This is to certify that the

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Sustainable Agriculture and Deforestation in the Peruvian Amazon

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David Russell Yanggen

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Major professor

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SUSTAINABLE AGRICULTURE AND DEFORESTATION IN THE PERUVIAN AMAZON

By

David Russell Yanggen

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics

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ABSTRACT

SUSTAINABLE AGRICULTURE AND DEFORESTATION
IN THE PERUVIAN AMAZON

By

David Russell Yanggen

Agriculture accounts for over 80% of deforestation in the Peruvian Amazon. However, agriculture in the region is not monolithic in nature. Farmers produce different products and use different production technologies. This thesis analyzes how different agricultural technologies and outputs affect deforestation.

This thesis uses econometric modeling based on a profit function approach to analyze the relationship between agriculture and deforestation. There are two levels to this analysis. The first level analyzes the relationship between agricultural production determinants (prices and fixed factors) and farmers' choices concerning production technologies and agricultural outputs. These econometric models use the methods of ordinary least squares (OLS) and seemingly unrelated regression equations (SURE). The second level analyzes how these input and output decisions affect deforestation. These models are generally recursive in nature but use a two stage least squares approach to correct for simultaneity when detected by the Hausman specification test.

This thesis found that in an environment where land is abundant relative to labor, farmer adoption of technologies that enhance land productivity is dependent upon whether or not these technologies increase returns to labor. The design and promotion of improved technologies should therefore focus on combining enhanced land productivity with increasing returns to labor. However, if increased returns to labor are primarily a

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result of decreasing per hectare labor requirements, then freed up labor is likely to increase deforestation. It is therefore necessary to find production practices that "absorb" labor away from deforestation by increasing labor requirements per hectare while at the same time increasing returns to labor.

This thesis also found that the use of capital inputs that increase land productivity diminishes farmer clearing of primary forest. The difficulty is that in most cases of abundant land and scarce capital it is more economical for farmers to use extensive slash-and-burn practices than to adopt these inputs. Research should therefore give priority to using economic analysis to identify crop and capital input combinations that are both affordable and profitable for farmers. In addition, capital in the form of credit was found to have a significant impact (both positive and negative) on forest clearing. Credit should therefore be tied to production practices that reduce deforestation.

This research also found that agricultural production practices can have different impacts on different *types* of deforestation (total, primary and secondary forest clearing). It is therefore critical for research to take a disaggregated approach to analyzing the impacts of agricultural on deforestation.

A final finding of this research is a clear evolutionary trend in land use patterns. Farmers start out clearing primary forest for annual crop production at the forest margins. In older settlement areas farmers progressively reduce annual crop production and clear degraded land in secondary forest areas for ranching.

DEDICATION

I dedicate this thesis to my grandmother Helen Yanggen who passed away at age 100 while I was completing my thesis research in the Peruvian Amazon.

For her infallible positive attitude, her kindness and generosity, her desire to see her family happy, her independent free spirit and her many other qualities I look to her as one of the great role models in my life.

I know she is now in heaven with a sign on her door that says "no uninvited visitors" and is reciting by heart verses of poetry learned in high school as she did at age 99.

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The International Center for Research in Agroforestry (ICRAF)

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I am also grateful to the Department of Agricultural Economics at Michigan State University (MSU) and the USAID Food Security II Project for providing me with work opportunities to support the studies that led to this thesis.

And to the following individuals:

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To Scott Swinton, Stephen Vosti, Sandra Batie, and Larry Leefers, my committee members for their guidance and encouragement

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To Dale Bandy, John Weber, Wagner Guzman, Carmen Sotelo, Jenny Paz, Leopoldo Rocca, Julio Alegre, Ricardo Labarta, Anne-Marie Izac, Jackeline Barbaran, and other colleagues from ICRAF as well as collaborators from CIAT, CIFOR, INIA, and the Ucayali Ministry of Agriculture for all their many forms of support

To Valerie Kelly, my research assistantship supervisor, who helped provide me my single most important learning experience while in residence at MSU working on applied issues of natural resource management related to agriculture production

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To the Peruvian farmers who participated in the surveys and presurveys for their time, patience, and insights

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To my parents Douglas and Victoria Yanggen for their support during the difficult moments and my brother Steve and sister Julie who I'm grateful to have as siblings

To the many students at the MSU Department of Agricultural Economics who generously collaborated so that we could succeed together

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To all the professors, students, friends and colleagues along the way from the University of Wisconsin-Madison and the Land Tenure Center, L'Institut d'Etudes Politiques-Aix-en Provence, L'Université de Geneve-L'Institut Universitaire d'Etudes du Developpement, and Peace Corps-Mali who inspired me to follow a career in international development

And last but not least to farmers such as Zoumana Sanago, Namu Koulibaly, Nvah Sanago, and Abdoulay Koulibaly who have my complete admiration for their intelligence and ingenuity. They taught me first hand a great deal about the technical and economic aspects of agriculture and confirmed my belief in the need to always speak with and listen to farmers to learn from their wealth of knowledge-a principal that has served me well

To all of you: Thank you – Gracias – I ni che – Merci

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INTRODUCTION

1. Introduction

This dissertation research is part of the Alternatives to Slash and Burn (ASB) initiative of the Consultative Group of International Agricultural Research (CGIAR) centers. Components of this initiative have taken place in various countries of Latin America, Africa, and Asia. The purpose of this research effort is to find economically and environmentally sustainable alternatives to the ecologically destructive practice of slash-and-burn agriculture in the world's humid tropical rainforests. Research results from each site are pooled together to identify general trends concerning the impact of agriculture on deforestation. This particular research took place in the lowland Amazon rainforest of Peru in the zone surrounding the city of Pucallpa. The International Center for Research in Agroforestry (ICRAF) was the principal sponsor providing financial and logistical support including office facilities at the Ecoregional Center in Pucallpa.

2. Overview of Dissertation

This thesis provides a case study analysis of the impact of agriculture on deforestation in the tropical rainforest environment surrounding Pucallpa Peru. Agriculture accounts for over 80% of deforestation in the Peruvian Amazon. The predominant agricultural production practice there is slash-and-burn agriculture. This involves felling and burning an area of rainforest. Ashes provide a brief flush of nutrients for crops planted by farmers. But infertile tropical soils cause farmers to abandon parcels after just 1-2 years of cultivation. They then repeat the cycle of slashing and burning a new area of forest (often fallow areas of secondary forest regrowth) to cultivate a new parcel. Th

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parcel. This continual shifting of areas in cultivation into areas of forest is what makes slash-and-burn agriculture so ecologically destructive.

However, agriculture in the zone of Pucallpa is not monolithic in nature. Farmers produce different products and use different production technologies. This thesis analyzes how different agricultural technologies and outputs affect deforestation.

Taking a step further back, it is also necessary to understand the determinants of farmer decisions about different outputs and inputs. In order to do so, this research uses a profit function approach. Profits are defined as follows:

(1) $\pi = pq - wx$

where p is a vector of prices for outputs, q is a vector of outputs produced by the farmer, w is a vector of input prices, and x is a vector of inputs. This approach allows the identification of the optimal levels of input use and output production defined as follows:

(2) $q^* = f(p,w,z)$

(3) $x^* = f(p,w,z)$

where z is a vector of fixed input factors (e.g., soil type, tenure security, education, etc.).

In sum, there are two levels to this analysis. First there is the causal relationship between production determinants (prices and fixed factors) and farmers' choices of production technologies used and agricultural outputs produced. Next, there is the causal relationship between these input and output decisions and their impact on deforestation. These relationships are outlined in the schema represented in figure 1.

As represented in this diagram, agricultural production decisions about input use and output production are the *immediate* causes of deforestation. Decisions, for example, to plant more annual crops or to use fertilizers (which may allow greater reuse of previously

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previously cleared land) are what directly lead a farmer to decide to clear (or not) more forest area. Production determinants such as a change in prices or variations in soil

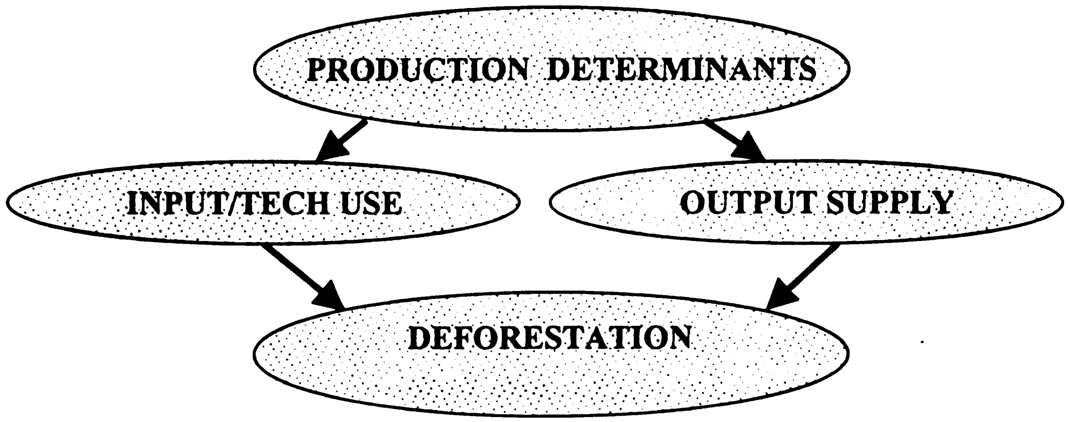

Figure 1: Causal relationships leading to deforestation.

quality do not *directly* cause deforestation. Rather, they lead to changes in production decisions that in turn are the immediate causes of deforestation. These production determinants are therefore *indirect* causes of deforestation. This conceptualization lays the basis for a more coherent and rigorous analysis of the relationship between agriculture and deforestation.

The principal methodological tool of this dissertation is econometric analysis. The use of two sets of regression equations reflects the two levels of analysis described above. In the first set of regressions models, production determinants (independent variables) lead to farmer's decisions concerning input use and output production (dependent variables). The second set of regression models uses farmers' input and output choices as independent variables that lead to deforestation, the dependent variable. The structure of this analysis permits a linkage from production determinants to production decisions through to the final deforestation outcome.

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This dissertation, however, does not rely on regression analysis alone. Extensive use of descriptive statistics (e.g., the evolution of land use patterns over time, the returns to land and labor of various production activities, and the costs and benefits of production technologies) gives further insights into the relationship between agriculture and deforestation. And, of course, logical argumentation based on a knowledge of economic theory and agricultural processes is also incorporated.

3. Thesis Structure

The thesis begins with this introduction. This introduction provides a brief overview of the dissertation's objectives, methodology, and content. Three essays in a journal article format then follow. The three essays are entitled as follows: "A Household-Level Analysis of the Impact of Agriculture on Deforestation in the Peruvian Amazon", "Kudzu-Improved Fallows in the Peruvian Amazon: A Case Study of the Impact of Technological Change on Deforestation", and "The Adoption of Improved Pastures and their Impact on Deforestation in the Peruvian Amazon". A concluding section synthesizes the key findings and lessons learned from this research. An appendix section includes material such as the survey instrument, supplementary information concerning the regression analysis, and a map of the zone.

The first essay, "A Household-Level Analysis of the Impact of Agriculture on Deforestation in the Peruvian Amazon", is the overview piece of the dissertation. It analyzes the determinants of input use and output production and, in turn, the impact of these production decisions on deforestation. The five input/technologies looked at are improved fallows, improved pastures, natural pastures, hired labor, and capital inputs. These are the most common production inputs and technologies used in the zone. Outputs are grouped in

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are grouped into the three major production categories found in the zone: annuals, perennials and livestock.

This dissertation also divides deforestation into three categories: primary forest, secondary forest, and total forest. Primary forests are areas that have never been felled (although in many cases have been selectively logged), secondary forests are areas of primary forest that have been cleared and have regenerated into forests, and total forest is the combination of primary and secondary forest. Deforestation is defined as the hectares of each type of forest felled by a farm household in 1998.

The second essay, "Kudzu-Improved Fallows in the Peruvian Amazon: A Case Study of the Impact of Technological Change on Deforestation", and the third essay, "The Adoption of Improved Pastures and their Impact on Deforestation in the Peruvian Amazon", are both case studies of improved technologies that farmers have widely adopted in the Pucallpa zone. National and international agricultural research centers have had limited success in promoting the improved technologies they have developed for the zone. The focus of these two essays is therefore on understanding i.) the factors that have led to the successful adoption of these two technologies and ii.) the impact these two technologies have had on deforestation. A better understanding of these two questions can provide important insights for the development of sustainable technologies and the design of policies to promote these technologies.

4. Thesis Data

Virtually all the data used in this thesis is primary data collected by the author in three household surveys. A general survey of the socio-economic characteristics and production practices (including deforestation) of 220 households provide the data for the econometric a

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econometric analysis. Two mini-surveys concerning the use of kudzu-improved fallows (n=24) and brachiaria-improved pastures (n=38) provide information on the costs and benefits of these technologies. The general survey took place in the zone surrounding the city of Pucallpa. This included a stratified sample of farm households based on their distance to Pucallpa and their type of infrastructure access. Farm households were sampled along the main paved highway, along the three principal secondary gravel roads, along numerous dirt feeder roads, and along the three principal rivers in the zone.

5. Summary

This research is part of a global initiative that seeks to identify sustainable alternatives to the environmentally destructive practice of slash-and-burn agriculture. This research analyzes the determinants of agricultural production practices in the Peruvian Amazon and, in turn, the impact of these production practices on deforestation. In addition, it provides two case study analyses of the adoption of improved technologies in the zone and their impact on deforestation. It is my hope that these research results will provide information useful to researchers in their attempts to design sustainable agricultural technologies as well as to policy makers in their efforts to promote sustainable agricultural practices.

A HOUSEHOLD-LEVEL ANALYSIS OF THE IMPACT OF AGRICULTURE ON DEFORESTATION IN THE PERUVIAN AMAZON

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1. Introduction

Worldwide tropical closed forest deforestation is taking place at an alarming rate. One to two percent of the world's total rainforest areas, totaling 10-20 million hectares, is lost every year (Ehui, Hertel and Preckel, 1990). In Peru, 59 percent of the national territory is covered by Amazon rainforest. 261,000 hectares a year are being deforested. In 1985, 7.5 percent of the total rainforest area had been deforested. Deforestation is estimated to reach 12.7 percent by the year 2000 (INRENA, 1995).

Deforestation of the Amazon, the world's largest rainforest, has led to growing concerns about possible environmental impacts. The Amazon is believed to mitigate potential global warming by sequestering carbon from the atmosphere. Furthermore, deforestation in this region, which has one of the world's highest concentrations of biodiversity, threatens the existence of many plant and animal species. Other consequences of deforestation include increased flooding, erosion, and dam siltation.

Researchers estimate that shifting cultivators are responsible for between 45 percent (UNEP, 1992) and 60 percent (Myers, 1992) of deforestation in developing countries. In Peru, research puts this figure even higher at 80 percent of total deforestation (Razzetto, 1997). The primary reason farmers slash and burn forest is not to clear land but rather to provide nutrients for crops. Most nutrients are contained in the aboveground biomass and not in the soil (Hecht, 1992). Burning the forest vegetation provides a brief flush of nutrient to crops. Within a few years, yield declines typically force farmers to abandon a parcel and clear another area of forest (Sanchez, 1976).

While initial studies of the Amazon concluded that most soils would not permit continuous cultivation (McNeil, 1967; Goodland and Irwin, 1975), later studies showed sedentary agr

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sedentary agriculture was feasible given appropriate soil amendments (Cochrane and Sanchez, 1981). Nevertheless, the low level of adoption of technological alternatives to slash-and-burn agriculture indicates this agronomic feasibility has not translated into economic viability for most farmers.

Households make agricultural production decisions based on calculations of private costs and benefits (Reardon and Vosti, 1992). And household agricultural production decisions are the immediate causes of deforestation (Kaimowitz and Angelson, 1998). However, not all production systems have the same impact on deforestation. Farmers produce different outputs and use different production practices to produce them. It is therefore important to understand what determines farmers' production decisions and how these decisions affect deforestation.

An important body of literature has focused on the national- and regional-level causes of deforestation (e.g., Barbier and Burgess, 1996; Southgate, Sierra, and Brown, 1991; Deacon, 1995, Rudal, 1989; Southgate, 1994). Others have analyzed the potential profitability of more intensive and/or sustainable production practices over slash-and-burn agriculture (e.g., Peters, Bentry, and Mendelsohn, 1989; De Almeida and Uhl, 1995; Tonolia and Uhl, 1995; Matteos and Uhl, 1994). Still others have focused on general household determinants of deforestation (Godoy et al. 1997; Pichon, 1997).

Existing research, however, does not draw the links between the determinants of household input and output choices and, in turn, how these household production decisions effect deforestation. Econometric analysis used in this article first models the determinants of household-level output supply and input demand and then models the impact of these production decisions on deforestation. This essay fills an important gap in the literature by systematically examining the links between household-level production determinants, production decisions, and deforestation.

The rest of this essay proceeds as follows. Section 2 gives an overview of the key characteristics of the research zone. Section 2 includes a subsection describing the evolution of on-farm land use patterns over time. Section 3 presents the modeling approach. This section includes a theoretical discussion of input technology use and output production based on a profit function approach. This theoretical discussion is linked to an empirical econometric model that examines the determinants of production decisions and how these decisions effect deforestation. Section four analyzes the econometric model results. The final section presents the conclusions and policy implications of this paper's analysis.

2. Characteristics of the Pucallpa Research Zone

2.1 Overview

The research study zone is located in the central lowland rainforest area surrounding Pucallpa, Peru. Pucallpa's population of approximately 200,000 makes it the second largest city in the Peruvian Amazon. Pucallpa's economy is relatively dynamic. It is the capital of the region of Ucayali, the largest producer of timber in the country. Oil and gas exploitation have also expanded greatly in recent years. In addition, it currently has the best road connection out of the jungle to the coast and capital city of Lima.

Rapid migration has made the Pucallpa zone the fasting growing area in the jungle. This migration has resulted from the push factors of poverty and land scarcity in other parts of the country (Riesco, 1993) and the pull factors of cheap land made accessible by timber and gas feeder roads into the jungle, job opportunities, and until recently coca

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recently coca production (Labarta, 1998). Immigrants to the zone are typically poor in capital resources for farm-level investment. Rural population density remains low, around 7 persons per km^2.

Agriculture in the Amazon confronts a competitive disadvantage due to jungle roads that are impassable during much of the rainy season and the need to traverse the Andes Mountains to commercialize goods outside the region. Import substitution industrialization policies over the past several decades have also been unfavorable to agriculture in the Amazon and elsewhere in Peru. Liberalization since the early 1990's has partially rectified this urban industrial bias but has greatly reduced credit available to farmers and has failed to provide the technical, infrastructural, and marketing support needed to modernize agricultural production (Escobal, 1999; Palomino, 1993). Political violence in the latter half of the 1980's and early 1990's further undermined agricultural development in the Amazon region.

Low soil fertility combined with high levels of acidity and aluminum content further limit agricultural development in the Amazon. Farmer use of capital inputs such as fertilizers, pesticides, and plows is minimal. A median farm is 30 hectares of which primary forest constitutes 31 percent, secondary forest fallows 30 percent, pasture 25 percent, annual crops 10 percent and perennials 4 percent.

Agricultural production in the Pucallpa zone by and large remains mired in slash-and-burn agricultural production of semi-subsistence crops, principally maize, rice, cassava, and plantains. In spite of low prices, virtually all farmers market a substantial proportion of these crops to meet cash needs. Cash crop development, in particular perennials such as rubber, cacao, black pepper, and achiote, has seen a series of booms and busts and

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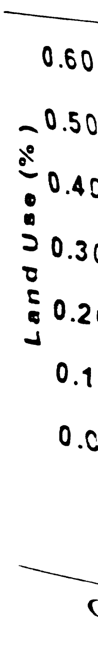
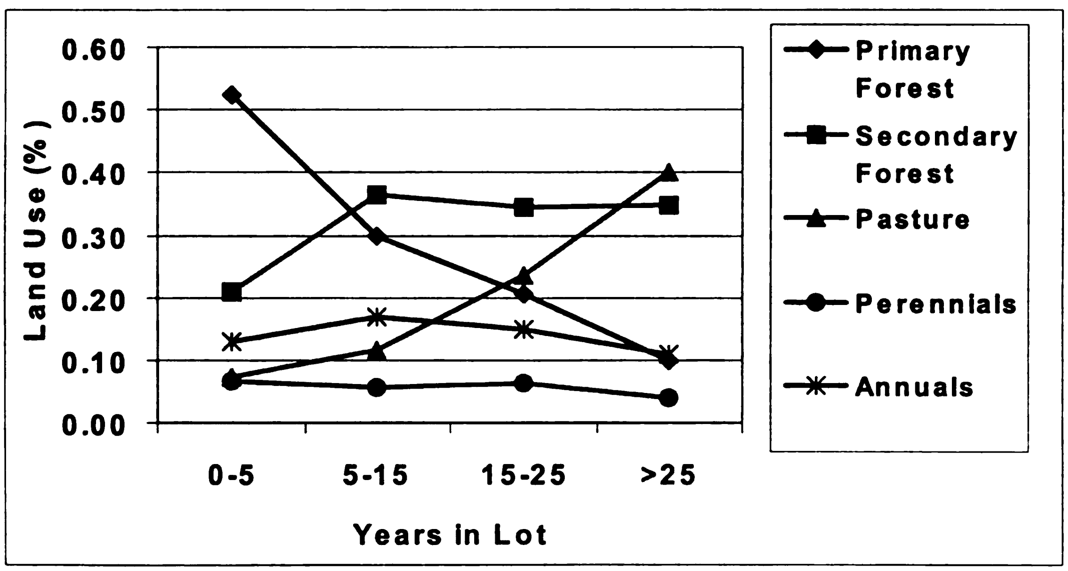


and busts and remains of limited importance[1]. Livestock production is important and growing slowly but is hindered by a lack of dairy processing facilities and high transportation costs out of the region.

In sum, migrants coming to Pucallpa are extremely poor. They spontaneously settle areas of abundant land recently opened up by gas, oil, and timber extraction. Agriculture remains stagnant due to low prices, high marketing costs, and limited government support. Capital input use is typically unaffordable for farmers. Farmers are essentially left with their labor to cultivate abundant land.

2.2 Evolution of Farm Land Use Patterns

A comparison of farms based upon the amount of time they have been in production helps trace the evolution of land use patterns over time. Graph 1 groups farms[2] together into four categories based on the number of years in production. This grouping gives insights into farmer production strategies over time.



Graph 1: The Evolution of Land Use Patterns

During the first ten years, the principal change in land use involves the conversion of primary forest into secondary forest fallows. Farmers slash and burn primary forest areas for annual crops, which after cultivating for 1-2 years, they then leave fallow to regenerate into secondary forests. After ten years, the principal land use change involves a continuing strong decline in primary forest cover and a sharp increase in pasture area. This change, however, does not imply a direct conversion of primary forest into pasture. The fertility obtained from slashing and burning primary forest gives the biggest productivity boost to annual crops. Pastures, on the other hand, grow well on land degraded by repeated cycles of annual cropping and fallowing. What in fact is taking place is a continued conversion of primary forest into secondary forest in the context of annual crop production and a conversion of secondary forest areas into pastures.

A second reason for this observed pattern is that migrant farmers initially lack the needed capital resources to enter into cattle ranching. So, although farmers generally consider cattle ranching the most profitable activity, they first focus on annual cropping while acquiring sufficient capital for livestock. Nevertheless, many farmers are not able to make the transition.

As farmers move progressively into livestock production, annual crop production falls. By the last time period (>25 years), land dedicated to annual crops had declined 35% relative to its peak at ten years. The progressive degradation of farmland as well as the increase in livestock production lead farmers to decrease annual cropping.

Perennial crop production, for its part, reaches a peak level of 6-7 percent of land in the first time period (0-5 years) then stagnates and declines. Because these are long-term investments and often high-value crops, it is reasonable to think they would increase over time. He

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3. Model

3.1 Theoretical Model

The theoretical model used in this essay describes the relationship between agriculture and deforestation. The principal cause of deforestation is the growing demand for crop and pasture land. However, not all agricultural products and production technologies have the same impact on deforestation. Conceptually, the impact of agriculture on deforestation can be described on three levels. The first level consists of conditioning factors. These include natural resources (e.g., farm size, hectares of primary and secondary forest, soils, etc.), family characteristics (e.g., education, origin, age, etc.) prices (inputs and outputs) and policies (e.g., credit, extension, land tenure, etc.). These factors determine the second level, which is farmer production behavior in terms of output supply and input demand. These production behaviors, in turn, are the immediate causes of deforestation, the third level of analysis.

More formally, the theoretical framework for understanding farmer behavior uses a profit function approach. This approach assumes that farmers choose a combination of variable inputs and outputs in order to maximize profit subject to a technology constraint i.e. the production function of the farm. Profit maximization should be understood in the broad sense of farmers using limited resources in as efficient a manner as possible to meet their livelihood (including social) objectives. Furthermore, strict profit maximization behavior is not a necessary prerequisite for specifying systems of output supply and factor demand equations, as long as the behavior of the individual agents is sufficiently st...

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sufficiently stable over time and can be aggregated over farmers (Sadoulet and DeJanvry, 1995).

The profit function for a farm is specified as follows:

(1) $\pi = pq - wx$

where p is a vector of prices for outputs, q is a vector of outputs produced by the farmer, w is a vector of input prices, and x is a vector of inputs.

Farmers' profit maximizing behavior is constrained by the production function where quantity of outputs q is a function of variable inputs x and fixed inputs z used in the production process:

(2) $q = f(x,z)$

The farmer chooses the optimal level of inputs x and outputs q in order to maximize profits. The input demand and output supply functions can be written as follows:

(3) $x = x(p,w,z)$ and $q = q(p,w,z)$

These equations indicate that the optimal levels of inputs and outputs are a function of output price, input price, and fixed factors.

Using the expressions in (3) the profit function can be written as follows:

(4) $\pi = pq(p,w,z) - wx(p,w,z)$

Using Shepard's lemma, it is possible to derive the output supply and factor demand functions by differentiating (4) with respect to output and input prices in the following manner:

(5) $d\pi/dp_i (p,w,z) = q_i \quad d\pi/dw_i (p,w,z) = -x_i$

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In sum, the profit-maximizing behavior of farmers determines output choice and input use. These production decisions are, in turn, the immediate causes of deforestation. This theoretical framework is used to specify the econometric models in the following section.

3.2 Econometric Models

A survey conducted in October of 1998 provides the data for the econometric models used in this research. A team of enumerators led by this author interviewed 220 households concerning their agricultural production practices, the socio-economic characteristics of their households, and the biophysical characteristics of their farms. The survey used the distance from the main market town and the type of infrastructural access[3] available to farmers as the criteria for sample stratification.

The econometric models are structured as follows. Two sets of regression equations have, respectively, input/technology use (x) and output production (q) as dependent variables. These are modeled as a function of the independent variables of price (p, w) and fixed factors (z). The regression specifications are outlined in table 1, which also provides averages and standard deviations of the variables.

Outputs are aggregated into the three principal categories of agricultural production activities: annuals[4], perennials, and livestock. Given the dominance of slash and burn agriculture, farmers use relatively few inputs or improved technologies. This research analyzes five of the most common inputs/technologies found in the zone: kudzu-improved fallows, brachiaria-improved pastures, natural pastures, capital inputs and hired labor. Because the capital inputs farmers use are varied and overall use is low, I created a single capital

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single capital input variable by summing the total monetary value of capital inputs used by each household.

