: Difference in LEV (\$/ha/yr)		
		4%	8%	12%	4%	8%	12%
NC	SPS Independent			\$21.50			\$3.81
	SPS Competitive	\$663.93	\$393.65	\$301.29	\$81.86	\$58.67	\$53.32
Peru	Typical SPS			\$71.19			\$12.60

The difference in land expectation values between the SPS competitive regime and cattle-forage systems decrease with higher discount rates, causing the necessary break-even annuity to decrease as well. Mixed-systems in Amazonas, both hypothetical and actual, experience higher returns than the monoculture alternatives utilizing discount rates of 4% and 8%. At 12%, typical silvopastures earn less in present-value terms than conventional cattle-forage systems and require an annuity of \$5.10 per acre

In Southeastern U.S.A., a combination of policies may be necessary to increase profitability of competitive agroforestry systems. When one policy intervention is not enough to increase net returns of less-profitable systems to approach the earnings from alternative systems, combinations of more than one policy can be implemented. Table 13 demonstrates the 10-yr annuities necessary to break even with traditional cattle systems in North Carolina after establishment costs are reduced by 50%.

Table 13: Cost Share Payment and Breakeven PES – Southeastern U.S.A.

Scenario	New LEV Diff (w/ 50% payment; \$/ha)			10-yr Annuity: Difference in LEV (\$/ha/yr)		
	4%	8%	12%	4%	8%	12%
NC SPS Competitive	\$608.01	\$337.73	\$245.37	\$74.96	\$50.33	\$43.43

Break-even annuities partnered with a 50% cost share payment for competitive silvopastures in the Coastal Plains range from as low as \$17.58 per acre per year for 10 years at 12% to as high as \$30.35 per acre per year for 10 years at 4%.

iii. Payments for Carbon Storage

Using growth rates of 2.4, 3.2, and 4.9 tons per acre per year and an approximate biomass volume of 50% dry wood volume, I estimated the net carbon flow of each tree-based land use system, modeled in figure 8. Due to the inconsistent nature and early stages of carbon modeling of agroforestry systems, we assumed the discount rate of carbon to be the same as the financial discount rates, 4%, 8%, and 12%. The baseline comparison to show additional carbon storage is traditional cattle-forage systems. Refer to table 14 for the price of carbon necessary to break-even with traditional cattle-forage systems in each respective region.

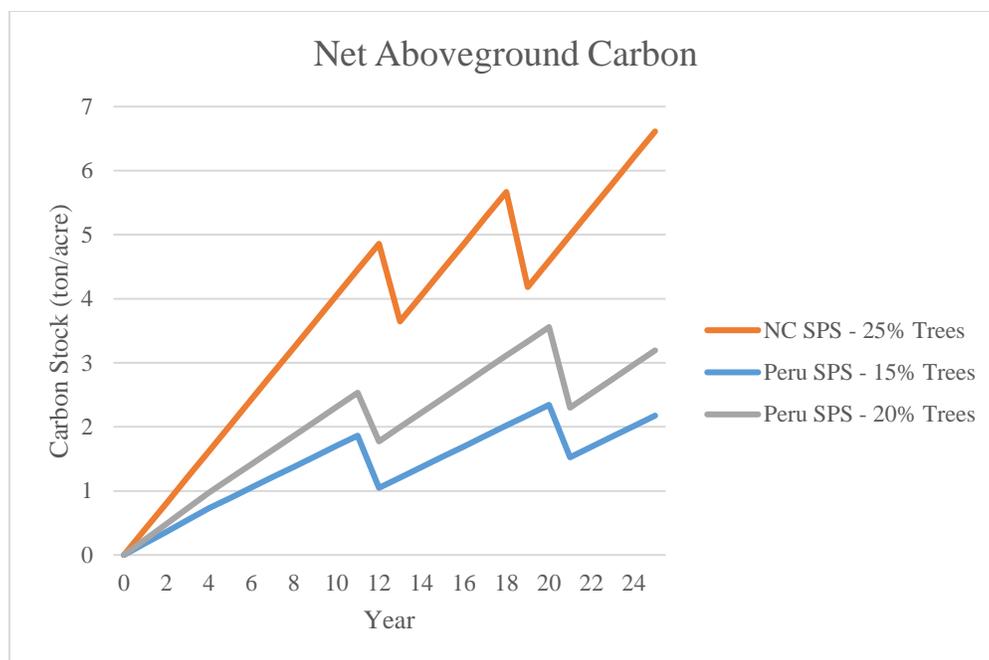


Figure 8: Net Carbon Flow of Tree-based Scenarios in North Carolina and Amazonas.

