THE IMPACT OF TECHNOLOGICAL CHANGE IN AGRICULTURE ON DEFORESTATION:

THE CASE OF IMPROVED FALLOWS IN THE PERUVIAN AMAZON

DAVID YANGGEN AND THOMAS REARDON

RESEARCH CONDUCTED AS PART OF THE
ALTERNATIVES TO SLASH AND BURN "ASB" INITIATIVE

PUCALLPA, PERU
MAY, 1999

These authors are respectively doctoral candidate in Agricultural Economics Michigan State University/ Research Associate ICRAF-Peru and Professor of Agricultural Economics Michigan State University.

These authors would like to express thanks for the funding of this research from ICRAF, the Interamerican Foundation, and USAID. The ideas expressed in this paper are those of the authors and do not necessarily reflect the ideas of these organizations.

Prepared for American Agricultural Economics Association 1999 Annual Meeting, Nashville, Tennessee.

1. Review of the Agricultural Technology and Deforestation Debate

There is substantial disagreement concerning the impact of technological change in agricultural on deforestation. Researchers such as Norman Borlaug (1997) argue that agricultural intensification reduces deforestation. Intensification allows increased production on the same amount of land thereby reducing pressures to expand agricultural production into the forest margins. Other researchers, however, point out that productivity-increasing technological change is also likely to increase profitability. Increased profitability leads farmers to expand the amount of land in production thereby increasing deforestation.

An exhaustive review of the deforestation literature by Angelson and Kaimowitz (1998) found a scarcity of empirical studies on this subject. Their general conclusion was that technological change's impact on deforestation depends on the specific characteristics of both the technology and the zone in which it is introduced, but that more empirical evidence was needed to draw more specific conclusions. This study seeks to help fill that gap in the literature by analyzing how the attributes of the agricultural technology kudzu improved fallows interact with the characteristics of the zone of Pucallpa Peru to produce a given deforestation outcome.

2. Methodological Approach

To explore this question we first present the key characteristics of the Pucallpa study zone. Descriptive statistics then compare the characteristics (land use, labor use, yields) of kudzu fallows to those of traditional fallows and primary forest (the land used in the dominant practice of slash and burn agriculture) to give qualitative insights into how the introduction of kudzu fallows may change deforestation patterns. We then use econometric analysis to quantitatively examine kudzu fallows impact on deforestation.

3. Description of the Pucallpa Peru Study Zone

Pucallpa is the second largest city in the Peruvian Amazon with around 200,000 inhabitants. Pucallpa's economy is relatively dynamic due to timber, oil and gas extraction and its road connection to Lima. Rapid migration into the Pucallpa zone is the result of the push factors of poverty and land scarcity in other parts of the country (Riesco, 1993) and the pull factors of infrastructural development (the Lima highway and timber and gas feeder roads into the jungle), cheap abundant land, job opportunities, and until recently coca production (Labarta, 1998). Farmers arriving in the zone are typically extremely poor in capital resources for farm-level investment. Rural population density remains low around 7 persons per km^2.

The principal semi-subsistence crops in the zone are maize, rice, cassava, plantains, and beans. Cash crops development has seen a series of booms and busts (rubber, cacao, black pepper, etc.) and remain of limited importance. Prices for semi-subsistence crops are low while marketing costs are high due to poor infrastructure (except for the main highway). In the early 1990's, the Peruvian government slashed its support for the agricultural sector eliminating most subsidized farm credit, guaranteed floor prices for major crops and extension services.

Soils have low fertility and high levels of acidity and aluminum content impeding crop growth. Most nutrients are contained in the above ground biomass. Use of capital inputs such as fertilizers, pesticides, plows, etc. is extremely limited. The dominant production practice is slash and burn agriculture. Most farmers slash and burn new areas every year. These are typically cultivated from a half year to two years before being fallowed. A median farm is 30 hectares and is constituted by five principal uses: primary forest (31%), forest fallows (30%), pasture (25%) annual crops (10%) and perennials (4%).