Price variation with cross-sectional data as used by this research is typically minimal. One solution is to calculate farm-gate prices. In the case of outputs, I did this for maize, the most frequently commercialized product, by subtracting transportation costs (vehicle plus labor time opportunity cost) from the market price received. The diversity of inputs and technologies and the variability of their costs of commercialization made it more difficult to choose a representative product. The distance to the principal market of Pucallpa therefore serves as a proxy for input costs.

The input use and output choice regression models use the technique of ordinary least squares (OLS). However, because economic theory indicates that farmer input and output decisions are simultaneous, a systems approach using seemingly unrelated regression equations (SURE), was also tested. The SURE modeling approach gave results similar to OLS[5], but sharply reduced the number of available observations[6]. This essay therefore uses the OLS results for this paper's analysis.

A third regression model examines the impact of agricultural output production and input/technology use on deforestation. The relationship of outputs and inputs to deforestation is hypothesized to be recursive: agricultural production results in deforestation and not vice versa. *Selective* extraction of timber leaves the residual forest largely intact. The clear-cutting type of deforestation examined by this research is an outcome of agricultural production. I tested the unidirectional causality of agriculture leading to deforestation using the Hausman specification test to detect simultaneity[7]. This test confirmed the recursivity between agricultural production and deforestation with the

Table 1: In

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Table 1: Input and Output Regression Specifications, Variable Averages and Standard Deviations

DEPENDENT VARIABLES[a]					
OUTPUTS (q)			*INPUTS/TECHNOLOGY (x)*		
	Average	**Std. Dev.**		**Average**	**Std. Dev.**
Annuals	3.71	3.97	**Improved Fallows**	2.07	3.80
Hectares of Annual Crops			*Hectares of fallows improved with kudzu*		
Perennials	1.47	2.09	**Improved Pasture**	7.24	15.93
Hectares of Perennial Crops			*Hectares of pastures improved with brachiaria*		
Livestock	6.93	27.40	**Natural Pasture**	.95	3.33
Head of Cattle			*Hectares of natural pasture*		
-	-		**Capital Inputs**[b]	216.59	734.76
-	-		*Total value of capital inputs used in 1998 (soles)*		
-	-		**Hired Labor**	64.05	142.50
-	-		*Number of person days of hired labor used in 1998*		
INDEPENDENT VARIABLES[a]					
♦OF OUTPUTS (q) ♦			*♦OF INPUTS/TECHNOLOGY (x) ♦*		
PRICE (p)			**PRICE (w)**		
	Average	**Std. Dev.**		**Average**	**Std. Dev.**
Fm-Gate Price Maize	.36	.056	**Market Distance**	60.97	27.76
Maize market price minus transpo costs (soles/kg)[b]			*Distance in km farm to Pucallpa*		
FIXED FACTORS (z)			**FIXED FACTORS (z)**		
	Average	**Std. Dev.**		**Average**	**Std. Dev.**
Farm Size	37.40	31.37	**Farm Size**	37.40	31.37
Hectares of land on farm			*Hectares of land on farm*		
Secondary Forest	11.56	16.05	**Secondary Forest**	11.56	16.05
Hectares of secondary forest on farm			*Hectares of secondary forest on farm*		
Primary Forest	10.98	16.70	**Primary Forest**	10.98	16.70
Hectares of primary forest on farm			*Hectares of primary forest on farm*		
Years in Lot	17.12	11.80	**Years in Lot**	17.12	11.80
Years a farm has been in production			*Years a farm has been in production*		
Education[c]	33%	n.a.	**Education**[c]	33%	n.a.
Household head > primary education (dummy)			*Household head > primary education (dummy)*		
Family Labor	2.72	1.34	**Family Labor**	2.72	1.34
Family members over 14 working on the farm			*Family members over 14 working on the farm*		
Off-farm Income[b]	1844.60	3074.50	**Off-farm Income**[b]	1844.60	3074.50
Off-farm income earned by farm household (soles)			*Off-farm income earned by farm household (soles)*		
Credit[c]	33%	n.a.	**Credit**[c]	33%	n.a.
Credit received in the past 5 years (dummy)			*Credit received in the past 5 years (dummy)*		
Land Tenure[c]	84%	n.a.	**Land Tenure**[c]	84%	n.a.
Farmer perceives tenure as secure (dummy)			*Farmer perceives tenure as secure*		
Alluvial Soils[d]	28%	n.a.	**Alluvial Soils**[d]	28%	n.a.
Alluvial soils dominate (dummy)			*Alluvial soils dominate (dummy)*		
Extension	3.28	11.74	**Sandy Soils**[e]	42%	n.a
Number of extension visits in the past year			*Sandy soils dominate (dummy)*		
Origin	25%	n.a.	**Distance Social Services**	5.67	5.57
Household head not from jungle region (dummy)			*Dist. in km farm to nearest: (school + health post)*		
Age	48.16	14.08	-	-	
Age of household head			-	-	

[a]All variables are measured on a farm household level for the year 1998

[b]One nuevo sol = $.32 in 1998

[c]Percentages not averages are presented for dummy variables

[d]Percentages are determined by sampling strategy (along rivers) and may not reflect regional average.

[e]Percentage of highland (not river) soils. Farmers chose between clayey or sandy soil descriptive.

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Table 2:

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exception of improved pastures in the total deforestation model. This result may make sense in the context of pasture installation being an evolutionary process. Land deforested for annual crops is later transformed into pastures. Deforestation may therefore lead to land being put into pasture and as well as pasture installation resulting in deforestation. A two stage least squares approach (2SLS) was used to correct for simultaneity in this case.

The deforestation dependent variable is measured as the hectares of forest felled in 1998[8] by a farm household. It is divided into three categories: total forest deforestation, primary forest deforestation, and secondary forest deforestation. Primary forests are areas that have never been felled[9]. Primary forests that have been felled and have

Table 2: Deforestation Regression Model Specifications

Total Deforestation	Primary Forest Deforestation	Secondary Forest Deforestation
Annuals	Annuals	Annuals
Perennials	Perennials	Perennials
Livestock	Livestock	Livestock
Improved Fallows	Improved Fallows	Improved Fallows
Improved Pastures	Improved Pastures	Improved Pastures
Natural Pastures	Natural Pastures	Natural Pastures
Capital Inputs	Capital Inputs	Capital Inputs
Hired Labor	Hired Labor	Hired Labor
Tenure Security	Tenure Security	Tenure Security
Family Labor	Family Labor	Family Labor
Alluvial Soils	Alluvial Soils	Alluvial Soils
Education	Education	Education
Total Forest	-	-
-	Primary forest	Primary forest
-	Secondary forest	Secondary forest
-	Primary Forest Products	Primary Forest Products

Table 3: Previously Undefined Variables

	Average	Std. Dev.
Total deforestation *Primary plus secondary forest felled (ha's)*	2.36	2.44
Primary Forest Deforestation *Primary forest felled (ha's)*	.66	1.42
Secondary Forest Deforestation *Secondary forest felled (ha's)*	1.72	2.13
Total Forest *Hectares of primary & second forest*	22.55	23.15
Primary Forest Prod's *Value prim. forest prod's harvested (soles[a])*	319.27	800.07

[a]One nuevo sol = $.32 in 1998

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regenerated are secondary forests. Total deforestation is the sum of both primary and secondary forest deforestation.

The distinction between primary and secondary forest deforestation is often not made. A common perception is that once primary forest has been cleared the forest is gone forever. However, research by FAO (1996) estimated that in 1990 there existed 165 million hectares of secondary forest in Latin America. In the Pucallpa area, survey results indicate that secondary forests (30%) virtually equal primary forests (31%) on farm holdings. Secondary forests on farms are areas of fallow that recuperate the soil fertility and are subsequently slashed and burned for renewed cropping.

Deforestation is modeled as a function of output choice, input/technology use, and general conditioning factors. General conditioning factors are those that may directly affect deforestation i.e. not only through their impact on input and output choices. These include land tenure, family labor, soils, education, forest area, and forest products.

4. Results

The discussion of regression results proceeds as follows. First I examine the determinants of output and input/technology variables and the impact these variables have on deforestation. I then examine the general conditioning factors from the deforestation models. This section ends with a cross-cutting analysis that summarizes the key linkages between production determinants, farmer input and output behaviors, and deforestation.

The following discussion considers variables significant up to the .15 level. The use of this level reflects, in part, the tendency of cross-sectional data to give lower significance levels. Furthermore, the choice of a significance level should reflect the costs of mak

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costs of making an error (Manderscheid, 1965). For the analysis at hand (identifying production and deforestation determinants), the consequences of a (type 1) error are not especially serious[10]. Exact significance levels are presented for the reader's consideration. The predictive power of these models (R^2) is generally good for cross-sectional data. The exceptions are the natural pasture and hired labor models which, nevertheless, provide useful insights about individual exogenous variables. Table 4 presents the deforestation model results and tables 5 and 6 respectively provide the results of the output and input/technology models.

4.1 Output Supply Variables

Annuals-Annual crops (e.g., maize, rice, cassava, etc.) stands out as the only variable positively correlated with all types of deforestation. They are indeed the only category of outputs that uses shifting slash-and-burn agriculture. Output regression

Table 4: Deforestation Regression Results

	Total Deforestation		Primary Forest Deforestation		Secondary Forest Deforestation	
	R^2.54 adj R^2.50		R^2.30 adj R^2.23		R^2.30 adj R^2.23	
	Coef (t-stat)	Signif	Coef (t-stat)	Signif	Coef (t-stat)	Signif
Constant		.18		.74		.74
Annuals	.490 (7.59)	.00***	.323 (3.69)	.00***	.301 (3.42)	.00***
Perennials	-.102 (-1.65)	.10*	-.040 (-0.53)	.60	-.008 (-0.10)	.92
Livestock	.039 (0.54)	.59	.020 (0.21)	.83	.197 (2.04)	.04
Improved Fallows	.049 (0.83)	.41	-.129 (-1.80)	.07*	.137 (1.91)	.06*
Improved Pastures	-.023 (-0.32)	.75	-.006 (-0.06)	.95	-.154 (-1.53)	.13*
Natural Pastures	-.094 (-1.50)	.13*	-.061 (0.75)	.45	-.163 (-2.00)	.05**
Capital Inputs	-.153 (-2.18)	.03**	-.125 (-1.41)	.16	.181 (2.03)	.04**
Hired Labor	.337 (5.73)	.00***	.011 (0.13)	.89	.019 (0.23)	.82
Family Labor	.060 (1.01)	.31	.021 (0.27)	.79	.202 (2.61)	.01***
Education	.129 (2.26)	.02**	.003 (0.05)	.96	.070 (0.98)	.33
Tenure Security	.097 (1.69)	.09*	.025 (0.32)	.75	.030 (0.39)	.69
Alluvial Soils	.028 (0.45)	.65	-.193 (-2.61)	.01***	.203 (2.75)	.01***
Total Forest	.108 (1.72)	.09*	-	-	-	-
Secondary Forest[a]	-	-	-.098 (-1.41)	.16	.166 (2.38)	.02**
Primary Forest	-	-	.254 (3.30)	.00***	-.093 (-1.20)	.23
Prim Forest Prod's	-	-	.168 (2.36)	.02**	- .034 (-0.48)	.63

*Significant at the .01 level ** Significant at the .05 level *** Significant at the .15 level
(a) High secondary forest >5meters

Table 5: Output Regression Results

	Annuals R^2.54 adj R^2.35		Perennials R^2.50 adj R^2.30		Livestock R^2.58 adj R^2.40	
	Coef (t stat)	Signif	Coef (t stat)	Signif	Coef (t stat)	Signif
[illegible]		.40		.06		.21

Table 5: Output Regression Results

	Annuals		Perennials		Livestock	
	R^2.54 adj R^2.35		R^2.50 adj R^2.30		R^2.58 adj R^2.40	
	Coef (t-stat)	Signif	Coef (t-stat)	Signif	Coef (t-stat)	Signif
Constant		.40		.06		.21
Farm Size	.177 (0.67)	.50	- .193 (-0.70)	.48	.912 (3.97)	.00***
Secondary Forest	.156 (0.93)	.36	.103 (0.59)	.56	- .052 (-0.36)	.72
Primary Forest	.343 (1.53)	.13*	.318 (1.37)	.18	- .588 (-2.93)	.01***
Alluvial Soils	.287 (2.09)	.04**	- .320 (-2.24)	.03**	.125 (0.90)	.37
Years in Lot	- .222 (-1.47)	.15*	- .109 (-0.70)	.49	.139 (0.99)	.33
Education	.068 (0.51)	.61	.038 (0.26)	.79	- .058 (-0.45)	.65
Age	- .084 (-0.63)	.53	.484 (3.51)	.00***	- .204 (-1.50)	.14*
Family Labor	.572 (3.48)	.00***	.437 (2.56)	.02**	.267 (1.81)	.08*
Origin (not jungle)	- .101 (-0.71)	.48	.294 (2.00)	.05**	.123 (0.92)	.36
Off-Farm Income	- .310 (-2.13)	.04**	- .233 (-1.54)	.13*	.028 (0.19)	.84
Credit	.144 (1.07)	.29	.179 (1.28)	.21	- .102 (-0.80)	.43
Extension	- .168 (-1.11)	.28	- .298 (-1.89)	.07*	- .070 (-0.46)	.64
Farm-Gate Price Maize	- .221 (-1.58)	.12*	- .007 (-0.05)	.96	.072 (0.55)	.59
Tenure Security	.140 (0.97)	.34	.075 (0.50)	.62	.313 (2.23)	.03**

Table 6: Input/Technology Regression Results

	Improved Fallows		Improved Pastures		Natural Pasture		Capital Inputs		Hired Labor	
	R^2.33 adj R^2.25		R^2.80 adj R^2.78		R^2.19 adj R^2.12		R^2.32 adj R^2.24		R^2.15 adj R^2.05	
	Coef (t-stat)	Signif	Coef (t-stat)	Signif	Coef (t-stat)	Signif	Coef (t-stat)	Signif	Coef (t-stat)	Signif
Constant		.01		.08		.01		.19		.80
Farm Size	.548 (4.85)	.00***	1.362 (21.48)	.00***	.448 (3.46)	.00***	.281 (1.98)	.05**	.223 (1.62)	.11*
Secondary Forest	- .066 (-0.78)	.44	- .575(-12.43)	.00***	- .186 (-2.03)	.05**	- .199 (-2.01)	.05**	- .076 (-0.75)	.46
Primary Forest	- .198 (-1.70)	.09*	- .907(-14.40)	.00***	- .164 (-1.29)	.20	- .151 (-1.11)	.27	- .083 (-0.60)	.54
Alluvial Soils	- .066 (-0.70)	.48	-	-	-	-	- .174 (-1.74)	.08*	- .045 (-0.43)	.67
Sandy Soils	.168 (1.95)	.05**	-	-	-	-	.026 (0.29)	.77	- .094 (-0.97)	.33
Years in Lot	.151 (1.55)	.12*	.053 (-1.14)	.26	.198 (2.18)	.03**	.109 (1.09)	.28	- .112 (-1.04)	.30
Education	.207 (2.50)	.01***	- .053 (-1.28)	.20	.098 (1.19)	.24	- .087 (-0.99)	.32	- .102 (-1.10)	.27
Family Labor	.091 (1.09)	.28	- .047 (-1.13)	.26	.028 (0.35)	.73	.290 (3.30)	.00***	.146 (1.56)	.12*
Off-Farm Income	.002 (0.02)	.99	- .005 (-0.11)	.91	.077 (0.92)	.36	- .068 (-0.75)	.45	- .054 (-0.50)	.57
Dist Soc'l Services	.140 (1.53)	.13*	- .110 (-2.40)	.02**	- .089 (-0.98)	.33	.033 (0.34)	.73	.143 (1.39)	.17
Credit	- .151 (-1.81)	.07*	- .087 (-2.06)	.04**	- .021 (-0.25)	.81	.292 (3.34)	.00***	.148 (1.59)	.11*
Market Distance	.189 (1.98)	.05**	- .084 (-1.97)	.05**	.029 (0.35)	.73	.081 (0.83)	.40	.102 (0.96)	.34
Tenure Security	.010 (0.12)	.91	.061 (1.42)	.16	-.033 (-0.38)	.70	.135 (1.44)	.15*	.132 (1.35)	.17

*Significant at the .01 level, ** Significant at the .05 level, *** Significant at the .15 levelresults indicate

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indicate that annuals tend to be found where there is more primary forest on relatively younger farms. They are negatively correlated with the farm-gate price of maize, the proxy for market access. These results confirm the evolutionary process of recently arrived migrant farmers first planting annuals on newly opened land on the edge of the forest frontier.

The negative correlation with off-farm income reflects the competition for labor and that, due to low returns, off-farm income is not invested in annual crop production. The positive correlation with family labor indicates both that labor is a constraining factor of production and that more food is needed to feed larger families in a semi-subsistence setting. The greater capacity to practice continuous cultivation of annuals on fertile alluvial soils explains the positive correlation with this variable.

Perennials-Perennial crops such as lemons, mangos, and oil palm require continuous cultivation of a parcel of land. Their labor-intensive nature leads to a strong correlation with family labor. Perennials "absorb" scarce labor away from shifting slash-and-burn agriculture and into sedentary production. This leads to a decline in total deforestation.

Off-farm income decreases perennial production reflecting once again the opportunity cost of scarce labor as well as the relatively low returns to most perennials in the zone. Their long-term nature leads to a positive correlation with household head age. Also, household heads from outside the jungle have more perennials due to the tradition of tree plantations in the coast and sierra (where natural forests have largely disappeared) as opposed to the more extractivist tradition in the jungle. Unlike annuals, most perennials do not grow well in areas of alluvial soils because of water logging from periodic inu

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periodic inundations. And extension's focus on traditional field crops explains its negative correlation with perennials.

Livestock-The only statistically significant relationship between livestock and deforestation is a positive correlation with secondary forest clearing. Livestock are found on farms with less remaining primary forest. This relationship reflects the evolutionary process whereby farmers first slash and burn primary forest for annual crop production and later install pastures in areas of secondary forest. The extensive nature of livestock leads to a positive correlation with farm size. So, over time, farmers' desire to raise livestock may indirectly lead to substantial clearing of primary forest.

The positive correlation with tenure security is due to the need to protect the long-term investments such as pasture installation, fencing, and wells associated with livestock production. Family labor's positive correlation with herd size indicates that labor remains a limiting factor of production despite ranching's low labor requirements. The negative correlation with a household head's age results from older farmers having less available family labor and being less physically able themselves to maintain large herds[11].

4.2 Input/Technology Demand Variables

Brachiaria-Improved Pastures-Farmer planting of grasses from the brachiaria genus (principally *Brachiaria decumbens*) increases pasture carrying capacity by over 50 percent relative to natural pastures in the Pucallpa zone. Brachiaria's vigorous growth, which reduces weed competition, lowers pasture maintenance costs. Increased productivity and lower costs explain why brachiaria now dominates, representing 78 percent of the total pasture area in the zone (Yanggen, 2000).

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As with livestock, brachiaria pastures' only significant correlation is with secondary forest clearing. However, the correlation is negative. In the Pucallpa zone, 54 percent of farms have pastures but no cattle. Surplus pasture capacity dampens the desire of farmers to fell more secondary forest for pasture. Furthermore, brachiaria pasture is negatively correlated with the presence of primary and secondary forest. Farmers first cut down primary forest for annual cropping then progressively install pastures in areas of secondary forest. But unlike shifting annual cropping, sedentary production on pastures suppresses the regeneration of secondary forests. In sum, surplus pasture capacity and pasture's repression of secondary forest regeneration explain brachiaria pastures' negative correlation with secondary forest clearing.

Farmers tend to install brachiaria-improved pastures nearer to Pucallpa and other population centers with social services. This tendency reflects the greater push to intensify production in areas with better access to markets and where land is scarce due to population pressures. This intensification with brachiaria nonetheless takes place on larger farms reflecting the land-using nature and low labor requirements of livestock. The negative correlation with credit reflects the cost-saving nature of this technology.

Natural Pastures-Natural pastures are similar to brachiaria pastures in that farmers tend to plant them on larger farms with less secondary forest. However, unlike brachiaria pastures, they have no statistical association with intensification or credit constraints. Also they are found on older farms, whereas this correlation is not significant with brachiaria, which farmers install on relatively newer more dynamic farms.

Kudzu-Improved Fallows-Kudzu (*Pueraria phaseloides)* is a leguminous vine that farmers plant or that spontaneously regenerates in areas that have recently come out of annual

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of annual crop production. It aggressively spreads throughout areas of secondary forest fallow vegetation, retarding the growth of trees and shrubs and smothering out herbaceous weeds. Its fixation of nitrogen and weed suppression increase yields of crops subsequently planted in the fallow area.

Kudzu-improved fallows are negatively correlated with primary forest deforestation and positively correlated with secondary forest deforestation. Yanggen and Reardon (In Press) have shown that when farmers plant kudzu in areas of secondary forest fallows, this reduces the labor costs of land clearing and weeding and increases yields[12]. This reduction in the costs (labor) and increase in the benefits (yields) of using secondary forest has a ceteris paribus effect of increasing the attractiveness of secondary forest clearing relative to primary forest clearing.

Despite increasing productivity, kudzu-improved fallows do not follow a typical scenario of intensification associated with land scarcity nearer to population centers (Boserup, 1965, 1981; Pingali et al. 1987). Instead they are positively correlated to farm size and farmers tend to adopt them at greater distances from Pucallpa and smaller market towns where social services are located. They are, however, associated with older farms and less primary forest, which reflect declines in land *quality*. Less primary forests implies a depletion of aboveground soil nutrients, whereas farms in production longer tend to suffer from below ground soil nutrient depletion. In sum, it is a land quality constraint and not a land quantity constraint that explains much of the adoption of kudzu-improved fallows.

A higher opportunity cost to educated farmers' labor may explain why these farmers adopt this labor-saving technology. Also the increased management of fallow with kudzu m

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with kudzu may require higher levels of knowledge. The negative correlation with credit makes sense as this technology requires no capital investment and reduces labor requirements. And finally, the positive correlation with sandy soils likely relates to the agronomic conditions in which kudzu flourishes.

Capital Inputs-Capital input use is negatively correlated to total forest clearing and primary forest clearing (.16 significance level) and positively correlated to secondary forest clearing. Farmers mainly use land-saving capital inputs such as fertilizer, improved seed, herbicides, and livestock health products in the zone. These inputs increase the productivity of land and permit more sedentary production. Sedentary land use eases pressures on total deforestation. These productivity-enhancing inputs also permit a greater reuse of degraded secondary forest fallow areas, which reduces pressures on primary forest clearing.

The positive correlation between capital input use and farm size indicates land scarcity is not driving intensification with these products. More likely, larger farmers have greater resources to purchase these inputs. The positive correlation with credit reflects the importance of the capital constraint to purchased input use.

The positive correlation with family labor reflects the fact that these inputs are of a land-saving and not a labor-saving nature. Also, farmers use fewer capital inputs in fertile alluvial areas where there is less need for productivity-enhancing inputs. The movement away from shifting fallow-based agriculture to more sedentary production may explain why capital input use is negatively correlated with secondary forest fallows. And finally, farmers' use of these inputs on farms with more tenure security likely reflects increased incentives to maintain land productivity.

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Hired Labor-Hired labor is positively correlated to total deforestation. This demonstrates the key role of labor as a limiting factor of production. A greater availability of hired labor permits more forest clearing for increased agricultural production.

As in the case of capital inputs, hired labor is positively correlated to farm size and credit. Larger farmers may have greater resources to hire labor as well as more production activities that increase labor needs. The positive correlation with credit reflects the importance of the capital constraint for purchased inputs.

The positive correlation with family labor may appear paradoxical. However, larger families with more available labor tend to cultivate more total land. Labor is hired during the key production bottlenecks periods of land clearing, planting, and harvesting. Larger families that cultivate more land also need to hire more labor at these times.

4.3 General Conditioning Variables

Apart from input/technology and output variables, a number of exogenous variables that may directly affect forest clearing also appear in the deforestation models. These general conditioning factors include: family labor, education, tenure security, alluvial soils, on-farm forest, and the value of harvested primary forest products.

Family labor is positively correlated to secondary forest clearing. This relationship further confirms the importance of the labor constraint to production in the zone. Education's positive correlation to total forest clearing indicates that it enables farmers to increase production at the extensive margin rather than to adopt more sustainable production technologies. Deforestation does not reflect farmer ignorance, but rather the current lack of profitable alternatives to slash-and-burn agriculture.

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Other research, notably in Brazil, has found that *insecure* tenure often pushes farmers to clear forest because laws require this as proof of productive land use (Hecht, 1985; Binswanger, 1991). This situation is not the case in the research area where untitled land is typically surveyed into lots soon after settlement and occupancy of a farm generally ensures tenure security. Because land clearing is not a prerequisite for solidifying tenure security in the case of Pucallpa, tenure *insecurity* does *not* lead to increased deforestation. Rather tenure *security* encourages greater total deforestation. Land clearing often represents a long-term investment in land and farmers are more likely clear land where tenure security ensures they receive the benefits of this investment.

Alluvial soils are correlated with increased secondary forest clearing and decreased primary forest clearing. These soils are more fertile and resilient that highland soils. Farmers can reuse areas of secondary forest to a greater degree thus reducing pressures to expand into primary forest areas.

Conservationists often propose the promotion of primary forest products as a means to induce farmers to conserve primary forests. A study by Pinedo et al. (1992) in the Peruvian Amazon found that the returns per hectare from primary forest products were substantially lower than those from agricultural production. A study in the Pucallpa zone (Smith et. al 1997) found that farmers use and sell more primary forest products in recently opened areas and progressively less as population and market access increase. These findings led to the hypothesis that the sale of these products may be used to help finance the conversion of primary forest to agricultural uses and not increase the conservation of primary forest during frontier development. The positive correlation betwe

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between the value of primary forest products harvested and primary forest clearing appears to confirm this hypothesis.

A last set of conditioning variables are the "control variables" of the hectares of on-farm forested land. Greater availability of forest land should allow farmers to clear more forest. As expected, each type of forest land is positively correlated with its respective type of forest clearing.

4.4 Cross-Cutting Results

This subsection synthesizes several broad themes from the regression analysis. This synthesis more explicitly links together production determinants with deforestation. The themes focused on are: the evolutionary nature of land use patterns, the role of labor, the role of capital, secondary vs. primary forest clearing, and patterns of intensification.

The regression results support the analysis of land use evolution in section 2.2. The results show that annual crop production is most strongly associated with early frontier development leading to deforestation at the forest margin. Livestock tends to come later after primary forest has been cleared and leads to clearing of less productive secondary forest fallow land. A lack of evolutionary indicators for perennials, on the other hand, reflects their stagnation over time.

The regression results confirm the key role of labor as a constraining production factor. Farmers with more family labor have greater production for all the principal output categories: annuals, perennials, and livestock. And hired labor and family labor respectively lead to greater amounts of total and secondary forest clearing. Furthermore, off-farm employment's competition with agriculture for labor decreases annual and perennial crop production. This competition for labor can reduce pressure to clear forest.

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These models also capture the importance of the capital constraint as reflected by the significance of the credit variable in the input/technology regressions. Credit is positively correlated with those inputs requiring a financial expenditure: capital inputs and hired labor. And the negative correlation of credit with the technologies that save on labor and capital, kudzu-improved fallows and brachiaria-improved pastures, may reflect attempts by farmers to overcome capital constraints. While the impacts of these particular inputs and technologies on deforestation are not uniform, it is nonetheless clear that the access or lack of access to credit plays a key role in determining the farmer production practices that influence deforestation patterns.