Table 14: Breakeven Analysis for the Price of Carbon.

Region	Scenario	Total Net C (ton/ac)	Breakeven Price for Carbon (\$/ton)		
			Discount rate	4%	8%
NC	SPS Independent	6.61			\$3.25
	SPS Competitive		\$0.89	\$0.53	\$0.40
Peru	Typical SPS - 15%	2.17			\$32.81
	Typical SPS - 20%	3.19			\$22.32
*Assuming carbon decays/discounts at same rate as financial discount rate					

The derived potential of carbon sequestration in Amazonas is 1.2 tons per acre per year and 1.6-2.4 tons per acre per year in North Carolina. With the estimated carbon storage rates and low carbon prices, achieving an annual payment of \$129.83 per acre is not possible. However, all break-even prices for carbon stored in NC silvopastures are less than current carbon offset prices at all discount rates (Independent: 12% = \$3.25 per ton CO₂; Competitive: 4% = \$0.89 per ton

CO₂, 8% = \$0.53 per ton CO₂, 12% = \$0.40 per ton CO₂). Break-even carbon prices for Peruvian silvopastures with a 12% discount rate are approximately ten times the required price for NC systems to break-even with cattle-forage regimes (Typical SPS with 15% trees: \$32.81 per ton CO₂; Typical SPS with 20% trees: \$22.32 per ton CO₂).

V. Discussion

We found that silvopasture regimes with complementary product-product systems produced higher returns than any conventional land use system in North Carolina and Peru at 4%, 8%, and 12% discount rates. The typical systems analyzed in North Carolina were beef cattle – southern pine silvopasture systems. In Amazonas, Peru, typical systems were dual-purpose dairy cattle with some forests, and often with on-farm small retail stands. This span of systems provides a mix of inputs and returns.

The increased profitability of complex agroforestry scenarios to private landowners may stem from the reduced management costs, compared to monoculture systems, and the resulting increased productivity of the systems through complementary biophysical characteristics. The typical systems in Peru were only moderately profitable. However, the Peruvian systems demonstrate that with increased system complexity, i.e. scenarios which harvest and sell fruits, returns can increase as well, at least by the best landowners.

There seems to be limits to the higher returns, depending on land management techniques and land uses. If products in an agroforestry regime are not complementary and/or at higher discount rates, the best financial investment choice for landowners in Southeastern U.S.A. is conventional cattle grazing systems, assuming cattle health is equivalent. However, quantifying

the rapidly emerging research on health and vigor of ruminants in silvopasture systems may alter this conclusion. Therefore, profitability of agroforestry systems in NC depends on the product-product relationships as well as the opportunity cost of alternative investments.

Planted forests in North Carolina and Amazonas appear to be the most cost-effective for landowners with limited capital, generating the highest ratio of returns in proportion to total expenditures. These land use methods may be appealing to those interested in low-input systems with moderate profitability. However, tree plantations in both regions earn relatively low returns at all discount rates utilized in the study, when compared to cattle or mixed-use systems, and require longer time periods to pay back establishment costs. Reducing high establishment costs coupled with long pay back periods represent areas of potential for governmental assistance through incentive programs.

Incentives such as cost-share payments or payments for ecosystem services encourage landowners to invest in land use systems by reducing the initial costs needed and increasing income sooner to establish a profitable system. The calculated cost-share payments necessary to break-even with conventional cattle systems, were less in both regions than the U.S. national average rental payments, \$62.55 per ac, offered in the Conservation Reserve Program (CRP) (USDA Farm Service Agency, 2016). With payments for environmental or ecosystem services, the payment amount needs to be at least the difference in returns between the environmentally sustainable land use option, i.e. incorporating forest cover through silvopasture, and the conventional more profitable uses to provide an equal choice to landowners.