In sum, migrants coming to Pucallpa are extremely poor. They spontaneously settle areas of abundant land recently opened up by gas and timber extraction. Agriculture remains stagnant due to low prices, high marketing costs, and cuts in government support. Use of capital inputs is typically both unprofitable and unaffordable for farmers. Farmers are essentially left with their labor to cultivate abundant land. Labor is a key limiting factor of production in the face of abundant land and the absence of capital. Slash and burn agriculture maximizes production by using lots of the abundant land resource while minimizing the use of scarce capital and labor resources.

4. Kudzu Improved Fallows in the Context of Slash and Burn Agriculture

There has been very limited adoption of improved agricultural production technologies in the Pucallpa zone. Most of the new technologies require intensive use of capital and/or labor. Kudzu improved fallows were chosen as a focus of this study because they are one of a very few improved technologies adopted by farmers in the zone. 52% of farmers use kudzu improved fallows and 94% of farmers have a favorable opinion of kudzu. Farmers' major reasons for using kudzu include fertilization, fodder, and weed control. The only significant drawback mentioned was competition with other crops.

Slash and burn agriculture is a production system based on a rotating use of land. Initially, primary forest is cut down and burned. The ashes provide nutrients for the crops planted in the parcel. The field is then left fallow in order to recuperate its fertility. Secondary forests grow back up in these fallow areas. After a certain number of years, the farmer once again slashes and burns the secondary forest fallow area to release the nutrients and plant crops.

Kudzu improved fallows are “improved” in the sense that they do not rely solely on natural vegetative regeneration to provide the biomass source of crop nutrients. Kudzu fixes large quantities of nitrogen in fallows to accelerate the process of soil nutrient recuperation. Kudzu is an aggressive vine that is planted or spontaneously regenerates in areas coming out of annual crop production. It grows throughout the secondary forest fallow area is then burned and crops are planted.

Farmers in the zone distinguish between low forest fallows less than 5 meters high and high forest fallows greater than 5 meters high. Kudzu improved fallows are a subcategory of low forest fallows. Trees and shrubs grow in these areas but kudzu vines grow over them slowing their growth. In sum, there are two basic types of forest: primary forest which has never been cut down and secondary forest which has been cut down and has regenerated. And there are three main types of secondary forests: high fallows, low fallows, and kudzu improved fallows.

5. Comparative Analysis of Kudzu Improved Fallows with Traditional Slash and Burn Agriculture

5.1 Introduction

In the dominant shifting agricultural system, farmers choose between slashing and burning an area of primary forest or secondary forest fallow (low or high) for crop production. In order to understand why a farmer would choose to use kudzu improved fallows and the implications of this choice on deforestation, we compare the different key socio-economic characteristics of these principal types of land.

5.2 Comparative Analysis of Total Land Use with Different Land Categories

Based on the average fallow period and subsequent average cultivation time of crops in each type of fallow, a schematic scenario can be outlined giving the total amount of land needed for a 3 hectare annual crop production system. Lessening the total amount of land needed in a shifting agricultural production system reduces deforestation. This is a form of "temporal" intensification in a shifting agricultural system.

The following formula calculates the total land needed in each fallow system with three hectares of annual crops: **LC = HP + [(FY/YC) * HP]**

FOC's: $\partial LC/\partial FY = > 0$ $\partial LC/\partial YC = < 0$

LC = Land Cleared **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 land needed for the initial parcel to recuperate its fertility so that it can once again be cultivated. The first order conditions indicate that total land cleared is an increasing function of needed fallow years and a decreasing function of the years a parcel can be cultivated after clearing.

In this model with 3 hectares of annual crops kudzu fallows reduce land clearing needs by 79% over high forest fallows and 40% over low forest fallows (table 1)

	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**	**.9**
Total Land Clearing: 3ha annual crop system	**8.1**	**14.5**	**11.3**
Increased land clearing relative to kudzu fallow	**0**	**79%**	**40%**

Table 1: Comparative Scenarios of Land Clearing with Differing Fallow Systems

5.3 Comparative Analysis of Labor Use with Different Land Categories

Primary forest and secondary forest fallows require substantial labor inputs for slash and burn land clearing. Kudzu is an aggressive vine that stifles secondary forest regrowth. Also, kudzu's shorter fallow period allows less time for the regeneration of trees and shrubs. Less secondary forest regeneration in kudzu fallows substantially reduces the labor needed for land clearing relative to traditional fallows and primary forest (table 2).