Kudzu improved fallows, capital inputs, and alluvial soils increase secondary forest clearing but decrease primary forest clearing. Increases in land productivity associated with these variables counteract or mitigate declines in soil fertility that result from the previous cultivation of a parcel of land. This productivity enhancement enables farmers to reuse secondary forest fallows, which decreases the need to clear primary forest.

Intensification does not follow a typical pattern of farmers increasing variable labor and capital inputs due to land area constraints. Kudzu-improved fallows and brachiaria-improved pastures increase land productivity but decrease labor needs and have essentially no capital requirements. Furthermore, these improved fallow and pasture technologies are associated with larger farm size. By easing these constraining production factors, farmers appear to be able to increase the land area they put into production (Yanggen 2000, Yanggen and Reardon, In Press). Intensification of land use does not result for a scarcity of land nor does it reduce the amount of forest land cleared for agricultural

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agricultural production. Declines in land *quality* in some cases, however, may reduce the effective carrying capacity of the land and push farmers to adopt these practices.

The case of land productivity enhancing capital inputs is different because they require farmers to increase capital expenditures and are associated with greater labor use. Their positive correlation with credit indicates that overcoming capital constraints may be more important than land area constraints in bringing about intensification. Larger farm size may also in some cases be associated with wealthier farmers. This result again would indicate that access to capital and not land area constraints leads to intensification.

6. Conclusions and Policy Recommendations

The production of annual crops using shifting slash-and-burn agriculture is the motor of deforestation in the Pucallpa research zone. And greater labor availability increases the extensive production practices that cause deforestation. A unifying theme for policy is how to reduce the labor availability for extensive annual crop production.

Off-farm income opportunities can siphon labor away from annual cropping and other agricultural activities that lead to forest clearing. Development of the non-agricultural sector is therefore key to taking pressures off the natural resource base. This implies the need for a broad-based development strategy including other sectors such as tourism, industry, and services.

Research and policy needs to help promote more sedentary annual cropping practices. The use of productivity-enhancing inputs reduces deforestation and encourages more intensive use of land. However, given low output prices and poor marketing infrastructure, it is not clear that most uses of these inputs are either affordable or profitable for farmers. Experiment station research that focuses on increasing yields may be of little r

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be of little relevance to farmers. Research needs to focus on combinations of inputs such as improved seeds, fertilizer, and pesticides that are *profitable* for farmers. This type of research should be conducted on-farm so that it reflects the conditions under which farmers operate.

Fertile alluvial soils permit more sedentary production of annual crops without the use of capital inputs. These soils are negatively correlated with primary forest clearing. Farmers, however, often prefer to settle along road infrastructure because access to markets is both quicker and cheaper than with river transportation. Most roads are built for timber, oil, or gas extraction without regards to the agricultural potential of the land. Studies should be undertaken to investigate the economic viability of improving road access to areas of alluvial soils along rivers.

Perennial crop production decreases deforestation by absorbing scarce labor into sedentary production. Their production has languished due to volatile markets and the high commercialization costs. The transformation of agricultural raw materials into products such as oils, preserves, and flour can dramatically lower the transportation costs relative to output value and refined products tend to suffer less market turbulence than raw materials. Policies that focus on promoting agricultural industries based in the jungle can help promote sustainable perennial crop production.

It is important, however, that perennial crop production involve small holder farmers. Large-scale mechanized plantation agriculture, as is typical of perennials in many areas of the world, is likely to increase deforestation and concentrate wealth in the hands of a limited number of individuals. Individual farmers, however, typically lack the capital and

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capital and collective organizational capability to identify promising crops and set up systems for input distribution, output transformation, and commercialization.

Government, private industry, and farmer organizations need to work together to promote perennial production so that economies of scale necessary for efficient input distribution and product transformation are achieved while at the same time involving as many farmers as possible. This approach will allow a greater distribution of wealth and absorb more farmer labor away from shifting slash-and-burn annual crop production.

Interviews with farmers in the research zone indicate their primary future production objective is to expand livestock production (Labarta, 1998). So while livestock may not be directly correlated with primary forest clearing, it does appear to increase deforestation as part of a long-term strategy of moving from annual cropping to ranching. Informal observations in the zone indicate that a small number of very large ranchers do clear extensive tracts of primary forest for livestock production. This clearing sacrifices large areas of rainforest without reducing the poverty of most farmers. Efforts by policymakers should therefore focus both on restricting the size of cattle ranches and as well as limiting production to older settlement areas where degraded land is less productive for annual crops but suitable for pastures. Given superior market access, these areas are also the most propitious for more intensive forms of cattle raising using improved pastures and combined meat and dairy production.

Kudzu-improved fallows and brachiaria-improved pastures both increase land productivity as well as reduce labor requirements. These technologies bring about an apparently paradoxical situation of intensification associated with increased land clearing. However, basic economic theory indicates that farmers maximize the returns to constrain

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constraining production factors. These technologies, by improving land productivity while reducing labor costs, increase the returns to the scarce labor factor. Increased land productivity is therefore a "byproduct" of farmers' attempts to increase returns to labor.

The challenge is to promote production that increases returns to labor without encouraging extensive production. Labor intensive production of high value perennial crops can do this by absorbing labor into sedentary production while still providing high returns to labor. Agroforestry techniques that incorporate trees with high value products into pastures and fallows may therefore increase both land productivity and returns to labor while absorbing labor away from forest clearing.

This research has demonstrated the key role that credit can play in determining production practices. In the late eighties, easy access to subsidized credit led to increased slash-and-burn agricultural production and therefore accelerated deforestation in the Pucallpa zone (Yanggen, 1999). A focused policy is therefore needed that links credit with more sedentary agricultural practices such as use of productivity-enhancing inputs and small holder perennial crop production. A more focused credit policy can both help reduce deforestation as well as limit the fiscal burden of subsidized credit.

This section has proposed a series of strategies to encourage more intensive agriculture. However, if these new practices or crops are sufficiently profitable, farmers may invest in labor-saving capital equipment or simply hire more labor. The cheap accessibility of land remains a potent incentive to expand land area under production. Intensive cultivation does not preclude land area expansion. There is a need to complement the promotion of intensive cropping systems with policies that restrict access to land. Op

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to land. Options such as reductions in new road construction, a progressive tax on farm size, and percentage limits on on-farm primary forest clearing merit consideration.

This strategy can be undertaken using a carrot and stick approach. Carrot incentives are offered to induce farmers to adopt more intensive cropping systems and sticks impeding access to land push farmers to adopt more intensive systems. Land access restrictions alone are unlikely to be effective if they are not accompanied by viable intensive production alternatives that enable farmers to make a living using less land. Likewise, the promotion of intensive cropping systems may not limit expansion into the forest areas if land continues to be the cheapest production factor.

The focus of this essay has been on reducing deforestation at the household level. But clearly continued migration into the jungle will accelerate forest clearing. The adoption of intensive cropping practices can only mitigate increased deforestation resulting from demographic pressures. The root cause of migration into the jungle is poverty in other areas of the country. Economic development in poverty-stricken areas of the country needs to take place in order to reduce migration to the jungle. In this sense, an important part of the solution to deforestation lies outside the jungle itself.

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[1] New perennial cash crops such as oil palm, palm heart, piyuayo, and camu-camu are being promoted and may be more successful than past experiences.
[2] Farms from the research's general survey of 220 households.
[3] Infrastructural access included locations on the paved highway Frederico Basadre, secondary gravel roads, tertiary dirt roads, and rivers.
[4] Annuals includes "semi-annual" crops notably plantains and cassava which may last more than a year.
[5] With the exception of the capital input use model, there were only a total of four sign changes (none of variables significant at the .15 level or lower). Further (again with the exception of capital inputs), variables significant at the .05 level or lower in the OL S models remained significant at the .15 level or better in the SURE systems approach. The standard errors generated by the two techniques were remarkably similar, although the SURE standard errors were generally slightly higher. In the case of capital inputs a review of a simple correlation matrix between inputs and outputs indicated that capital inputs have the highest level of correlation with other inputs and outputs. This may explain the changes shifting from OLS to SURE.
[6] With the SURE technique, all missing variables from any equation in the system result in an observation being deleted. Combining all the missing observations in this way resulted in only 40 of the initial 220 observations being available.
[7] I performed the Hausman test in order to check for simultaneity in the deforestation regression models between the deforestation dependent variables and the input/technology and output independent variables. In order to do so I first estimated the reduced form equations for all the input/technology and output variables. I then took the estimated residual from each reduced form equation and plugged it into each of the deforestation regression models as a right-hand-side variable. I then performed a t-test on the coefficient of the estimated residual from the reduced form equation. I used a .10 cut-off as a criteria to judge for significance.
[8] Rainfall comes in a bimodal pattern and there are two cropping seasons. Farmers fell forest and let the felled vegetation dry before burning and then planting crops. The first cropping season lasts roughly from mid February to mid May and is generally preceded by a relatively dry period in January. The second cropping season lasts roughly from mid September to the end of December and is preceded by a relatively dry period from June to early September. Deforestation was measured as the sum of the two forest clearing periods in January and July-August of 1998. This survey was conducted in October of 1998.
[9] A substantial proportion of primary forest on farm land has been selectively logged. Often this was done by the timber companies that opened the initial feeder roads into the jungle where farmers subsequently settled or by the farmers themselves. These areas retain most of their vegetative cover and biodiversity and are typically indistinguishable from undisturbed primary forest to the untrained eye. They are sometimes referred to as areas of "residual" primary forest.
[10] The consequences of making a type 1 error, rejecting the null hypothesis which is in fact true (that a variable is not significantly different from zero in this case) may be devastating, for example, when analyzing the impact of a medicine on human health. Understanding the effect a variable has on deforestation or production decisions 85% or more of the time is reasonable for most policy decisions.
[11] Farm household are dominated by small nuclear families. Farmers' adult children, if they remain in agriculture, tend to start their own farms. This is due i.) to the availability of new land and ii.) to the relativity low production risks of land-abundant humid tropical agriculture that reduce the insurance role provided by extended family production networks (Binswanger and McIntire, 1987)
[12] Kudzu-improved fallows accelerate the process of soil fertility regeneration. This allows a shortening of the fallow period. Kudzu also acts as an aggressive cover crop climbing over shrubs and trees retarding their growth. Shorter fallow periods and retarded vegetative growth lessens land clearing costs. Similarly, kudzu reduces weeding costs by smothering herbaceous weeds. Yields increase due to nitrogen fixation, the provision of other nutrients, and weed reduction.

KUDZU-IMPROVED FALLOWS IN THE PERUVIAN AMAZON

A CASE STUDY OF THE IMPACT OF TECHNOLOGICAL CHANGE ON DEFORESTATION

ESSAY NUMBER 2

1. Introduction

Some 200-300 million people practice fallow-based slash-and-burn agriculture on roughly 30 percent of the world's exploitable soils (Crutzen and Andrae, 1990; Sanchez, 1976). The purpose of a fallow is to allow land to recuperate its productive capacity after cropping. Forest fallow vegetation extracts nutrients from the air and from deep in the soil beyond the reach of crops. These nutrients are returned to the topsoil through leaf litter and when farmers burn fallow vegetation (Sanchez, 1976; Nair, 1993). Fallow vegetation also shades out herbaceous weeds, a major source of productivity decline (de Rouw, 1995).

In regions where low population densities and abundant land permit adequately long fallow periods, slash-and-burn agriculture is a sound way to manage land (Nair, 1993; Kleinman et al. 1995). However, increasing population pressures, shorter fallow periods, and the removal of primary forest cover tend to cause declines in agricultural productivity (Nair, 1993; Thiele, 1993). Farmers can slow down or reverse this decline by seeding or encouraging the natural regeneration of plant species that help land to recuperate more rapidly such as leguminous nitrogen fixers (Kang and Wilson, 1987). This is known as improved fallowing.

Most research on alternatives to traditional slash-and-burn fallows has focused on the agronomics of accelerating soil fertility recuperation during the fallow period. Empirical research analyzing the economic rationality of farmer management of fallow-based slash-and-burn agriculture is lacking (Dvorak, 1992). This essay helps fill that gap by comparing the costs and benefits of traditional and improved fallowing practices and assessing how improved fallow adoption affects deforestation. Specifically, it analyses the impact of kudzu-improved fallows on deforestation in the lowland tropical rainforest areas surrounding the city of Pucallpa, Peru.

The data for this research comes from a survey in 1998 of 220 farm households that focused on input use, output production, and forest clearing and a smaller survey of 24 households that looked at farmer use and management of kudzu-improved fallows, traditional forest fallows, and primary forest. Section 2 of this chapter describes the Pucallpa study zone and the kudzu-improved fallows found there. Section 3 uses survey data to compare kudzu-improved fallows with traditional slash-and-burn practices in terms of land use, labor use, and yields. This leads to hypotheses about how kudzu-improved fallows affect deforestation discussed in section 4. Section 5 contains a theoretical model and three econometric models of how farmer decisions concerning output production and input/technology use affect deforestation. Section 6 presents the regression analysis results and interprets them. This essay concludes with a summary of results and policy recommendations.

2. The Pucallpa Research Zone and Kudzu-Improved Fallows

This research analyzes the impact of kudzu-improved fallows on deforestation in the lowland tropical rainforest areas surrounding the city of Pucallpa, Peru. This section presents the key characteristics of the Pucallpa research zone as well as those of kudzu fallows.

2.1 Characterization of the Pucallpa Peru Study Zone

Pucallpa is located 85 kilometers from the Brazilian border in the middle of the lowland rainforest (<500 m.a.s.l.). A paved road that crosses over the Andes Mountains connects it to the capital, Lima. With a population of approximately 200,000, it is the second largest and the fastest growing city in the Peruvian Amazon. Low per capita income, land scarcity, and civil unrest in other regions of the country have been the principal push factors causing rapid migration into the zone. Infrastructural development, cheap abundant land, job opportunities, and until recently coca production have been the major pull factors (Labarta, 1998; Riesco, 1993).

Pucallpa's economy revolves primarily around timber, gas and oil extraction, ranching, and annual crops. The principal semi-subsistence crops in the zone are maize, rice, cassava, plantains, and beans. Cash crops such as oil palm, palm heart, pineapple, peach palm, cotton, and *camu-camu* are being promoted in the zone but remain of limited importance.

In the early 1990's, the Peruvian government substantially reduced its support for the agricultural sector. In the Amazon, this included the virtual elimination of subsidized farm credit and guaranteed floor prices for major crops such as rice and maize. Budget cuts and a recent history of political violence have limited extension services in the zone, but those services are now slowly improving. Apart from areas along the main highway, poor infrastructure results in high marketing costs, while prices for the principal semi-subsistence crops are low. To obtain secure land tenure, farmers generally do not need to clear forest. Occupation of unclaimed land typically suffices.

Low soil fertility and high levels of acidity and aluminum content impede crop growth in the zone. The above ground biomass contains most nutrients (Hecht, 1992). Farmers use few capital inputs such as fertilizers, pesticides, and plows. The dominant production practice is slash-and burn agriculture. Most farmers clear forest areas every year. They typically cultivate a parcel for six months to two years before leaving it in fallow. Average rainfall of around 2000 mm comes in a bimodal pattern, which permits two cropping seasons per year.

Median farm size is 30 hectares of which primary forest accounts for 31 percent, forest fallows 30 percent, pasture 25 percent, annual crops 10 percent and perennials 4 percent. Rural population density is low at 7 persons per km^2. Farmland is abundant and cheap but of low quality for agricultural production. Farmers' capital and labor resources are limiting factors of production relative to plentiful land.

2.2 Description of Kudzu-Improved Fallows

Survey results indicate that a majority (52%) of farmers has adopted fallows improved with kudzu (*Pueraria phaseloides*) in the study zone. This stands in contrast to the limited adoption of other improved production practices. I chose kudzu fallows as a case study in order to understand why farmers have adopted them on a wide scale while not adopting other improved practices and the effect this technological change has had on deforestation.

Kudzu is a leguminous vine that farmers plant or that spontaneously regenerates in areas coming out of annual crop production. It spreads rapidly throughout the fallow area covering the ground and climbing up bushes and trees. Eventually, farmers once again slash and burn fallow areas and plant annual crops there.

Research on kudzu in the Peruvian Amazon indicates that it not only fixes nitrogen but also increases soil available phosphorus, potassium, magnesium and calcium (Wade and Sanchez, 1983). Furthermore, kudzu's aggressive growth impedes the regeneration of secondary forest and the spread of weeds in fallow areas. This acceleration of soil fertility recuperation and weed reduction allows a shortening of the fallow period. The reduction in secondary forest regeneration and weed presence also lowers land clearing and weeding labor costs. And finally, kudzu fallows require no capital investment.

Farmers first began using kudzu about 50 years ago as a cover crop underneath rubber plantation trees. When rubber production declined, national and international research centers actively promoted kudzu as an improved pasture. However, grazing and trampling by livestock rapidly eliminate kudzu, it dries up during the low rainfall months between June and September, and *Brachiaria decumbens*, the dominant improved pasture, tends to out-compete and displace it.

Farmers themselves have been the principal force in adapting kudzu for use in improved fallows, its current dominant use. Kudzu's informal diffusion led some researchers to question whether farmers were truly "adopting" kudzu-improved fallows or whether it was simply spreading spontaneously. Survey results, however, indicate that farmers actively manage kudzu in fallow areas. Further doubts have related to the negative experience in the southern United States where kudzu has disrupted the ecological balance. In fact, kudzu does not invade primary forest and only temporarily slows secondary forest regeneration, although it does occasionally invade annual and perennial crop parcels. Nevertheless, 94 percent of farmers expressed an overall positive opinion of kudzu due to its improvement of soils, control of weeds, and its use as fodder.

3. Comparative Economic Analysis: Kudzu-improved Fallows vs. Traditional Slash-and-Burn Agriculture

This section compares the total land use, labor use, and yields of kudzu-improved fallows with those of traditional fallows and primary forest used in extensive slash-and-burn agriculture. Farmers in the zone distinguish between two different types of fallows:

low fallows "purma baja" and high fallows "purma alta". The former has secondary forest vegetation below 5 meters high, whereas the latter has vegetation above this height. Farmers also have the option of slashing and burning primary forest areas to grow crops. A key distinction made by this research concerns the choice of farmers whether to clear secondary forests (high and low fallow areas) or primary forests.

Farmers classify kudzu-improved fallows as low fallows. Trees and shrubs grow in these areas but kudzu vines climb over them and slow their regeneration. The shortened fallow period farmers use when working with kudzu-improved fallows further reduces secondary forest regrowth. Therefore the tress in these fallows may not regenerate enough to be considered full-fledged secondary forest by some classifications. However, they grow in areas that would otherwise become secondary forest and perform many of the same functions as secondary forest with regards to regenerating fertility and controlling weeds. Therefore, for the purpose of this research, I consider kudzu-improved fallow areas to be incipient secondary forest.

3.1 Total Land Use

Since shifting slash-and-burn agricultural systems require farmers to place a parcel of land in fallow, they must clear and cultivate other land until the fallow area is ready to be cultivated once again. I use the term "total land use" to refer to the entire area cleared and cultivated before the farmer can return to his or her initial parcel and reinitiate the rotational cycle.

One can calculate the total amount of land needed to maintain a given area of annual crops in production based on the average fallow period and average time farmers cultivate a parcel before leaving it fallow. The less time that land must be left in fallow to

restore its soil fertility, the earlier farmers can return there. Therefore, they need less total land to produce crops. Similarly, the longer a farmer can cultivate a parcel before abandoning it, the more time fallow areas have to recuperate. This also reduces total land needs.

Farmers leave land in high and low forest fallows an average of 6.3 and 2.5 years respectively. For kudzu-improved fallows, the average is only 1.7 years. The average time farmers cultivate their fields before leaving them in fallow is 1 year for kudzu fallows and 1.3 and 0.9 years for high and low forest fallows (see table 1).

Based on these figures, one can calculate the total amount of land a farmer would need to maintain three hectares[1] in production using each type of fallow. The principal simplifying assumptions are that yields are maintained and that only one type of fallow is used in each scenario. The following formula calculates total land use:

$$\mathbf{TL = HP + [(FY/YC) * HP]}$$

TL =Total Land Use **HP** = Hectares Planted **FY** = Fallow Years **YC** = Years Cultivated

The first HP is the original amount of land in production, in this example, the first 3 hectares. The part in brackets is the average needed fallow years divided by the average years of cultivation multiplied by the hectares planted. This gives the amount of additional land needed for cultivation until the initial land has recuperated its fertility and is once again ready to be cultivated. The sum of these two gives the total amount of land needed in each type of fallow production system.

The principal result of this calculation is that kudzu fallows substantially reduce the amount of land needed to support annual crop production compared to high and low forest fallows. In this simplified model, kudzu fallows reduce land clearing needs by 116 percent over high forest fallows and 40 percent over low forest fallows (table 1). Reducing the total amount of land use in a shifting agricultural production system represents an intensification of land use. As long as farmers cultivate the same area of annuals, this will reduce their forest clearing needs.

Table 1: Comparative Analysis of Total Land Use for Differing Fallow Systems

	Kudzu-Improved Fallows	High Secondary Forest Fallow	Low Secondary Forest Fallow
Average Years of Fallow	1.7	6.3	2.5
Average Years Of Cultivation	1.0	1.3	0.9
Total Land Clearing: 3ha Annual Crop System	8.1	17.5	11.3
Comparative Land Use (Kudzu Fallow = Base 100%)	100%	216%	140%

An important question is the sustainability of these simplified systems. A study by CIFOR in the Pucallpa zone (Smith et al., 1998), found that fallow vegetation takes longer to regenerate after each cropping cycle. A low forest fallow system is likely to cause rapid land degradation. A high forest fallow system can be sustainable for a longer period. The sustainability of kudzu fallows appears relatively promising. Of the 24 farmers interviewed in the improved fallow survey, none reported a decline in productivity over time. However, the majority had been using kudzu fallows for less than 10 years, while four farmers had been using kudzu for ten years, and one each for 12, 21, and 30 years. Thus at least the medium-term sustainability of kudzu-improved fallows appears likely.

3.2 Labor Use

Primary forest and secondary forest fallows require substantial labor inputs for slash-and-burn land clearing. Since kudzu permits shorter fallow periods and suppresses secondary forest regeneration, it reduces the amount of trees and shrubs in the improved fallow. This reduces land clearing labor needs (table 2). Further, about half the time kudzu fallows regenerate naturally and for the other half farmers broadcast the seed, so seeding requires either no labor or minimal labor.

Table 2: Comparative Use of Labor for Land Clearing (labor days/ha)

	Average Use	Comparative Use (Kudzu Fallow = base 100%)
Primary Forest	26.5	323%
High Forest Fallow	21.8	266%
Low Forest Fallow	13.0	159%
Kudzu Fallow	8.2[2]	100%

Kudzu also reduces the amount of labor required for weeding. In general, the more light that penetrates the forest canopy, the greater the presence of herbaceous weeds. Since little light penetrates the primary forest canopy, these areas have the fewest weeds, while those cleared from traditional forest fallows have significantly more. Kudzu, however, is an aggressive cover crop that smothers herbaceous weeds that invade fallow areas. Areas cleared from kudzu fallows require less weeding labor than other forest fallows (table 3).

Table 3: Comparative Use of Labor for Weeding (labor days/hectare)

	Rice (t/ha)	Comparison	Maize (t/ha)	Comparative Use
Primary Forest	3.6	37%	3.1	24%
High Forest Fallows	39.7	409%	20.2	159%
Low Forest Fallows	31.6	326%	23.2	181%
Kudzu Fallows	9.7	100%	12.8	100%

Labor is a limiting factor of production relative to available land. On average, farmers cultivate annual crops on only 14 percent of land available on their farms (cropland, fallows, and primary forest). Forest clearing and weeding are two critical labor bottlenecks in the agricultural calendar in slash-and-burn fallow systems (Thiele, 1993).

By reducing labor needs at these key moments, farmers can put more land into production. This could potentially increase deforestation.

3.3 Yields

In slash-and-burn agricultural systems, yields increase when the amount of biomass burned is higher and hence the quantity of nutrients made available for crop uptake increases. Primary forest has the most biomass. But many of the trees are too large to burn well so their nutrients are not released and tree trunks take up field space. Therefore, according to farmer interviews, high forest fallows often provide the highest nutrient flush from burning while low fallows typically provide the lowest. Weeds are the second principal factor affecting yields. Primary forest has the least weed presence followed by kudzu then by other forest fallows.

Kudzu fixes nitrogen and provides other nutrients that accelerate the regeneration of soil fertility. And kudzu's function as a cover crop is effective at reducing weed competition. The net result of these two factors is a substantial yield increase over both traditional forest fallows and primary forest (table 4).

Table 4: Comparative Yields (Kudzu Fallow = base 100%)

	Rice (t/ha)	Comparison	Maize (t/ha)	Comparison
Primary forest	1.6	76%	1.3	76%
High Forest Fallow	1.9	90%	1.5	88%
Low Forest Fallow	1.0	48%	1.4	82%
Kudzu-Improved Fallow	2.1	100%	1.7	100%

4. Hypotheses Concerning Kudzu Fallows and Deforestation

The hypotheses concerning the impact of kudzu fallows on deforestation are based upon the analysis of their key characteristics in section 3. To review, these characteristics are shortened fallows, reduced labor cost, and increased yields. The first two hypothesized impacts are as follows:

***Hypothesis 1*: Thanks to its shorter fallow period, kudzu fallows decrease deforestation by reducing the total land needed in a shifting slash-and-burn production system.**

***Hypothesis 2*: Kudzu-improved fallows easing of labor constraints increases deforestation by allowing farmers to put more land into crop production.**

These two hypotheses predict that kudzu-improved fallows have two contradictory effects on deforestation. *A priori* therefore the net impact on total deforestation is uncertain.

I have defined fallows in general as secondary forest areas and kudzu fallows as a type of (emerging) secondary forest. The adoption of kudzu-improved fallows decreases the costs (land clearing and weeding) and increases the benefits (yields) of clearing secondary forest relative to clearing primary forest. This leads to hypothesis 3:

***Hypothesis 3*: Changes in the relative costs and benefits of secondary versus primary forest clearing due to kudzu fallows increase secondary forest clearing and decrease primary forest clearing.**

In sum, the labor cost and fallow length impacts of kudzu fallows operate in different directions on total forest clearing giving an ambiguous net outcome. However, kudzu fallows change relative costs and benefits in a way that encourages secondary forest clearing and discourages primary forest clearing.

5. Theoretical and Empirical Models

5.1 Theoretical model

This theoretical section provides a conceptual framework for understanding the relationship between agriculture and deforestation. Deforestation is not a primary activity of farmers. This would be the case if farmer deforested in the process of harvesting timber or other forest products. Farmers do *selectively* extract and sell high-value hardwood and other species from primary forest areas of their land holdings. However, because the timber harvesting is selective, the "residual" primary forest remains intact with a relatively small proportion of the biodiversity having been removed.

Farmers practice slash-and-burn agriculture in order to convert vegetative biomass into ashes that provide nutrients accessible for crop uptake. This results in a clear cutting type of deforestation. Deforestation is therefore an *outcome* of agricultural activities, a means to the end of agricultural production. In order to understand the deforestation outcome, it is therefore necessary to understand how farmers make agricultural production decisions.

