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Explaining the Adoption and Disadoption of Sustainable Agriculture: The Case of Cover Crops in Northern Honduras*

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I. Introduction

It has been estimated that by the middle of the next century, Central America's forests will have largely disappeared[1]. The prevalence of "slash-and-burn" (or swidden) agriculture in the region, like many other parts of the tropics, is widely held to be a primary cause. Slash-and-burn agriculture is not only a key contributor to tropical deforestation, but may adversely affect evapotranspiration and rainfall, contribute to greenhouse gas emissions, and threaten an important corridor for North-South species interchange[2.] At the local household level, it jeopardizes the livelihoods of farmers who depend on forest areas for fuelwood and threatens the viability of fragile soils and watersheds.

However, it is not the slash-and-burn clearing of land *per se* but, more generally, poor land management that causes primary damage to the environment[3]. If followed by a sufficient fallow period, slash-and-burn can be an effective strategy for improving the soil, managing weeds, and enabling resource-poor farm households to eke out a subsistence livelihood. Increasingly, however, lengthy fallows are proving unsustainable in Central America, as elsewhere. This results from a prototypical development path wherein poor or landless farmers migrate to public or open access lands on the agricultural frontier, cut down tropical forest areas and cultivate staple crops for several years before clearing new plots. As frontier areas develop, in-migration increases, progressively reducing the pool of available land and causing farmers to reduce fallow length. With more intensive land use and the frequent inability to purchase expensive fertilizers, land productivity declines, cultivation becomes economically unsustainable, and exhausted parcels are frequently sold to other farmers or ranchers[4]. This cycle makes the traditional swidden system an unsustainable method of maintaining soil fertility.

In recognition of the need for better management techniques, a substantial literature on "sustainable" alternatives to slash-and-burn agriculture has emerged in recent years[5]. One of the more promising techniques that researchers have rediscovered is "slash-mulch" agriculture, in which instead of annual double-cropping, the farmer fallows the land during one of the growing seasons, the accumulated biomass is then slashed and the following crop sown directly into the decaying plant matter. These cultivation systems confer numerous benefits: maintaining soil moisture, controlling weeds, reducing soil temperature, preventing erosion and enriching the soil[6]. Slash-mulch techniques reach maximum effectiveness when they are integrated with an improved fallow such as a leguminous cover crop.

During the 1970s and 80s, an effective slash-mulch system utilizing the legume, velvet bean (*mucuna ssp.*), spread over much of Northern Honduras[7]. Planted as part of the maize rotation, *mucuna* boosted maize yields through exceptional biomass production and nitrogen fixation, reduced labor use, mitigated the need for expensive fertilizers and herbicides, and enabled farmers to take advantage of higher dry season maize prices[8]. By enriching the soil, the maize-*mucuna* system enabled farmers to produce more maize on less land, reducing the

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need for slash and burn cultivation. The rapid spread of the maize-*mucuna* system in Honduras has generated widespread interest internationally among researchers, non-governmental organizations and sustainable development practitioners not only for its environmental and economic benefits but because it diffused rapidly and spontaneously from farmer to farmer with little or no outside intervention[9]. As the traditional "extension" model of technical assistance and farmer education has come under increasing criticism in the past decade for its inability to improve low-input agricultural productivity, researchers and practitioners have begun to emphasize the "farmer to farmer" model of research and technology diffusion, wherein farmer educators themselves teach their neighbors new and improved practices[10]. While the success of farmer-to-farmer technology diffusion elsewhere in Honduras has been widely documented[11], the spontaneous diffusion of maize-*mucuna* on Honduras' Honduras' North Coast has itself become one of the widely heralded "success stories" of sustainable agricultural technology diffusion[12].

In light of this background, a relatively recent phenomenon is rather striking—the widespread decline of the maize-*mucuna* system on Honduras' North Coast. Prompted by anecdotal reports from the region, survey-based research was initiated to document this decline and its causes. Initial results revealed that by 1997, farmers were abandoning the system at a rate exceeding ten percent per year. The central purpose of the research reported here is to explain the nature and extent of abandonment and to attempt to explain some of the factors that may be contributing to it. The lessons learned offer insights into the food security prospects of limited resource farm households and into the prospects for low external input agricultural practices to mitigate deforestation and improve natural resource management in areas of tropical agricultural intensification. The maize-*mucuna* experience also has important broader implications for the diffusion and durability of "sustainable" development practices.

After explaining the dynamics of the maize-*mucuna* system and describing some elements of the changing context of development in Northern Honduras, this paper selectively reviews the literature on technology adoption and sustainable agriculture diffusion. The empirical modeling approach employed here, bivariate probit, is applied to the two-step process of maize-*mucuna* adoption and abandonment. Empirical results from an extensive 1997 survey of maize-producing households are summarized, and the bivariate probit regression results of factors influencing maize-*mucuna* adoption and abandonment are discussed in the context of general approaches for the promotion of sustainable development practices.

II. Maize-*mucuna* vs. Traditional Maize Cultivation

In the moist climate of Northern Honduras, farmers can take advantage of two growing seasons, a wet season beginning in July and a dry season in December or January. Those cultivating maize using traditional methods typically plant both dry and wet season crops on the same plot for two years consecutively, after which the plot lies fallow for four years. The system is land-extensive; since a plot is cultivated for only two years, two additional plots are necessary to assure continuous maize production to meet household food and income needs. The system is also labor intensive, requiring anywhere from 24 to 35 days per *manzana*[13] for land preparation, planting, application of a pre-emergence herbicide, and manual weeding. Sometimes additional weeding is necessary. Traditional maize cultivation may also employ considerable purchased inputs: commercial fertilizers—urea or a formula fertilizer or both—and herbicides (2-4D and paraquat) which substitute capital for labor in weeding. Yields are generally low—one study indicating a total of 3349 kg/mza over the two years of cultivation[14] -- and risky[15].

Alternatively, the maize-*mucuna* system involves less investment of labor and capital than traditional maize farming. Thirty to forty days after clearing and planting a dry season maize crop, the farmer relays *mucuna* seed between the rows of maize. The bean sprouts and forms a thick layer of vines at the base of the maize stalks. After the dry season harvest, the *mucuna* gradually takes over the plot during the wet season, pulling down the dry maize stalks and engulfing the land in a sea of foliage. At the end of the season, when *mucuna* is at maturity, the farmer slashes the accumulated biomass and sows the following dry season maize crop directly into the decaying mulch. After the initial planting of *mucuna*, the dry season maize plot must be left fallow during each succeeding wet season so that the bean can develop. A plot improved in this way with *mucuna* is called an *"abonera."*

The system begins to yield benefits in terms of increased production and decreased labor in the second and third years. Farmers find it relatively easy to slash a stand of *mucuna* in preparation for planting, while the mulch layer smothers many of the weeds that compete with maize. Overall, *mucuna* has been estimated to reduce pre-harvest labor by 15-20% compared with the traditional system[16]. With fewer weeds there is less need for expensive herbicides. Neither are commercial fertilizers necessary, since a *manzana* of *mucuna* fixes nitrogen equivalent to that contained in 300 kg of urea[17] and produces green foliage with nutrients equivalent to nearly a ton of formula fertilizer[18]. *Mucuna* use provides all of these advantages even as it intensifies maize production. While the traditional system produces four harvests over six years on a single plot (including the four fallow years), a *manzana* of maize-*mucuna* can produce six harvests, one in each dry season, at yields that are far higher (50-100%) than the traditional system and much less risky[19]. The increased production may decrease pressure on farmers to exploit remaining farmland and thus assist in retaining the remaining tropical forests in the region.

III. Maize-*Mucuna* Adoption and Decline

In light of the apparent agronomic and economic benefits of the maize-*mucuna* system and the widely reported success of its dissemination, recent reports of its decline in Honduras have come as a surprise to many observers.[20] Buckles' 1992 study of adoption in Atlántida found that nearly 65% of maize farmers used the rotation, 19% had used the system in the past, and only 17% had no experience with maize-*mucuna*[21]. However, survey research for this paper reveals a dramatically different situation only five years later. Of the 370 farm households interviewed in the course of this research in 1997 -- covering many of the same villages in the Department of Atlántida surveyed by Buckles and colleagues five years earlier -- 45% of maize farmers interviewed reported having abandoned the maize-*mucuna* system, with only 39% continuing to use the system. Sixteen percent of farmers reported never having adopted its use. The system clearly appears to be in a process of long-term decline.

What is it about maize-*mucuna*—or perhaps, more appropriately, the setting in which it has been used—that has made it so widely and spontaneously accepted by farmers but later abandoned? Particularly in light of the prominence of widespread maize-*mucuna* adoption in the sustainable development literature, what does its subsequent disadoption tell us about the prospects for the use of low-input sustainable agricultural practices elsewhere, and the resultant lessons for researchers, development practitioners, and for farmers themselves? The answers to these questions are complex. Survey evidence and conversations with farmers, researchers and development practitioners reveal that there is no single overriding factor that explains the adoption-disadoption cycle of maize-*mucuna*. Rather, it is useful to consider three categories of factors: external factors; agronomic and climatological factors internal to the maize-*mucuna* system: and management-related issues.

External Factors

At least three types of exogenous structural changes are taking place in Northern Honduras that affect the viability of the maize-*mucuna* system: changes in land markets, distribution and tenure; the expansion of the cattle industry; and modernization of the infrastructure of Northern Honduras. Although maize-*mucuna* is a land intensive-system, it appears more vulnerable to changes in land distribution and tenurial arrangements than is traditional maize farming. Secure access to a given plot is necessary over the long-term, since the benefits of *mucuna* introduction are not realized until the second or third year, when soil organic matter improves and farmers reap the benefits of higher yields. In addition, because farmers must leave their *aboneras* in *mucuna*-fallow during the wet season, one or two additional plots are necessary for cultivating wet season maize[22]. Therefore, a minimum farm size of two to three hectares is necessary to enjoy the benefits of the maize-*mucuna* system.

However, over the last two decades, landholdings in Atlántida have tended to become both smaller and less secure[23]. In other words, even as the maize-*mucuna* system arrived in the early 1970s and began to take hold, it appears that the proportion of farmers with the minimum farm size necessary to effectively use the full rotation was decreasing[24]. Meanwhile, in the early 1980s, the Honduran government initiated a land titling program intended to stimulate land markets. Research suggests that rather than stimulating markets, however, the expensive, highly bureaucratic program created strong incentives for speculation in land such that titled farmers have been less willing to sell territory[25]. Passage of a national "Agricultural Modernization Law" in 1992 (part of a broader set of structural adjustment initiatives) may have exacerbated the problem[26], and, according to many observers, has boosted speculative land-buying. Paradoxically, land titling by largeholders may have generated greater tenure insecurity for subsistence farmers, who are no longer able to take advantage of former informal usufructory relationships with largeholders, while lacking the means to obtain title for their small parcels.

A second major change taking place in Northern Honduras has been the rise of extensive cattle production[27]. Cattle may have affected the maize-*mucuna* rotation in a variety of ways. It is possible, as some have suggested, that farmers are simply abandoning maize in favor of cattle production, which they may perceive as more profitable. However, agricultural census data do not indicate a decline in maize cultivation in recent years[28]. On the other hand, it may be the case that ranchers find the maize-*mucuna* system incompatible with pasture rotation, preferring to rotate maize land with pasture rather than commit a plot to *mucuna* for an extended period of time.