The returns per hectare for the complex dairy-fruit-silvopasture systems were the greatest in Amazonas. However, we did not include on farm home labor as a cost in any of our costs. In Amazonas, the profits essentially represent the family income so their profits per acre were high,

but total area was relatively small. The adjusted AEI values for the field trials in Amazonas are comparable to annual returns experienced by NC silvopastures. Generally, systems in Peru are smaller in size and utilize family labor when possible. As system size increases, the need for additional labor increases. The 25-hectare and 65-hectare systems including stores did not earn as high of returns as the 10-hectare and 30-hectare systems without stores at the lowest discount rate. The 10-hectare and 65-hectare systems use mostly family labor while the other two systems employ more outside laborers. With multiple variables, it is difficult to isolate the effect of diversifying systems through fruit and dairy product sales and a store or restaurant onsite on landowner returns.

The land use regimes in Amazonas are complex. Two of the large systems hired outside labor; the others used on farm owners. These varying results do suggest that different mixes of production systems along with management intensities may play a role in determining landowner profitability. For example, both the 10- and 65-ha regimes include relatively low-intensity management, in terms of inputs, including but not limited to their self-sufficiency in labor without the need to hire additional laborers. However, the 10-ha farm, both smaller in size and less profitable per dollar invested, generates higher annual net returns in present-value terms than the 65-ha system at all discount rates. This smaller farm, however, sold fruit and home-made cheese, which increased returns, so did the larger 25-ha farm. The relationship between the resource variables and the capital budgeting results requires more analysis regarding the relationship between cost-intensity and the marginal increase or decrease in returns per unit of land.

Small landowners often have limited capital and need frequent streams of income, which limits long-term investments. Payback periods in Amazonas vary slightly more than the systems

in the coastal plains of North Carolina. Nevertheless, the same trend is present: it takes much more time to cover establishment costs in forest systems when compared to cattle and agroforestry systems. The difference in returns as well as the turn-around time for landowners to start generating positive profits represent challenges that governmental policies and extension agents can alleviate in order to encourage investment in expanding forest cover in agricultural systems.

PES such as offsets for forest carbon storage have the potential to increase and diversify returns as well as make less profitable land uses such as competitive silvopastures more attractive. The prices of carbon are currently higher on average than the derived breakeven prices for carbon stored in NC silvopastures in this study. The average price of offsets for carbon stored in forests in 2016 was \$5.10 per ton CO₂, which is higher than the calculated break-even prices for carbon sequestered in NC silvopastures and less than the Peruvian break-even prices (Hamrick & Gallant, 2017). Governmental intervention may be necessary through PES programs such as payments for carbon sequestration to make less profitable land use systems competitive with conventional cattle-forage systems in NC and Amazonas.

The LEVs of the scenarios in North Carolina were fairly consistent with returns estimated by Bruck et al. (2016). Bruck et al. conclude that traditionally stocked loblolly pine stands earn higher profits than silvopastoral systems (\$1,776.92) which is contradictory to the results in this study. The study estimates a silvopasture system with cool season forage and loblolly pine to return \$1,025.91 per acre, compared to returns of \$1,268.89-\$1,653.31 per acre from warm season forage-loblolly pine systems modeled in this study. Bruck et al. state that traditional cattle-forage systems in the coastal plains of North Carolina earn more than any other system in the region (\$2,069.64 per acre).

To the best of our knowledge, at the time of this study, no other projects have analyzed the economic returns of silvopasture systems compared to planted trees monocultures and traditional cattle grazing regimes in Amazonas or Peru. Nevertheless, since the cost of land purchase was not considered in the analysis, we are able to compare LEV values with the average sale price of land in both regions to determine if the expected returns from the systems correlate with market prices for agricultural land. In 2015, the average land price of cropland and pasture in North Carolina was \$4,100 per ac and \$4,700 per ac, respectively (USDA National Agricultural Statistics Service, 2015). The average price of productive land for sale in Northern Peru, based off three lots currently for sale, is \$3,894 per ac (Realigo Real Estate, 2015). None of the land use systems analyzed in this study surpass the average land cost in each respective region.