The theoretical framework for understanding farmer agricultural production decisions uses a profit function approach. This approach assumes that farmers choose a combination of variable inputs and outputs in order to maximize profit subject to a technology constraint i.e. the production function of the farm. Farmer decisions about what to produce (outputs) and how to produce it (inputs/technologies) determine the impact of agriculture on deforestation. This is the basis for the econometric regression modeling in the following section.

Profit maximization should be understood in the broad sense of farmers using limited resources in as efficient a manner as possible to meet their livelihood (including social) objectives. Furthermore, strict profit maximization behavior is not a necessary prerequisite for specifying systems of outputs supply and factor demand equations, as long as the behavior of the individual agents is sufficiently stable over time and can be aggregated over farmers (Sadoulet and De Janvry, 1995).

The profit function for a farm is specified as follows:

$$(1)\ \pi = pq - wx$$

where p is a vector of prices for outputs, q is a vector of outputs produced by the farmer, w is a vector of input prices, and x is a vector of inputs.

Farmers maximize profits subject to the production function which represents how farmers use fixed inputs (z) and variable inputs (x) to produce outputs (q):

$$(2)\ q = f(x,z)$$

Variable inputs are those factors a farmer can change in the short run (e.g., fertilizer, seed, labor, etc.). Fixed factors are those that can't be adjusted in the short run. Fixed factors include private factors (e.g., land, education, family labor, etc.) public factors (e.g., infrastructure, credit, extension, etc.) and exogenous factors (e.g., soils and market distance).

The farmer maximizes profits by choosing the optimal level of inputs x and outputs q. The input demand and output supply functions can be represented as follows:

$$(3)\ x = x(p,w,z) \text{ and } q = q(p,w,z)$$

This indicates that the optimal levels of inputs and outputs are a function of output price, input price, and fixed factors. Combining equations (1) and (3), the profit function can be rewritten in the following manner:

$$(4)\ \pi = pq(p,w,z) - wx(p,w,z)$$

Using Shepard's Lemma, differentiation of equation (4) with respect to output and input prices in the following manner derives the output supply and input demand functions:

$$(5)\ d\pi/dp_i\,(p,w,z) = q_i \qquad d\pi/dw_i(p,w,z) = -x_i$$

The principal cause of deforestation is growing demand for crop and pasture land. However, not all agricultural products and agricultural production technologies have the same impact on deforestation. It is therefore necessary to understand the determinants of agricultural production and how agricultural production affects deforestation. The econometric modeling that follows analyzes the determinants of kudzu-improved fallow adoption and its impact on deforestation.

5.2 Econometric model

Based on the theoretical model above, this research uses two sets of econometric models. The first set analyzes the determinants of output production and input/technology use. The second set analyzes the impact of output production and input/technology use on deforestation. Outputs are divided into three principal categories: annual crops, perennial crops, and livestock. Inputs and production technology include improved fallows, improved pastures, natural pastures, capital inputs and hired labor. Deforestation is measured as the hectares of forest felled by a farm household in 1998. Three deforestation variables are examined: total forest (primary plus secondary forest), primary forest, and secondary forest deforestation.

The econometric modeling for the input and output regressions uses the ordinary least square method (OLS). A system approach using SURE gave similar results[3] but sharply reduced the number of available observations[4]. The deforestation regressions use recursive modeling due to the unidirectional causality running from agricultural production to deforestation hypothesized in the preceding theoretical section. The Hausman specification test generally verified this hypothesis[5]. The technique of two-stage least squares corrected for simultaneity when necessary.

The econometric models are specified as follows. Exact definitions of the variables are found in appendix 1.

OUTPUT$_{ij}$ = f (farm size$_i$, secondary forest$_i$, primary forest$_i$, alluvial soils$_i$, years in lot$_i$, education$_i$, age$_i$, family labor$_i$, origin$_i$, off-farm income$_i$, credit$_i$, extension$_i$, farm-gate price maize$_i$, land tenure$_i$)

j = annuals, perennials, and livestock
i = 1,..., N observations

INPUT$_{ij}$ = f (farm size$_i$, secondary forest$_i$, primary forest$_i$, alluvial soils$_i$ sandy soils$_i$, years in lot$_i$, education$_i$, family labor$_i$, off-farm income$_i$, distance social services$_i$, credit, market distance$_i$, land tenure$_i$)

j = kudzu fallows, improved pastures, natural pastures, capital inputs and hired labor
i = 1,..., N observations

DEFOR$_{ij}$ = f (annual$_i$, perennial$_i$, livestock$_i$, kudzu fallows$_i$, improved pasture$_i$, natural pasture$_i$, capital input use$_i$, hired labor$_i$, family labor$_i$, land tenure$_i$, education$_i$, forest$_i$, alluvial soils$_i$, forest product income$_i$

j = total, primary, and secondary forest deforestation in 1998.
i = 1,..., N observations

6. Model Results and Interpretation

The results presented here focus on the adoption of kudzu-improved fallows and the deforestation hypotheses presented in section 4. The four regression model results presented in table 5 are for kudzu fallow adoption, total deforestation, primary forest deforestation, and secondary forest deforestation. Due to the cross sectional nature of the data and the diversity of the agricultural systems, I consider variables as significant up to the .15 level. I also provide the exact significance levels for the reader's consideration.

6.1 Kudzu-Improved Fallow Adoption

Kudzu fallow adoption is positively and significantly correlated to farm size, distance to social infrastructure (schools and health posts located in population centers) and distance to markets. Adoption therefore does not appear to be due to a closing land frontier. The traditional scenario of intensification due to land scarcity, increasing population, and proximity to population centers (Boserup, 1965, 1981; Pingali et al. 1987) does not appear to explain the adoption of this land productivity enhancing technology.

On the other hand, farms with parcels that have been in production longer and with less primary forest have a significantly higher probability of adopting kudzu fallows. Both of these variables are indicative of decreasing land *quality*. The longer a farm has been in production, the greater the soil nutrient depletion (fallows take longer to regenerate). And the less remaining primary forest, the greater the depletion of above ground nutrient stocks contained in the vegetative biomass.

In the land abundant environment around Pucallpa one can not yet talk of a closing land frontier in quantitative terms. Farmers typically cultivate only a small proportion of their farms and/or have access to nearby land. However, given that farmers are subjecting the region's fragile tropical soils to slash-and-burn agriculture with declining fallow periods, land *quality* increasingly constrains production. Much of the adoption of kuzu-improved fallows can be related to a closing of the land "quality" frontier.

Three other significant variables of note are the positive correlation of kudzu fallows with education and sandy soils and the negative correlation with credit. Education's positive correlation indicates that understanding the process of nitrogen fixation and the management of kudzu in an improved fallow system requires a relatively higher level of knowledge. This is particularly true given that kudzu fallows have tended to spread informally by farmers without much support from extension services.

Furthermore, higher educational levels may give a greater opportunity cost to labor. More educated farmers may adopt labor-saving kudzu fallows in order to free themselves up to benefit from increased opportunities to work off farm.

The negative correlation with credit makes sense in that kudzu-improved fallows enhance productivity without using capital and decrease labor requirements. Thus, they offer an attractive alternative for increasing yields for farmers without access to credit. The positive correlation with sandy soils probably relates to the agronomic conditions in which kudzu flourishes.

The overall significance of the model is reasonably good (R^2 .39 Adj R^2 . 26) for this type of cross-sectional adoption analysis. This is particularly true given the multipurpose nature of kudzu in the zone. Farmers use kudzu to improve fallows, as pasture/fodder and as a perennial cover crop. The research survey may not always have clearly distinguished between these three uses and that may have reduced the model's predictive power.

6.2 The Impact of Kudzu-Improved Fallows on Deforestation

To analyze the impact of kudzu fallow on deforestation rates, I examine the sign and significance of the kudzu fallow variable in the deforestation regression models. The deforestation models contain numerous interesting results and significant variables. However, for the focus of this essay, I limit the analysis to the kudzu fallow variables and others pertinent to the analysis of the impact of kudzu fallows on deforestation. First, I briefly review the three hypotheses concerning kudzu fallows.

i.) Decreased fallow periods reduce deforestation.
ii.) Easing labor constraints increases deforestation

Table 5: Kudzu Fallow Adoption And Deforestation Regression Results:

Variable Variables	Kudzu Fallows		Variables	Total Deforestation		Primary Forest Deforestation		Secondary Forest Deforestation	
	R^2.33 adj R^2.25			R^2.54 adj R^2.50		R^2.30 adj R^2.23		R^2.30 adj R^2.23	
	Coef[a]	Signif		Coef[a]	Signif	Coef[a]	Signif	Coef[a]	Signif
Constant		.01	Constant		0.182		.74		.74
Farm Size	***.548	.00	Annuals	***0.490	.00	***.323	.00	***.301	.00
Secondary Forest	-.066	.44	Perennials	*-.102	.10	-.040	.60	-.008	.92
Primary Forest	*-.198	.09	Livestock	0.039	.59	.020	.83	**.197	.04
Alluvial Soils	-.066	.48	Kudzu Fallows	0.049	.41	*-.129	.07	*.137	.06
Sandy Soils	**.168	.05	Improved Pastures	-0.023	.75	-.006	.95	*-.154	.13
Years in Lot	*.151	.12	Natural Pastures	*-0.094	.13	-.061	.45	**-.163	.05
Education	***.207	.01	Capital Inputs	**-0.153	.03	-.125	.16	**.181	.04
Family Labor	.091	.28	Hired Labor	***0.337	.00	.011	.89	.019	.82
Off-Farm Income	.002	.99	Family Labor	0.060	.31	.021	.79	***.202	.01
Dist Soc'l Services	*.140	.13	Education	**0.129	.02	.003	.96	.070	.33
Credit	*-.151	.07	Tenure Insecurity	*0.097	.09	-.025	.75	-.030	.69
Market Distance	**.189	.05	Alluvial Soils	0.028	.65	***-.193	.01	***.203	.01
Tenure Insecurity	-.010	.91	Total Forest	*0.108	.09	-	-	-	-
			Secondary Forest[b]	-	-	-0.98	.16	**.166	.02
			Primary Forest	-	-	***.254	.00	-.093	.23
			Prim Forest Prod's	-	-	**.168	.02	-.034	.63

*** Significant at the .01 level
** Significant at the .05 level
* Significant at the .15 level

(a) All Coefficients are Standardized
(b) High secondary forest (> 5 meters)

iii.) Changing the relative costs and benefits of land clearing in favor of secondary forest leads to declining primary forest clearing and increasing secondary forest clearing.

The three deforestation regression models examine total, primary, and secondary forest deforestation. This permits an examination of the impact of kudzu fallows on each type of deforestation. While it is not possible to empirically separate out the two opposite effects posited in the first two hypotheses using regression analysis, the total deforestation regression model allows an estimation of which effect may be stronger. The primary and secondary forest deforestation models allow a direct analysis of the third hypothesis.

The sign of kudzu-improved fallows in the total deforestation model is positive through not significant. This may indicate that kudzu fallows' easing of labor production constraints increases deforestation more than shortened fallow periods decrease deforestation. The importance of the labor constraint (and hence its easing) is indicated by the positive and highly significant correlation of hired labor in the total deforestation model and family labor in the secondary forest deforestation model. These indicate that increased availability of labor has a strong positive effect on deforestation. Easing the labor constraint via the adoption of a labor-saving technology should therefore have the same impact.

When total deforestation is broken down into secondary and primary forest deforestation, the kudzu fallow variable becomes significant. Kudzu-improved fallows are negatively correlated with primary forest deforestation and positively correlated with secondary forest deforestation. This supports hypothesis 3. The changes in the relative costs and benefits of land clearing associated with kudzu fallows lead farmers to reduce primary forest clearing and increase secondary forest clearing.

7. Conclusions and Implications for Policy and Technology Development

This research has analyzed one particular technology (kudzu-improved fallows) in one specific setting (the lowland Amazon surrounding Pucallpa, Peru). Perhaps the most basic conclusion drawn from this analysis is that the impact of technological change on deforestation depends fundamentally on the profile of the new technology and the biophysical and socio-economic characteristics of the zone where it is introduced.

It would be wrong to assume that the introduction of any and all improved fallows in the Pucallpa zone would increase total deforestation. For example, another type of improved fallow may have greater labor requirements and not free up this limiting production factor. Or, if kudzu-improved fallows were introduced in a socio-economic environment where labor was not a constraining production factor, deforestation again might not increase. There is therefore a need for both site-specific and technology-specific analysis to understand the impact of a technology on deforestation.

This research has also shown that agricultural technology and land clearing patterns may interact in a complex fashion. Kudzu fallows simultaneously ease the limiting labor production factor (increasing deforestation) and shorten needed fallow times (decreasing deforestation). In addition, they have opposite effects on the clearing of primary and secondary forests. Researchers need to recognize that new technologies may simultaneously affect deforestation in several distinct ways and may need to undertake a more disaggregated analysis of these effects.

Kudzu improved-fallow adoption has been successful precisely because it fits with the relative factor scarcity of the zone and provides a superior alternative to slash-and-burn agriculture (by reducing labor while increasing yields). Many other improved production technologies focus on reducing deforestation via soil conservation and/or increasing productivity. While this approach is not wrong per se, it may blind researchers to the fundamental fact that labor and capital, and not land, are typically the main production constraints in agricultural frontier contexts. Under such circumstances, attempts to get farmers to conserve land with technologies that require greater use of capital and/or labor are likely to fail. The general lesson is that soil conservation is not a primary objective of farmers in a land abundant environment. Soil fertility enhancing technologies will only be attractive to farmers when their costs and benefits are superior to the current practice of extensive slash-and-burn agriculture.

A key factor in this analysis has been labor availability. Labor is a limiting production factor in the Pucallpa zone. Basic economic theory tell us that farmers attempt to maximize returns to scarce production factors. Kudzu-improved fallows have been successful precisely because they increase labor productivity. Herein lies a paradox: the reduced labor requirements that encourage adoption of this land conserving production technique also free up labor so that overall deforestation increases. One possible solution might be to introduce high value crops such as certain perennial and horticultural crops that demand a lot of labor but still increase the return to scarce labor resources.

In general, improved fallows appear to be a technology with important potential for reducing deforestation. In the simple model, kudzu-improved-fallows decreased total land clearing needs by 116 percent and 40 percent compared to high and low forest fallows respectively. The challenge of future research is to find creative ways to harness this potential and minimize the negative impacts.

Designing improved fallows that use more labor while increasing returns to labor might also help resolve the "labor paradox". Improved fallows that produce a useful product at the same time they fix nitrogen and provide other nutrients for the soil may achieve these dual goals. Agroforestry fallows systems merit consideration in this respect.

For example, farmers can plant fast growing leguminous trees in association with annual crops. For the first year and a half they weed the trees together with the annual crops. This reduces the key labor weeding constraint associated with the installation of tree plantations. By the time the farmer abandons annual cropping, the trees are developed enough to survive in the fallow without weeding. These trees help recuperate land productivity while providing useful products that absorb farmer labor. For these systems to succeed, the initial labor and capital costs should be minimized (e.g., by using bare root bed tree nurseries, direct seeding, planting in association, etc.) and the secondary tree products must have a high value for home consumption or commercial sale. Research should focus on finding creative ways to reduce the costs of improved fallows and on identifying tree species that combine soil amelioration with the provision of valuable secondary products.

In the specific case of kudzu-improved-fallows, they increase secondary forest clearing but reduce primary forest clearing. Although higher secondary forest clearing is not a desired outcome, the reduction of primary forest clearing is clearly a positive environmental impact, since these forests typically provide the greatest amount of environmental services. And even though secondary forest clearing increases, the easing of the labor constraint allows total production to rise and that helps reduce poverty.

This research, to some extent is a case study of trade-offs often necessary between different goals. In this case, primary forest deforestation and poverty decreased but secondary forest increased. An economist cannot scientifically evaluate the worthiness of these particular trade-offs. This analysis can, however, help policy makers understand the nature of the trade-offs in order to make better informed decisions. Moreover, this type of analysis can aid in analyzing strategies for changing trade-offs to achieve outcomes desired by policy makers.

A final set of conclusions and policy recommendations deals with where kudzu and other improved fallows are most likely to be successful and how this relates to deforestation. Kudzu-improved fallows are not associated with the typical intensification scenario of land scarcity nearer to urban centers. Kudzu-improved fallow adoption increases on farms that have been in production longer and on those with less primary forest. It is the land *quality* constraint and not the land *quantity* constraint that leads farmers to adopt kudzu fallows. This knowledge can help extension services save their limited resources by targeting farms for introduction of kudzu and other improved fallows where they are most likely to be successful.

In addition, a CIFOR study (Smith et al., 1998) in the Pucallpa zone and another by Schelhas (1996) in Costa Rica found that farmers in older more developed frontier zones with less primary forest put a higher value on preserving it. The products and services provided by the remaining primary forest acquire a higher scarcity value.

Improved fallows are likely to be particularly well received in these zones not only because of declining soil fertility, but also because of a stronger desire to preserve remaining primary forest. Thus, farmers in older settlement areas may be particularly receptive to adopting improved fallows in order to conserve the remaining primary forest.

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APPENDIX 1: VARIABLE DESCRIPTION

Years in Lot	Number of years a farm has been in production (past & current owners)
Sandy Soils	Dummy variable, sandy soils dominant on farm
Alluvial Soils	Dummy variable, farm located in alluvial soil zone
Farm size	Total hectares of a household's land holdings
Secondary Forest	Hectares of secondary forest fallow on a household's land holdings
Primary Forest	Hectares of primary forest on a household's land holdings
Forest	Hectares of total forest on a household's land holdings
Family Labor	Number of family members 14> years old working on the farm
Education	Dummy variable, household head has secondary education or higher
Forest Prod. Income	Value (in *soles*) of products harvested from the primary forest in the previous year
Off-farm Income	Value (in *soles*) of off-farm income earned by a household in the past year.
Age	The age of a household head
Annual	Hectares of annual crops on a household's land holdings
Perennial	Hectares of perennial crops on a household's land holdings
Livestock	Head of cattle owned by a household
Kudzu Fallows	Hectares of kudzu-improved fallows on a household's land holdings
Nature Pasture	Hectares of natural pasture on a household's land holdings
Improved Pasture	Hectares of pasture improved with *Brachiaria* on a household's land holdings
Capital Input Use	Value (in *soles*) of capital inputs used in the past year by a household
Hired Labor	Days of paid labor used on farm (includes labor exchange "minga")
Land Tenure	Dummy variable, household head perceives tenure as insecure
Market Distance	Household's distance in kilometers to the principal market Pucallpa
Dist Social Serv's	Household's distance in kilometers to nearest (school + health post)
Credit	Dummy variable, household received credit in the last five years
Extension	The number of extension visits a household received in the past year
Fm-Gate Pr Maize	The price for maize received by a household minus transportation and labor marketing cost

[1] This is the average amount of annual crops cultivated by a farm household in the study area

[2] This includes labor for collecting kudzu seeds and seeding a kudzu fallow.

[3] With the exception of the capital input use model, there were only a total of four sign changes (none of variables significant at the .15 level or lower). Further (again with the exception of capital inputs), variables significant at the .05 level or lower in the OL S models remained significant at the .15 level or better in the SURE systems approach. The standard errors generated by the two techniques were remarkably similar, although the SURE standard errors were generally slightly higher. In the case of capital inputs a review of a simple correlation matrix between inputs and outputs indicated that capital inputs have the highest level of correlation with other inputs and outputs. This may explain the changes shifting from OLS to SURE.

[4] With the SURE technique, all missing variables from any equation in the system result in an observation being deleted. Combining all the missing observations in this way resulted in only 40 of the initial 220 observations being available.

[5] I performed the Hausman test in order to check for simultaneity in the deforestation regression models between the deforestation dependent variables and the input/technology and output independent variables. In order to do so I first estimated the reduced form equations for all the input/technology and output variables. I then took the estimated residual from each reduced form equation and plugged it into each of the deforestation regression models as a right-hand-side variable. I then performed a t-test on the coefficient of the estimated residual from the reduced form equation. I used a .10 cut-off as a criteria to judge for significance.

THE ADOPTION OF IMPROVED PASTURES AND THEIR IMPACT ON DEFORESTATION IN THE PERUVIAN AMAZON

ESSAY NUMBER 3

1. Introduction

1.1 Environmental and Economic Impacts of Livestock

Most rainforest cleared in the tropics of Latin America eventually ends up as pasture (FAO, 1993; Houghton et al., 1991). The environmental impact of this transformation is stark. The conversion of one hectare from rainforest to pasture results in the reduction of hundreds of tons of biomass containing thousands of species over 40 meters of vertical space into a field containing a few native and exotic species compacted one to two meters high. Some 170 tons of carbon per hectare are released into the atmosphere potentially aggravating global warming (Mattos and Uhl, 1994).

The social and economic benefits derived from tropical forest clearing for ranching appear limited. According to Ledec (1992), per land area deforested, cattle raising produces much smaller benefits than other production systems-whether these benefits are measured as foreign exchange, financial revenues, employment, calories, or animal protein. His data indicate that a dollar's worth of beef requires the deforestation of between 37 and 119 times more land than a dollar's worth of coffee, 15-24 times more land than sugar, 34-43 times more land than cotton, and about 145 times more land than bananas.

Nevertheless, cattle raising in tropical Latin America offers advantages that make it attractive to small and large farmers alike. Cattle is a relatively low risk economic activity compared to other land uses both in terms of production and market price (Fearnside, 1990; Seré and Jarvis, 1992, Schelhas, 1996). In addition, cattle have more flexibility in the timing of their sale than most agricultural crops and farmers can walk the product to market in areas with inadequate infrastructure (Hecht, 1993; Seré and

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Jarvis, 1992). Furthermore, cattle production can take place on degraded land that is unproductive for other agricultural activities (Hecht, 1993; Seré and Jarvis 1992; Thrupp, 1980).

At the heart of the mixed picture of cattle's environmental and economic impacts in the tropics lies cattle's extensive use of land and low labor requirements. In Brazil for example, a typical large cattle ranch uses only one cowboy for every 1500 hectares of cleared land (Hecht, 1993). So while returns to land may be low, returns to labor tend to be quite high. This use of resources reflects the fact that land is relatively abundant and cheap relative to available labor. Maximizing returns to the limiting factor of production is a rational response that maximizes profitability. This private rationality nevertheless entails a heavy social cost particularly in environmental terms.

In the Peruvian Amazon, 46 percent of farmers own livestock and 95 percent of these have less than a hundred head of cattle (INEI, 1986). These farmers tend to be very poor and depend upon livestock to meet basic material subsistence needs. Thus short-term survival needs take precedence over longer-term environmental costs. The reality is that, for better or for worse, ranching has an established presence in the Amazon that will not soon go away (Mattos and Uhl, 1994; Serrao and Toledo, 1990; Larbarta, 1998).

1.2 Sustainable Livestock Production in the Amazon?

Given the likelihood that ranching will remain in the region, is there a hope for improving the sustainability of livestock production? This section introduces the key issues related to sustainable livestock production in the Amazon.

1.2.1 Intensification in the Land-Abundant Tropics

Research has shown that intensification of agriculture and ranching is agronomically feasible on lowland tropical soils (Rao et al., 1993; Serrao and Toledo, 1992; Smith, 1992). Seré and Jarvis (1992) and Ledec (1992), however, point out that the track record of livestock intensification efforts in tropical Latin America is poor and that extensive land-using production practices remain the norm. Numerous studies have shown that, given the abundance of cheap land, extensive production practices are more profitable than intensification. (Hecht et. al 1988; Serrao and Toledo, 1990; Griffith and Zepeda, 1994; Muñoz, M., P. Odermatt, and J. Reyes, 1994)

Boserup (1965 and 1981) maintains that intensification of agricultural production results from increasing population pressures on a limited land base. As a result, land becomes more valuable relative to other inputs, and increases in land productivity become desirable. The increase in the value of land relative to labor stimulates an increase in input use per hectare of land (Smith et al. 1994).

In the Peruvian Amazon, however, land remains abundant and cheap relative to labor and capital. Induced technological innovation theory (Hayami and Ruttan, 1985) states that the adoption of agricultural technologies will tend to reflect the factor scarcity of the zone. Farmers tend not to adopt technologies that conserve an abundant resource (land) by using relatively scarce resources (capital and/or labor). Indeed Boserup (1965) argues that agricultural intensification is unlikely as long as a frontier of unexploitated agricultural land persists. Nevertheless, widespread adoption of pastures improved with grasses from the *brachiaria* genus (principally *Brachiaria decumbens*) has substantially increased average pasture carrying capacity in the zone of Pucallpa, Peru.

1.2.2 The Impact of Improved Technologies on Deforestation

Pasture degradation has been the rule throughout the Amazon region (Serrao and Toledo, 1990). This degradation has led to the frequent abandoning of pastures within ten years of their installation (Mattos and Uhl, 1994; Hecht, 1982, 1985). This abandonment often forces ranchers to move further out into the agricultural frontier and clear more forest for pastures. Buschbacher (1986) has referred to this dynamic of land use as "shifting ranching".

Numerous authors have stated that intensification of livestock production has the potential to reduce deforestation (Serrao and Toledo, 1992, 1993; NRC, 1993; Steinfeld et al. 1998; Seré and Jarvis, 1992). They argue that improved pastures would obviate the need to abandon degraded pasture and clear new forest. In addition, adapted forage germplasm that permits farmers to raise more cattle using less land would further reducing forest clearing (Serrao and Toledo, 1990; Seré and Jarvis, 1992).

Other authors, however, point out the potential of improved pastures (Kaimowitz, 1996) and productivity-enhancing technologies in general (Tomich et al., 1999) to increase deforestation. If these technologies increase the profitability of agriculture, they also increase the opportunity cost of conserving natural forest. Increased returns may encourage both current farmers and new migrants to expand production into the forest margins. In fact, very little empirical work documents the impact of technological change in agriculture on deforestation (Kaimowitz and Angelsen, 1998).

1.3 Paper's Objectives and Organization

Given that agricultural intensification typically does not take place in land abundant areas, the first objective of this paper is to understand the widespread adoption of improved pastures by farmers in the Pucallpa zone. Secondly, given the lack of empirical evidence concerning the impact of technological change in agriculture on deforestation, what effect has the adoption of this land-intensifying technology had on forest clearing?

This paper is organized in the following manner. Section 2 describes the key characteristics of the Pucallpa, Peru research zone. An analysis of the evolution of land use patterns on farm land holdings in section 3 gives insights into the process of deforestation over time. Section 4 compares the socio-economic characteristics of *brachiaria*-improved pastures to natural pastures and livestock production with *brachiaria* pastures to annual and perennial crop production. Section 5 presents a theoretical model that uses a profit function approach to outline the relationship between the determinants of farmer adoption of livestock and pasture and how these production decisions in turn effect deforestation. This theoretical discussion provides the basis for the specification of three econometric models that examine the determinants of livestock and pasture adoption and the effect these have on deforestation. The results of the econometric models are discussed in section 6. Because the econometric models use cross-sectional data, they capture the *current* dynamic of agricultural production and deforestation. Section 6 therefore complements these models with an examination of the *historical* impact of livestock and pastures on deforestation using correlation analysis. Section 7 presents conclusions and policy recommendations.

1.4 Research Data

The data used in this essay comes from two surveys led by this author in 1998. The main survey interviewed 220 households concerning their agricultural production practices, the socio-economic characteristics of their household, and the biophysical characteristics of their farm. This survey used the distance from the main market town and the type of infrastructural access[1] available to farmers as the criteria for sample stratification.