It is more likely, however, that the effects of cattle production on maize-*mucuna* have been primarily indirect, through input (land rental and labor) markets. The smallest farmers are able to dedicate their own plots to maize-*mucuna* if they can obtain rental land or off-farm labor alternatives to generate employment and income during the wet season, when the *abonera* must lie fallow. Landless farmers can use the system only if land markets offer long-term rental contracts. Our survey research and other evidence suggest, however, that rental markets in Atlántida have contracted in scope. The growth of cattle production has enabled large farmers to make use of immense tracts of land with dramatically lower labor requirements per hectare as compared with maize. As a result, rental land in many areas has become scarce, and long-term rental contracts rare[29]. Increasingly, then, land and labor markets may no longer offer the flexibility they once did to enable small and landless farmers to use the maize-*mucuna* rotation.

A third structural change that has taken place in Northern Honduras has to do with the relative profitability of maize and improvements in infrastructure on the North Coast. Notwithstanding structural adjustment and regional trade liberalization initiatives, real producer prices for maize have in fact risen somewhat in recent years[30] (Mendoza, 1998). The decline of maize-*mucuna* is, therefore, not associated with any downturn in maize prices.

Rather, the access provided by the paving and gradual improvement of a major highway that runs the length of the coast in Atlántida may have made maize less attractive relative to both other crops and to off-farm employment alternatives. Increased access to markets has raised land values such that, for some farmers, maize no longer covers the land's opportunity cost. Many have sold out to ranchers and citrus farmers willing to pay more for direct access to urban coastal markets. As a result, extensive pasture and fruit crops are now the most prevalent types of land use visible from the highway, a phenomenon called the "edge effect." It is possible, then, that the decline of maize-*mucuna* on the North Coast is merely the displacement of the system to more isolated plots further from the highway, where the opportunity costs of the land are much lower.

Climatic and Agronomic Factors

During the course of the research reported here, it became clear that two new aspects of the agronomic environment on the North Coast of Honduras are increasingly influencing the viability of the maize-*mucuna* system: the arrival of a particularly noxious weed and recent extremes of climate. Over the past two decades, itchgrass (*Rottboellia Cochinchinensis*) has spread throughout many parts of Honduras. Called "*invasor*" (the "invader") or "*caminadora*" (the "walker") by farmers, *rottboellia* is an erect, tufted annual grass capable of producing up to 2,200 seeds per plant[31]. The weed has disastrous effects on maize production, reducing yields anywhere from 50% to 72%[32]. Eradicating *rottboellia* is exceedingly difficult—burning infested plots tends to worsen the problem, and herbicides provide only a temporary reprieve. At the time of Buckles' 1992 survey, *rottboellia* was not yet well-established on the Atlantic Litoral[33], but has since become prevalent throughout the region. Despite the fact that research has shown a thick coverage of mucuna to be among the best defenses against *rottboellia*[34], the weed presents a serious threat to the viability of the maize-*mucuna* system. If gaps develop in the velvet bean coverage due to prolonged drought or poor management, *rottboellia* is quick to fill them. Farmers can address this process with vigorous weeding, but as a result the weed may rob the maize-*mucuna* system of its most important economic attribute: labor savings.

To make matters worse, the North Coast has experienced recent extremes of climate that may have pushed the maize-*mucuna* system to the limits of its resilience.[35] In the field research reported here, numerous farmers reported that the rainy season of 1996 brought so much water that the *mucuna* rotted in the pod. Others claimed that the drought that followed dried out their *aboneras* to such an extent that they never recovered. No controlled studies of *mucuna* resilience are available, but drought resistance is considered one of the velvet bean's more important virtues. Moreover, it is likely that the *aboneras* would have survived both heavy rains and a long drought had they been properly harvested and reseeded, an issue to be taken up in the next section[36].

Management Factors

Finally, two aspects of system management may be implicated in the decline of *aboneras*: failure to reseed *mucuna*, and inappropriate application of herbicides. Harvesting *mucuna* seed and reseeding the *abonera* at the beginning of the wet season is a critical step that the majority of maize-*mucuna* farmers neglect. Asked if they reseed, most farmers reply that "*el solo nace*" ("it comes up on its own")[37]. It may be that, before *rottboellia* became prevalent, an *abonera* could successfully reestablish full coverage without reseeding. Currently, however, the weed appears to take advantage of farmers' reliance on natural reseeding to exploit any gaps that appear in the foliage[38]. Moreover, it is likely that recent climatic disturbances—heavy rains followed by extended periods of drought—have served to increase the number and size of these gaps, making reseeding even more essential to the success of the system.

Along with the failure to reseed, inappropriate use of herbicide may hamper the growth of velvet bean. Each of the commonly used herbicides on the North Coast – Paraquat, 2-4D, and glyphosate ("Round-up") can cause serious damage to cover crops at high concentrations[39], although most farmers remain unaware of the danger. A prominent extensionist on the North Coast believes that misuse of these herbicides is the single most important contributor to the decline of *mucuna*[40] (L. Canas, personal communication). The increased presence of r*ottboellia* has made the problem still worse as the weed promptly fills the gaps in the *mucuna* coverage created by herbicides. It is also likely that *rottboellia* has itself stimulated greater use of the chemicals as farmers have sought to eradicate the weed.

IV. Factors Influencing Sustainable Technology Adoption

Due to its potential to increase production and household incomes and to enhance food security, an extensive literature has developed around the process of technology adoption[41]. However, the literature offers little in the way of research on technology abandonment, since it is typically considered to precede a new round of adoption in a "cycle of innovation"[42]. In the case at hand wherein farmers appear to be reverting to earlier, traditional methods rather than innovating, it is still the decision framework for technology adoption that is most useful for analyzing this process. Traditionally, developing country research has concentrated on Green Revolution-type technologies such as high yielding varieties (HYVs), fertilizers, and, to a lesser extent, machinery, irrigation and higher value crops. Classical technology adoption studies have generally posited a logistic curve path for adoption and have considered four kinds of factors influencing the rate and extent of adoption: family and demographic attributes of the farm household, such as age or education; the physical characteristics of the farm, usually soil, slope and farm size; economic factors such as input and output prices; and the institutional landscape, including the land tenure regime and the availability of extension and information services.

An expanding body of work focusing on farmer adoption of "sustainable agriculture" technologies and practices has also emerged in recent years. This literature considers many of the same factors influencing technology adoption, but generally focuses on low-input systems used by small, resource-constrained producers farming marginal lands. Most work thus far has addressed the adoption of practices and technologies such as cover crops ("green manures"), contour hedgerows, and zero tillage. Specific farmer characteristics have not generally been found to significantly affect adoption of these practices. A negative relationship between age and adoption of minimum tillage has been documented in Honduras, and between age and adoption of soil protection measures in the Phillipines[43]. Farm physical characteristics influencing technology adoption have been more widely considered. In Rwanda, farmers tended to invest in conservation efforts on slopes of medium grade, while in the Phillipines, adoption of hedgerows was less likely on parcels with greater soil depth or on older, exhausted parcels[44]. Some studies have considered the roles of both slope and soil quality in the adoption of improved soil management practices[45]. In the case of maize-*mucuna*, however, the use of soil quality variables in explaining adoption raises obvious endogeneity concerns, since mucuna improves the soil. Previous work does indicate, however, that slope is positively related to the establishment of an *abonera*[46].

Similarly, previous research has consistently shown farm size to be significantly related to the adoption of sustainable agriculture practices[47]. Sureshwaran, *et al.* find that adoption of soil improvement measures increases with farm size up to one hectare, after which size is no longer significant. Similarly, Buckles, *et al.* find a minimum farm size for adoption of *mucuna* around 1.6 hectares[48]. Small farmers appear hesitant to commit their only plot to *mucuna* if no other land is available for the wet season, a time when many farmers often plant upland rice[49].

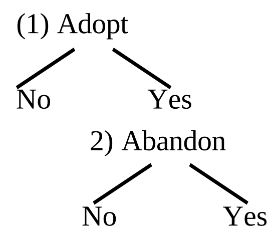
Among the most critical determinants of sustainable agriculture practices are the opportunity costs of labor and land. Previous work has shown that off-farm or non-farm income availability is negatively related to the adoption of contouring[50]. Especially important in the Honduran context is the opportunity cost of land use. Both Triomphe and Ruben, *et al.*, have argued that a chief threat to the future of the maize-*mucuna* system lies in generally low maize prices and low relative returns to maize cultivation compared to other crops[51]. Farmers able to rotate maize with pasture or to cultivate higher value crops, such as citrus or coffee, may be unwilling to make a multi-year commitment to an *abonera* that restricts production flexibility. This hypothesis appears to be supported by a significant, negative relationship estimated between pastureland and maize-*mucuna* adoption[52]. As noted above, these production shifts are more likely to take place where alternative land uses are most economically viable, such as on land proximate to the coastal highway in Northern Honduras, where market access is best.

Finally, research results are equivocal with regard to the importance of tenancy. In the Phillipines, landownership increases the likelihood of using soil protection measures, generally; land security is positively and significantly associated with hedgerow adoption, in particular[53]. Studies of maize-*mucuna* have produced similar results. A planning horizon of three to four years appears to be necessary to compensate for the investment in developing a *mucuna* plot[54]. It is unclear, however, whether formal title increases the incentive for using sustainable agriculture techniques. Neither possession of an official INA title nor even "perceived ownership" are found to be related to improved soil management practices[55].

Studies that have modeled technology adoption treat it as either a discrete or a continuous decision. Discrete choice analysis considers the factors that influence whether or not a farmer adopts a given technology, and continuous models analyze those that determine the extent of adoption. Most studies of technology adoption have used a dichotomous choice approach[56], although some studies have sought to include a continuous element[57], frequently using Tobit-based modeling approaches. Logit and probit approaches to modeling dichotomous choices account for the non-normal disturbance terms generated by the limited dependent variable, and yields estimators that reflect the marginal role of specific explanatory variables in explaining the probability of adoption.

V. Modeling Technology Adoption and Abandonment

Analyses of technology choice typically compare adopters and non-adopters in attempting to discern what characteristics of the farm, the household or the environment explain adoption. In the case of the maize-*mucuna* system, farmers on Honduras' North Coast have typically made two decisions: whether to adopt the system, and later, whether to abandon it. The initial adoption decision and the sustainable use of the technology once it has been adopted can thus be explained by two discrete sequential decisions with the following decision tree:



Regarding choice of models, the two most important aspects of the decision framework are the dichotomous dependent variables and the contingent nature of the decisions. Classical linear methods are inappropriate for dichotomous choices, since they can lead to heteroscedastic variances[58]. This problem is typically remedied by using maximum likelihood estimation (MLE). However, the contingent nature of the decision further complicates estimation. Coefficients of the abandonment equation should reflect not simply the factors affecting the probability of abandonment, but rather the factors that affect the conditional probability that a farmer will abandon, given that he or she has already adopted: $P(y_1=1 | y_2=1)$. Since the second decision is the reversal of the first, the disturbance terms of the two equations are likely to be correlated; that is, some unobservable characteristics, captured in the error terms of the adoption equation, are likely to influence the error terms in the abandonment decision. Heteroscedasticity in maximum likelihood estimation is also a potentially serious problem, leading to inconsistent estimators[59]. Moreover, the correlation *between* equations in this case may be of particular interest, since the disturbance terms may reveal how those unobservable factors associated with adoption are related to abandonment. Therefore, the dichotomous decisions and the contingent nature of abandonment require use of a model that allows for multiple (here, two) equations and which accounts for the correlation between their error terms.