	Average	Labor reduction w/kudzu fallow
Primary Forest	**26.5**	**-69%**
High Forest Fallow	**21.8**	**-62%**
Low Forest Fallow	**13.0**	**-37%**
Kudzu Improved Fallow	**8.2**[1]	**--**

Table 2: Reduction in Labor for Land Clearing with Kudzu Fallows (labor days/ hect.)

Kudzu also reduces weeding labor. In general, the less light that penetrates the forest canopy, the smaller the weed presence in a parcel. For this reason, areas cleared from primary forest have fewer weeds than all categories of secondary forests. Kudzu is an aggressive cover crop that smothers out weeds in fallow areas. Table three shows that areas cleared from kudzu fallows require less weeding labor than other forest fallows. Labor is a key limiting factor of production, therefore easing this constraint is likely to allow farmers to increase production leading to greater deforestation.

	Rice Weeding	Change w/Kudzu	Maize Weeding	Change w/Kudzu
Primary Forest	**3.6**	**+266%**	**3.1**	**+413%**
High Forest Fallow	**39.7**	**-76%**	**20.2**	**-36%**
Low Forest Fallow	**31.6**	**-69%**	**23.2**	**-45%**
Kudzu Improved Fallow	**9.7**	**--**	**12.8**	**--**

Table 3: Change in Weeding Labor Using Kudzu Improved Fallows (labor days/hectare)

5.4 Comparative Analysis of Yields with Different Land Categories

Yields in a slash and burn agricultural system are positively related to the quantity of nutrients made available for crop uptake by burning vegetation. Primary forest has the most biomass, but many of the trees are too large to burn so their nutrients are not released and their trunks take up field space. High forest fallows typically provide the most nutrients and low fallows the least according to farmer interviews. Weeds competition also effects yields. Primary forest has the fewest weeds followed by kudzu then other forest fallows.

Kudzu fixes nitrogen in fallows and reduces weed competition. The net result is a substantial yield increase over both traditional forest fallows and primary forest (table 4).

	Rice (Tn./Ha.)	Increase	Maize (Tn./Ha.)	% Increase
Primary Forest	1.6	30%	1.3	27%
High Forest Fallow	1.9	10%	1.5	12%
Low Forest Fallow	1.0	103%	1.4	22%
Kudzu Improved Fallow	2.1	-	1.7	-

Table 4: Increase in Yields with Kudzu Fallow Relative to Other Land Uses

5.5 Summary of the Comparative Analysis's Implication for Deforestation

Kudzu fallows reduction of total land use in a rotating slash and burn agricultural system is likely to decrease deforestation. The easing of the labor production constraint is likely to allow increased production and thereby increase deforestation. And finally, the introduction of kudzu improved fallows decreases the costs (land clearing and weeding) and increases the benefits (yields) of secondary forest deforestation relative to primary forest deforestation. This change in relative costs and benefits should increase secondary forest deforestation and diminish primary forest deforestation.

6. Theoretical and Econometric Models

6.1 Theoretical Model

The theoretical framework for understanding farmer behavior is based on 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 they produce (outputs) and how they produce it (inputs/technologies) are what determine agriculture's impact on deforestation. This approach serves as a guide for the econometric regression modeling of the relationship between agriculture and deforestation.

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[1] Includes seed collection and seeding labor

The profit function for a farm is specified as follows:

$$\textbf{(1)} \qquad \pi = pq - wx$$

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, which describes the technical relationship between the fixed and variable inputs and outputs produced. Quantity of outputs q is a function of variable inputs x and fixed inputs z used in the production process:

$$\textbf{(2)} \qquad q = f(x,z)$$

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:

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

indicating 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 expressed as follows:

$$\textbf{(4)} \qquad \pi = pq(p,w,z) - wx(p,w,z)$$

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

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

The principal cause of deforestation is growing demand for crop and pastureland. However, not all agricultural products and agricultural production technologies have the same impact on deforestation. It is therefore necessary to understand farmer decision-making concerning outputs produced, production technologies used, and the impact of these two on deforestation. The econometric modeling that follows focuses on the technology of kudzu improved fallows and its impact on deforestation.