This research principally uses the main survey data for the econometric modeling. A second follow-up survey of 38 households with pasture collected more detailed data concerning farmers' experiences with natural pastures, *brachiaria*-improved pastures, and livestock. This second survey provides information for this essay's section on the socio-economic characterization of natural and *brachiaria*-improved pastures.

2. Characteristics of the Research Zone

This essay's research zone is in the lowland tropical rainforest surrounding the city of Pucallpa, Peru. This relatively new frontier area was first connected to the capital, Lima, approximately 60 years ago when Pucallpa was little more than a village of 2000 inhabitants. Pucallpa's population has since grown to approximately 200,000 making it the second largest urban center of the Peruvian Amazon.

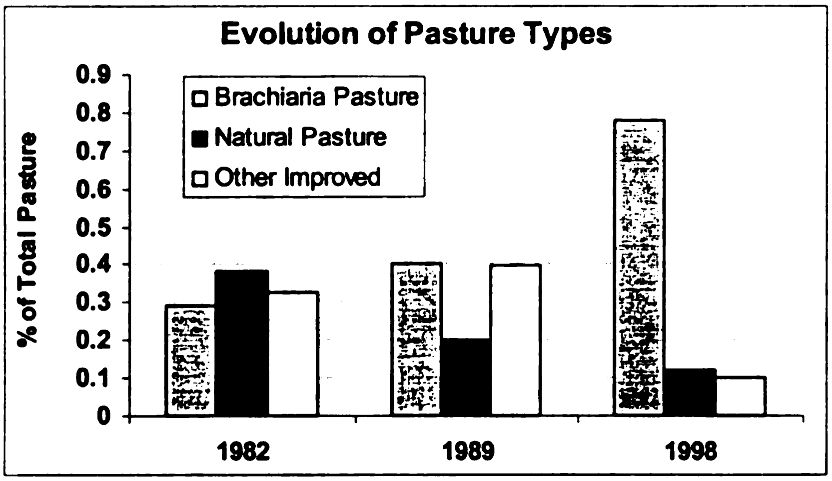
Nevertheless, the Pucallpa zone remains a land abundant environment. Population density is low at 7 individuals per km^2. Data from this research's main survey indicates that median farm size is 30 hectares. Only 39 percent of farmland is in some form of agricultural use (pastures 25%, annuals 10%, perennials 4%) with the remaining 61 percent in secondary forest fallows (30%) and primary forest (31%). In addition, new lands areas are continuously made accessible by feeder roads opened up for timber, gas, and oil extraction.

Virtually all farmers continue to practice shifting slash and burn agriculture for annual crop production. The predominant crops are maize, rice, cassava, and plantains. 23 percent of farmers have livestock holdings. Of these 96 percent are small holders owning 50 head of cattle or less and 92 percent of cattle owners have mixed farming systems including the production of annual crops.

Although only 23 percent of all farmers own cattle, 49 percent have installed pasture on their farmland. A majority of farmers with pasture (52%) therefore have no cattle. Virtually all these farmers stated their intention was to acquire cattle. In general, farmers state that their primary future production objective is to increase cattle production (Labarta, 1998). There is little evidence of farmers planting pasture for land speculation, as was frequently the case in Brazil (Hecht, 1985). Numerous well located ranches on the principal highway leaving Pucallpa had for sale posted signs during 1998-99 without evidence of many sales taking place. And, apart from a small program of rotating in-kind livestock credit[2], the Peruvian government does not actively promote cattle production in the zone.

Pucallpa does not have a milk processing plant. Most milk sold in the zone is brought in from other parts of the country in evaporated form. Efforts by both national and international agricultural research centers to promote the production of milk have met with limited success. Most cattle are raised for beef production and milk is generally for home consumption. The evolution of pasture use in the zone has been markedly in the direction of a reduction in natural pastures and an increase in pastures improved with *brachiaria*. *Brachiaria*-improved pastures have also come to dominate other types of improved pastures (graph 1).

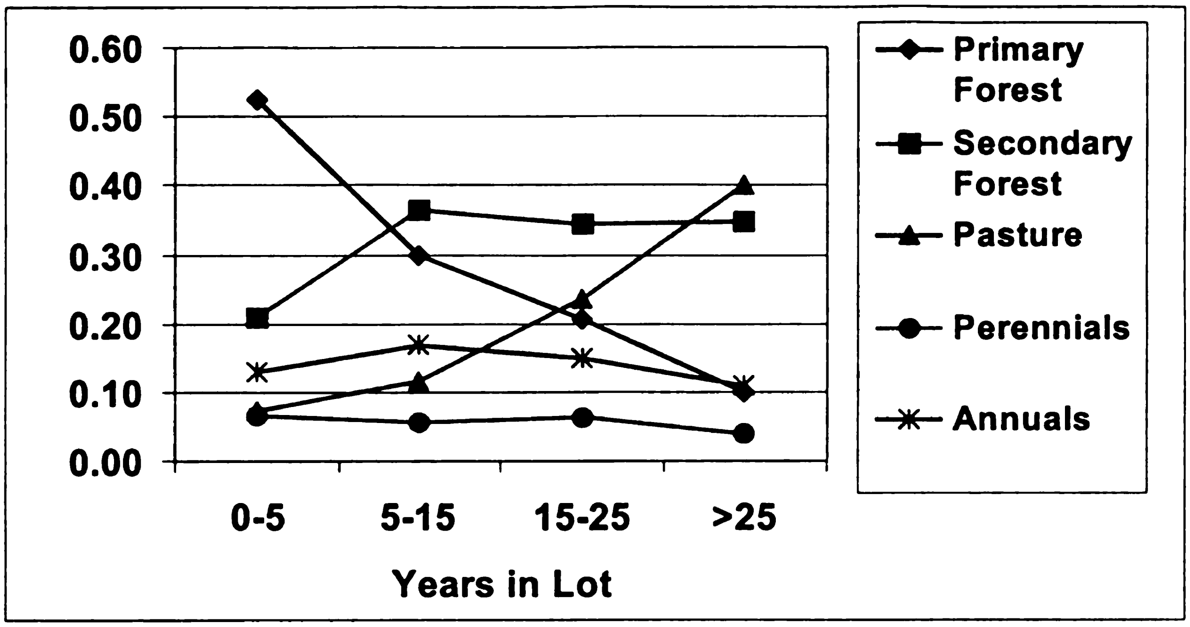
In sum, the zone surrounding Pucallpa can be characterized as a relatively early frontier area. Population density remains low, land is cheap and abundant, and market development is limited. Furthermore, virtually all livestock owners are small holders with mixed production systems. Yet despite this relatively early stage of frontier development and a large surplus capacity of pastureland, farmers have intensified the productive capacity of their pastures by adopting the improved pasture grass *brachiaria*. Given that intensification is typically associated with population increases, land scarcity, and market integration, the rest of this essay will attempt to explain the widespread adoption of this improved production technology in the early stages of frontier development and the impact it has had on deforestation.



Graph 1: The Evolution of Pasture Use in Pucallpa (Riesco 1993 and author survey 1998)

3. The Evolution of Land Use Patterns in the Pucallpa Zone

An examination of the evolution of land use patterns gives insights into how cattle production fits into farmers' production strategies over time and its relation to deforestation. Graph 2 shows that during the first ten years the principal change in land use patterns involves the conversion of primary forest into secondary forest fallows. This conversion is the result of annual crop production using shifting slash-and-burn agriculture. Primary forest areas are cut down for annual crops, cultivated for 1-2 years and then left fallow to regenerate into secondary forests. The amount of land put into pasture remains low and increases only slightly.



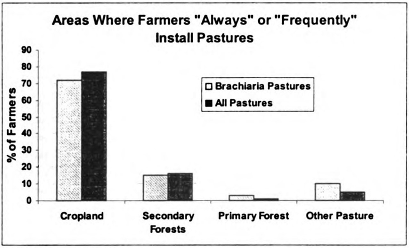
Graph 2: The Evolution of Land Use Patterns on Farmer Land Holdings (Author Survey 1998).

After ten years, the major change involves a continuing strong decline in primary forest cover and a sharp increase in pasture area. However, primary forest areas are rarely converted directly into pastures. Graph 3 shows that pastures are rarely planted in areas cleared from primary forest, rather they are almost always installed in areas coming out of annual crops or in secondary forest.

Several reasons explain this transformation in land use. First, most migrants come to the Pucallpa zone due to poverty in their region of origin. They initially lack the needed financial resources to enter into ranching (cattle purchase, fencing, etc.). Farmers begin practicing slash and burn annual crop production because it has low capital start-up costs. Farmers need time accumulate capital to purchase cattle and ranching infrastructure such as fencing and wells. Secondly, farmers prefer to install pastures on degraded areas with falling annual crop yields. Pastures have lower soil fertility requirements than most crops and therefore extend the effective utilization of degraded areas (Seré and

Jarvis, 1992; Hecht 1992). Finally, farmers install pastures in cropland because this avoids the double labor of clearing land for both pasture and annual crops.

The importance of the capital constraint is demonstrated by the fact that 85 percent of farmers who were able enter into livestock production used off-farm sources of income. Almost no farmers reported financing livestock acquisition solely from farm sales. This further explains why more than half of farmers have pasture but have not yet been able to accumulate enough capital to purchase cattle.



Graph 3: Land Use Conversion to Pasture (Author Survey 1998).

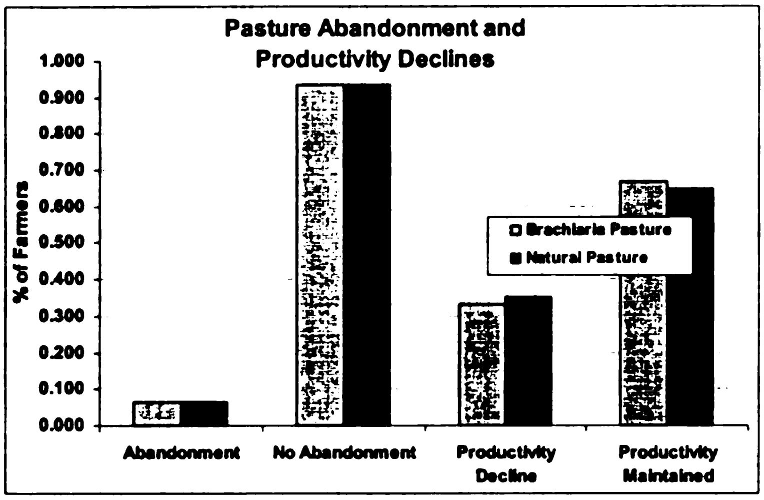
In sum, the sharp increase in pasture land use begins after approximately 10 years when farmers have accumulated enough capital to purchase cattle and when declining soil fertility decreases crop yields. A similar evolution of land use patterns has been observed in other tropical regions of Latin America (Thiele, 1993; Ledec, 1992; Fujisaki, 1996).

4. Socio-Economic Characteristics of *Brachiaria*-Improved Pastures

An analysis of the key socio-economic characteristics of *brachiaria*-improved pastures provides insights concerning their widespread adoption and impact on deforestation. This sections examines the productivity and costs of brachiaria improved pastures relative to natural pastures and compares livestock production (with brachiaria), annuals, and perennials in terms of their use of labor and returns to labor and land.

4.1 The Productivity of *Brachiaria*-Improved Pastures

Grasses of the *Brachiaria* genus have low soil fertility requirements and good nutritional quality (Lapointe and Miles, 1992). A study by Abanto and Vela (1997) of pastures dominated by *brachiaria* in the Pucallpa zone found that they substantially increase fodder production relative to natural pastures (known as "tourouco" in the zone). Natural pastures produced 807 kg/ha during the rainy season compared to 1337 kg/ha for *brachiaria*.



Graph 4: Pasture Abandonment and Productivity Declines (Author Survey 1998).

This increase in fodder production raises the carrying capacity of pastures in the zone by 53 percent (from 1.01 to 1.55 tropical animal units).

Abanto and Vela also identify other productivity benefits associated with *brachiaria*-improved pastures relative to natural pastures. Calf production, for example, increased by 26 percent whereas mortality rates declined by 70 percent. In addition, total annual meat production increased by 31 percent from 68.6 kg/ha to 89.6 kg/ha.

Another important indicator of productivity is the sustainability of production over time. In the Amazon, degraded pastures have frequently been abandoned after only

10 years. Pastures of the *brachiaria* genus, however, persist for greater periods of time in the phases of high and intermediate productivity as long as insect pests such as spittlebug do not damage them (Serrao and Toledo, 1990).

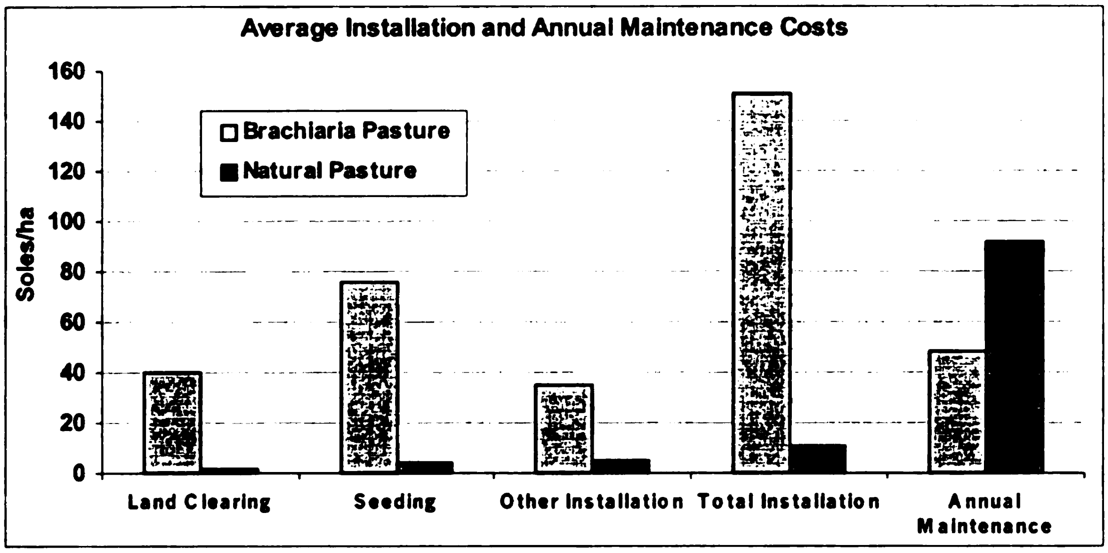
In the case of Pucallpa, there is very little evidence of pastures being abandoned due to productivity declines. Less than 10 percent of farmers reported ever having abandoned a *brachiaria*-improved pasture due to productivity declines (graph 4). However, approximately a third of farmers had noted some decline in productivity in these pastures. Interestingly, however, these results are virtually the same for tourouco natural pastures. In fact, a study by Toledo and Serrao (1987) found that natural pastures in the Peruvian Amazon generally maintain a stable carrying capacity.

4.2 The Costs of *Brachiaria*-Improved Pastures

As mentioned in section 1.2.1, it is typically less profitable to augment production with intensive technologies than with an increase in the amount of land under production using extensive systems. Mattos and Uhl (1994), on the other hand, calculate that some intensive and specialized systems may be more profitable than extensive systems but their high costs combined with the capital constraints faced by farmers make them unaffordable.

Graph 5 compares the per hectare costs of natural pasture with those of *brachiaria*-improved pastures. There are two key differences. First, the installation costs (land clearing, seeding, etc.) associated with *brachiaria* pastures are substantially higher than those associated with natural pastures. Tourouco pasture is "natural" in the sense that it spontaneously appears when an area of land is cleared. Installation costs are therefore negligible. *Brachiaria*, on the other hand, needs to be planted, requires more careful land clearing, and in some cases needs an initial weeding to facilitate its installation.

Nevertheless, the installation costs of *brachiaria* are still quite low. Capital requirements are typically nil (1 percent of total installation costs) and labor requirements



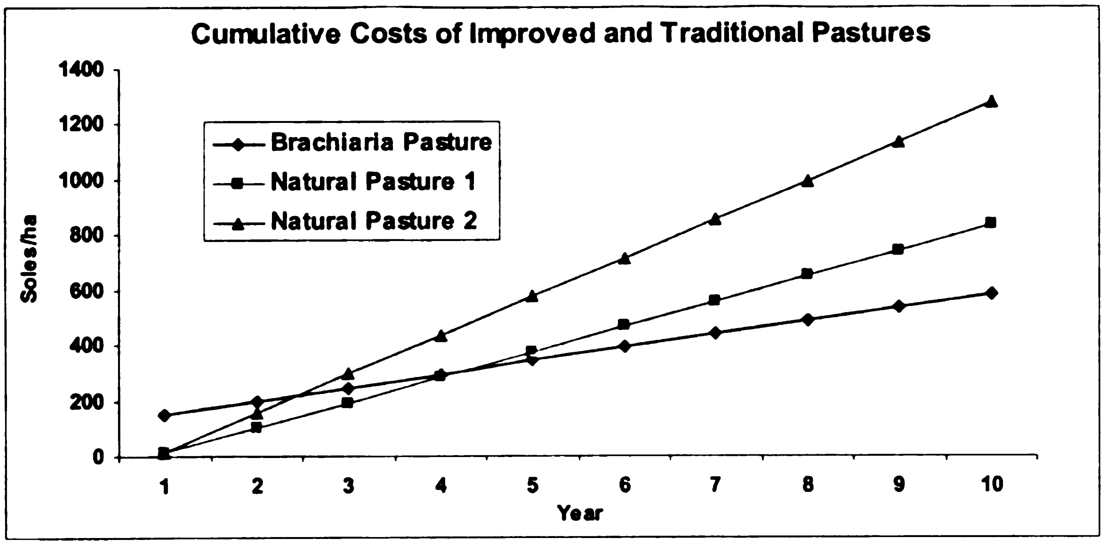
Graph 5: Average Installation and Annual Maintenance Costs for Pastures (Author Survey 1998).
(One nuevo sol =$.32 in 1998)

are 18.7 person days per hectare. Use of areas coming out of annual crop production minimizes land clearing costs and seasonal labor demands are typically low after harvest so labor is generally available. Brachiaria, which is typically transplanted by hand in small clumps spaced at regular intervals in a field, rapidly spreads and takes over a field and only occasionally requires weeding during installation. One of the most commonly mentioned advantages of *brachiaria* by farmers in the survey was the ease of its propagation.

This manner of installing *brachiaria*-improved pastures makes it a completely divisible technology. There are no economies of scale due, for example, to tractor use or bulk fertilizer purchases. It is proportionally as cheap to plant 1 hectare as it is to plant 10. Farmers are thus able to take a progressive approach to pasture installation. Farmers typically only install from 1-3 hectares per year. This progressive approach spreads out labor requirements so they do not impede adoption.

The second difference between *brachiaria* and traditional pastures is that the recurrent annual costs of pasture maintenance (weeding, cutting, and burning) are nearly twice as high for natural pasture as those of *brachiaria*-improved pastures. *Brachiaria* is a much more aggressive pasture than tourouco and therefore minimizes weed regrowth. Farmers mentioned pasture weed reduction a key advantage of *brachiaria*. A study by Riesco (1992) also identifies weed reduction as the principal advantage of *brachiaria*.

Graph 6 shows that, when one sums the initial installation and annual maintenance costs, in the span of a few years the cumulative total costs of *brachiaria* are less than those of natural pasture. The line marked natural pasture 1 shows that in approximately 4 ½ years the cumulative costs of one hectare of natural pasture surpass those of one hectare of *brachiaria* pasture. By the end of ten years, the cumulative costs of natural pasture are 43 percent greater than those of *brachiaria* pasture. Furthermore, this one-to-one comparison is biased in favor of natural pasture. The carrying capacity of *brachiaria* pastures is slightly over 50 percent higher than that of natural pastures. Farmers need about 1.5 hectares of natural pasture to feed the same quantity of livestock as one hectare of *brachiaria* pasture. Accounting for this difference, the line labeled natural pasture 2 shows that the cumulative costs of natural pasture surpass those of *brachiaria* pasture within about 2 ½ years and are 118 percent higher by the end of ten years.



Graph 6: The Costs of Improved and Traditional Pastures (author survey 1998)

Discounting these costs over the ten year time span shows that *brachiaria* - improved pastures remains less expensive up to a discount rate just over 25 percent. Researchers generally believe that small holder farmers in developing countries have high rates of discount. However, given the low post-harvest opportunity cost of labor when pastures are installed and maintained, farmers are likely to have a low discount rate for these expenditures. The cost advantage of *brachiaria* pastures thus appears to be relatively robust.

In sum, although the initial installation costs of *brachiaria* pastures are higher than those of natural pasture, the annual maintenance costs make it a cheaper option within a brief period of time, particularly when one controls for pasture carrying capacity. Also, installation costs do not represent a constraint to adoption because *brachiaria* pastures are a completely divisible technology.

4.3 Comparative Labor Use and Financial Returns: Livestock, Annuals, and Perennials

This section compares the average labor use and the financial returns to land and labor for the principal output categories-cattle, annuals, and perennials-in the Pucallpa area (table 1). More specifically, these categories consist of cattle ranching using *brachiaria* pastures; a proportional mix of the dominant annual crops[3] in the zone (maize, rice, plantains, and cassava); and oil palm, the current dominant perennial cash crop. This comparison gives insights into farmer logic concerning resource use and land clearing patterns. The main focus of this study, however, is on comparing *brachiaria*-improved pastures with natural pastures.

Annuals and perennial oil palm production require respectively 148 percent and 218 percent more labor per hectare than cattle with *brachiaria* pastures. Although reputed to give low returns to land, cattle's returns are 49 percent higher than annual crop production.

Table 1: Comparative Labor Use and Returns to Different Land Uses (author survey 1998).

	Cattle (*Brachiaria*)	Annuals[a]	Perennials (Oil Palm)
Labor days/ha/yr	12.3	30.5	39.1
Soles[b]/ha/yr	497.4	334.9	1125
Soles/labor day	40.4	11.1	28.8

[a]Shifting fallow system requires an average of 4.8 ha's to maintain 1 ha of annual crops in production
[b]One Sol = $.28 U.S in 1998

Perennial crops, however, provide returns to land 126 percent higher than those of cattle. The returns to labor for cattle are greater than both annuals and perennials by 236 percent and 40 percent respectively.

The low labor requirements of cattle allow an expansion of pasture into forested areas in a zone where land is abundant and labor is a constraining factor of production. Cattle's returns to land indicate that it provides a more productive use of land than the dominant practice of slash-and-burn annual crop production. And finally, given that farmers maximize returns to scarce factors of production, cattle's high returns to labor make it an attractive option relative to the other alternatives.

5. Model

This research uses a theoretical model based on a profit function approach to describe farmer production decisions. These production decisions are the direct causes of deforestation. The research then uses empirical regression analysis based on this profit function approach to model the determinants of production decisions and, in turn, how these production decisions affect deforestation.

5.1 Theoretical Model

A profit function approach provides the theoretical foundation for explaining farmer production behaviors. A farm's profit function can be represented as follows:

$$(1)\ \pi = pq - wx$$

where p is a vector of prices for outputs, q is a vector of outputs produced by the farmer, w is a vector of input prices, and x is a vector of inputs.

Farmers' profit maximization is constrained by the production function. This function represents how farmers use variable inputs (x) and fixed inputs (z) to produce a level of output (q):

$$(2)\ q = f(x,z)$$

Variable inputs are factors the farmer can change in the short term (e.g., fertilizer, seed, labor, etc...) Fixed factors are those that can not be adjusted in the short term. These factors include private factors (e.g., land, education, family labor, etc.), public factors (e.g., infrastructure, credit, extension, etc.) and exogenous factors (e.g., soils and market distance).

A farmer maximizes profits by choosing the optimal level of inputs x and outputs q. The optimal levels of inputs and outputs are a function of output price, input price, and fixed factors.

(3) $x = x(p,w,z)$ and $q = q(p,w,z)$

Combining equations (1) and (3) the profit function can be rewritten as follows:

(4) $\pi = pq(p,w,z) - wx(p,w,z)$

Shepard's lemma allows the derivation of the output supply and input demand functions by differentiating (4) with respect to output and input prices in the following manner:

(5) $d\pi/dp_i\,(p,w,z) = q_i \qquad d\pi/dw_i\,(p,w,z) = -x_i$

Equation (5) provides the basic structure for the econometric modeling of the determinants of output supply and input demand in the econometric models.

5.2 Econometric Models

The econometric regressions model two levels of relationships. The first level is the impact of production determinants on input use and output supply. The second level is the impact of inputs use on output supply on deforestation. Table 2 provides a description of the variables used in the regression analysis.

The first two sets of econometric models have, respectively, input/technology use (x) and output production (q) as dependent variables. As described in the theoretical framework, these input and output regressions are specified as a function of the independent variables of price (p, w) and fixed factors (z). Table 2 provides the averages and standard deviations of the variables.

Table 2: Regression Variables

OUTPUTS		
	Average	**Std. Dev.**
Annuals	3.71	3.97
Hectares of Annual Crops		
Perennials	1.47	2.09
Hectares of Perennial Crops		
Livestock	6.93	27.40
Head of Cattle		
INPUTS/TECHNOLOGY		
Improved Fallows		
Hectares of fallows improved with kudzu		
Improved Pasture		
Hectares of pastures improved with brachiaria		
Natural Pasture		
Hectares of natural pasture		
Capital Inputs[b]		
Total value of capital inputs used in 1998 (soles)		
Hired Labor		
Number of person days of hired labor used in 1998		
FIXED FACTORS		
Farm Size	37.40	31.37
Hectares of land on farm		
Secondary Forest	11.56	16.05
Hectares of secondary forest on farm		
Primary Forest	10.98	16.70
Hectares of primary forest on farm		
Years in Lot	17.12	11.80
Years a farm has been in production		
Sandy Soils[e]	42%	n.a
Sandy soils dominate (dummy)		
Distance Social Services	5.67	5.57
Dist. in km farm to nearest: (school + health post)		
Origin	25%	n.a.
Household head not from jungle region (dummy)		
Age	48.16	14.08
Age of household head		

FIXED FACTORS cont.		
	Average	**Std. Dev.**
Education[c]	33%	n.a.
Household head > primary education (dummy)		
Family Labor	2.72	1.34
Family members over 14 working on the farm		
Off-farm Income[b]	1844.60	3074.50
Off-farm income earned by farm household (soles)		
Credit[c]	33%	n.a.
Credit received in the past 5 years (dummy)		
Land Tenure[c]	84%	n.a.
Farmer perceives tenure as secure (dummy)		
Alluvial Soils[d]	28%	n.a.
Alluvial soils dominate (dummy)		
Extension	3.28	11.74
Number of extension visits in the past year		
PRICES		
Fm-Gate Price Maize	.36	.056
Maize market price minus transpo costs (soles/kg)[b]		
Market Distance	60.97	27.76
Distance in km farm to Pucallpa		
DEFORESTATION		
Prim. Forest Clearing	.66	1.42
Primary forest felled (ha's)		
2nd. Forest Clearing	1.72	2.13
Secondary forest felled (ha's)		
Total Forest Clearing	2.36	2.44
Primary plus secondary forest felled (ha's)		
OTHER CONDITIONING FACTORS		
Total Forest	22.55	23.15
Hectares of primary & second forest		
Primary Forest Prod's	319.27	800.07
Value prim. forest prod's harvested (soles[a])		
-	-	-
-	-	-
-	-	-

[a]All variables are measured on a farm household level for the year 1998
[b]One nuevo sol = $.32 in 1998
[c]Percentages not averages are presented for dummy variables
[d]Percentages are determined by sampling strategy (along rivers) and may not reflect regional average.
[e]Percentage of highland (not river) soils. Farmers chose between clayey or sandy soil descriptive.