In recognition of these factors, the bivariate probit model is employed in this analysis[60]. Bivariate probit allows for a continuous structure of utility between the decisions. It provides a correlation term, ρ, that represents how the unobserved characteristics affecting utility maximization implicit in the first decision are related to the second.[61] Moreover, the bivariate probit model may be modified to account for the sample selection problem inherent in the decision framework. It is not possible to abandon *mucuna* unless one has first adopted it; therefore, y_2 is not observed when y_1 is equal to zero. Adapted from Greene[62], the specification for a two-equation bivariate probit model with sample selection is given by:

$$\begin{aligned}
&z_{i1} = b_1' x_{i1} + e_{i1},\; y_{i1} = 1 \text{ if } z_{i1} > 0,\; y_{i1} = 0 \text{ if } z_{i1} < 0\\
&z_{i2} = b_2 x_{i2} + e_{i2},\; y_{i2} = 1 \text{ if } z_{i2} > 0,\quad y_{i2} = 0 \text{ if } z_{i2} < 0\\
&e_1, e_2 \sim \text{BVN}(0,0,1,1,p),\; \text{Var}e_1] = \text{Var}[e_2] = 1,\\
&Cov[e_1, e_2] = r, \qquad (1)\\
&(y_{i2}, x_{i2}) \text{ is observed only when } y_{i1} = 1
\end{aligned}$$

where z is a latent variable representing the utility the ith farmer receives from using maize-*mucuna* . The model considers the effect of the x_{ij} on three outcomes: the probability that a farmer adopts and continues to use the rotation, the probability that a farmer adopts and later abandons the system, and the probability that a farmer never adopts[63]. The probability of abandonment for the ith individual is the product of each of these individual probability density functions, more easily expressed in log form. Summing over all individuals in the sample gives the log likelihood function

$$\begin{aligned}
\ln L = &\sum_{y_1=1, y_2=1} \ln \Phi_2 [b_1' x_{i1}, b_2' x_{i2}, r]\\
&+ \sum_{y_1=1, y_2=0} \ln \Phi_{2\ i1}]\, [b_1' x_{i1}, -b_2' x_{i2}, -r]\\
&+ \sum_{y_2=0} \ln \Phi[-b_1' x_{i1}] \qquad (2)
\end{aligned}$$

Maximum likelihood estimates are obtained by taking the derivatives of the log likelihood function with respect to the coefficients and the correlation term

$$\frac{\partial \ln L}{\partial \beta_1} = \frac{\partial \ln L}{\partial \beta_2} = \frac{\partial \ln L}{\partial \rho} = 0 \qquad (3)$$

and setting them simultaneously equal to zero (Greene, 1990). The estimation software used here, LIMDEP 7.0, generates maximum likelihood coefficients, standard errors, and p values based on

$$W = \frac{\hat{b}_1}{\text{SE}(\hat{b}_1)} \qquad (4)$$

which exhibits a standard normal distribution. If the null hypothesis that $\rho = 0$ cannot be rejected, there is no correlation between the error terms of the two equations, and they may be estimated with separate probit specifications.

VI. Empirical Model Specification

For simplicity, y_1=1 will be assigned to the adoption decision and y_2=1 to continued use of maize-*mucuna*. Failure to adopt will, therefore, be indicated by y_1=0 and abandonment by y_2=0. In this way, positive coefficients in both decisions will be associated with increasing the probability of using *mucuna* maize, and negative coefficients with decreasing probability[64]. Two different equation specifications were estimated, represented in general form as follows (where y_1 = adoption; y_2 = abandonment/continued use):

$$\begin{aligned}
\text{y}_1 = &b_0 + b_1\text{ACCESS} + b_2\text{SECURE}\\
&+ b_3\text{FARMSIZE} + b_4\text{AGE} + b_5\text{BIGSLOPE} \qquad (5)\\
&+ b_6\text{MEDSLOPE} + b_7\text{WORKERS}\\
&+ b_8\text{VISEXTEN} + e_1
\end{aligned}$$

$$\begin{aligned}
\text{y}_2 = &b_0 + b_1\text{ACCESS} + b_2\text{SECURE}\\
&+ b_3\text{FARMSIZE} + b_4\text{AGE} + b_5\text{ INVASOR}\\
&+ b_6\text{RESEED} + b_7\text{WORKERS} \qquad (6)\\
&+ b_8\text{PROPSOWN} + b_9\text{HIGHVAL}\\
&+ b_{10}\text{NMZEINCO} + b_{11}\text{YRSUSE}\\
&+ b_{12}\text{OFFFARM} + b_{13}\text{CATTLE} + e_2
\end{aligned}$$

Only a limited number of variables can be included in the adoption equation because adoption took place on average more than eight years ago. This inter-temporal problem is addressed by using variables which are highly stable (access, farm size, plot slope, etc.) or which do not change across farmers over time (age). For the second step, the abandonment or continued use equation, variables that reflect current activities are included as regressors. Expected signs on the coefficients of the variables hypothesized to influence adoption and abandonment are summarized in Table 1.

Farm Size and Tenure Variables

Since they are assumed to be relatively fixed over time, farm size and tenure variables are included in both adoption and abandonment equations[65]. Given that a minimum farm-size, estimated at roughly three hectares, is necessary for efficient adoption of the maize-*mucuna* system[66], a positive sign should be associated with access to this minimum land area. Survey work and background research suggest that land rental markets in Atlántida have contracted such that rental land is difficult to obtain, and that in response to rising land values some farmers have felt compelled to sell off portions of their farms. This process should be reflected in a positive sign for the coefficient of the farm size variable ("FARMSIZE") in the abandonment equation as well. The variable characterizing land tenure security ("SECURE") distinguishes farmers who own land, formally (with INA title) or informally (through various usufructury arrangements, often with family members), from those who rent land. The latter are likely to have a shorter planning horizon than land-secure farmers[67]. Secure access should therefore be positively associated both with initial adoption and continued use of maize-*mucuna.* Again, survey work indicated that rental land is increasingly scarce and long-term contracts rare[68]. As demand for land increases on the North Coast, secure land rights are likely to become more important and those without title or other informal secure rights to land may be less willing to make investments in improving land with *mucuna,* which pays off primarily in the long run[69].

Community and Household Variables

In order to measure the impact of market access on production and labor decisions, communities were categorized according to their accessibility[70]. The coefficient of the binary variable "ACCESS" (measuring whether or not a farmer lives near a main road) should have a negative sign in both the adoption and abandonment equations, since the opportunity cost of land dedicated to maize production is higher closer to a main road. The signs of the household variables representing age of head of household and household labor availability are more difficult to predict, however. Though previous research has often revealed a negative relationship between age and likelihood of adoption due to younger farmers being presumably more willing to innovate, older farmers have had more time to observe the maize-*mucuna* system and to experiment with it on their own land. In considering whether to continue to use or abandon the technology once adopted, older farmers may be less willing to continue given the heavy labor requirements and greater likelihood of infirmity, but are also more experienced in maize-*mucuna* management and thus may be more likely to follow improved practices such as reseeding and proper herbicide use. Thus, in the cases of both initial adoption and subsequent abandonment, the effects of age appear uncertain, *a priori*. Similarly, it is unclear whether lower labor requirements in the maize-*mucuna* system would appeal mainly to households with lower family labor availability (variable "WORKERS"), thus a negative expected relationship, or whether higher marginal labor productivity in the maize-*mucuna* system would encourage greater numbers of household members to work on the farm, a positive relationship. Lastly, the literature strongly suggests that the visit of an extensionist ("VISEXTEN") should bear a positive sign in explaining the likelihood of adoption[71], although once adopted, it is not clear that this factor would play a role in the abandonment decision.

Table 1. Description of Explanatory Variables and Expected Signs

Explanatory Variable	Description	Expected Sign for Adoption	Expected Sign for Continued Use
ACCESS	1 if farmer lives near a main road, 0 otherwise	-	-
SECURE	1 if farmer has secure access to land, 0 otherwise	+	+
AGE	age of the household head	?	?
FARMSIZE	1 if a farmer has access to least 3 hectares of land; 0 otherwise	+	+
BIGSLOPE	1 if main maize plot has >40% slope, 0 otherwise	+	
MEDSLOPE	1 if main maize plot has 10-40% slope, 0 otherwise	+	
INVASOR	1 if farmer has problems with *rottboellia*, 0 otherwise		-
RESEED	1 if farmer reseeds (or reseeded) the *abonera* yearly, 0 otherwise		+
HIGHVAL	1 if farmer grows a high value crop, 0 otherwise		-
PROPSOWN	Proportion of a farmer's gross cropped area planted to maize.		+
YRSUSE	Number of years the farmer has used maize-*mucuna*		+
NMZEINCO	Non-maize income (1000 Lempiras)		-
CATTLE	Number of cattle on the farm		-
OFFFARM	1 if a household member performs off-farm work, 0 otherwise		?
VISEXTEN	1 if a farmer has received the visit of an extensionist, 0 otherwise	+	
WORKERS	number of laborers resident in the household who work on farm	?	?
ρ	Correlation term between decisions		?

Economic Variables

Several economic variables are included in the maize-*mucuna* abandonment equation to assess the effect of farmer diversification into other activities which may reveal differences in farmer land use and labor allocation. Since the growing of higher value crops ("HIGHVAL") may imply decreased dependence on maize income and a shift in land allocation away from maize, the effect on continued use of maize-*mucuna* is expected to be negative[72]. Conversely, those farmers who allocate a greater proportion of their cropped area to maize (variable "PROPSOWN") are expected to continue using *mucuna*, with a positive expected coefficient[73]. The influence of off-farm labor is less clear. While the literature suggests that off-farm income availability may enable the smallest farmers to focus on maize-*mucuna* in the dry season, it may also imply a decline in a farmer's reliance on own-farm production that could be associated with *mucuna* abandonment. Therefore, the predicted sign for the OFFFARM variable (measuring whether a family member works off-farm during the year or not) is uncertain.

Inclusion of the continuous variable measuring household non-maize income ("NMZEINCO") represents a more direct attempt to measure shifts in emphasis away from maize. It is assumed that those farmers who derive greater income from non-maize sources will manifest less interest in investing in a more productive, sustainable technique for maize production. The sign on the coefficient of variable "NMZEINCO" is, therefore, expected to be negative. The continuous variable measuring number of cattle on the farm should also yield a negative coefficient, since each additional animal implies a greater need for pasture land and pasture rotation, as well as a relative shift in emphasis away from maize.