Using discount rates of 4%, 8%, and 12% provides a range of potential returns from land use systems with various opportunity costs. Without established literature and known landowner discount rates, using multiple discount rates allows us to estimate returns with multiple preferences in mind. Lower discount rates give more weight to long-term returns and less weight to short-term costs and benefits. While, higher discount rates represent higher opportunity costs of alternative investments and/or involve riskier investments. As discount rates increase, more weight is put on expenditures and revenues earned earlier rather than farther in the future of an investment. For the scope of the study, we are able to see which land use practices are more sensitive to high discount rates in Amazonas and North Carolina.

Forests, which return periodic, long-term revenues and typically require high establishment costs, experience negative returns at 8% and 12% discount rates in both regions. While, conventional cattle-forage systems in Amazonas and North Carolina appear more resilient

to high discount rates with relatively high returns at each discount rate. Silvopastures with high proportions of cattle-forage production, the complementary and independent scenarios in North Carolina, maintain slightly higher returns as the discount rate increases. The low-input case studies in Amazonas, the 10-ha and 65-ha regimes, maintain high returns at all discount rates, compared to the 25-ha and 30-ha intensively managed systems.

VI. Conclusion

The silvopasture systems analyzed could provide higher returns than conventional land uses in both Peru and the Southeastern U.S.A. if managed to ensure complementary production relationships. However, if the systems are not managed to maintain an open canopy, forage production decreases due to resource competition. Competitive tree – cow/forage relations can even result in negative returns at high discount rates. This would make traditional cattle-forage systems the most financially profitable land use in North Carolina, *ceteris paribus*.

The emerging literature reviewed in the study suggests that silvopastures in temperate regions have considerable promise to increase landowner profitability. The nature of the relationship between trees and forage (complementary, independent, or competitive) as well as the opportunity cost of alternative investments will determine whether diversifying land use through agroforestry will increase landowner returns while also allowing for more ecologically sustainable production systems. It is important to identify both the levels of production and the management regimes that could make silvopasture financially competitive.

Government support through direct payments could increase the profitability of silvopastures with competitive and independent relationships between cattle and trees in order to

gain ecosystem service benefits such as carbon storage or improved water quality. Cost-share payments may make land uses that expand forest cover more desirable to landowners by reducing establishment costs. Cost-share payments also have the potential of shortening payback periods so limited income landowners can reach net positive cash flow sooner. When cost-share payments are not enough to make silvopasture more profitable, payments for ecosystem services, such as carbon storage, may be employed to provide a stream of annual benefits over some time period, e.g. the first ten years when revenue is at its lowest.

Payments to landowners for carbon sequestration represent a promising solution to the low profits of competitive and independent silvopasture regimes. However, with low carbon prices, the absence of mature markets, and competitive resource relationships, carbon payments may not be sufficient to make silvopasture competitive with conventional cattle-forage systems in Peru and North Carolina. In these cases, multiple forms of aid may be necessary to encourage landowners to adopt land uses such as agroforestry. Overall, mixed-systems in Amazonas, Peru and Southeastern U.S.A. represent essential models of land use regimes which can be altered and/or replicated to produce supportable livelihoods for landowners.

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APPENDICES

Appendix A: Landowner Interview Introduction

Soy Stephanie y soy estudiante de maestría en la Universidad de Carolina del Norte. Estoy cooperando con la Universidad Agraria – La Molina y la Universidad Nacional Toribio Rodríguez de Mendoza. Espero aprender sobre los sistemas silvopastorales para una investigación de transferencia de tecnología. Agradezco la oportunidad de visitar su finca y espero poder preguntarle sobre sus prácticas y costos para ayudar los sistemas sostenibles en Chachapoyas. ¿Tenemos su permiso? Puede contestar o rechazar contestar si usted prefiere.

I am Stephanie and I am a master's student at North Carolina State University. I am cooperating with the University Agraria – La Molina and the National University of Toribio Rodriguez de Mendoza. I hope to learn more about silvopastoral systems for a research project in extension. I appreciate the opportunity to visit your farm and I hope to ask you questions about your practices and costs in order to help sustainable systems in Chachapoyas. Do we have your permission? You may choose to answer or refuse to answer if you prefer.