5.2 Econometric Model

The econometric modeling uses the ordinary least square method. The deforestation regression is a recursive model that includes the inputs and outputs as exogenous variables and annual deforestation as the dependent variable. Farmers' deforest in practicing slash and burn agriculture to provide nutrients for crops. Deforestation is therefore an *outcome* of agricultural activities, a means to the end of agricultural production. In sum, there is a unidirectional causality of agriculture leading to deforestation and not vice versa. This is the justification of modeling deforestation in a recursive manner.

The final form of the econometric model specification is as follows.

$\mathbf{DEFOR_{ij}}$ = f(annuals$_i$, perennials$_i$, livevsotck$_i$, hired labor$_i$, kudzu fallow$_i$, brachiaria pasture$_i$, natural pasture$_i$, capital inputs$_i$, market distance$_i$, road condition$_i$, family labor$_i$, land tenure$_i$, education$_i$, gender$_i$, origen$_i$, low fallow$_i$, high fallow$_i$, primary forest$_i$, forest income$_i$)

j = total deforestation, primary forest deforestation, secondary forest deforestation (1998).
i = 1,…, N observations

7. Analysis of the Impact of Kudzu Improved Fallows on Deforestation

The qualitative analysis of kudzu fallows key characteristics led to the following predictions: decreased total land use diminishes total deforestation, decreased labor constraints increase deforestation and the changing of relative costs and benefits augment secondary forest deforestation and diminish primary forest deforestation. Analysis of the sign and significance of the kudzu improved fallow independent variables in the regressions models of total, primary, and secondary forest deforestation provides a more rigorous quantitative evaluation of kudzu fallows' impact on each type of deforestation.

The sign of kudzu improved fallows in the total deforestation model is positive though not significant (.53). This tends to indicate that kudzu fallows' easing of labor production constraints increases deforestation more than shortened fallow periods' diminishing of total land use decreases deforestation. The importance of the labor constraint (and hence its easing) is reflected in the positive correlation of deforestation with hired labor (.00) and family labor (.21). The fact that the kudzu variable is not significant is to be expected given the two opposing factors at work.

When deforestation is broken down into its two principal component parts, secondary and primary forest, the significance of the kudzu improved fallow variable greatly improves. Kudzu improved fallows are negatively correlated with primary forest deforestation (.14) and positively correlated with secondary forest deforestation (.14). This appears to confirm the qualitative analysis that kudzu fallows' decreasing of the costs and increasing of the benefits of secondary forest clearing relative to primary forest clearing reduces primary forest deforestation and increases secondary forest deforestation.

The kudzu fallow variables are moderately though not highly significant (.14 for both). This should be expected. The changing the relative costs and benefits of land clearing in favor of secondary over primary forests is mitigated by the labor and total land use effects. Although more production is drawn towards secondary forests, decreased fallow periods still allow less total land use. Likewise, decreases in primary forest deforestation may be partially offset by freed up labor time.

8. Conclusions and Implications for Policy and Technology Development.

This paper has analyzed how the particular technological profile of kudzu improved fallows has interacted with the site-specific characteristics of Pucallpa to produce a given deforestation outcome. An initial broad conclusion is that there is a need for both site-specific and technology-specific analysis to understand the impact of a technology on deforestation. Assuming that any and all improved fallows increase total deforestation in the Pucallpa zone would be erroneous. 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 zone where labor was not a limiting production factor, deforestation again might not result.

Kudzu improved fallows have a positive though not significant effect on total deforestation. When analyzing the type of deforestation, more statistically significant results showed that kudzu fallows decrease primary forest deforestation and increase secondary forest deforestation. While increasing total deforestation is not a desired outcome, the reduction of deforestation in the generally most highly valued areas, i.e. primary forest, is a positive environmental outcome. And although secondary forest deforestation increased, this is associated with an easing of the labor constraint permitting increased total production. This is favorable in terms of the goal of reducing poverty.