Other Farm Characteristics

Since the maize-*mucuna* system requires no tillage and prevents erosion, it is particularly appropriate for hillsides. The coefficients of both of the dummy variables representing plot slope --"BIGSLOPE" ("1" for plots of greater than 40% grade, "0" otherwise) and "MEDSLOPE" ("1" for plots of 10% to 40% grade, "0" otherwise) -- should be positive, since reduced tillage and the anti-erosive qualities of *mucuna* should appeal more than on flatter plots. Once adopted, there is no *a priori* reason to include these variables in assessing the decision to continue using maize-*mucuna* . On the other hand, the variable "INVASOR", indicating that the farmer has experienced problems with *Rottboellia Cochinchinensis*, is appropriate only for the abandonment decision, since *Rottboellia* was not highly prevalent on the North Coast when most farmers adopted. The expected sign on its coefficient is clearly negative, since *Rottboellia* can severely jeopardize the viability of maize-*mucuna* plots.

System Management Variables

The practice of reseeding *aboneras* (variable "RESEED"), particularly in the presence of *rottboellia*, is an important element in maintaining the productivity of the system, and is an indicator of management ability. The sign on its coefficient in abandonment equation should unambiguously be positive[74]. The length of a farmer's experience with maize-*mucuna* is reflected in the variable "YRSUSE." Those farmers who have used the system for a longer period of time are expected to have a greater understanding of and experience with the technique and (likely) a greater appreciation of its benefits compared to recent adopters. They are more likely to have developed adequate management practices for coping with agronomic threats to the system. Length of experience with *mucuna* should therefore have a positive influence on continued use of the system.

Correlation term "r"

The correlation term between the errors from the adoption and abandon/continue equations is a complex aspect of the analysis and deserves discussion. Since $y_2=1$ is associated with continued use of the system, a positive sign on its coefficient would indicate that the unobservable characteristics that led farmers to adopt are the same ones that contribute to continuance of the system. A negative estimated sign would suggest that these unobservable factors contribute to abandonment. This question gets at the heart of the analysis of the maize-*mucuna* system, since it requires a broad conception of the motivations behind a farmer's interest in the practice and how those motivations are related to the decision whether or not to abandon. For example, no variable in the empirical model adequately captures the degree of a farmer's labor-aversion. If a farmer adopted the maize-*mucuna* system principally for the labor savings it provides, presumably that fact would contribute to continued use of the system and a positive "ρ." On the other hand, if the system ceased to offer significant labor savings or if a less labor-intensive activity had become available, one would expect the correlation term to be negative. Therefore, the expected sign on the correlation term "ρ" is uncertain.

VII. Survey Design and Summary Statistics

The data used to estimate the model were gathered through a survey of 370 farm households during June-August, 1997. The survey collected extensive data on land use, agricultural production systems (emphasizing *abonera* management), and relevant demographic information. Twelve villages were selected as broadly representative of maize-growing communities in Atlántida, six located in the same municipality of Jutiapa where the earlier work of Buckles and collaborators had focused and six elsewhere in the department to try to discern the generalizability of the abandonment process across the North Coast. In order to capture the "edge effect" -- the influence of infrastructure development on production decisions -- communities were selected in pairs, one close to the paved highway or main access road and the other relatively more isolated[75]. Within communities, farmers were selected at random, with roughly thirty respondents per site[76]. The sample was not restricted to maize growers. Yet, nearly every household in the sampled communities, even those who had abandoned the maize-*mucuna* system, cultivated at least some maize[77].

The figures in Table 2 report summary statistics from surveyed farm households separated into three groups: adopters of the maize-*mucuna* system, abandoners, and non-adopters[78]. The sample data reveal striking differences between the three groups as well as surprising similarities. The characteristic that immediately distinguishes most non-adopters is lack of land ownership. Often landless, they are forced to rely on rental plots, the scarcity of which explains their significantly smaller farm size. Between adopters and abandoners, however, there is little difference in terms of landownership (formal or informal), the proportion renting land, or farm size[79].. One might expect more pronounced tenure and farm size differences, given that 25% of those abandoning maize-*mucuna* gave lack of ownership as a reason for discontinuing maize-*mucuna* (that is, that the landlord had reclaimed their *aboneras*) and 18% indicated that they had sold land or moved (Table 3).

The data do not reflect a significant distinction between adopters and abandoners until we consider land use. Though their average farm sizes are roughly equal, adopters plant significantly more cropland, both in gross and net terms, than abandoners or non-adopters[80]. Much of this difference is attributable to maize -- adopters plant, on average, nearly 30% more maize area than abandoners and 63% more than non-adopters, and sell a much greater proportion of their dry season harvest. In addition, their yields and profits are significantly higher and their variable costs much lower.

Total income figures were highly variable and did not reflect significant differences, although the sources of earnings did vary among the three groups. Adopters earned significantly more of their total income from farming and significantly less from off-farm activities. Contrary to expectations, however, there were only modest differences between adopters and abandoners with regard to the cultivation of high value crops and cattle ownership, alternatives largely unavailable to non-adopters since most do not own land. Another marked difference between the three groups of survey respondents is reflected in the effect of road access on land use. Abandoners and non-adopters were far more

Table 2. Mean Comparisons of Adopters, Abandoners and Non-Adopters

	Adopter	Abandoner	Non-adopter
Owns Land (Formally or Informally)	79%	71%	33%
Rents or Farms Land on Loan	21%	29%	67%
Farm Size (Mzas)	16.47	15.7	4.69[a]
Net Cropped Area (Mzas)	4.92 [a]	3.66 [a]	2.29 [a]
Gross Cropped Area (Mzas)	5.24 [b]	4.35 [b]	2.93 [a]
Gross Maize Area (Mzas)	4.01 [a]	3.2 [d]	2.45 [d]
Dry Season Maize Sold	37%	23%	27%
Total Dry Season Maize Profit (L/Mza)	2065 [a]	1014 [a]	1258 [a]
Variable Cost of Dry Season Maize (L/Mza)	1147 [e]	1271	1290
Total Dry Season Maize Yield (Ton/Mza)	2.21 [f]	1.62	1.79
Average Total Income (L)*	26,181	24,452	19,419
Farm Income	82%[a]	71%	62%
Off-farm Income	18%[a]	29%	38%
Grows High Value Crops	15%	11%	7%
Owns Cattle	40%	37%	17%
High Access	41%	59%	72%
Age of Household Head	42.71 [b]	46.88 [c]	40.78
Rottboellia problems	58%	69%	50%
Reseed(ed) Abonera	49%	21%	NA
Years of Mucuna Use	7.25[g]	5.84 [g]	NA

[a] different from the other two means, Bonferroni test at α=0.01
[b] mean for adopter different from abandoner, Bonferroni test at á=0.05
[c] different from the other two means, Bonferroni test at á=0.05
[d] mean for abandoners different from non-adopters, Bonferroni test at á=0.05
[e] different from mean for abandoners at 0.05 and mean for non-adopters at 0.1
[f] different from mean for abandoners at 0.01 and mean for non-adopters at 0.1
[g] means different, two-tailed t-test of independent samples at á=0.05 $1≈ 13 Lempiras

Table 3. Farmers' Stated Reasons for Abandonment

Reason for Abandonment	Proportion of Abandoners*
Rottboellia (or other grasses)	27%
Landlord Reclaimed Plot	25%
Sold Land or Moved	18%
Prefers Pasture or Other Crop	11%
Drought, Excess Rain or Landslides	11%
Herbicide/Inadequate Maintenance	8%
Insufficient Land	4%
Other	3%

*Due to multiple responses in some cases, percentages do not sum to 100.

likely to live in communities with relatively good road access, while adopters tended to live in more remote areas.

Lastly, the data indicate notable differences between farmers in terms of weed management. Far more abandoners mentioned problems with *Rottboellia* than did adopters. Significantly, 27% of them cited problems with the weed as among their primary reasons for abandonment. Adopters were much more aware of the importance of reseeding an *abonera* than abandoners, most of whom did not reseed yearly during the time they used the maize-*mucuna* system. Enumerators were surprised at the frank admissions by some eight percent of abandoners that they had lost their *aboneras* through poor care or indiscriminate use of herbicide. Better management practices may be part of the reason why adopters had generally used the system for a significantly longer period of time than abandoners[81].

VIII. Empirical Results

Recall that y_i=1 corresponds to adoption and to continued use of *mucuna*-maize, and y_i=0 to abandonment or failure to adopt, so that positive coefficients in both decisions are associated with an *increasing* probability of using maize-*mucuna*, and negative coefficients with a *decreasing* probability. In interpreting the estimated coefficient results, it should also be noted that, rather than reflecting the magnitude of the impact on y of a marginal change in x_j, the coefficients indicate the impact of x_j on the bivariate normal distribution of y, an impact that is not the same for all x. Interpretation of the correlation term is somewhat more straightforward. If ρ is significant, than the unobservable attributes that affect the decision to adopt are also relevant for the decision to continue using *mucuna*. In order to test the robustness of the maximum likelihood estimators, two specifications of the bivariate probit model for adoption and abandonment of the *mucuna*-maize system are reported below (Table 4). Care was taken not to include potentially collinear variables in the same specification.[82] Coefficient estimates exhibit a high degree of robustness, both in terms of magnitude and statistical significance.

Overall, model results largely confirm previous findings regarding initial adoption of the maize-*mucuna* system. Significant and positively signed coefficients for farm size and tenure security are as expected, confirming Buckles, *et al.*'s earlier results that possession of a minimum threshold farm size and a long-term planning horizon are critical for adoption. Improved road access to farming communities is negatively associated with maize-*mucuna* adoption; easier road access increases the economic viability of alternative productive uses of labor and land and thus increases the opportunity cost of committing resources to a long-term land use like maize-*mucuna.* Variables measuring the increasing slope of maize land also exhibited positive and significant effects on adoption, again as expected. Household labor availability was positively and significantly associated with maize-*mucuna* adoption, suggesting that although *mucuna* use involves less labor use per hectare, *overall* household labor constraints likely limit its adoption. Neither variables representing age of head of household nor visitation by an extensionist proved significant in the adoption equation. The former result was not unexpected (Table 1); the latter can be explained by the fact, as noted previously, that dissemination of cover crop use on Honduras' North Coast has been largely spontaneous, not necessarily spurred by formal extension programs.