Outputs are aggregated into the three principal categories of agricultural activities: annuals, perennials, and livestock. This research analyzes five of the most common inputs/technologies used by farmers in the Pucallpa zone: improved fallows, improved pastures, natural pastures, capital inputs and hired labor. The focus of the essay is on comparing the results of *brachiaria* and natural pastures.

The cross-sectional data used by this research has minimal price variation. The effect of prices on production is therefore difficult to estimate. To deal with this situation, I chose to use farm-gate prices in order to capture greater variation in these variables. For outputs, I did this with maize, the most frequently commercialized product, by subtracting transportation costs (vehicle cost plus labor time opportunity cost) from the market price received. In the case of inputs and technologies, it was not possible to choose a reasonably representative product due to the variability of their costs of commercialization. The distance to the principal market of Pucallpa therefore serves as a proxy for the variation in input prices.

The input use and output choice regression models used both ordinary least squares (OLS) and a systems approach using seemingly unrelated regression equations (SURE). The SURE modeling approach gave results similar to OLS[4], but sharply reduced the number of available observations[5]. This paper therefore uses the results from the OLS analysis.

The third set of regression models examines the impact of agricultural output production and input/technology use on deforestation. In the Pucallpa zone, forests are clear cut and then burned for agricultural production. Logging companies, on the other hand, are not allowed to clear cut forests but rather practice *selective* extraction that leaves the forest largely intact. Timber extraction therefore does not clear land that farmers then choose to cultivate. For these reasons, the relationship of outputs and inputs to deforestation is hypothesized to be recursive: agricultural production results in deforestation and not vice versa.

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I used the Hausman specification test[6] to examine the hypothesis of recursivity between agricultural production and deforestation. With the exception of improved pastures in the total deforestation model, this test confirmed the recursive nature all inputs and outputs with deforestation. This exception appears logical given the evolutionary process of pasture installation. Farmers first clear forest for annual crops and later plant pastures in areas of previously cultivated land. Simultaneity may therefore exist in so much as deforestation can lead to pasture installation and pasture installation can result in deforestation. A two-stage least squares approach (2SLS) corrects for simultaneity in this case. The input and output regression models are specified as follows:

$\mathbf{OUTPUT_{ij}}$= f(farm $size_i$, secondary $forest_i$, primary $forest_i$, alluvial $soils_i$, years in lot_i, $education_i$, age_i, family $labor_i$, $origin_i$, off-farm $income_i$, $credit_i$, extension, real price $maize_i$, land $tenure_i$)

j = annuals, perennials, and livestock
i = 1,..., N observations

$\mathbf{INPUT_{ij}}$ = f(farm $size_i$, secondary $forest_i$, primary $forest_i$, alluvial $soils_i$, sandy $soils_i$,years in lot_i, $education_i$, family $labor_i$, off-farm $income_i$, distance social $services_i$, $credit_i$, market $distance_i$, land $tenure_i$)

j = improved fallows, improved pastures, natural pastures, capital inputs and hired labor
i = 1,..., N observations

The deforestation regression models measure the dependent variable as the hectares of forest cut in 1998[7] by each farm household. This research distinguishes between three types of deforestation: total deforestation, primary forest deforestation, and secondary forest deforestation. Primary forests are areas that have never been felled[8]. Primary forests that have been felled and have regenerated are secondary forests. Total deforestation is the sum of both primary and secondary forest deforestation.

The literature on deforestation rarely distinguishes between different types of forest clearing. People frequently equate deforestation with primary forest clearing and assume that once a primary forest has been cleared the forest is gone forever. Research by

FAO (1996), however, estimated that in 1990 there existed 165 million hectares of secondary forest in Latin America. In the Pucallpa area, survey results indicate that secondary forests virtually equal primary forests on farm holdings and that 72 percent of forest clearing is secondary forest and only 28 percent is primary forest.

Deforestation is modeled as a function of output choice, input/technology use, and general conditioning factors. General conditioning factors are those that may directly affect deforestation i.e. not only through their impact on input and output choices. These include land tenure, family labor, soils, education, forest area, and forest products. The deforestation model is specified as follows:

$\mathbf{DEFOR_j}$ = f(annual$_i$, perennial$_i$, livestock$_i$, kudzu fallows$_i$, improved pasture$_i$, natural pasture$_i$, capital input use$_i$, hired labor$_i$, family labor$_i$, land tenure$_i$, education$_i$, $_i$, forest$_i$, alluvial soils$_i$, forest product income$_i$)

j = total, primary, and secondary forest clearing in 1998.
i = 1,..., N observations

6. Results

The results presented here focus on the determinants of the adoption of *brachiaria*-improved pastures, natural pastures, and livestock and the effect these have had on forest clearing. Because cross-sectional data tends to give less significant results and due to the diversity of production systems, variables are considered significant up to the .15 level. Furthermore, for the purposes of policy analysis in this context, this level is reasonable in most instances. However, the exact degree of significance of each variable is reported for the reader's consideration.

6.1 The Impact of Pastures and Livestock on Deforestation

*Brachiaria-i*mproved pastures, natural pastures and livestock are all significantly correlated with secondary forest clearing and not statistically correlated with primary forest clearing (table 3). This result reinforces the temporal analysis of land use changes in section 3 which found that primary forest is initially cleared by new migrant farmers for annual cropping. Farmers then progressively install pastures on degraded areas that have already been cropped and have regenerated into secondary forest. Increased livestock is therefore positively related to secondary forest clearing.

Brachiaria and nature pasture, on the other hand, are negatively correlated to secondary forest clearing. The surplus capacity of pastures in the zone dampens the need for those farmers who already have pastures to clear more forest area. Furthermore, unlike shifting fallow-based annual cropping, sedentary production on pastures suppresses the regeneration of secondary forests. In sum, pasture's surplus capacity and repression of secondary forest regeneration explain the negative correlation of both types of pasture with secondary forest clearing.

A comparison of the regression results for natural pastures relative to *brachiaria* pastures shows that the magnitude and significance of the decrease in deforestation is consistently greater for natural pastures. The greater dynamism of *brachiaria* pastures due to their lower cost and higher productivity appears to mitigate the decrease in deforestation.

6.2 Pasture Use and Livestock Production

Results from the *brachiaria* pasture regression (table 4) show that its adoption is significantly correlated to larger farms with less remaining primary and secondary forest. They are most often found nearer to the main market town of Pucallpa (market distance) and to smaller population centers with schools and health posts (dist. soc'l services). The greater presence of *brachiaria* nearer to population centers indicates farmers have more

Table 3: Deforestation Regression Results

	Total Deforestation		Primary Forest Deforestation		Secondary Forest Deforestation	
	R^2.54 adj R^2.50		R^2.30 adj R^2.23		R^2.30 adj R^2.23	
	Coef (t-stat)	Signif	Coef (t-stat)	Signif	Coef (t-stat)	Signif
Constant		.18		.74		.74
Annuals	.490 (7.59)	.00***	.323 (3.69)	.00***	.301 (3.42)	.00***
Perennials	-.102 (-1.65)	.10*	-.040 (-0.53)	.60	-.008 (-0.10)	.92
Livestock	.039 (0.54)	.59	.020 (0.21)	.83	.197 (2.04)	.04**
Improved Pastures	-.023 (-0.32)	.75	-.006 (-0.06)	.95	-.154 (-1.53)	.13*
Natural Pastures	-.094 (-1.50)	.13*	-.061 (0.75)	.45	-.163 (-2.00)	.05**
Improved Fallows	.049 (0.83)	.41	-.129 (-1.80)	.07*	.137 (1.91)	.06*
Capital Inputs	-.153 (-2.18)	.03**	-.125 (-1.41)	.16	.181 (2.03)	.04**
Hired Labor	.337 (5.73)	.00***	.011 (0.13)	.89	.019 (0.23)	.82
Family Labor	.060 (1.01)	.31	.021 (0.27)	.79	.202 (2.61)	.01***
Education	.129 (2.26)	.02**	.003 (0.05)	.96	.070 (0.98)	.33
Tenure Security	.097 (1.69)	.09*	.025 (0.32)	.75	.030 (0.39)	.69
Alluvial Soils	.028 (0.45)	.65	-.193 (-2.61)	.01***	.203 (2.75)	.01***
Total Forest	.108 (1.72)	.09*	-	-	-	-
Secondary Forest[a]	-	-	-.098 (-1.41)	.16	.166 (2.38)	.02**
Primary Forest	-	-	.254 (3.30)	.00***	-.093 (-1.20)	.23
Prim Forest Prod's	-	-	.168 (2.36)	.02**	-.034 (-0.48)	.63

[a]High secondary forest >5meters

Table 4: Livestock and Pasture Adoption Regression Result

OUTPUT REGRESSION	**Livestock**		***INPUT REGRESSION***	**Improved Pastures**		**Natural Pasture**	
	R^2.58 adj R^2.40			R^2.80 adj R^2.78		R^2.19 adj R^2.12	
	Coef t-stat	Signif		Coef	Signif	Coef	Signif
Constant		.21	**Constant**		.08		.01
Farm Size	.912 (3.97)	***.00	**Farm Size**	1.362 (21.48)	***.00	.448 (3.46)	***.00
Secondary Forest	- .052 (-0.36)	.72	**Secondary Forest**	- .575 (-12.43)	***.00	- .186 (-2.03)	**.05
Primary Forest	- .588 (-2.93)	***.01	**Primary Forest**	- .907 (-14.40)	***.00	- .164 (-1.29)	.20
Years in Lot	.139 (0.99)	.33	**Years in Lot**	.053 (-1.14)	.26	.198 (2.18)	**.03
Education	- .058 (-0.45)	.65	**Education**	- .053 (-1.28)	.20	.098 (1.19)	.24
Family Labor	.267 (1.81)	*.08	**Family Labor**	- .047 (-1.13)	.26	.028 (0.35)	.73
Off-Farm Income	.028 (0.19)	.84	**Off-Farm Income**	- .005 (-0.11)	.91	.077 (0.92)	.36
Credit	- .102 (-0.80)	.43	**Credit**	- .087 (-2.06)	**.04	- .021 (-0.25)	.81
Tenure Security	.313 (2.23)	**.03	**Tenure Security**	.061 (1.42)	.16	.033 (0.38)	.70
Real Price Maize	.072 (0.55)	.59	**Market Distance**	- .084 (-1.97)	**.05	.029 (0.35)	.73
Origin not jungle	.123 (0.92)	.36	**Dist Soc'l Services**	- .110 (-2.40)	**.02	- .089 (-0.98)	.33
Extension	- .070 (-0.46)	.64					
Age	- .204 (-1.50)	*.14					
Alluvial Soils	.125 (0.90)	.37					

*Significant at the .01 level ** Significant at the .05 level *** Significant at the .15 level

incentive to intensify production due to better access to markets and other elements of social infrastructure.

This pattern of land use coincides closely with the barbecho[9] crisis model (Thiele, 1993). This model predicts that near population centers small holder slash-and-burn annual crop production uses up primary forests and subsequent production cycles using secondary forest fallows leads to progressively declining yields. This loss in yields forces many farmers to move further out to the forest margins in search of more productive land. Farmers remaining in older frontier areas tend to specialize in cattle production on larger consolidated farmland holdings. This pattern of land use is driven by declining soil fertility, the ability of livestock to occupy degraded land, and the land-using nature of livestock production.

Natural pastures and *brachiaria*-improved pastures are both positively correlated with farm size and negatively correlated with the presence of secondary forests. However, there are several important differences between them. Natural pastures tend to be found on older lots whereas this correlation is not significant for *brachiaria* pastures. This is because *brachiaria* pastures are progressively replacing natural pastures and farmers are installing few new areas of natural pasture. In addition, unlike *brachiaria* pastures, natural pastures are not found nearer to markets where farmers have greater incentives to intensify production. The cheaper costs of *brachiaria*-improved pastures are reflected by their negative relationship with credit which may indicate that farmers adopt them when faced with a capital constraint. This relationship is not found with natural pastures.

Livestock and *brachiaria* pastures are both positively correlated to farm size and negatively correlated with on-farm primary forest. This correlation reflects both the evolution of land use and the extensive nature of livestock production. Livestock is also positively correlated with tenure security reflecting the greater need to protect land investments associated with ranching such as pasture installation, fencing, and wells. Its negative correlation with household head age is due the fact that older farmers are likely to find themselves with less available family labor and are less physically able themselves to maintain large herds. Household structure is dominated by small nuclear families. Farmers' adult children, if they remain in agriculture, tend to start their own farms. This is due to the availability of new land and the relativity low production risks associated with land-abundant humid tropical agriculture[10] (Binswanger and McIntire, 1987).

An important relationship is the positive correlation between livestock and family labor. This correlation may appear paradoxical given the low labor requirements of livestock. However, compared to annuals and perennials, this relation is weaker both in terms of it magnitude and significance (Yanggen, 2000). This relative weakness demonstrates that despite livestock's low labor requirements, labor remains a key limiting factor of production.

I have demonstrated (Yanggen 2000) the importance on the labor constraint in the Pucallpa zone. As just mentioned, family labor is positively correlated with the three principal agricultural activities. But when farmers have access to off-farm employment, this competition for scarce labor leads to a reduction in annual and perennial cropping. Also, hired labor and family labor are positively correlated with total and secondary forest clearing respectively. Put simply, more labor increases agricultural production and more agricultural production increases deforestation.

6.3 Correlation Analysis Results

The regression analysis uses cross-sectional data that identifies the determinants of deforestation at a given moment in time. The correlation analysis done here introduces three new deforestation variables that complement that analysis by giving a historical picture of livestock and pasture's impact on deforestation.

The first variable is the annual rate of primary forest clearing over time. This rate is calculated as: (total farm size minus farm area in primary forest)/(years farm in production). The second variable is aggregate deforestation, which measures the total hectares of primary forest cleared on a farm. This is the total farm size minus the hectares of remaining primary forest. The last variable is the percentage of the farm in secondary forest. This indicates to what extent cattle production tends to eliminate secondary forest regeneration.

In general, both head of cattle and pasture are associated with higher average annual rates of primary forest clearing over time, larger aggregate area deforested, and a diminished presence of secondary forest. The one exception is natural pastures with the

Table 5: Correlation Analysis of the Impact of Livestock and Pastures on Deforestation

	Head of Cattle		***Brachiaria* Pastures**		**Natural Pastures**	
	Coef.	Signif.	Coef.	Signif.	Coef.	Signif.
Annual Deforestation Rate	.58	.00	.40	.00	.02	.85
Aggregate Deforestation	.43	.00	.60	.00	.18	.01
% Secondary Forest	-.19	.00	-.36	.00	-.16	.02

annual rate of deforestation. This result can be explained by the fact that natural pastures tend to persist on older and less dynamic farms. The greater age and slower current growth tend to reduce the average annual deforestation rate.

In general, the *brachiaria* pasture variable has a higher degree of significance and a coefficient of greater magnitude than the natural pasture variable. This indicates that the introduction of *brachiaria*-improved pastures tends to increase deforestation relative to natural pastures. This coincides with the evidence of the regression analysis.

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These results further clarify the impact of pastures on deforestation. The rather counterintuitive result in the regression analysis was that pastures decrease secondary forest clearing whereas livestock has the opposite effect. The current excess pasture capacity and pasture's suppression of secondary forests lead to a reduction in this type of deforestation. The correlation results show that, given a longer time framework, pastures are indeed associated with higher rates of secondary forest clearing as they should be if they are a complement to cattle production.

7. Conclusions and Policy Recommendations

This essay has examined two principal questions. First, why have farmers adopted an intensive technology that increases pasture carrying capacity in a zone with cheap and abundant land? Second, what impact has the adoption of this improved technology had on deforestation? This concluding section examines the weight of the evidence concerning the adoption and deforestation questions and proposes a series of recommendations to promote more sustainable production practices.

A key finding of this research is that *brachiaria*-pastures reduce costs over time relative to natural pastures by over 50 percent. This outcome results from the labor-saving nature of *brachiaria* pastures. *Brachiaria* pastures also provide productivity benefits including increased pasture carrying capacity, low mortality and higher calf rates, and increased meat production.

A technology that increase land productivity while reducing labor costs has the effect of increasing returns to labor. Basic economic theory indicates that farmers maximize returns to scarce production factors. The adoption of *brachiaria*-improved pastures can be explained by farmer's attempts to increase returns to scarce labor.

Furthermore, the intensification of land, which is not a limiting factor of production, is *not* the principal motivation of farmers but rather a secondary outcome of maximizing returns to labor.

A slight nuance, however, can be added to this conclusion. Farmers tend to install pastures in degraded areas where land is becoming scarce in terms not of its quantity but rather it terms of its quality. Livestock production with improved pastures allows productive use of degraded land and raises returns to land relative to shifting annual crop production. This is one manner of overcoming *qualitative* land scarcity.

This "qualitative" land scarcity may be compounded by localized quantitative land scarcity near to the principal market Pucallpa and smaller population centers where *brachiaria* pastures tend to be installed. Land with superior infrastructure and access to markets is relatively scarce. Most farms in the Pucallpa area have serious problems of accessibility to markets during much of the 8 month rainy season due to impassable roads. Farmers therefore have greater incentives to increase the productivity of these well located farmland areas.

There are nevertheless many examples of farms that have installed and continue to install *brachiaria*-improved pastures without having any cattle. Land scarcity thus appears to be a secondary explanation of adoption. The driving force behind the adoption of *brachiaria*-improved pastures is that they help maximize returns to the scarce labor factor of production.

The weight of the evidence indicates that *brachiaria*-improved pastures do *not* reduce deforestation. The key limiting factor of production in the zone is labor. *Brachiaria*- improved pastures ease this constraint and therefore allow a greater expansion of land under agricultural production. *Over time, brachiaria* and natural pastures are both positively correlated to deforestation, but the magnitude and statistical significance of the impact on deforestation is greater for *brachiaria* pastures.

A key argument supporting improved pasture germplasm's ability to reduce deforestation is that it avoids pasture abandonment due to degradation, which forces farmers to clear more land at the forest margins. However, the abandonment of natural pastures has been negligible and no greater than that of *brachiaria*-improved pastures. The introduction of improved pastures therefore does not have the potential to reduce this source of deforestation.

In sum, the introduction of *brachiaria*-improved pastures has tended to accelerate deforestation over time. *Brachiaria* eases the key labor constraint to increased pasture expansion and increases the returns to forest conversion for livestock production. Furthermore, *brachiaria* pastures do not reverse a situation where farmers abandon degraded pastures and clear new ones at the forest margins.

The paradox of the success of *brachiaria*-improved pastures is that a principal reason they have been adopted—their reduction of labor costs—has also led to an aggravation of livestock's impact on deforestation. Reduced labor inputs and greater pasture productivity increase the returns to labor. The challenge is therefore to find ways to increase the returns to labor without freeing labor up for increased forest clearing. An example of how this can be done is with silvopastoral systems.

A small number of farmers in the zone have begun integrating livestock with fruit tree and oil palm production. The principal cost of maintaining most tree plantations is weeding labor. If cattle are able to graze among the trees, this can greatly reduce weeding labor for the perennials while providing income from the livestock. Livestock can benefit from the shading of the intense tropical sun and nutritionally from fruit that falls to the ground.

Overall labor requirements per hectare of land are increased due to the management of both the livestock and the trees. This "absorbs" labor away from extensive agricultural production into the forest margins. Yet silvopastoral systems with these types of complementarities can increase the returns to labor by providing high value output of both livestock and perennials. In order for these systems to work, more research needs to be done in order to find systems where the tree and livestock components are truly complementary and avoid problems such as soil compaction by livestock and pasture fires damaging trees.

Nevertheless, as long as abundant low cost land remains readily available, farmers will have a potent incentive to expand production into the forest margins. Restrictions on land access therefore merit consideration as a complementary policy to improved technologies. Indeed, limiting access to land gives farmers a greater incentive to adopt intensive production practices such as silvopastoral systems, improved pastures, legume associations, and pasture rotation because they make land artificially scarce and therefore more expensive. Greater pasture scarcity and improved production practices would also push farmers to increase the current low stocking rates to higher levels. This would limit deforestation as well promote a more productive use of land cleared for pasture.

One policy option would be to limit livestock to areas where it is most appropriate: older frontier areas no longer productive for annual crop production. Another potential restriction would be to limit the size of ranches. Larger ranches have a high cost in terms of deforestation, but the benefits are concentrated in the hands of a few individuals. Another option is to focus on improving existing infrastructure and limiting the construction of new roads. This would increase the value of existing land and limit access to new land. Issues of the institutional and political feasibility of these policies require careful consideration of the most appropriate option.

While livestock in general and the use of *brachiaria*-improved pastures in particular accelerate deforestation in the zone, they also have a series of advantages that make them attractive to farmers. The reality is that livestock has established a long-term presence in the zone and by all indications is likely to expand. The challenge is to find the best ways to manage the development of the livestock sector to minimize its negative impact on deforestation and to maximize the social returns that it provides.

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[1] Infrastructural access included location on the paved highway Frederico Basadre, secondary gravel roads, tertiary dirt roads, and rivers.

[2] Farmers are given a small number of "seed" cattle to begin a herd. They return these initial head of cattle after approximately 5 years but retain the offspring from these cattle.

[3] Plantains and cassava can last for more than one year and are sometimes referred to as "transitory" crops.

[4] With the exception of the capital input use model, there were only a total of four sign changes (none of variables significant at the .15 level or lower). Further (again with the exception of capital inputs), variables significant at the .05 level or lower in the OL S models remained significant at the .15 level or better in the SURE systems approach. The standard errors generated by the two techniques were remarkably similar, although the SURE standard errors were generally slightly higher. In the case of capital inputs a review of a simple correlation matrix between inputs and outputs indicated that capital inputs have the highest level of correlation with other inputs and outputs. This may explain the changes shifting from OLS to SURE.

[5] With the SURE technique, all missing variables from any equation in the system result in an observation being deleted. Combining all the missing observations in this way resulted in only 40 of the initial 220 observations being available.

[6] I performed the Hausman test in order to check for simultaneity in the deforestation regression models between the deforestation dependent variables and the input/technology and output independent variables. In order to do so I first estimated the reduced form equations for all the input/technology and output variables. I then took the estimated residual from each reduced form equation and plugged it into each of the deforestation regression models as a right-hand-side variable. I then performed a t-test on the coefficient of the estimated residual from the reduced form equation. I used a .10 cut-off as a criteria to judge for significance.

[7] Rainfall comes in a bimodal pattern and there are two cropping seasons. Farmers fell forest and let the felled vegetation dry before burning and then planting crops. The first cropping season lasts roughly from mid February to mid May and is generally preceded by a relatively dry period in January. The second cropping season lasts roughly from mid September to the end of December and is preceded by a relatively dry period from June to early September. Deforestation was measured as the sum of the two forest clearing periods in January and July-August of 1998. This survey was conducted in October of 1998. s

[8] A substantial proportion of primary forest on farm land has been selectively logged. Often this was done by the timber companies the opened the initial feeder road into the jungle where farmers subsequently settled or by the farmers themselves. These areas retain most of their vegetative cover and biodiversity and are typically indistinguishable from undisturbed primary forest to the untrained eye. They are sometimes referred to as areas of "residual" primary forest.

[9] Barbecho is Spanish for fallow.

[10] The diversity of crops and low probability of drought reduce the need for families to work together in an extended family unit as a risk sharing mechanism.

CONCLUSIONS

This dissertation consists of three essays examining agriculture's impact on deforestation in the lowland rainforest zone surrounding Pucallpa, Peru. The first essay is an overview piece examining household-level determinants of agricultural production practices and how these practices in turn effect deforestation. The following two essays are case studies of agricultural technologies that farmers have widely adopted in this same zone: kudzu-improved fallows and *brachiaria*-improved pastures.

These two technology adoption case studies are of interest due to the limited success national and international agricultural research institutions have had in promoting the adoption of technologies they have developed for the zone. This research therefore examines two key questions. First, why have farmers adopted these two technologies and not others? Second, what impact have these two technologies had on deforestation?

In general, most sustainable technology development efforts have focused on reducing deforestation by improving land productivity. The rationale of this approach is that increased land productivity allows more production with less land and therefore farmers clear less forest. Or by simply maintaining land productivity, farmers are not forced to practice shifting slash-and-burn agriculture in forested areas.

The problem with this approach is that increases in land productivity typically require greater per land unit use of capital and/or labor inputs. In the Pucallpa area, land is abundant and cheap relative to capital and labor. It is generally not economical for farmers to use relatively expensive labor and capital inputs in order to increase the productivity of the relatively cheap land input.

Historically, intensification of land use has taken place in land *scarce* areas. Pucallpa is a land *abundant* area. What then explains the adoption of these land productivity enhancing fallow and pasture technologies? The answer lies in their use of labor.

This dissertation has shown that both kudzu-improved fallows and *brachiaria*-improved pastures not only increase land productivity but also reduce labor requirements relative to their traditional counterparts without increasing capital requirements. Labor is scarce relative to land. Basic economic theory indicates that farmers maximize the returns to scarce production factors. By definition, a technology that decreases labor requirements and increases land productivity (crop yields or pasture carrying capacity) increases returns to labor. Farmers' primary objective in adopting these technologies is *not* to increase land productivity but rather to increase labor productivity. Increased land productivity in these cases is a secondary result of farmers' primary focus on increasing labor productivity.

This finding has important policy implications for the development and promotion of improved technologies. Traditionally, agronomic research efforts have focused their energies on increasing yields (i.e. land productivity) with greater input use. Where land is abundant relative to labor and capital, these efforts have typically failed and will continue to fail. If farmers are to adopt "improved" technologies in these conditions, the primary focus of research must be on increasing returns to labor.

Unfortunately, the story is not as "simple" as that. This dissertation has shown that labor availability in the Pucallpa area is positively correlated to increased deforestation. The reduction in labor requirements that leads to the successful adoption of these technologies also frees up labor for increased deforestation. Essay 2 on kudzu-improved fallows referred to this situation as the "labor paradox". *Brachiaria*-improved pastures led to a similar phenomena. The challenge is to find way of increasing returns to labor without freeing up labor for increased deforestation.

Essay 3 on *brachiaria*-improved pastures compared the average per hectare labor requirements, returns to land, and returns to labor of cattle, annuals, and perennials. This comparison found that while the shift from annuals to perennials (oil palm) increased per hectare labor requirements by 28 percent, returns to labor nevertheless also increased by 159 percent. Increasing per hectare labor requirements while increasing financial returns to labor are *not* mutually exclusive objectives. Furthermore, regression results indicate that perennial crop production does indeed decrease deforestation.

The key to success in this case is that perennial crops are relatively demanding in labor and, by their nature, "sedentarize" farmers on a given parcel of land. Shifting annual crop production, on the other hand, requires on average a total of 4.8 hectares to maintain one hectare in production over time. Perennial crop production therefore "absorbs" scarce labor away from clearing new forest areas.

The key lesson here is not simply about the potential of perennials to decrease deforestation under certain circumstances. Other agricultural production may also increase both per hectare labor requirements and returns to labor. Horticultural production typically is intensive in its labor use per hectare of land but, because they are higher value crops, may also increase returns to labor. Dairy production may follow a similar pattern.