This paper 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 and total deforestation increased. This analysis can help policy makers understand the nature of the trade-offs in order to make better informed decisions. Moreover, this type of analysis can help analyze strategies for changing trade-offs to achieve outcomes desired by policy makers.

In general, improved fallows appear to have an important potential for reducing deforestation. In our simple model, kudzu improved fallows decreased total land use by 79% and 40% over 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.

There is a "labor paradox" of improved fallows in a land abundant environment with scarce labor and capital resources: reduced labor requirements leading to successful adoption also increase total deforestation. One possible solution is the introduction of an improved fallow that both uses more labor and simultaneously increases returns to labor. The principal way of increasing labor use and productivity with improved fallows is by using nitrogen fixing plants or trees that also produce a useful product. Shortened fallows would still decrease deforestation. At the same time, labor would be “absorbed” and labor returns would increase in the management and harvesting of valuable fallow products. In this manner, labor is drawn away from new land clearing. Priority areas for research should include identifying leguminous plants and trees with valuable products.

Slash and burn shifting agriculture uses lots of land and minimizes the use of scarce labor and capital resources. It is a rationale response by the zone’s farmers trying to maximize their production with relatively scarce capital and labor resources in a land abundant environment. Most of the improved production technologies introduced in the zone focus on reducing deforestation via soil conservation and/or increasing land productivity. This focus risks blinding researchers to the fundamental fact that land is not the constraining factor of production--labor and capital are.

Technologies that require increased use of relatively scarce and expensive capital and/or labor inputs to conserve relatively abundant and cheap land resources will typically fail. Kudzu improved fallow adoption has been successful precisely because it fits with the relative factor scarcity of the zone and offers a superior alternative to the current dominant practice (by reducing labor inputs while increasing yields). Research into the design of improved technologies needs to incorporate analysis of the returns to the limiting factors of production, labor and capital in the Pucallpa zone, if they are to be adopted by farmers.