Results for the second step of the adoption-abandonment process, the conditional decision to abandon or maintain *aboneras* in maize-*mucuna*, are also presented in Table 4. These results generally support the case that significant effects external to the maize-*mucuna* system have been largely responsible for *mucuna* abandonment. The age of the household head is negatively and significantly associated with continued maize-*mucuna* use, perhaps reflecting a declining interest in commercial maize production due to the physical demands of cultivation, an increase in the viability of non-maize alternatives over time, or the provision by younger farmers for their elderly parents. This interpretation is consistent with the fact that abandoners tend to plant less maize area.[83] Road access to the community of residence also

Table 4. Bivariate Probit Coefficient Estimates for Adoption and Abandonment

		Model 1		Model 2	
Decision	Variable	Coefficient Estimate	Standard Deviation	Coefficient Estimate	Standard Deviation
Adopt	Constant	-0.7255	*0.4495*	-0.7140	*0.4420*
	ACCESS	-0.3793[c]	*0.1947*	-0.3852[b]	*0.1937*
	SECURE	0.8202[a]	*0.2269*	0.8127[a]	*0.2278*
	FARMSIZE	0.4548[c]	*0.2352*	0.4657[b]	*0.2352*
	AGE	0.0047	*0.0079*	0.0045	*0.0077*
	BIGSLOPE	0.7280[b]	*0.3188*	0.6992[b]	*0.3145*
	MEDSLOPE	0.7644[a]	*0.2955*	0.7669[a]	*0.2904*
	WORKERS	0.1982[c]	*0.1119*	0.2102[c]	*0.1124*
	VISEXTEN	0.4890	*0.3370*	0.4531	*0.3405*
Abandon	Constant	0.4889	*0.5557*	0.3899	*0.5640*
	ACCESS	-0.3226[b]	*0.1613*	-0.2925[c]	*0.1605*
	SECURE	-0.2539	*0.2621*	-0.3074	*0.2578*
	FARMSIZE	0.0058	*0.1917*	-0.0221	*0.1972*
	AGE	-0.0151[a]	*0.0054*	-0.0160[a]	*0.0052*
	INVASOR	-0.2780[c]	*0.1501*	-0.2961[c]	*0.1534*
	RESEED	0.8084[a]	*0.1608*	0.7420[a]	*0.1603*
	WORKERS	-0.0604	*0.0754*	0.0102	*0.0756*
	PROPSOWN	0.8472[c]	*0.4553*	0.9129[b]	*0.4647*
	HIGHVAL	0.5839[b]	*0.2769*	0.6122[b]	*0.2822*
	NMZEINCO	-0.0035	*0.0039*		
	YRSUSE			0.0256[c]	*0.0149*
	OFFFARM	-0.1999	*0.1661*	-0.2480	*0.1643*
	CATTLE			-0.0117	*0.0091*
	Correlation (ρ)	-0.8890[a]	*0.1889*	-0.9172[a]	*0.1578*
Log Likelihood		-307.00		-302.69	
Likelihood Ratio Test		67.03[a]		66.44[a]	
Likelihood Ratio Index		0.0984		0.9890	

[a] significant at the α=0.01 level
[b] significant at the α=0.05 level
[c] significant at the α=0.10 level

proved to be a powerful factor explaining the abandonment decision. Farmers living near a primary road were less likely to adopt and, having adopted, were significantly less likely to continue using the maize-*mucuna* rotation.[84] It is important to note that all of the abandoners in high access areas continue to grow maize, but what they grow is principally for subsistence rather than for sale[85].

The results for the explanatory variables reflecting economic alternatives to maize are consistent with this story. The proportion of land sown to maize is positively and significantly associated with the continuation of maize-*mucuna* use, indicating that households having a continued orientation to maize production in general are less likely to abandon the maize-*mucuna* system. Moreover, the significant positive estimated relationship between the cultivation of high-value crops (notably, coffee and citrus) with the continued use of maize-*mucuna* also suggests that a more commercialized orientation to agriculture in general appears to complement maize-*mucuna* use.

Estimation results also confirm the critical importance of both agronomic factors and farmer management in abandonment of the *mucuna*-maize system. Whether farmers have experienced problems with the weed, *rottboellia*, exerts a significant negative influence on continuation of the rotation. At the same time, improved management practices — notably, the practice of annual reseeding of *mucuna* — is positive and significantly related to farmers'continuing to use the system, as is the number of years of maintaining with the rotation, likely reflecting the role of farmer experience and presumably the higher yields achieved through its use (Table 2).

Contrary to expectations, changes in labor and land rental markets were not reflected in the significance of farm size and land access variables in accounting for maize-*mucuna* abandonment. Both variables may have been affected by the inability to capture out-migrants in the survey or by the low proportion of very small farmers in the sample. Even more likely, the variables are inadequate proxies for the complex changes taking place in land markets in Atlántida. The lack of significance of land security in the abandonment equation is consistent with results obtained in other studies, as well as qualitative evidence, which suggest that formal title may be associated with speculative rather than necessarily productive land uses[86]. The estimated coefficients obtained for off-farm labor are not statistically significant, likely reflecting the offsetting effects of these factors for continued maize-*mucuna* use (see Table 1 and accompanying discussion). It is uncertain whether households with members working off-farm are likely to farm their land less intensively over the short term (leaving a dry season plot in *mucuna* fallow for the wet season), or to shift away from agriculture entirely. For similar offsetting reasons, household labor availability is not significant in the abandonment decision[87].

Whether farmers have experienced problems with the weed, *rottboellia,* exerts a significant negative influence on continuation of the rotation. At the same time, improved management practices – notably, the practice of annual reseeding of *mucuna* -- is positive and significantly related to farmers'continuing to use the system, as is the number of years of maintaining with the rotation, likely reflecting the role of farmer experience and presumably the higher yields achieved through its use (Table 2).

Surprisingly, the number of cattle a farmer owns proved insignificant with regard to maize – *mucuna* abandonment[88]. The growth of the cattle industry may have indirect effects on the sustainability of maize-*mucuna*(specifically via land markets), but it does not appear that, for individual households, cattle ownership is at all incompatible with use of the system[89]. Finally, the significance of ρ indicates a high degree of correlation in the disturbance terms between the two equations, suggesting that the model could not have been estimated efficiently using separate probit models. That ρ appears to be an important feature in each of the models also serves as *post hoc* justification for use of the bivariate probit versus the nested logit model, which provides no such readily observable measure of correlation. Results for summary statistics, the Likelihood Ratio Test (G) and the Likelihood Ratio Index (LRI) are also reported in Table 4[90]. The likelihood ratio test indicates that each of the specified models is highly significant[91].

Marginal Effects

Since this research is primarily concerned with the abandonment phenomenon, marginal effects were computed only for the key variables in the second equation[92]. Initially, all dichotomous variables are set at zero and continuous variables at their means. For dichotomous variables, the values in Table 5 show the impact when the variable is allowed to take the value of 1, all other variables unchanged. For continuous variables, the values in the table show the average impact when the variable is allowed to vary over a specified range, all other variables unchanged[93].

Table 5. Estimated Marginal Effects of x_j on $P(y_2=1| y_1=1)$

Variable	Average Change in $P(y_2=1 \mid y_1=1)$
ACCESS	-0.12
AGE	-0.02
INVASOR	-0.10
RESEED	0.19
PROPSOWN	0.03
HIGHVAL	0.16
YRSUSE	0.01

Taken together, these results suggest that continued use of maize-*mucuna* may be related to a household's orientation to agriculture generally, and to maize cultivation specifically. Farmers cultivating high-value crops are 16% more likely to continue using the maize-*mucuna* system, and for every 10% increase in the proportion of cropland a farmer plants to maize, the probability of rotating with *mucuna* increases by roughly three percent. These results may at first appear to be contradictory. How can diversification into higher value crops as well as a greater dedication to maize cultivation be associated with use of the system? First, it should be noted that only 15% of farmers in the sample grow high value crops, limiting their influence on the proportion of maize sown.[94] Second, descriptive statistics reveal that adopters grow and market relatively more maize than abandoners. Together, then, the results suggest that farmers who maintain a production orientation to maize production, and indeed to agriculture in general (as indicated by the positive effect of high value crops), are more likely to use the maize-*mucuna* system. As expected, a significant negative impact on the maize-*mucuna* system comes from the weed, *rottboellia.* Other factors held constant, households that have problems with the weed are on average 10% less likely to continue using the *mucuna*-maize rotation than those not experiencing this problem.

Perhaps the most compelling results stemming from the marginal effects estimates are those that reflect farmer management practices. Recent extremes of climate and the arrival of *rottboellia* may have hampered the ability of *aboneras* to renew full coverage year after year. Drought or herbicide may cause gradual thinning, while grassy weeds quickly take advantage. However, the effects of these influences should be mitigated by annual reseeding of the *abonera*, a practice which modeling suggests is strongly related to continued use of the maize-*mucuna* system. Farmers that reseeded their plots are, on average, nearly 19% more likely to maintain the system. The significance of the variable representing years of experience with maize-*mucuna* appears to confirm the importance of proper management. For every year a farmer has practiced the rotation, the likelihood of continuing its use increases by just over one percent. While the magnitude of the effect is not dramatic, this, together with the reseeding results, suggest that farmers with better management practices are able to sustain the system for a longer period of time[95].

IX. Conclusions and Implications

On Honduras' North Coast, the revival of slash-mulch techniques involving leguminous cover crops seemed capable of mitigating the cycle of soil degradation and migration that is destroying Central America's forests. The spontaneous diffusion of the technique and its prominence in the literature has encouraged researchers and development practitioners promoting similar methods in Central America and elsewhere. The results presented here suggest caution in the promotion of specific technologies or practices as panaceas. Yet the adoption and decline of maize-*mucuna* offers valuable insights into the factors that may condition the success of these and other low-input "sustainable" agricultural practices.

Broadly, the results suggest that the sustainability of technology adoption is determined not only by fundamental agronomic characteristics, but the economic context framing household decision-making and by the knowledge and understanding of decision-makers. Descriptive and econometric results confirmed the almost universal appeal of the maize-*mucuna* system in Atlántida. Fully 84% of respondents had experience with the system. Among those who had never used the technique, landless renters predominated. Model results confirmed the critical importance of secure land tenure and access to a minimum farm size of roughly three hectares for the initial adoption of maize-*mucuna*.

Abandonment of maize-*mucuna* proved to be a complex phenomenon, stemming from a wide range of internal and external factors. On the one hand, several important processes taking place on the North Coast of Honduras were not demonstrably related to abandonment. Variables representing changes in tenure security, shifting land markets, and the rise of extensive cattle do not, based simply on statistical evidence, appear to exert significant influence on maize-*mucuna* abandonment[96]. Far more relevant appear to be the production orientation of farmers and infrastructure development. Farmers who continue to use *mucuna* tend to grow more maize and to depend more on on-farm income. Econometric results suggest that road access plays a critical role in determining that orientation, given the higher opportunity costs of land and labor where market access is greater and alternatives to maize are economically viable.

As long as we define utility in terms of income, however, it is not sufficiently clear why a farmer would choose to abandon maize-*mucuna*, the more profitable system of production. Abandoners do not make more money on average than adopters. The decision to substitute one income source for another implies a disutility associated with maize cultivation, a notion that is easy to understand in the context of the steep hillsides of the Nombre de Dios range. Fifty-five percent of farmers sampled said they grew maize "*para el gasto*"("for basic needs") or "*para no comprarlo*"("so as not to buy it"). Given other opportunities to earn income, abandoners would prefer to grow less. Still, the connection to abandonment remains a tenuous one. Farmers need not abandon maize-*mucuna* simply because they cultivate less total maize area. Indeed, a paradox revealed by this research is that maize-*mucuna* is less labor-intensive and should, therefore, be the preferred system of farmers who would prefer to spend more time working off-farm. But it is, in fact, abandoners who tend to work more off-farm, while adopters devote a larger proportion of their labor time to on-farm activities.