Appendix B: Landowner Interview Questions

Preguntas	Questions
Arboles	Trees
1. ¿Cuáles especies de árboles tiene?	1. What species of trees do you have?
2. ¿Cuántos años tienen los arboles?	2. How old are the trees (years)?
3. ¿Usa o venda la madera? Si así, ¿Cuál son los usos de los arboles?	3. Do you use or sell the Wood? If so, what are the uses?
3a. Si así, ¿Qué es el precio?	3a. If so, what is the sale price?
4. ¿Cuándo cosecha la madera?	4. When do you harvest the wood?
5. ¿Cómo rápido crecen los arboles?	5. How rapidly do the trees grow?
5a. ¿Qué edad crecen hasta?	5a. What age do the trees grow until?
Vacas	Cows
6. ¿Cuántas vacas tiene?	6. How many cows do you have?
7. ¿Cuáles razas de vacas tiene?	7. Which breeds of cows do you have?
8. ¿Cuántas son terneros, terneras, vaquillas, vaquillonas, y macho de reproductor?	8. How many are male calves, female calves, adult females, milk-producing adult females, and males used for reproduction?
9. ¿Cuántos litros de leche producen sus vacas por día?	9. How many liters of milk do your cows produce per day?
10. ¿Cuánto cuesta una vaquillona?	10. How much does a milk-producing adult female cow cost?
10a. ¿Qué tipo de pasto tiene?	10a. What type of pasture do you have?
Césped/Pasto	Grass/Pasture
11. ¿Crece y venda césped/pasto o granjas?	11. Do you grow and sell grass/pasture or grains?
11a. Si así, ¿Cuáles las cantidades y precios?	11a. If so, what are the quantities and prices?
11b. ¿Tiene plantas o pasto cultivados?	11b. Do you have cultivated plants or pasture?
11c. ¿Cuánto cuesta el establecimiento del pasto?	11c. How much does establishing your pasture cost?
Administración	Administration
12. ¿Cuánto cuesta los materiales para cercas?	12. How much does the fencing materials cost?
13. ¿Hay algunos otros costos de establecimiento?	13. Are there any other establishment costs?
14. ¿Tiene máquina para su finca?	14. Do you have mechanized equipment for your farm?
14a. Si así, ¿Cuánto cuesta para comprarla?	14a. If so, how much does it cost to purchase it?
14b. ¿Cuánto cuesta para operarla por mes?	14b. How much does it cost to operate per

	month?
15. ¿Cuánto tiempo por mes en días:	15. How many days per month:
15a. Trabaja con vacas	15a. Do you work with cows?
15b. Trabaja con arboles	15b. Do you work with trees?
15c. Trabaja con pasto	15c. Do you work with pasture?
16. ¿Cuánto tiempo tiene el pasto?	16. How old is your pasture (years)?
17. ¿El pasto produjo menos con tiempo?	17. Has your pasture produced less with time?
17a. Si así, ¿ha reducido la cantidad de las vacas?	17a. If so, have you reduced the number of cows you have?
18. ¿Los arboles producen frutas?	18. Do your trees produce fruit?
18a. Si así, ¿Qué es la cantidad y el precio?	18a. If so, what is the quantity and price?

Appendix C: Peruvian Wood Products Price Transformations

1. “Carga,” 50 kilograms, of fuelwood
 - a. $\times 2.2$ pounds per kilogram $\div 2000$ pounds per ton $\times 0.822$ cubic meters per ton (from TimberMart South) = 22 “cargas” per cubic meter of fuelwood,
 - b. $\times 15$ soles per carga = S/. 331 (\$102.16) per cubic meter of fuelwood
2. Posts, 2.5 meters by 11 centimeters in diameter
 - a. Volume = $250 \times 5.5^2 \times 3.14 = 23,746$ cubic centimeters
 - i. $1,000,000$ cubic centimeters / $23,746$ cubic centimeters = 42 posts per cubic meter
 - ii. S/. 5 per post translates to S/. 210 (\$64.81) per cubic meter of posts
3. “Pies tabla,” 1 inch by 12 inches by 12 inches
 - a. cubic foot contains 5 board feet cut by chainsaw (Experts in forest products)
 - b. 5 board feet $\times 35$ cubic feet per cubic meter
 - c. S/. 175 (\$75.62) per cubic meter