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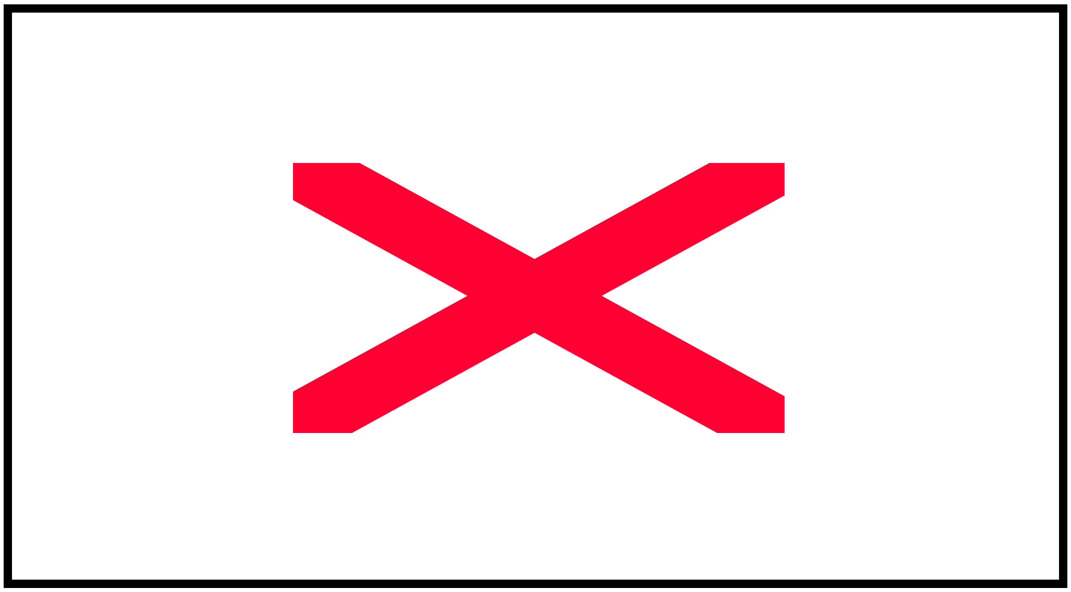
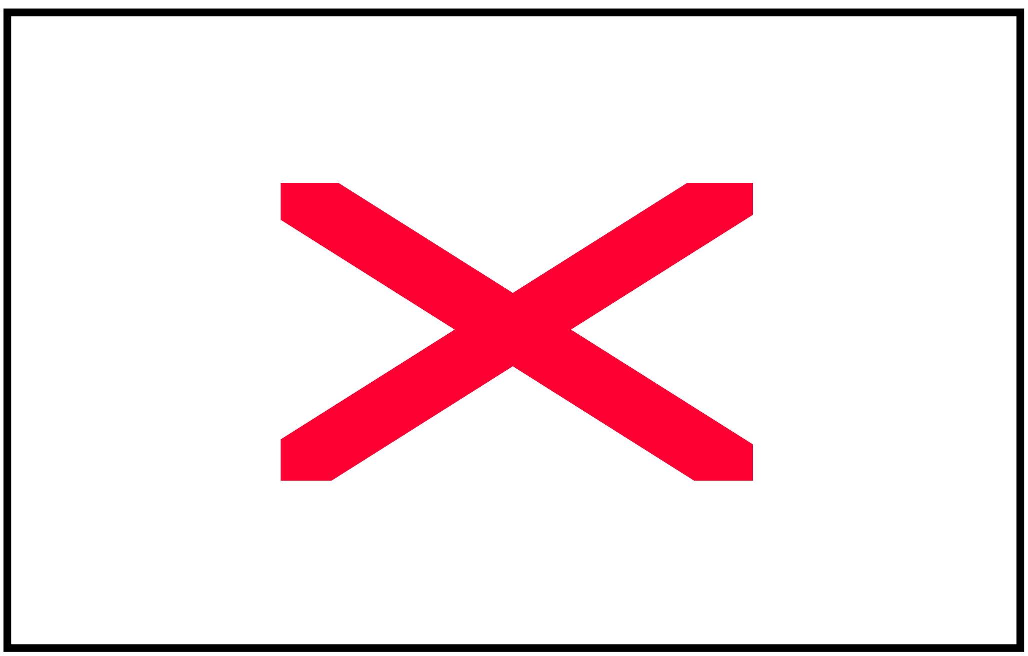
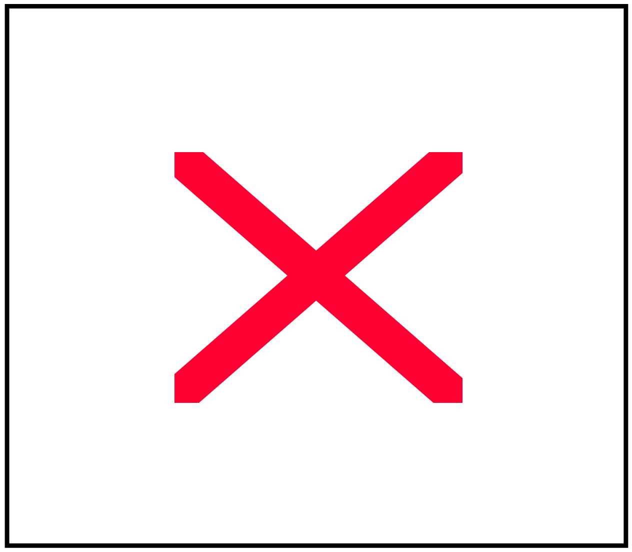
APPENDIX 1: GRAPHS