These findings also have interesting implications for agroforestry and agrosilvopastoral systems. Adding a tree component to an annual crop or livestock system may have the same effect of increasing both per hectare labor requirements and increasing returns to labor. Because these systems are more complex, they typically have greater per hectare (labor) management requirements as well as increasing the productivity of land (i.e. total output per unit of land).

There are two keys to the success of these systems. First, there must exist some sort of synergy between the trees and the other component of the system (otherwise they could be produced on separate land units). For example, trees shade livestock from the harsh tropical sun and fruit that falls to the ground provides a nutrition supplement. Grazing by livestock controls the competition of other plants with the trees and reduces weeding needs. Second, the trees must provide some product of value so that increased per hectare labor requirements are accompanied by increasing returns to labor.

In sum, these two technology adoption case studies provide useful insights for technology development and policy design. In an environment where land is abundant relative to labor, farmer adoption of technologies that enhance land productivity is dependent upon whether or not these technologies increase returns to labor. The design and promotion of improved technologies should therefore focus on combining enhanced land productivity with increasing returns to labor. However, if increased returns to labor are primarily a result of decreasing per hectare labor requirements, then freed up labor is likely to increase deforestation. It is therefore necessary to find production practices that "absorb" labor away from deforestation by increasing labor requirements per hectare while at the same time increasing returns to labor.

This thesis has found that labor availability plays a key role in determining land use patterns. The case study essays on kudzu-improved fallows and *brachiaria*-improved pastures just described have already provided numerous insights into labor's key role. The following paragraphs briefly expand upon these findings.

Greater availability of hired and family labor are positively correlated to total forest clearing and secondary forest clearing respectively. This is logical given that regression analysis also shows that households with more family labor have more land in annual and perennial crops and have larger cattle herds. In short, more labor leads to more agricultural production which in turn leads to greater deforestation.

It is therefore important to orient labor away from extensive slash-and-burn agriculture and towards more sedentary forms of agriculture. Two examples of more sedentary agriculture mentioned previously include perennial crops and agroforestry systems. Another potential solution involves greater exploitation of areas of alluvial soils along rivers. These areas are much more fertile than "highland" soil areas because periodic inundations deposit nutrient rich sediments. This greater fertility allows farmers to cultivate fields for greater periods of time and thereby decreases pressures to clear new areas of primary forest.

Farm households typically prefer to settle along areas of road infrastructure because this allows quicker and cheaper access to markets. New roads into the jungle, however, are most often constructed by timber, gas, and oil companies without regards to the productive potential of the agricultural land they are opening up. Research should be undertaken to examine the costs and benefits of road infrastructural policies that provide better access to areas of alluvial soils.

Another key labor-related finding of this research is that off-farm income opportunities decrease the amount of land put into annual and perennial crop production. Off-farm employment therefore has the potential to take pressure off the natural resource base and decrease deforestation. So while slash-and-burn agriculture is the main cause of deforestation in the Peruvian Amazon, improving the sustainability of agriculture is not the only means of addressing this problem. Economic development policies that provide off-farm income opportunities can also help alleviate deforestation.

Although this concluding section noted that both labor and capital are limiting factors of production relative to abundant land, the focus until now has been on labor. This focus has been due to the fact that, in spite of labor being relatively scarce, all households have some access to labor whereas purchased input use is quite limited. Nevertheless, this research found that when farmers do have access to capital this plays an important role in determining land use patterns.

Use of capital inputs diminishes farmer clearing of primary forest. Most of the capital inputs used in the zone (e.g., fertilizers, herbicides, improved seed, and phytosanitary livestock products) enhance land productivity. Increased land productivity permits a greater reuse of previously cleared land which, in turn, decreases the need for farmers to clear new areas of primary forest.

This impact of capital inputs on deforestation bears out the rationale of the traditional focus of improved technology development and promotion as previously described in this concluding section. The problem with this approach is that in most cases of abundant land and scarce capital it is more economical for farmers to use extensive slash-and-burn practices than to adopt these technologies. Research should therefore give priority to using economic analysis to identify crop and capital input combinations that are both affordable and profitable for farmers.

This research also found a significant correlation between farmer access to capital in the form of credit and farmer use of production technologies. Credit is positively correlated with hired labor and capital inputs. This is logical given that these inputs require a financial expenditure. In addition, credit is negatively correlated to farmer adoption of kudzu-improved fallows and *brachiaria*-improved pastures. This again is logical because these technologies conserve on scarce labor and capital resources. A lack of access to credit may therefore push farmers to adopt these technologies.

In sum, access (or lack of access) to capital plays an important role in the decision of farm household to use hired labor, capital inputs, *brachiaria*-improved pastures, and kudzu-improved fallows. The use of these inputs and technologies has an important impact on deforestation outcomes as previously described in this concluding section. However, the impact on deforestation of these technologies is not uniform. There is therefore a potential for using linked credit to promote agricultural production that reduces deforestation such as the use of land productivity enhancing capital inputs or perennial crop production.

Another key finding of this research concerns the relationship between agricultural production practices and different *types* of deforestation. The literature on deforestation often does not clearly define what is meant by deforestation. Often the perception is that once primary forest is cleared the forest is gone forever. In recent years, however, there has been a tremendous amount of secondary forest regeneration in Latin

America. In the case of the zone surrounding Pucallpa, secondary forest area is approximately equal to primary forest area on farm household land holdings.

This thesis defined three different types of deforestation: primary forest clearing, secondary forest clearing, and total forest clearing. Each of these was measured as the hectares of forest cleared by a farm household on their land holdings during 1998. Primary forests are areas that have never been felled in a clear cutting manner (though often selective extraction has taken place), secondary forests are areas that have been clear cut and have regenerated back into forest, and total forest is the sum of primary and secondary forest.

This research found that kudzu-improved fallows, capital input use, and agriculture in alluvial areas decreased primary forest clearing and increased secondary forest clearing. The common thread in each of these cases is enhanced soil fertility. Agricultural cultivation rapidly degrades most soils in the Peruvian Amazon. Secondary forests are fallow areas that are recuperating soil fertility of degraded land in a system of shifting agriculture. Greater soil fertility allows farmers to increase the reuse of these degraded secondary forest fallow areas. Greater reuse of secondary forest fallows in turn reduces the need for farmers to clear new areas of primary forest.

Increased use of secondary forest and decreased use of primary forest constitute an intensification of land use. By reusing previously cultivated land (secondary forest) there is less need to clear new areas of previously uncultivated land (primary forest). This allows greater agricultural production using less total land over time. In terms of deforestation, the ideal situation would be if farmers were able to continuously cultivate a given parcel of land. Nevertheless, the reuse of secondary forest areas and decrease in primary forest clearing is a step in the right direction of decreasing the negative environmental impact of agriculture.

This finding demonstrates the need for research to distinguish between the different *types* of deforestation. In the case of this research, several agricultural variables had opposite effects on primary and secondary forest clearing. A failure to make this distinction would have missed a critical insight into the dynamics of how agricultural production affects forest clearing. This finding also suggests that, where economically feasible, technology development should focus on land productivity increasing practices that allow greater reuse of secondary forests in order to reduce primary forest clearing.

A final finding of this research involves the identification of an evolutionary trend in land use patterns from annual crops to livestock. New migrant farmers tend to settle on the edges of the agricultural frontier and slash and burn primary forest in order to cultivate annual crops. During the first ten years of settlement, this leads to a decrease in primary forest area and an increase in secondary forest area as trees regenerate in the fallow areas of the shifting agricultural system.

In the time periods 10-20 years and greater than 20 years after farmers settle a plot of land, there is a continued decline in primary forest and an increase in pasture area. However, this trend does not reflect a direct conversion of primary forest into pasture. Rather, farmers continue to slash-and-burn primary forest for annual crop production and install pastures in degraded areas of secondary forest.

This pattern of land use is due to two factors. First, migrant farmers rarely have enough capital to immediately invest in cattle ranching. They therefore initially cultivate annual crops, which require much lower start-up capital outlays. Cattle is considered a more profitable and less risky activity so many farmers progressively accumulate capital in order to purchase livestock. The time needed to accumulate capital explains why pasture areas do not significantly increase until this second time period.

A second explanation is that pasture grows well on degraded land whereas annual crops need relatively more fertile land. Farmers therefore first cultivate more fertile land with annual crops and then progressively install pastures as land begins to degrade. Herd size's lack of correlation with primary forest clearing and positive correlation with secondary forest clearing further reflects the evolutionary nature of agricultural production from annuals to livestock (and the importance of distinguishing between types of deforestation).

The fact that pastures tend to be installed on previously cleared land and allow a productive use of degraded areas is a positive result. Furthermore, pastures in the Pucallpa area maintain their productivity and do not require shifting slash-and-burn practices. For a given year, cattle is not correlated with primary forest deforestation. Correlation analysis of cattle and deforestation *over time*, however, indicates that ranching both increases primary forest clearing and decreases the presence of secondary forest.

This outcome is due to the fact that livestock is less intensive in its use of labor and more extensive in its use of land. The labor requirements for a hectare of land in cattle ranching for a given year of production are only about 8.4 percent those of annual crops. This allows an expansion of production onto more land.

In sum, the effect of cattle ranching on deforestation is mixed. Over time it does increase deforestation. However, it does permit a productive use of already cleared land that is less suitable for annual cropping. If farmers were not able to move into cattle ranching they would probably eventually be forced to abandon degraded land and move out to the agricultural frontier and clear more primary forest for annual cropping. Furthermore, essay 3 found that ranching increases financial returns to both labor and land relative to annual cropping. This indicates that livestock is a relatively productive use of land and can have a positive impact on reducing poverty.

This dissertation has focused on analyzing ways of promoting more sustainable production practices that reduce deforestation. However, if these improved production practices are sufficiently profitable, then farmers may hire more labor or invest in labor-saving inputs such as chain saws and tractors that allow more total land to be brought into production. As long as land is cheap and abundant, farmers have a strong incentive to increase the amount of land in production even when using more sustainable production practices. This can have the perverse effect of accelerating deforestation. Restrictions on access to land may therefore by a necessary complement to any attempts to promote sustainable agriculture in the Peruvian Amazon. Policy research needs to investigate what types of land use controls are feasible and effective.

This dissertation thesis has analyzed deforestation at the household level. This is a relevant level of analysis because household agricultural production decisions are the direct causes of deforestation. However, if immigrants continue arriving in the jungle to farm, it is clear that deforestation on the landscape level will accelerate. The principal cause of migration into the jungle is land scarcity and poverty in regions outside the jungle. Programs of economic development are therefore necessary in these regions to provide economic opportunities to individuals that would otherwise migrate to the jungle.

In this sense, an important part of the solution to deforestation of the rainforest lies outside of the Amazon region.

APPENDIX A

Main Household Survey

AGRICULTURA SOSTENIBLE EN LA AMAZONIA PERUANA
INVESTIGACION DE ASB-ICRAF– 10-98.

Encuestador........................Fecha...................Encuesta Código..........

Coordenada X .... Coordenada Y................

Por ejemplo: Coordenada X =0528283 Coordenada Y =9068226

SECCION 1: INTRODUCION

1. Nombre completo del informante: .... **(NOMINF)**
2. Nombre completo de la persona que toma decisiones en la parcela.

   .... **(NOMJEF)**

   (SEXJEF) Hombre(1) Mujer(2)
3. Relación del informante con la persona que toma decisiones en la parcela:

   .... **(RELINF)**
4. Sitio donde se encuentra el predio: km. Fed. Basad................. **(KMFB)**
   km. 1 entrada.................... **(KMENT1)**
   km. 2 entrada.................... **(KMENT2)**
   km. 3 entrada.................... **(KMENT3)**
   Izquierda(1) Derecha(2) **(LADO)**
5. Nombre del caserío: .... **(CASERI)**

   Colono (1) Nativo (2) **(ETHNIA)**

SECCION 2: USOS GENERALES DE LA TIERRA *(USA UN CROQUIS)*

6. ¿Cuántas hectáreas totales tiene su fundo incluyendo todas las parcelas (*que estén en producción o no, incluso: purmas, cultivos anuales, monte alto, cultivos perennes, pastos, etc.)*

   Parcela 1 .... Has.
   Parcela 2 .... Has.
   Parcela 3 .... Has.
   Parcela 4 .... Has.
   Total .... **(HTOTAL)**

7. ¿Cuántas hectáreas están en purma? **(HPURMA):** ....Has.

- ¿Cuántas hectáreas están en purma baja de menos de 5 metros incluso kudzales? *(haz un punto de referencia de 5 metros tal como la altura de la casa o un árbol)* **(HPURBA)**

..........Has.

- ¿Cuántas hectáreas están en purma alta de más de 5 metros?**(HPURAL)** ....Has.
- ¿Hay problemas de incendios incontrolados en sus purmas Si (1) No (2)
- Observaciones..

8. ¿Cuántas hectáreas están en monte alto? **(HMONTE)** ....Has.
9. ¿Cuántas hectáreas están en pastos? **(HPASTO)** ....Has.
10. ¿Cuántas hectáreas están en cultivos anuales? **(HANUAL)** ....Has.

- ¿Cuántas hectáreas son de cada cultivo anual y asociaciones.

CULTIVO ANUAL	**Has.**
Plátano **(HPLAT)**	
Yuca **(HYUCA)**	
Maíz **(HMAIZ)**	
Frijol **(HFRIJ0)**	
Arroz **(HARROZ)**	
Asociación1 Anual-Anual:	
Asociación2 Anual-Anual	
Otro:	
Otro:	

11. ¿Cuántas hectáreas (o arboles) en <u>total</u> están en cultivos permanentes? **(HPERM)** .... Has.

- ¿Cuántas hectáreas (o arboles) hay de cada cultivo permanente que Ud. produce.

CULTIVO PERMANENTES	**Has.**	**Arboles**	**Total**

Limón

Naranja

Papaya

Palma Aceitera

Palmito

Asociación1 Perm-Annual

Asociación2 Perm-Perm

Otro:

Otro:

Otro:

Total:

12. ¿Cuántas hectáreas de reforestación tiene Ud.? .... Has. **(HREFOR).**

- Cuáles especias tiene Ud. ....
- Observaciones..

13. ¿Ud. dijo que tiene ____ hectáreas en purma no? ¿Usa Ud. algo para mejorar la recuperación de los suelos en purma por ejemplo kudzu u otra cosa?

Si(1) No (2) **(RECUP)**

Purmas Mejoradas	**Has.**
Kudzu **(HKUDZU)**	
Otro:	
Otro:	

- ¿Ud. siembra kudzu o crece solo? **(SEMKUD)** Siembra(1) Crece solo(2)
- ¿Piensa Ud. que el kudzu es sobre todo una planta positiva con beneficios o sobretodo negativo con inconvenientes **(KUDZOK)**: Positivo(1) Negativo(2)

- Cuales son los aspectos positivos <u>importantes</u> de kudzu para su producción **(KUDPOS)**

Aspectos Positivos de Kudzu	√
Abona la tierra(1)	
Disminuye las malezas(2)	
Forraje(3)	
Otro:	
Otro:	
Otro:	

- Cuales son los aspectos negativos importantes para Ud. en su producción **(KUDNEG)**

Aspectos Negativos de Kudzu	√
Invade áreas de otros cultivos(1)	
Otro:	
Otro:	
Otro:	

14. ¿Ud. dijo que tiene _____ hectáreas de pastos, no?

- ¿Qué tipos de pastos hay? ¿Cuántas hectáreas hay de cada uno?

Tipo de Pastos	Has.
Pasto Natural (tourouco) **(PASTNA)**	
Braquiaria **(PASTBR)**	
Brachiaria-Kudzu **(PASTBK)**	
Otro:	

15. ¿Cuántas cabezas de ganado tiene usted **(CABGAN)** ....cabezas

SECCION 3: EVOLUCION HISTORICA DEL USO DE LA TIERRA

(Explica al agricultor que queremos saber cómo se ha cambiado el uso de sus tierras al través del tiempo)

16. ¿Alguien cultivo éste lote antes que usted? Si No

- ¿Por cuánto tiempo? **(LOTANT)** .... Años

17. ¿Cuánto tiempo ha estado su familia cultivando esta tierra sin contar años de ausencia?

Parcela 1	**(TLOTP1)**.................	Años
Parcela 2	**(TLOTP2)**.................	Años
Parcela 3	**(TLOTP3)**.................	Años
Parcela 4	**(TLOTP4)**.................	Años

- Cuando llegaron cuántas hectáreas de __________ había:

Uso de Tierra	PARC1	PARC2	PARC3	PARC4
Purma (alta y baja) (LPURMA)				
Pastos (LPASTO)				
Cultivos Permanentes (LPERM)				
Cultivos Anuales (LANUAL)				
Monte Alto (LMONTE)				

- Hace cinco años en 1993 *(menciona un acontecimiento)* cuántas hectáreas de __________ había: *(si el agricultor no estaba, pasa a la siguiente pregunta).*

Uso de Tierra	PARC1	PARC2	PARC3	PARC4
Purma (alta y baja) **(5PURMA)**				
Pastos **(5PASTO)**				
Cultivos Permanentes **(5PERM)**				
Cultivos Anuales **(5ANUAL)**				
Monte Alto **(5MONTE)**				

18. ¿Cuáles son los cambios mayores que han ocurrido en la zona desde su llegada y que han tenido un impacto sobre la producción en su finca?

CAMBIOS	EFECTOS (pos, neg, igual)		
	PRODUCCION (+ - =)	INSUMOS (+ - =)	MONTE ALTO (+ - =) TUMBADO

1.

2.

3.

4.

5.

19. ¿Qué precios recibió Ud. para los productos agrícolas siguientes:

PRODUCTO AGRICOLA	LUGAR DE VENTA	UNIDAD DE MEDIDA	PRECIO: S/. POR UNID. MEDIDA	TRANSPO: S/. POR UNID.MED.
YUCA				
MAIZ				
ARROZ				
PLATANO				

FRIJOL

OTRO
IMPORTANTE

CULTIVO
PERMAN1

CULTIVO
PERMAN2

CULTIVO
PERMAN3

GANADO
VACUNO

20. Si Ud. solo va con ____________ al mercado, ¿Qué cantidad llevarías en promedio?

PRODUCTO	CANTIDAD	UNIDAD DE MEDIDA	TIEMPO AL MERCADO (Ida y Vuelta)
Yuca			
Plátano			
Maíz			

Arroz

Cultivo Perm1:

Cultivo Perm2:

Cultivo Perm2:

Ganado

Otro:

Otro:

SECCION 5: CARACTERISTICAS DE LA FAMILIA

21. ¿Cuánto tiempo hace que vive usted en la zona de Pucallpa?

(AÑOZON) .... Años

23. ¿Reciben Uds. más que 10% de sus ingresos de personas que no viven en el predio?

(REMIT) Si (1) No (2)

24. ¿Mandan Uds. más que 10% de sus ingresos a personas que no viven en el predio?

(MAND) Si (1) No (2)

25. ¿Es la persona que toma las decisiones en la parcela originalmente de la costa, sierra o selva? **(REGNOR)** Costa (1) Sierra (2) Selva (3)

26. ¿La persona que toma las decisiones en esta parcela antes de venir acá, ha vivido alguna vez en una chacra o fundo? **(AGEXP)** Si (1) No (2)

27. ¿Cuántos meses (semanas, días) durante el año, no hay mucho trabajo que hacer en su proprio fundo: Meses............ Semanas .... Dias ....

(ESTBAJ) Total.............. días

28. ¿Ha habido momentos en los últimos 5 años cuando la producción en su chacra no bastaba para las necesidades de alimento de la familia? ¿Cuántas veces?

(SEGALI)........... veces

29. ¿Cree Ud. que su familia va a estar cultivando este mismo fundo en 5 años?

Si (1) No (2)

- Porqué____

____

SECCION 6: CARACTERISTICAS DEL PREDIO/SITIO

31. ¿Qué tipo de suelo predomina en su predio.(SUELOS)

TIPO DE SUELO QUE PREDOMINA	Parc1	Parc2	Parc3	Parc4
CARRETERA:				
Arcilloso: (Gredoso; tierra roja,blanca, amarilla,gris, negra)				
Arenoso:				
Limoso (bajiales, aguajales, suelos inundables)				
RIOS:				
Franco arcilloso-arenoso: (Restinga alta)				
Arenoso: (Restinga baja)				
Arenoso limoso: (Barrizal, suelos aluviales)				

32 ¿Hay más tierras fuera de su predio disponibles que Ud. podría adquirir para cultivar?

(TERNVA) Si (1) No (2)

33.¿Cuántos kilómetros hay entre su predio y Pucallpa, usando la ruta que tomas para ir a Pucallpa? **(DISMKT)** ....km.

34. ¿Cuántos kilómetros hay entre su ***predio*** y: la escuela más cerca? .... km.

el puesto de salud mas cerca?......... ....km.

(DISINF) total..............km.

35. OJO!! Encuestador llena lo siguiente (no se lo pregunta al agricultor!!)

Tipo de Infraestructura donde se Encuentra el Predio (INFRA)	√
Federico Basadre **(1)**	
Carretera Secundaria **(2)**	
Carretera Terciaria **(3)**	
Río _________________ **(4)**	

SECCION 7: APOYO INSTITUCIONAL

36. ¿Cuántas visitas ha tenido usted de cualquier tipo de agente de extensión agropecuaria durante el año pasado? **(EXTENS)** .... Visitas

37. ¿Ha recibido crédito en los últimos cinco años incluso crédito en especie?

(CREDIT) Si(1) No(2)

TIPO DE CREDITO	CANTIDAD	INSTITUCION O PERSONA QUE OTORGA	REQUISITOS

SECCION 8: SEGURIDAD DE TENENCIA

38. ¿Tiene Ud. algún documento de propiedad de su chacra-para cada uno de sus parcelas si tiene más que una?

Nro. DE PARCELA	TIENE DOCUMENTO Si = 1, No = 2	TIPO DE DOCUMENTO	FORMA DE PROPIEDAD Propio = 1 Alquilado=2 Prestado=3 Possesionario Precaria=4	ALGUN PROBLEMA PARA SEGUIR CULTIVANDO POR INSEGURIDAD DE PROPIEDAD? Si=1 No=2
Parcela 1				
Parcela 2				
Parcela 3				
Parcela 4				

39. ¿Porqué no podría seguir cultivando parcela_____...…

…………………………………………………………………………………………

……………………………………………………………………………………..

SECCION 9: INGRESOS SUPLEMENTARIOS

40. ¿Qué productos ha cosechado su familia en el último año del <u>MONTE ALTO</u> que se encuentra en su predio? ***(dile toda la lista!!)***

PRODUCTO	UNIDAD DE MEDIDA	CANTIDAD	PRECIO/ POR UNID. DE MEDIDA	VALOR TOTAL SOLES
Fruta1:				
Fruta2:				
Fruta3:				
Madera1:				
Madera2:				
Madera3:				
Madera4:				
Leña				
Carbón				
Miel de Abeja				
Hojas				
Fibra				
Semillas				
Otro:				
Otro:				
Otro:				
Otro:				
Otro:				

41. ¿Qué **OTROS PRODUCTOS PRODUCE EN LA CHACRA** su familia que no son los cultivos anuales, cultivos perm's, o ganado vacuno? Por ejemplo: ***(dile la lista!!)***

ACTIVIDAD	√
Gallinas	
Chancho	
Leche	
Piscigranja	
Otro:	
Otro:	
Otro:	
Otro:	
Otro:	
Otro:	
Otro:	
Otro:	

42. ¿Cuantos días *(o semanas o meses)* en el año cada individuo del hogar **TRABAJA FUERA DE LA CHACRA** y qué actividades hacen por ejemplo: trabajo jornal agrícola, trabajo jornal agrícola, extracción madera fuera de su chacra caza fuera su chacra, fruta fuera su chacra? ***(obligatorio decirle la lista!!)***

PERSONA	**ACTIVIDAD** **por ejemplo: trabajo jornal agrícola, pesca, extracción madera fuera de su chacra caza fuera su chacra, fruta fuera su chacra?**	**TIEMPO**	**SOLES/ TIEMPO**	**TOTAL**

SECCION 10: USO DE INSUMOS

43. ¿Durante el último año han venido personas que no son de su familia a trabajar en su fundo? (que sean jornales contratados, minga, u otra). Si No

Actividades	No Personas (jornal, minga, etc.)	Cantidad de días	Pago por día por persona
Tumba y Quema			
Siembra			
Deshierbo			
Cosecha			
Otra:			

44. ¿Durante el último año, ha Ud. usado los siguientes insumos:

TIPO DE INSUMO	UNIDAD DE MEDIDA	CANTIDAD TOTAL	COSTO SOLES (S/.)	ESPECIES	CULTIVO
Fert Quim1:					
Fert Quim2:					
Fert Quim3:					
Fert Quim4:					
Fert. Org1:					
Fert. Org2:					
Fert. Org3:					
Herbic1:					

Herbic2:

Semilla Cert:

Insecticidas

Fungacidas

Otro:

Otro:

SECCION 11: PRACTICAS DE TUMBA Y QUEMA

45. ¿Cuántas hectáreas en total tumbaste y quemaste en el último año?

(HT&Q) .... Has.

46. ¿De las ____ hectáreas en total que tumbaste y quemaste el último año, cuántas hectáreas tumbaste y quemaste de

HECTAREAS TUMBADA Y QUEMADA ULTIMO AÑO

Monte Alto **(MTT&Q)**

Purma Alta **(PAT&Q)**

Purma Baja **(PBT&Q)**

Pasto **(PST&Q)**

TOTAL **(TLT&Q)**

47. ¿En promedio, durante los últimos tres años, cuántas hectáreas en total tumbaste y quemaste cada año? **(3HT&Q)** .... Has.

- ¿De las ____ hectáreas en promedio que tumbaste y quemaste cada año durante los últimos tres años, cuántas hectáreas en promedia tumbaste y quemaste de:

PROMEDIO DE HECTÁREAS POR AÑO TUMBADA Y QUEMADADE LOS3 ULTIMOS AÑOS

Monte Alto **(3MTT&Q)**

Purma Alta **(3PAT&Q)**

Purma Baja **(3PBT&Q)**

Pasto **(3PST&Q)**

TOTAL **(3TT&Q)**

48. ¿De la cantidad total de tierras trabajado en la campaña pasada cuanta de ellas va Ud. a dejar enpurmar?

	SUPERFICIE PARA ENPURMAR ÉSTE AÑO (HAS.)
Cultivos anuales **(ANPRM)**	
Cultivos permanentes **(PEPURM)**	
Pastos **(PAPURM)**	
Otro:	
Otro:	

49. ¿Cuáles son los rendimientos promedios por hectárea de sus cultivos principales?

CULTIVO ANUAL	**Rendimientos /Has.**
Plátano **(RPLAT)**	
Yuca **(RYUCA)**	
Maíz **(RMAIZ)**	
Frijol **(RFRIJ0)**	
Arroz **(RARROZ)**	
Cultivo Perm1:	
Cultivo Perm2:	
Cultivo Perm3:	

Otro:

Otro:

Otro:

30. CARACTERISTICAS DE LAS PERONAS QUE VIVE EN EL PREDIO

Nombre de la persona	Parentesco	Edad	Educación (Prim=1 Secund =2 Técnica =3 Super=4)	Año de estudio	Años que vivió en la ciudad	Trabaja dentro del predio? Si= 1 No= 2	Trabaja afuera del predio? Si= 1 No= 2

HIJOS<15 ANOS TOTAL: **NUMERO DE HIJOS<15 ANOS EN LA ESCUELA:**

APPENDIX B

Kudzu-Improved Fallow Survey

ENCUESTA SOCIO-ECONOMICO SOBRE BARBECHOS MEJORADOS
ICRAF-ASB PUCALLPA PERU ENERO 1999

Encuestador........................Fecha....................Encuesta Código.........