The arrival of the weed, *Rottboellia cochinchinensis*, on the North Coast helps to explain this paradox. A higher proportion of abandoners cited the weed as a problem than adopters, and estimation results indicate a significantly negative effect on the system. The weed may have worked in tandem with recent droughts or with herbicides, quickly filling gaps in the *mucuna* coverage and rendering the system less effective. Most importantly, it has likely robbed maize-*mucuna* of its two most desirable benefits: higher land productivity and lower labor use. Rather than invest considerable labor to free their *aboneras* of the weed, farmers may find it more economical simply to spray herbicide or even burn the plot.[97] *Rottboellia's* effects may also help explain the high correlation between the decision to adopt and the decision to abandon. The results suggest that the same unobservable characteristics of farmers that led them to adopt are those that also cause them to abandon. If farmers adopted for the labor-savings associated with maize-*mucuna* or to pursue intensive, commercial maize production, it is conceivable that these same goals compelled them to pursue alternative methods and sources of income generation when *rottboellia* made maize more labor intensive and less profitable.

Finally, both descriptive statistics and econometric modeling suggest that farmer management practices have contributed to the decline of the maize-*mucuna* system. Levels of herbicide application could not be included in the econometric modeling given obvious concerns about endogeneity[98]. The practice of annual reseeding could be modeled, however, since it applies to both past and present management of the system. Proper reseeding proved to be a critical factor for maintaining a viable *mucuna* plot. While it may be difficult to separate the practice of reseeding from intentional neglect of the system, the vast majority of abandoners professed disappointment at the loss of their *aboneras*. Often, however, these farmers indicated that "*el frijol de abono solo nace*" ("*mucuna* sprouts on its own").

Several important policy implications emerge from this analysis. The relationship of abandonment to declining interest in growing maize suggests that a farming practice is not sustainable if it is not associated with a crop that will remain important to the household. Perhaps more importantly, the experience of maize-*mucuna* in Northern Honduras suggests that spontaneous diffusion of sustainable agricultural practices may be a mixed blessing at best. Many farmers surveyed adopted the maize-*mucuna* system, after having seen the good harvests obtained by neighbors and having managed to obtain seed. That a sustainable technique can spread rapidly from farmer to farmer on the basis of demonstrable results is certainly encouraging. However, spontaneous diffusion does not necessarily provide farmers with an understanding of system dynamics, which may prove critical for system sustainability. Survey work suggests that farmers had an inadequate grasp of nutrient cycles, nitrogen fixation, and the effects of herbicide, for example[99]. Perhaps the decline of maize-*mucuna* would have been mitigated if knowledge of the agronomic principles involved with velvet bean cultivation and a consciousness of the importance of soil health and preservation had accompanied its diffusion. Certainly, modeling results suggest that that the rate of abandonment might have been less had farmers been informed of the importance of reseeding.

In Honduras, where government extension is in the process of privatization, the "farmer to farmer" approach is needed more than ever. The maize-*mucuna* experience reinforces the importance not simply of the diffusion of technologies among farmers but of farmers educating each other. Central to the farmer-to-farmer model of extension is the trained "farmer educator"[100] who lives in the community and not only promotes new techniques but situates them within an agronomic context that farmers can appreciate. Clearly forces beyond the control of farmers are playing a role in maize-*mucuna* abandonment, but the evidence suggests that a weak understanding of the system on the part of farmers may have contributed to a somewhat superficial adoption and subsequent decline.

Another important lesson of the maize-*mucuna* experience in Honduras concerns the danger posed by crop monoculture. It is still the case today that aficionados of one cover crop or another often promote adoption of that species to the exclusion of other techniques. Some of the weaknesses of such an approach are revealed in the survey results from this research. The fact that *rottboellia* and other grassy weeds have proliferated may be the direct result of the fact that *mucuna* is much more effective at eliminating broad-leaf species. The exclusive adoption of *mucuna* eliminates these sources of diversity and leaves fields vulnerable to invasion by insects, disease and weeds, not to mention landslides, that may otherwise have been thwarted by sheer variety of species[101]. It is important to recognize that neither *mucuna* nor any other single species represents a "silver bullet" alternative to slash-and-burn agriculture. Ideally, *mucuna* should be part of an integrated approach that includes a range of plants (*gliricida sepium*, *sesbania sesban*, *leucaena* *leucocephala*, pigeon peas and chickpeas to name a few) as well as a range of methods (relay cropping, alley cropping, live barriers). Diversity is an essential element of sustainability. As extensionists and development experts develop the "second generation" of alternative techniques, they must insure that the techniques they advocate are not static, monocultural cropping systems.

Notes

[1] D. Kaimowitz, *Livestock and Deforestation: Central America in the 1980s and 1990s: a Policy Perspective*. Center for International Forestry Research, Jakarta, 1996; P. Utting, "Deforestation in Central America: Historical and Contemporary Dynamics." in J. De Groot and R. Rubén, eds., *Sustainable Agriculture in Central America*. St. Martin's Press, New York, 1997, pp. 9-29.

[2] On rainfall effects, see G.K. Walker, Y.C. Sud, and R. Atlas, "Impact of the Ongoing Amazonian Deforestation on Local Precipitation: a GCM Simulation Study." *Bulletin of the American Meteorological Society*. 76 (1995): 346-360; on climate change, N. Brady, "Alternatives to Slash-and-Burn: a Global Imperative." *Agriculture, Ecosystem and Environment*. 58 (1996): 3-11, and P.B. Tinker, J. I. Ingram, and S. Strowe, "Effects of Slash-and-Burn Agriculture and Deforestation on Climate Change."*Agriculture, Ecosystems and Environment* 58 (1996): 13-22; on biodiversity effects, W.V. Reid and K.R. Miller, *Keeping Options Alive: the Scientific Basis for Conserving Biodiversity*. World Resources Institute, Washington, D.C., 1989.

[3] J.C. Alegre and D.K. Cassel, "Dynamics of Soil Physical Properties Under Alternative Systems to Slash-and-Burn." *Agriculture, Ecosystems and Environment*. 58(1996): 39-48.

[4] J. Jones, Colonization and Environment: Land Settlement Projects in Central America. United Nations University Press: Tokyo, 1990.

[5] The literature in this area is substantial; for a review, see D.M. Robison and S.J. McKean, *Shifting Cultivation and Alternatives: an Annotated Bibliography, 1972-1989*. International Center for Tropical Agriculture, Cali. 1992.

[6] D. Thurston, "Slash/Mulch Systems: Neglected Sustainable Tropical Agroecosystems" in D. Thurston, *et al*. eds, *Tapado: Slash/Mulch : How Farmers Use It and What Researchers Know About It*. Cornell International Institute for Food Agriculture and Development, Ithaca, New York. 1994, pp. 29-42.

[7] D. Buckles, B. Triomphe and G. Saín, *Cover Crops in Hillside Agriculture: Farmer Innovation with Mucuna*. International Development Research Centre and International Maize and Wheat Improvement Center, 1998; S. Humphries, "Milk Cows, Migrants and Land Markets: Unraveling the Complexities of Forest-to-Pasture Conversion in Northern Honduras." *Economic Development and Cultural Change*. 47(1998) 96-123.

[8] B.L. Triomphe, Seasonal Nitrogen Dynamics and Long Term Changes in Soil Properties Under the Mucuna/Maize Cropping System on the Hillsides of Northern Honduras. Ph.D. Dissertation. Cornell University, 1996.

[9] D. Buckles, I. Ponce, G. Saín, and G. Medina, "'Cowardly Land Becomes Brave': the Use and Diffusion of Fertilizer Bean (*Mucuna deeringianum*) on the Hillsides of Atlantic Honduras," in D. Thurston, *et al*. eds, *ibid.*

[10] S. Fujisaka, "A Method for Farmer-Participation Research and Technology Transfer: Upland Soil Conservation in the Phillipines." *Experimental Agriculture*. 25(1989): 423-433; P. Oakley, "Bottom-up Versus Top-Down: Extension at the Crossroads." FAO. *CERES Review*. 26 (1994): 16-20.

[11] R. Bunch, "The Potential of Slash/Mulch for Relieving Poverty and Environmental Degradation." in Thurston, *et al*., *ibid.*

[12] See, for example, R. Chambers, A. Pacey and L.A. Thrupp, eds. *Farmer First: Farmer Innovation and Agricultural Research*. London: Intermediate Technology Publications, 1989.

[13] The *manzana*, a traditional measure of land area used widely in Central America, is equal to 0.73 hectares.

[14] G. Saín, I. Ponce and E. Borbón, "Profitability of the *Abonera* System Practiced by the Farmers on the Atlantic Coast of Honduras." in Thurston, *et al*., *ibid*., pp. 469-484.

[15] Buckles, Triomphe and Saín estimate that the probability of obtaining a yield of less than 763 kg/mza from a manzana of bush fallow maize is 70% in the wet season and 62% in the dry season.

[16] Buckles, Triomphe and Saín, *ibid*.; confirmed by data from this study.

[17] J. Jackson, "Los Abonos Verdes" ("Green Manures") *Publicaciones Varias* No.1, Second Edition. CIDICCO, Tegucigalpa, 1993.

[18] M. Flores, "The Use of Leguminous Cover Crops in Traditional Farming Systems in Central America." in D. Thurston, *et al.*, eds., 1994. pp.149-155.

[19] Buckles, *ibid.;* Triomphe, *ibid.* Buckles, Triomphe and Saín estimate that in a given dry season the probability of a yield level less than 763 kg/mza is 40%, much lower than traditional maize farming.

[20] However, this is not the first time that *mucuna* has enjoyed a period of popularity followed by a marked decline. After widespread use as livestock feed in the southern United States during the 1920s and '30s, velvet bean was replaced by the more lucrative soybean (U.S. Department of Agriculture, *The Velvet Bean*, Farmer's Bulletin No. 1276, 1922). Roughly a decade later, U.S. fruit companies introduced the velvet bean in Guatemala, where lowland Kekchi indians eventually incorporated it into a maize rotation. As the maize-*mucuna* system declined in Guatemala, migrating farmers brought the bean to Northern Honduras in the early 1970s (D. Buckles, "Velvetbean: a 'New' Plant with a History." *Economic Botany*. 49 (1995): 13-25.

[21] Buckles, Triomphe and Saín, *ibid*.

[22] This assumes that individual farm households are likely to meet subsistence requirements from own production, not market purchases, an assumption which is confirmed by survey evidence.

[23] Census data reveal an increasingly bipolar distribution of land, with the proportion of farms under three hectares increasing from 45% of the total in 1974 to 52% in 1993, and the number of farms of less than one hectare increasing from 16% to 25% (Dirección General de Estadísticas, *Censo Nacional Agropecuario: 1974* (National Agricultural Census, 1974), Ministerio de Economia, Tegucigalpa, 1974; Dirección General de Estadísticas, *Cuarto Censo Nacional Agropecuario: 1993* (Fourth National Agricultural Census, 1993), Ministerio de Recursos Naturales, Tegucigalpa, 1993). Over the same period, the number of farms over 100 hectares increased by 51%, twice the rate of increase of mid-range farms (five to 100 hectares).

[24] There are multiple reasons for this progressive process of "minifundización," including the continuing arrival of poor migrants from other regions with the means to purchase only single or small plots; the splintering of larger farms as multiple heirs receive their inheritances; and increasing land prices due to land speculation and consolidation.