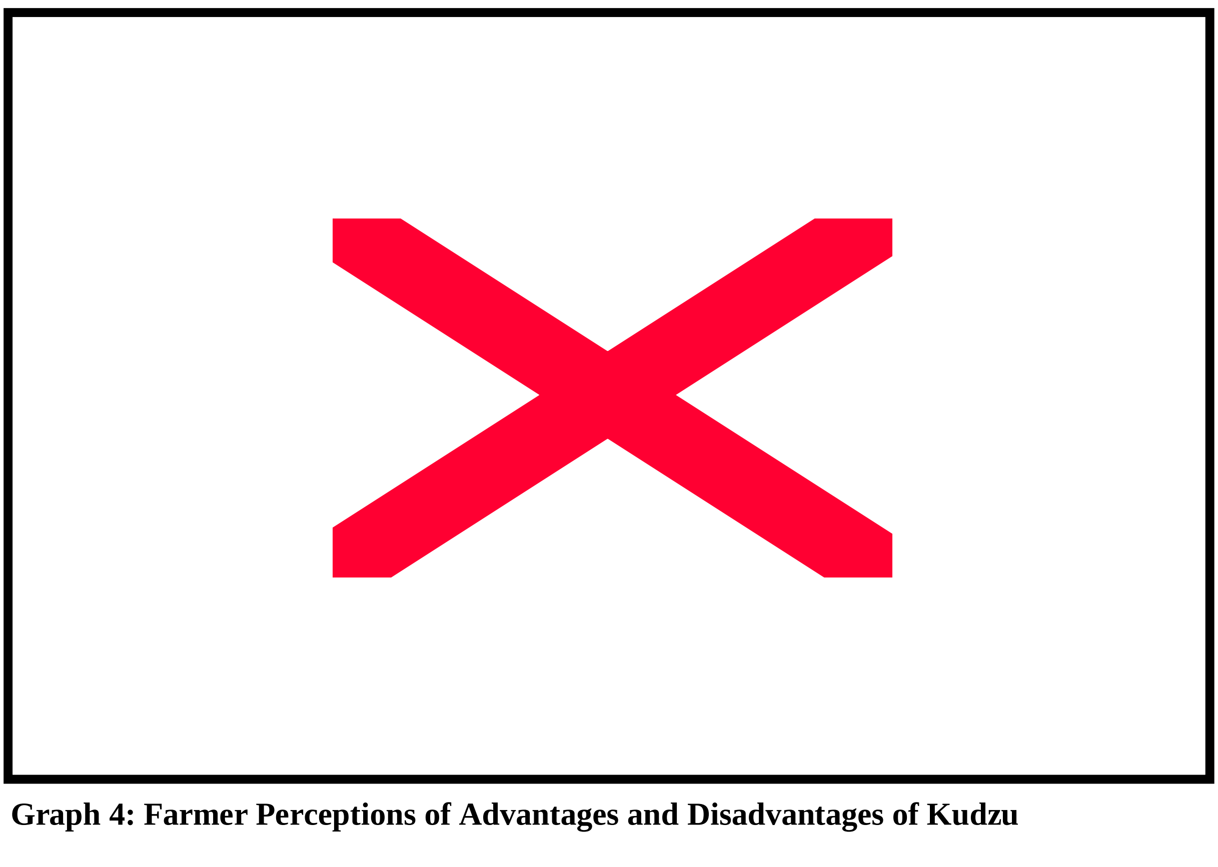
Graph 1: Dispersion of Farm Size



Graph 2: Farm Level Land Use Shares



Graph 3: Farmer Use of Improved Fallows



Graph 4: Farmer Perceptions of Advantages and Disadvantages of Kudzu

APPENDIX 2: VARIABLE DESCRIPTION

Dismkt:	Distance in kilometers to the principal market Pucallpa
Infra1:	Dummy variable, paved highway Federico Basadre (base reference)
Infra2:	Dummy variable, farm located on secondary roads
Infra3:	Dummy variable, farm located on tertiary roads
Infrario:	Dummy variable, farm located on river
Socinfra:	Distance in kilometers from nearest: (school + health post)
Famlab:	Number of family members working on the farm
Yrslot:	Number of years a farm has been in production (past & current owners)
Claysoil:	Dummy variable, clay soils dominant on farm (base reference)
Sandsoil:	Dummy variable, sandy soils dominant on farm
Riv1soil:	Dummy variable, highland river soils dominant on farm
Riv2soil:	Dummy variable, low flooded river soils areas dominant on farm
Farmsize:	Total hectares of the farm
Lowfal:	Hectares of low forest fallow (<5m)
Highfal:	Hectares of high forest fallow (>5m)
Primfor:	Hectares of primary forest
Annual:	Hectares of annual crops
Peren:	Hectares of perennial crops
Cattle:	Head of cattle
Hkudzu:	Hectares of kudzu improved fallows
Pastna:	Hectares of natural pasture
Pastbr:	Hectares of improved pasture with brachiaria
Capinp:	Value (soles) of capital inputs used in the past year
Hirelb:	Days of paid labor used on farm (includes labor exchange "minga").
%Prod:	% of farm in active production (pasture, annuals, and perennials)
Tenurepb:	Dummy variable, household head perceives tenure as insecure
Credit:	Dummy variable farm household received credit in the last five years
Noamaz:	Dummy variable, household head is not from amazon region
Edhigh:	Dummy variable, household head has secondary education or higher.
Female:	Dummy variable, female makes farm production decisions
Forprod:	Value (soles) of products harvested from the primary forest last year
Offince:	Value (soles) of off-farm income earned by household in the past year
Defor:	Hectares of forest cleared in 1998 (dependant variable)
Pdefor:	Hectares of primary forest cleared in 1998 (dependant variable)
Sdefor:	Hectares of secondary forest cleared in 1998 (dependant variable)