Coordenada X .... Coordenada Y...............

SECCION 1: INTRODUCION

3. Nombre completo del informante: ....

(NOMINF)

4. Nombre completo de la persona que toma decisiones en la parcela.

....

(NOMJEF)

3. Relación del informante con la persona que toma decisiones en la parcela:

.... **(RELINF)**

15. Sitio donde se encuentra el predio: km. Fed. Basad................ **(KMFB)**

km. 1 entrada.................. **(KMENT1)**

km. 2 entrada.................. **(KMENT2)**

km. 3 entrada.................. **(KMENT3)**

Izquierda(1) Derecha(2) **(LADO)**

16. Nombre del caserío: ....

(CASERI)

1. (a) ¿Durante cuántos años en promedio cultiva Ud. una parcela que limpió de un área de ___________antes de dejarlo cansar?
   (b) ¿Cuáles son los cultivos principales siembran Uds. en orden de importancia cada año después de tumbar una área de __________(incluso pastos y cultivos perennes)?

	Año 1-Cultivos		Año 2-Cultivos		Año 3-Cultivos		Año 4-Cultivos		Año 5-Cultivos	
Monte Alto	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña
Años:	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
Purma Alta	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña
Años:	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
Purma Baja	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña
Años:	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
Kudzal	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña	1° Campaña	2° Campaña
Años:	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
	2.	2.	2.	2.	2.	2.	2.	2.	2.	2.
	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.

2. (a) ¿Cuál es la diferencia entre limpiar una parcela del--monte, purma alta, purma baja, kudzal en lo que es: (1) el trabajo de tumba roza y quema (2) la presencia de malezas (3) la fertilidad del suelo.

MENOS: Trabajo, Deshierbo, Fertilidad	1	2	3	4	MAS: Trabajo, Deshierbo, Fertilidad

	Trabajo deTumbar Rozar y Quemar	Presencia de Malezas	Fertilidad	Otro factor clave:
Monte Alto	4	4	3	
Purma Alta	3	2	2	
Purma Baja	2	3	1	
Kudzal	1	1	2	

(b) ¿Hay otro factor más que trabajo de roza, malezas, y fertilidad que afecta su preferencia de limpiar un área de monte alto, purma alto, purma baja, o kudzal.

3. a.) ¿Cuántas personas durante cuántos días usan Ud. para _________una hectárea de_________ .

	Tumba (jornales/ha)		Roza (jornales/ha)		Quema (jornales/ha)		Total
	Personas	**Días**	**Personas**	**Días**	**Personas**	**Días**	
Monte Alto							
Purma Alta							
Purma Baja							
Kudzal	**Siembra**						

3 b.) ¿Paga Ud. para otra cosa para limpiar una parcela (por ejemplo moto sierra)

Cosa	Uso	Costo por			
		Monte Alto	Purma Baja	Purma Alta	Kudzal
1.					
2.					
3.					

4. Cuántas veces desyerba Ud. una hectárea de *(cultivo)* que Ud. ha sembrado en un *(tipo tierra)* ___ el ________ año?

		Arroz			**Maíz**			**Yuca**			**Plátano**			**Fréjol**		
		Veces	**Pers**	**Días**	**Veces**	**Pers**	**Días**	**Veces**	**Pers**	**Días**	**Veces**	**Pers**	**Días**	**Veces**	**Pers**	**Días**
Desyerbo Monte Alto (Jornales/ha)	**Año 1:**															
	Año 2:															
	Año 3:															
Desyerbo Purma Alta (Jornales/ha)	**Año 1:**															
	Año 2:															
	Año 3:															
Desyerbo Purma Baja **(Jornales/ha)**	**Año 1:**															
	Año 2:															
	Año 3:															
Desyerbo Kudzal (Jornales/ha)	**Año 1:**															
	Año 2:															
	Año 3:															

4 b.) ¿Paga Ud. para otra cosa para desyerbar una parcela (por ejemplo herbicidio)?

Cosa	<u>Costo Total</u>			
	Monte Alto	Purma Baja	Purma Alta	Kudzal
1.				
2.				
3.				

5. Cuál es su rendimiento promedio de los siguientes cultivos después de limpiar un área de ________ por cada año después de la limpieza

	Arroz	**Maíz**	**Yuca**	**Plátano**	Fréjol
Rendimiento Promedio Monte Alto (unidad/ha)	Año 1:	Año 1:	Año 1:	Año 1:	Año 1:
	Año 2:	Año 2:	Año 2:	Año 2:	Año 2:
	Año 3:	Año 3:	Año 3:	Año 3:	Año 3:
Rendimiento Promedio Purma Alta (unidad/ha)	Año 1:	Año 1:	Año 1:	Año 1:	Año 1:
	Año 2:	Año 2:	Año 2:	Año 2:	Año 2:
	Año 3:	Año 3:	Año 3:	Año 3:	Año 3:
Rendimiento Promedio Purma Baja (unidad/ha)	Año 1:	Año 1:	Año 1:	Año 1:	Año 1:
	Año 2:	Año 2:	Año 2:	Año 2:	Año 2:
	Año 3:	Año 3:	Año 3:	Año 3:	Año 3:
Rendimiento Promedio Kudzal (unidad/ha)	Año 1:	Año 1:	Año 1:	Año 1:	Año 1:
	Año 2:	Año 2:	Año 2:	Año 2:	Año 2:
	Año 3:	Año 3:	Año 3:	Año 3:	Año 3:

6. a.) ¿Cuántos años tienen en promedio sus: purma bajas? __________ años
purma altas? __________ años

b.) ¿Cuántos años hay que dejar un kudzal antes de volver a cultivarlo? __________ años

c.) ¿Desde cuántos años tiene Ud. kudzales en su fundo __________ años

d.) ¿Ha notado Ud. un reducción de rendimientos después de usar un kudzal durante cierta cantidad de años? Si(1) No (2)
después de cuántos años ___________ años

APPENDIX C

Brachiaria-Improved Pasture Survey

**ENCUESTA SOCIO-ECONOMICO SOBRE PASTOS MEJORADOS
ICRAF-ASB PUCALLPA PERU ENERO 1999**

Encuestador..........................Fecha.....................Encuesta Código.........

Coordenada X .... Coordenada Y................

5. Nombre completo del informante: ....
   (NOMINF)
6. Nombre completo de la persona que toma decisiones en la parcela.

....

(NOMJEF)

3. Relación del informante con la persona que toma decisiones en la parcela:

.... **(RELINF)**

17. Sitio donde se encuentra el predio: km. Fed. Basad................ **(KMFB)**

km. 1 entrada.................. **(KMENT1)**

km. 2 entrada.................. **(KMENT2)**

km. 3 entrada.................. **(KMENT3)**

Izquierda(1)   Derecha(2) **(LADO)**

18. Nombre del caserío: ....
    (CASERI)

19. ¿Cuántas hectáreas de pastos tiene Ud.? ____________ has.

- ¿Qué tipos de pastos hay? ¿Cuántas hectáreas hay de cada uno?

Tipo de Pastos	**Has.**
Pasto Natural (torouco) **(PASTNA)**	
Braquiaria **(PASTBR)**	
Brachiaria-Kudzu **(PASTBK)**	
Otro:	

7. ¿Cuántas cabezas de ganado tiene usted? **(CABGAN)**

..............cabezas

8. ¿Dónde instala Ud. un nuevo pasto en su fundo? (donde había:)

Cultivos **Purma Baja** **Purma Alta** **Monte** **Otro:**

Brachiaria

Torouco

Otro:

Siempre (1) Frecuente (2) A Veces (3) Muy Poco (4)

9. ¿Cuántas personas durante cuántos días usan Uds. para **INSTALAR** una nueva hectárea de pasto de _______________

- **MANO DE OBRA DE LIMPIEZA:**

*BRACHIARIA

Limpieza de ___________	**Limpieza de** ___________	**Limpieza de** ___________
Personas:	Personas:	Personas
Días:	Días:	Días
Total:	Total:	Total

TOROUCO

Limpieza de ___________	**Limpieza de** ___________	**Limpieza de** ___________
Personas:	Personas:	Personas
Días:	Días:	Días
Total:	Total:	Total

OTRO:

Limpieza de ___________	**Limpieza de** ___________	**Limpieza de** ___________
Personas:	Personas:	Personas
Días:	Días:	Días
Total:	Total:	Total

- **Mano de obra de siembra:**

SIEMBRA

Brachiaria	**Torouco**	**Otro:**
Personas:	Personas:	Personas:
Días:	Días:	Días:
Total:	Total:	Total:

- **Mano de obra de otra actividad de instalación:**

OTRA ACTIVIDAD DE INSTALACION DE PASTO:

Brachiaria	**Torouco**	**Otro**
Personas:	Personas:	Personas:
Días:	Días:	Días:
Total:	Total:	Total:

10. a. ¿Hace Ud. **MANTENIMIENTO** de sus pasto Si(1) No (2)
(por ejemplo desyerbo, quema, etc...)

b. ¿Qué tipo de **MANTENIMIENTO** hace Ud. en su sus pastos?

Desyerbo si	**Quema si**	**Otro: si**	**Otro: si**
¿Cada cuánto tiempo?	¿Cada cuánto tiempo?	¿Cada cuánto tiempo?	¿Cada cuánto tiempo?
________	________	________	________
________	________	________	________

c. ¿Cuántas personas durante cuántos días usan Uds. para **MANTENER** una hectárea de pasto de ________ en un año?

BRACHIARIA

Deshierbo	**Quema**	**Otro:**	**Otro:**
Personas	Personas	Personas	Personas
Días	Días	Días	Días
Total	Total	Total	Total

TOROUCO

Deshierbo	**Quema**	**Otro:**	**Otro:**
Personas	Personas	Personas	Personas
Días	Días	Días	Días
Total	Total	Total	Total

OTRO:

Deshierbo	**Quema**	**Otro:**	**Otro:**
Personas	Personas	Personas	Personas
Días	Días	Días	Días
Total	Total	Total	Total

11. ¿Usa Ud. algunos insumos o máquina para el pasto como fertilizantes, tractor *(para el pasto no para el ganado)*

	Brachiaria (Soles/ha/año)	**Torouco (Soles/ha/año)**	**Otro(Soles/ha/año)**
Insumo1:			
Insumo2:			
Insumo3:			

12. ¿Un hectárea de ___________ puede alimentar cuántas cabezas de ganado

Brachiaria	**Tourouco**	**Otro:**
Cabezas:	Cabezas:	Cabezas:

13. a. ¿Cuántos años tienen sus más antiguos pastos de ___________?

Brachiaria	**Tourouco**	**Otro:**
__________ años	__________ años	__________ años

b. ¿A su conocimiento, hay que abandonar un pasto de _____________después de cierto numero de años porque ya no produce suficiente forraje?

Brachiaria	**Tourouco**	**Otro:**
Si(1) _____ años No (2)	Si(1) ____ años No(2)	Si(1) _____ años No(2)

c. ¿Se baja la producción de forraje después de cierta cantidad de años en un pasto de:

Brachiaria	**Tourouco**	**Otro:**
No (2)	No (2)	No (2)
Si: un poco mucho	Si: un poco mucho	Si: un poco mucho
Después de _______ años	Después de _______ años	Después de _______ años

- Si sí, ¿por qué? ____

____

___

14. Si Ud. tiene pasto sin ganado, ¿porqué ha sembrado pasto?
    - Rango de importancia: más importante (1) .... (5) menos importante

Compraré ganado con ahorro personal	**Ayuda a obtener crédito para ganado**	**Aumenta valor de la fundo para venderlo**	**Invadió el ____ por Por motivo de __**	**Otro:**
RANGO:	**RANGO:**	**RANGO:**	**RANGO:**	**RANGO:**
Observaciones:	**Observaciones:**	**Observaciones:**	**Observaciones:**	**Observ.:**

15. Si Ud. tiene ganado, ¿cómo lo obtuvo?
    - Rango de importancia: más importante (1) .... (5) menos importante

Ahorro personal de la venta de productos del fundo	**Crédito del gobierno**
Ahorro personal de trabajo fuera de la finca	**Otro:**
Ayuda de pariente/amigo	**Otro:**

Observaciones

____

____

_

____

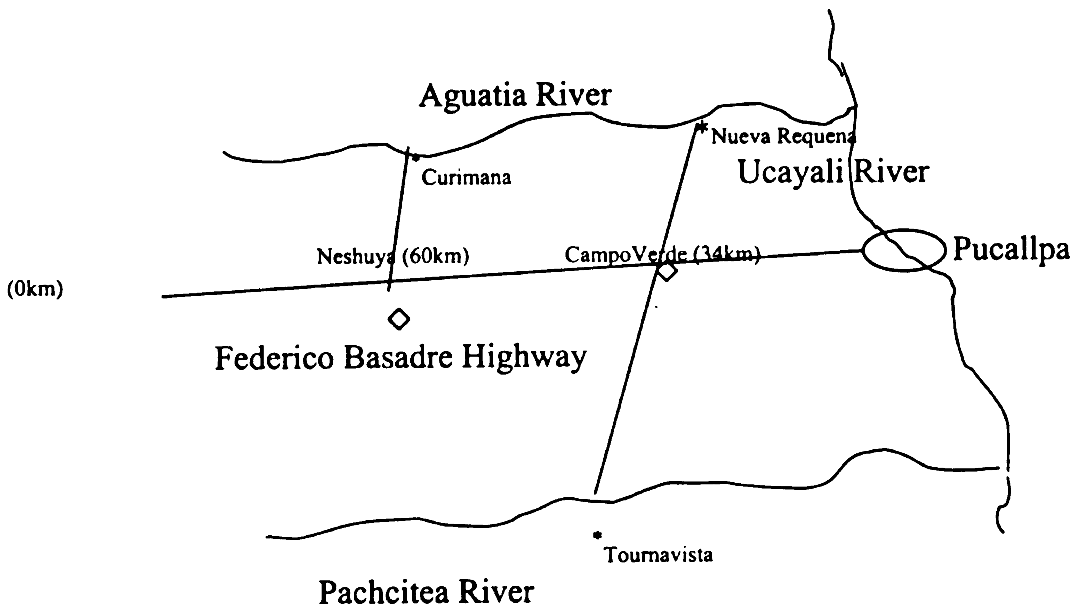
_

16. ¿Cuáles son las ventajas y desventajas de:

BRACHIARIA **TOROUCO** **OTRO:**

APPENDIX D

Map of the Pucallpa Research Zone


Aguatia River
Nueva Requena
Curimana
Ucayali River
Neshuya (60km)
CampoVerde (34km)
Pucallpa
(0km)
Federico Basadre Highway
Tournavista
Pachcitea River

APPENDIX E

Comparison of Input and Output Regression Models Using Ordinary Least Squares (OLS) and Seemingly Unrelated Regression Equations (SURE)

OUTPUT REGRESSION RESULTS USING OLS AND SURE

	ANNUALS (OLS)			ANNUALS (SURE)		
	R^2 .54	Adj R^2 .35				
	Coefficient	Stand Err	Signif	Coefficient	Stand Err	Signif
CONSTANT	2.3107	2.7267	0.403	1.9484	2.4799	0.433
FARM SIZE	0.0193	0.0286	0.504	0.0306	0.0273	0.263
SECONDARY FOREST	0.0472	0.0506	0.357	0.0295	0.0523	0.573
PRIMARY FOREST	0.0521	0.0339	*0.134	0.0353	0.0321	0.272
ALLUVIAL SOILS	1.5672	0.7492	**0.044	1.5082	0.8202	*0.067
YEARS IN LOT	-0.0654	0.0442	*0.148	-0.0596	0.0476	0.211
EDUCATION	0.3694	0.7260	0.614	0.0376	0.7480	0.960
AGE	-0.0181	0.0284	0.528	0.0052	0.0269	0.846
FAMILY LABOR	1.2812	0.3673	***0.001	1.3439	0.3619	***0.000
ORIGEN (not jungle)	-0.5672	0.7947	0.480	0.4650	0.8164	0.570
CREDIT	0.7699	0.7173	0.291	0.1904	0.7754	0.806
OFF-FARM INCOME	-0.0003	0.0001	**0.040	-0.0003	0.0001	***0.006
EXTENSION	-0.0652	0.0588	0.275	-0.0651	0.0563	0.249
REAL PRICE MAIZE	-9.0094	5.6918	*0.123	-6.2960	5.1639	0.224
TENURE SECURITY	1.8436	1.8945	0.337	-2.6879	1.5196	*0.078

	PERENNIALS (OLS)			PERENNIALS (SURE)		
	R^2 .50	Adj R^2 .30				
	Coefficient	Stand Err	Signif	Coefficient	Stand Err	Signif
CONSTANT	-3.6355	1.8869	*0.062	-2.3615	1.8417	0.201
FARM SIZE	-0.0140	0.0198	0.484	-0.0253	0.0204	0.217
SECONDARY FOREST	0.0206	0.0350	0.559	0.0371	0.0392	0.345
PRIMARY FOREST	0.0322	0.0235	0.179	0.0432	0.0240	*0.073
ALLUVIAL SOILS	-1.1651	0.5185	**0.031	-1.1109	0.6149	*0.072
YEARS IN LOT	-0.0215	0.0306	0.488	-0.0286	0.0357	0.423
EDUCATION	0.1351	0.5024	0.790	0.0348	0.5613	0.951
AGE	0.0691	0.0197	***0.001	0.0700	0.0200	***0.001
FAMILY LABOR	0.6514	0.2542	**0.015	0.4071	0.2706	*0.134
ORIGEN (not jungle)	1.1024	0.5499	**0.053	1.0765	0.6053	*0.077
CREDIT	0.6360	0.4964	0.209	0.5633	0.5832	0.335
OFF-FARM INCOME	-0.0001	0.0001	*0.132	-0.0001	0.0001	0.333
EXTENSION	-0.0770	0.0407	*0.067	-0.0396	0.0417	0.344
FM-GATE PR MAIZE	-0.1838	3.9387	0.963	-0.1540	3.8249	0.968
TENURE SECURITY	0.6538	1.3110	0.621	-0.6622	1.0687	0.536

	LIVESTOCK (OLS)			LIVESTOCK (SURE)		
	R^2 .58	Adj R^2 .40				
	Coefficient	Stand Err	Signif	Coefficient	Stand Err	Signif
CONSTANT	-10.0943	7.8384	0.207	4.973432	8.253966	0.547
FARM SIZE	0.3262	0.0820	***0.000	0.3199041	0.0932539	***0.001
SECONDARY FOREST	-0.0556	0.1541	0.721	-0.1021822	0.1849813	0.581
PRIMARY FOREST	-0.2996	0.1022	***0.006	-0.2700278	0.1127295	**0.017
ALLUVIAL SOILS	2.3259	2.5750	0.373	2.617264	2.930292	0.373
YEARS IN LOT	0.1375	0.1386	0.328	0.1180356	0.1702934	0.489
EDUCATION	-1.0624	2.3444	0.653	0.6935119	2.668329	0.795
AGE	-0.1511	0.1003	*0.141	-0.2461703	0.0906417	***0.007
FAMILY LABOR	1.9733	1.0900	*0.079	1.805333	1.283831	0.161
ORIGIN (not jungle)	2.3586	2.5465	0.361	-0.412634	2.621776	0.875
CREDIT	-1.8472	2.2939	0.426	-2.615343	2.836407	0.358
OFF-FARM INCOME	0.0001	0.0004	0.844	0.0001541	0.0004553	0.735
EXTENSION	-0.0925	0.1980	0.643	-0.1803244	0.1776334	0.311
FM-GATE PR MAIZE	9.8958	17.9265	0.585	0.6506359	16.12668	0.968
TENURE SECURITY	5.5646	2.4881	**0.032	-6.615253	2.514173	***0.009

***Significant at the .01 level **Significant at the .05 level *Significant at the .15 level

Coefficients are unstandardized

INPUT/TECHNOLOGY REGRESSION RESULTS USING OLS AND SURE

	IMPROVED FALLOWS (OLS)			IMPROVED FALLOWS (SURE)		
	R^2 .33	Adj. R^2 .25				
	Coefficient	Stand Err	Signif	Coefficient	Stand Err	Signif
CONSTANT	-3.7446	1.4882	0.013	-4.794328	2.775335	0.086
FARM SIZE	0.0646	0.0162	***0.000	0.060682	0.0414451	0.145
SECONDARY FOREST	0.0245	0.0304	0.421	-0.1981938	0.108374	*0.069
PRIMARY FOREST	-0.0332	0.0258	0.201	-0.0216657	0.0496884	0.663
ALLUVIAL SOILS	-0.4832	0.7259	0.507	-1.971985	1.371748	*0.152
SANDY SOILS	1.1615	0.5916	**0.052	3.379892	1.378916	**0.015
YEARS IN LOT	0.0421	0.0288	*0.147	0.2015417	0.0747249	***0.008
EDUCATION	1.4630	0.5749	***0.012	2.365908	1.125242	**0.037
FAMILY LABOR	0.2880	0.2416	0.236	0.313289	0.495412	0.528
OFF-FARM INCOME	0.0000	0.0001	0.952	0.0000646	0.0001925	0.738
DIST SOC'L SERVICES	0.0811	0.0522	*0.123	0.0927358	0.0805555	0.251
CREDIT	-1.0076	0.5739	*0.082	-0.8415701	1.28104	0.512
MARKET DISTANCE	0.0216	0.0112	*0.057	0.003346	0.0214731	0.876
TENURE SECURITY	-0.0323	0.9557	0.973	0.4651375	2.871959	0.871

	IMPROVED PASTURES (OLS)			IMPROVED PASTURES (SURE)		
	R^2 .80	Adj. R^2 .78				
	Coefficient	Stand Err	Signif	Coefficient	Stand Err	Signif
CONSTANT	1.8618	3.1693	0.558	4.1291	5.3539	0.441
FARM SIZE	0.7880	0.03607	***0.000	0.5658	0.0955	***0.000
SECONDARY FOREST	-0.8445	0.0679	***0.000	-0.5155	0.1777	***0.004
PRIMARY FOREST	-0.8022	0.0557	***0.000	-0.6292	0.1143	***0.000
ALLUVIAL SOILS	-	-	-	-	-	-
SANDY SOILS	-	-	-	-	-	-
YEARS IN LOT	-0.0674	0.0591	0.256	-0.0295	0.1437	0.837
EDUCATION	-1.6209	1.2645	0.202	-1.1193	2.3544	0.635
FAMILY LABOR	-0.6221	0.5470	0.258	-1.0336	1.0247	0.314
OFF-FARM INCOME	0.0000	0.0002	0.910	0.0013	0.0004	***0.002
DIST SOC'L SERVICES	-0.2780	0.1155	**0.018	-0.3796	0.1739	**0.030
CREDIT	-2.6357	1.2741	**0.041	-4.0337	2.6629	*0.131
MARKET DISTANCE	-0.0441	0.0223	**0.050	-0.0044	0.0439	0.921
TENURE SECURITY	3.1313	2.2075	0.159	-9.3548	5.9530	*0.118

	NATURAL PASTURES (OLS)			NATURAL PASTURES (SURE)		
	R^2 .19	Adj. R^2 .12				
	Coefficient	Stand Err	Signif	Coefficient	Stand Err	Signif
CONSTANT	-1.2139	1.0211	0.237	-0.5747	0.4257	0.179
FARM SIZE	0.0494	0.0143	***0.001	0.0219	0.0070	***0.002
SECONDARY FOREST	-0.0518	0.0255	**0.045	-0.0352	0.0141	***0.013
PRIMARY FOREST	-0.0277	0.0214	0.198	-0.0216	0.0087	***0.013
ALLUVIAL SOILS	-	-	-	-	-	-
SANDY SOILS	-	-	-	-	-	-
YEARS IN LOT	0.0483	0.0221	**0.031	0.0148	0.0116	0.202
EDUCATION	0.5695	0.4780	0.236	0.1872	0.1901	0.326
FAMILY LABOR	0.0639	0.1831	0.728	0.0598	0.0822	0.468
OFF-FARM INCOME	0.0001	0.0001	0.362	0.0000	0.0000	0.317
DIST SOC'L SERVICES	-0.0429	0.0436	0.326	-0.0015	0.0142	0.919
CREDIT	-0.1190	0.4811	0.805	-0.0514	0.2189	0.814
MARKET DISTANCE	0.0030	0.0086	0.729	0.0055	0.0035	*0.119
TENURE SECURITY	-0.1812	0.4750	0.703	-0.1025	-0.5150	0.607

***Significant at the .01 level **Significant at the .05 level *Significant at the .15 level

Coefficients are unstandardized

APPENDIX F

Results of the Hausman Specification Test and Total Deforestation Model Using Ordinary Least Squares (OLS) and Two-Stage Least Squares (2SLS)

Hausman Specification Test Results

HAUSMAN SPECIFICATION TEST RESULTS			
(Significance of Reduced Form Error Term in Initial Regression)			
	Total Defor	**Primary Defor**	**Second Defor**
ANNUAL	0.237	0.346	0.112
PERENNIALS	0.166	0.305	0.209
LIVESTOCK	0.225	0.558	0.326
IMPROVED FALLOWS	0.631	0.994	0.238
IMPROVED PASTURES	0.078	0.756	0.646
NATURAL PASTURE	0.806	0.167	0.692
CAPITAL INPUTS	0.562	0.945	0.370
HIRED LABOR	0.987	0.576	0.503

Total Deforestation Regression Model Using Ordinary Least Squares (OLS) and Two Stage Least Squares (2SLS) with Predetermined Value for Improved Pastures

	TOTAL DEFORESTATION (OLS)			TOTAL DEFORESTATION (2SLS)		
	R^2 .54	adj. R^2 .50		R^2 .53	adj. R^2 .49	
VARIABLE	Coef	Stand Err	Signif	Coef	Stand Err	Signif
CONSTANT	-0.6334	0.4546	0.165	-0.6208	0.4636	0.182
ANNUAL	0.3617	0.0455	***0.000	0.3591	0.0473	***0.000
PERENNIALS	-0.1058	0.0619	*0.090	-0.1029	0.0624	*0.101
LIVESTOCK	0.0065	0.0060	0.285	0.0032	0.0059	0.588
IMPROVED FALLOWS	0.0204	0.0299	0.495	-0.0036	0.0115	0.751
IMPROVED PASTURES	-0.0118	0.0105	0.265	0.0250	0.0302	0.409
NATURAL PASTURE	-0.0671	0.0384	*0.082	-0.0584	0.0388	*0.134
CAPITAL INPUTS	-0.0004	0.0002	**0.037	-0.0004	0.0002	**0.030
HIRED LABOR	0.0102	0.0018	***0.000	0.0104	0.0018	***0.000
FAMILY LABOR	0.1657	0.0967	*0.089	0.1052	0.1033	0.310
EDUCATION	0.6011	0.2484	**0.017	0.5781	0.2552	**0.025
TENURE SECURITY	0.5342	0.3500	*0.129	0.6114	0.3616	*0.093
ALLUVIAL SOILS	0.0892	0.2823	0.752	0.1299	0.2865	0.651
TOTAL FOREST	0.0115	0.0068	*0.094	0.0120	0.0070	*0.086

***Significant at the .01 level **Significant at the .05 level *Significant at the .15 level
Coefficients are unstandardized