[25] A. Coles-Coghi, *Agricultural Land Rights and Title Security in Honduras*, Ph.D. Dissertation. University of Wisconsin-Madison, 1993; R. Salgado, ed., *El Mercado de Tierras en Honduras* (*Land Markets in Honduras*), Centro de Documentación de Honduras, Tegucigalpa, 1994; P. Bonnard, *Land Tenure, Land Titling, and the Adoption of Improved Soil Management Practices in Honduras*, Ph.D. Dissertation, Michigan State University, 1995. The titling process established in the 1980s was bureaucratic and expensive. A University of Wisconsin/CEDOH study found that, in the two departments studied, the percentage of land under definitive title increases with farm size (Salgado, *ibid*.). Those farms that managed to obtain titles tended to be larger and wealthier. Titled land, it turns out, was worth 160% more than untitled, and with inflation around 20% in Honduras, the titling program may have established the basis for speculative hedging in land. Survey research for this paper indicates that in many parts of Atlántida land prices have risen between two and fourfold over the last three or four years.

[26] Humphries, *ibid.*

[27] Kaimowitz (*ibid*.) calls this conversion of forest and cropland to pasture the most important change in land use in Latin America during the last thirty years. Humphries (*ibid*.) provides a recent and thorough analysis of forest-to-pasture conversion in Northern Honduras.

[28] Finding a farmer or rancher on the North Coast of Honduras who does not grow at least some maize is extremely difficult.

[29] The average number of laborers per hectare (both hired and resident) in Atlántida is among the lowest in the country (Dirección General de Estadísticas, 1993).

[30] J. Mendoza, The Central American Price Band Policy and Its Effects on Price Variability and Welfare. M.S. Thesis, Cornell University, 1998.

[31] L Holm, D. Plucknett, J. Pancho and J.P. Herberger, *The World's Worst Weeds: Distribution and Biology*. East-West Center, Honolulu, 1977.

[32] See P. Bridgemohan, C.R. McDavid, I. Dekele, and R.A.I. Braithwaite, "The Effects of *Rottboellia Cochinchinensis* on the Growth, Development and Yield of Maize." *Tropical Pest Management*. 38(1992): 400-407; F. Lao, E. Perez, E. Paredes and Y.R. Garcia, "Umbrales de Daño y Economico de *Rottboellia Cochinchinensis* en Papa y Maiz." *Protección de Plantas*. 2 (1992): 53-65; E. Rojas, R. de la Cruz and A. Merayo, "Efecto Competitivo de la Caminadora (*Rottboellia Cochinchinensis)* en el Cultivo del Maiz (*zea mays L.*)" *Manejo Integrado de Plagas* (Costa Rica), 27 (1993): 42-45.

[33] A. Munguia, personal communication, 1997; Triomphe, *ibid*.

[34] R. de la Cruz, E. Rojas and A. Merayo, "Manejo de la Caminadora *Rottboellia Cochinchinensis* (Lour.) W.D. Clayton) en el Cultivo de Maiz y Periodo de Barbecho con Leguminosas de Cobertura." *Manejo Integrado de Plagas* (Costa Rica) 31 (1994): 29-35; B.E. Valverde, A. Merayo, C.E. Rojas and T. Alvarez, "Interaction Between a Cover Crop (*Mucuna. Sp*.), a Weed (*Rottboelllia Cochinchinensis*), and a Crop (Maize)." *Brighton Crop Protection Conference: Weeds,* 1995, pp. 197-201.

[35] This research was concluded before the catastrophic devastation of Hurricane Mitch in late 1998. Though peaks and troughs in rainfall have been common over the last several decades, the early 1990s have seen particularly low rainfall with dry seasons lasting nearly five months (Buckles, Triomphe and Saín, *ibid*.). On the other hand, a drought in 1997, the year in which the field research reported here was conducted, was preceded by an unusually wet season.

[36] Landslides were also mentioned as a problem in the *abonera* system. With the increasing marginalization of maize production, maize farmers have cleared progressively steeper hillsides. Landslides are not uncommon whatever the system of cultivation, but *mucuna* may smother deeper rooting vegetation and, by retaining a great deal of moisture, increase the chances of landslides (Buckles, *et al*. 1994). According to one farmer, the land under *mucuna* "turns to butter" around the fifth year. The issue has not been studied formally, but it is a potential source of farmer discontent with the system.

[37] Indeed, the belief that reseeding is unnecessary persists even among some professionals working with cover crops.

[38] Buckles, Triomphe and Saín, *ibid*.

[39] R.H. White and A.D. Worsham, "Control of Legume Cover Crops in No-Till Corn (*Zea Mays*) and Cotton (*Gossypium Hirsutum)." Weed Technology*. 4 (1990): 57-62; J.L. Griffin and S.M. Dabney, "Preplant-Postemergence Herbicides for Legume Cover-Crop Control in Minimum Tillage Systems." *Weed Technology* 4 (1990): 332-336; Triomphe, *ibid*.

[40] L. Canas, personal communication, 1997.

[41] A well-known summary is provided in G. Feder, R.E. Just and D. Zilberman, "Adoption of Agricultural Innovations in Developing Countries: A Survey." World Bank Staff Working Paper No. 542, 1982.

[42] Y. Kislev and N. Shchori-Bachrach, "The Process of an Innovation Cycle." *Amer. J. of Agric. Econ.* 55 (1973): 28-37.

[43] For Honduras, see P. Arellanes, *Factors Influencing the Adoption of Hillside Agriculture* Technologies in Honduras, M.S. Thesis, Cornell University, 1994; for the Phillipines, see S. Sureshwaran, S. R. Londhe, and P. Frazier, "A Logit Model for Evaluating Farmer Participation in Soil Conservation Programs: Sloping Agricultural Land Technology on Upland Farms in the Phillipines." *Journal of Sustainable Agriculture*. 7 (1996): 57-69.

[44] See D. Clay, T. Reardon and J. Kangasniemi, "Sustainable Intensification in the Highland Tropics: Rwandan Farmers' Investments in Land Conservation and Soil Fertility." *Economic Development and Cultural Change* 46 (1998): 351-377, and G.E. Shively, "Consumption Risk, Farm Characteristics, and Soil Conservation Adoption among Low-Income Farmers in the Phillipines." *Agricultural Economics*. 17 (1997): 165-77.

[45] Arellanes, *ibid*.; Bonnard, *ibid*.

[46] Buckles, Triomphe, and Saín, *ibid*.

[47] Shively, *ibid*.

[48] Buckles, Triomphe, and Saín, *ibid*.

[49] See Triomphe, *ibid.*, and M. Flores, "Tienen Razon los Agricultores de Usar el Frijol de Abono: La Contribución de Esta Leguminosa a la Economia de Algunos Grupos Campesinos de la Costa Norte de Honduras" ("Farmers are Right in Using Fertilizer Bean: The Contribution of this Legume to the Economy of Farmer Groups on Honduras' North Coast"), Paper presented at the CIMMYT Workshop "Participative Methods for the Investigation and Applied Extension of Green Manure Technologies," Veracruz, Mexico, March, 1993.

[50] S. Fujisaka, "A Case of Farmer Adaptation and Adoption of Contour Hedgerows for Soil Conservation." *Experimental Agriculture* 29 (1993): 97-105; Shively, *ibid.*

[51] See Triomphe, *ibid.*, and R. Ruben, P. van den Berg, M. Siebe van Wijk, and N. Heerink, "Evaluación Economica de Sistemas de Producción con Alto y Bajo Uso de Recursos Externos: el Uso de Frijol Abono en la Agricultura de Ladera," ("Economic Evaluation of Production Systems Under High and Low Use of External Inputs: The Case of the Fertilizer Bean in Hillside Agriculture,") Paper presented at the Kellogg Center Workshop, "Support for the Investigation of Policies for the Management of the Natural Resource on Mesoamerican Hillsides," Zamorano, Honduras, February, 1997.

[52] Buckles, Triomphe, and Saín, *ibid.*

[53] Sureshwaran, *et al., ibid.;* Shively, *ibid.*

[54] Buckles (1994), *ibid.;* Saín, *ibid.;* Ruben, *et al., ibid.*

[55] Bonnard, *ibid.*

[56] Arellanes, *ibid.;* Bonnard, *ibid.;* Shively, *ibid.;* J. Hayes, M. Roth, and L. Zepeda, "Tenure Security, Investment and Productivity in Gambian Agriculture: a Generalized Probit Analysis," *Amer. Jo. of Agr. Econ.* 79 (1997): 369-382.

[57] G.P. Rauniyar and F.M. Goode, "Technology Adoption on Small Farms," *World Development* 20 (1992): 275-282.; A.A. Adesina and M. M. Zinnah "Technology Characteristics, Farmers' Perceptions and Adoption Decisions: A Tobit Model Application in Sierra Leone," *Agricultural Economics* 9 (1993): 297-311; A. Saha, A.H. Love, and R. Schwart, "Adoption of Emerging Technologies Under Output Uncertainty,"*Amer. Jo. of Agr. Econ*. 76 (1994): 836-846; Clay, *et. al, ibid.*

[58] J.H. Aldrich and F.D. Nelson. *Linear Probability, Logit, and Probit Models*. Sage University Paper Series on Quantitative Applications in the Social Sciences 07-045, Beverly Hills and London: Sage Publications, 1984.

[59] W.H. Greene, *Econometric Analysis*. New York: Macmillan Press, 1990.

[60] Nested logit models are commonly used to model contingent decision-making, but are most commonly applied to multiple choice scenarios, the classical example being travel choice (see M. Ben-Akiva and S.R. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand*, Cambridge, London: MIT Press, 1985). While this approach allows for dependence among the levels of decisions, it does not provide for meaningful interpretation of the correlation between them.

[61] Often the bivariate probit is justified on the basis of sample selection bias; that is, if the censoring that takes place in the determination of y_1 generates a non-random sample for the estimation of y_2, there is a selection bias that must be accounted for through the inclusion of a correlation term. However, if sample selection is deterministically governed by the attributes of the individuals observed, as we have assumed in the case of abandonment, it does not lead to biased estimators (W.J. Boyes, D.L. Hoffman and S.A. Low, "An Econometric Analysis of the Bank Credit Scoring Problem," *Jo. of Econometrics* 40 (1989): 3-14). Bivariate techniques for the logistic distribution have not received much attention, perhaps because the bivariate normal distribution has some appealing characteristics. It is the joint distribution of two random variables which are themselves normally distributed. The conditional distribution of y_2 given y_1 is also normal. Also, the bivariate normal has the property, unique among pairs of random variables, that if $\rho = 0$ then y_1 and y_2 are statistically independent (G.G. Judge, R.C. Hill, W.E. Griffiths, H. Lutkepohl, and T.C. Lee, *Introduction to the Theory and Practice of Econometrics*, New York: John Wiley and Sons, 1988).

[62] W.H. Greene, *LIMDEP Manual, Version 7.0.* New York: Econometric Software, Inc., 1997. Greene's notation reverses y_2 and y_1 to indicate that the model is estimated recursively. It is confusing, however, to think of y_2 as referring to adoption, which necessarily occurs first.