APPENDIX 3: REGRESSION MODEL RESULTS

Kudzu Improved Fallows				**Total Deforestation**		
Variables	**Standardized ß Coefficient**	**Significance**		**Variables**	**Standardized ß Coefficient**	**Significance**
1 (const)		.03		1 (const)		.83
Dismkt	.149	.13		Perenne	-.109	.09
Infra2	.059	.64		Annual	.499	.00
Infra3	-.139	.30		Cattle	.108	.17
Infrario	-.143	.35		Infra 2	.028	.76
Famlab	.160	.08		Infra 3	.061	.52
Yrslot	.182	.09		Infrario	.074	.44
Female	-.092	.27		Hkudzu	.038	.53
Sandsoil	.139	.13		Pastna	-.129	.05
Riv1soil	.019	.87		Pastbr	-.116	.15
Riv2soil	.138	.15		Capinp	-.144	.05
Credit	-.128	.12		Hirelab	.371	.00
Highfal	-.102	.29		Pbtenure	-.098	.10
Primfor	-.262	.07		Edhigh	.135	.03
Offinc	.012	.89		Female	-.044	.45
Annual	.084	.38		Noamazon	- .023	.72
Peren	.022	.81		Offinc	.015	.80
%Prod	-.133	.25		Famlab	.080	.21
Socinfra	.156	.10		Dismk't	.133	.04
Farmsize	.575	.00				
Cattle	.077	.48				
Edhigh	.145	.08				
	R^2 .39	**Adj R^2 .26**	///		**R^2 .54**	**Adj R^2 .49**

Adoption of Kudzu Fallows and Total Deforestation Regression Results

Primary Forest Deforestation				**Secondary Forest Deforestation**		
Variables	**Standardized ß Coefficient**	**Significance**		**Variables**	**Standardized ß Coefficient**	**Significance**
1 (Constant)		.31		1 (Constant)		.97
Peren	.000	.99		Peren	-.031	.69
Annual	.243	.01		Annual	.358	.00
Cattle	.054	.59		Cattle	.175	.07
Infra2	-.059	.61		Infra2	-.047	.67
Infra3	.051	.68		Infra3	-.084	.48
Infrario	-.183	.15		Infrario	.104	.39
Hkudzu	-.120	.14		Hkudzu	.110	.14
Pastna	-.001	.99		Pastna	-.194	.02
Pastbr	-.077	.45		Pastbr	-.181	.07
Capinp	-.133	.17		Capinp	.079	.40
Hirelab	.037	.66		Hirelab	.227	.07
Tenurepb	-.047	.54		Tenurepb	-.073	.33
Edhigh	.063	.41		Edhigh	.111	.14
Noamaz	.051	.54		Female	-.054	.46
Offinc	-.096	.22		Noamaz	-.037	.65
Famlab	.134	.10		Offinc	.017	.82
Primfor	.201	.02		Famlab	.103	.21
Lowfal	.041	.60		Primfor	-.132	.09
Highfal	-.111	.14		Highfal	.173	.02
Forprod	.105	.17		Forprod	-.071	.34
Dismk't	.170	.04		Dismk't	.005	.52
	R^2 .33	**Adj R^2 .23**	///	**R^2 .37**	**Adj R^2 .28**	

Primary and Secondary Forest Deforestation Regression Results