[63] This can be expressed as:

(1a) adopts and continues to use mucuna:

$$P(y_{i1}=1, y_{i2}=1) = P(z_{i1}>0, z_{i2}>0) = \Phi_2(b_1'x_{i1}, b_2'x_{i2}, r);$$

(1b) adopts and abandons mucuna:

$$P(y_{i1}=1, y_{i2}=0) = P(z_{i1}>0, z_{i2}<0) = \Phi_2(b_1'x_{i1}, -b_2'x_{i2}, -r);$$

(2) never adopts

$$P(y_{i1}=0, y_{i2}\text{ unobserved}) = P(z_1<0) = \Phi(-b_1'x_{i1}),$$

where M₂ represents the bivariate normal cumulative distribution function and M the univariate. The derivation from the z's is as follows:

$$P(z_{i1}>0, z_{i2}>0) = P(b_1'x_{i1}+e_{i1}>0, b_2'x_{i2}+e_{i2}>0) = P(e_{i1}>-b_1'x_{i1}, e_{i2}>-b_2x_{i2}) = P(e_{i1}<b_1'x_{i1}, e_{i2}<b_2x_{i2})$$

and likewise for the other equations.

64 If y_2=1 were assigned to abandonment, the signs of the estimated coefficients would switch between equations, and interpretation would become counter-intuitive.

65 Partial support for this assumption comes from the fact that those farmers not born in the communities where they were surveyed had lived there an average of twelve years.

66 Though earlier estimates suggest a figure of 1.6 ha (Buckles, *et al*. 1994), this lower figure likely reflects the influence of rental and labor markets. Three hectares is considered sufficient for a family to maintain a portion of territory under *mucuna* and rotate wet season crops on the remaining land.

67 Rather than use the maize-*mucuna* system, they will often seek to maximize nutrient off-take during the period they occupy the land. They may also fear that improving the land with *mucuna* will lead to their eviction.

68 Survey work revealed that some of the farmers who owned no land had in fact used the maize-*mucuna* system on plots they had formerly owned or on rental land for which they had long term agreements.

69 Concerns regarding potential endogeneity prevented the addition of other seemingly salient variables, including land and labor use variables used in previous technology adoption studies. In their logit model of maize-*mucuna* adoption, for example, Buckles, *et al*. utilize variables that represent the use of rental land and the proportion of maize sold from the second season harvest. However, the production system approach taken here implies that these variables are necessarily endogenous. Since rental land, for example, appears to be a *sine qua non* of the maize-*mucuna* system for smaller farmers, do farmers use maize-*mucuna* because they have access to rental land, or are they compelled to find rental land because they have their maize land under *mucuna*? Similarly, since *mucuna* is associated with higher yields, is it more likely to generate a surplus over consumption needs for those farmers who use it? It may be tautological to suggest, thus, that a farmer adopts the *abonera* system because he or she sells more of the dry season maize crop. Similarly with off-farm labor allocation. Variables that reflect methods of maize production, yields, or cropping intensity were omitted from the equations to avoid endogeneity. Unfortunately, this also meant avoiding the use of a variable for herbicide use, potentially an important factor related to abandonment.

70 Specific effort was made in survey design to capture the "edge effect," the extent to which land use changes near a main road. While it is certainly the case that some farmers walk long distances from their villages of residence to their maize plots, even in more remote villages, it is generally assumed that farmers living near the road have greater access to markets than those higher up on a hillside.

71 Sureshwaran, *et al., ibid;* Bonnard, *ibid.*

72 Crops grown for purposes other than subsistence are considered higher value crops. These are principally coffee, cacao, citrus, pineapple, or vegetables.

73 To avoid endogeneity problems, this measure was obtained by dividing gross maize area by gross cropped area. If net area had been used, the result would have been biased toward the more land-extensive maize-*mucuna* system, and against farmers who double-crop their maize plots. (For a farmer who grows two *manzanas* of maize per year, one in an *abonera* during the dry season and one on a bush fallow plot during the wet season, the net cropped area is two manzanas. For a farmer who grows two *manzanas* of maize per year but both are planted on the same plot (double-cropped) the net is one. Therefore, the net measure may give a biased representation of land allocation to maize.)

[74] On its face, it would seem to be endogenous -- if abandoners reseed their *aboneras*, they would not be abandoners. However, the survey question was phrased carefully. Farmers were asked whether, *when* they used the maize-*mucuna* system, they reseeded their *mucuna* plots each year or allowed the bean to sprout on its own. Those who no longer had *aboneras* understood that the question referred to their management of the system in the past, not whether they continued to use *mucuna*.

[75] The isolated villages were three kilometers or more from the main access road. Considerable differences in accessibility existed within pairs as well as between them. Sorting out the relative accessibility of individual plots proved extremely difficult.

[76] Since much of the enumeration took place during a lull between growing seasons, labor requirements of the maize production cycle did not appear to create any particular pattern of presence or absence from the household.

[77] Omission of non-maize producing households might have excluded important information about maize-*mucuna* abandonment. One limitation is that out-migrants, who may constitute an important element of the maize-*mucuna* story, could not be included in the survey for self-evident reasons.

[78] More than 90% of landowners in the sample had used the maize-*mucuna* system, a remarkably high proportion.

The number of farmers who grew only part of their dry season maize in *aboneras* (21 of 146 adopters, or 14%) was considered insufficient to justify a fourth category of partial adopters; that is, adopters were predominantly complete adopters. The result is somewhat surprising, given that Buckles, *ibid*., found a distinctly different pattern of cultivation in 1992, with only 55% of adopters cultivating all of their dry season maize in *aboneras.*

[79] It is important to note that the distribution of farm sizes reflected an unexpectedly high number of non-landowning farmers, nearly a third of the sample. Small farmers, those owning fewer than five hectares, constituted only 16% of the sample, a result that is markedly different from the 36% found by Buckles, *et al.* in 1992. Landless farmers were less than a quarter of that 1992 sample. The finding tends to reinforce the possibility of speculative pressure on land and resulting out-migration.

[80] Net cropped area indicates only the area sown over the course of the year, netting out the influence of plots cropped in both wet and dry seasons.

[81] Survey data (not reported here) do not support the hypothesis that mucuna adopters use significantly lower levels of fertilizers, and thus substitute mucuna use for purchased fertilizer inputs.

[82] Neither a variance/covariance matrix of the variables nor a matrix of pairwise correlations revealed generally high levels of correlation between the independent variables. The cattle variable exhibited correlation with non-maize income of 0.6. These two variables are not included in the same regression equation. Similarly, given the argument that farmer's age and years of experience with maize-*mucuna* might be measuring similar underlying attributes, they are not both included in equation 1.

[83] It is also possible that older farmers may have learned the *mucuna*-maize technique when agronomic conditions were most favorable and failed to adapt well to new conditions.

[84] See discussion of marginal effects which follows.

[85] As a proxy for many other factors, it is possible that the incorporation of the ACCESS variable "weakens" the effect of other explanatory variables. Preliminary estimations performed excluding the variable did not, however, produce conclusive evidence of problems due to multicollinearity.

[86] See Bonnard *ibid*., for further details.

[87] That farmers abandon the system regardless of the labor available suggests that the surplus labor is more profitably applied elsewhere.

[88] In preliminary estimations, pasture variables and the ratio of cattle to pasture were incorporated, but neither proved significant.

[89] In fact, increasing cattle numbers and increasing maize land have been occurring simultaneously on the North Coast (Dirección General de Estadisticas y Censos, Ministerio de Recursos Naturales, *Censo Nacional Agropecuario: 1974,* and *Cuarto Censo Nacional Agropecuario: 1993,* Republica de Honduras, Tegucigalpa.

[90] For a univariate probit model, it is common to report the percentage of correct predictions given by the estimated model. However, Greene (1990)

emphasizes that the maximum likelihood estimator is not meant to maximize the accuracy of prediction of *y*, but to maximize the joint density of *y*. Therefore, the percentage of correct predictions may be a misleading measure of goodness of fit. The more accepted method is the likelihood ratio test, which involves fitting a model with only a constant term, then calculating the model with the independent variables of interest (see Hosmer and Lemeshow, *ibid*.). The value of the likelihood ratio test (G) is determined by: $G = -2(\hat{L} - L_0)$ where $\hat{L}$ is the maximized log likelihood from the estimated model and L_0 is the log likelihood computed with a constant term. The resulting value is chi-square distributed with degrees of freedom equal to the number of parameters in the model. Greene (1990) suggests the likelihood ratio index as another potential measure of goodness of fit. It is similar to the R2 from linear regression in that it is bounded by zero and one. But rather than revealing the proportion of the variance explained, the likelihood ratio index gives the extent to which the estimated model constitutes an improvement over the log likelihood computed with only a constant term. The likelihood ratio index is given by $LRI = 1 - \frac{\ln \hat{L}}{\ln L_0}$

Unlike the likelihood ratio test, however, the LRI does not account for the number of parameters included in the model specification.

91 To the extent that the LRI constitutes a measure of "fit", however, the performance of the models suggests a level of explanation that is rather less than perfect. Given the myriad factors with the potential to influence maize-*mucuna*, a relatively small LRI should not be surprising. Of the three models, the third model appears to perform best considering that it is relatively parsimonious, and all variable coefficients are significant.

92 A procedure for deriving the marginal effects for the conditional mean function of a bivariate probit model is given in W.H. Greene, "Marginal Effects in the Bivariate Probit Model. "Department of Economics Working Paper Series, New York University, EC-96-11, 1996. However, as Greene suggests, this is quite involved computationally. Moreover, the fact that several of the variables are dichotomous further complicates the procedure. Estimates of marginal effects come from the partial derivatives of the variables computed at their means. For a binary variable, of which there are several in the specified models, the computation is not meaningful. The approach taken below is to compute the bivariate normal distribution of y values, $\Phi_2(x_1\beta_1, x_2\beta_2, \rho)$, over a range of *x* values, a method suggested by Greene (1990). By giving the average change in the slope of $P(y_2=1 \mid y_1=1)$ plotted against *x*, the marginal effect of each variable can be approximated (see Table 5).

93 The ranges are as follows: age was allowed to vary from 20 to 70, proportion of the cropland planted to maize from 0 to 1, non-maize income from 0 to 30,000 Lempiras, and years of experience with mucuna from 0 to 10.

94 Cultivation of high value crops should *decrease* the proportion of cultivated area sown to maize (the two variables are in fact negatively correlated with each other, with a coefficient of –0.49), which is why the opposite signs of these coefficients are particularly striking. However, the fact that only 15% of farmers grow high value crops makes their relative effect on the coefficient of the proportion variable (PROPSOWN) small.

95 The result is particularly compelling considering that abandoners began to use the system on average two years before adopters. In other words, the significance of the variable is not merely attributable to an earlier time of adoption

96 It must be noted, however, that the farmers for whom tenure security and a minimum farm size were expected to be most relevant were not well represented in the sample. Much of the literature on maize-*mucuna* is premised on a population of small landowners, whose prospects for *mucuna* rotation are subject to marginal changes in land or labor markets—farmers requiring extra land or off-farm income in order to dedicate their own small plots to *mucuna*. Quite unexpectedly, small farmers owning from one to five manzanas represented a very small proportion of those surveyed. The disparity between the size of randomly sampled farms and the farm size distributions given in the recent agricultural census and in Buckles, *et al*. (1994), raises the possibility that smaller farmers may have increasingly sold out, joining the ranks of the landless, moved to forest margins further east, or left agriculture altogether. In these cases, these households would not have appeared in the survey.

97 Rottboellia appears to have reinforced a trend away from maize cultivation, as abandoners devote lower proportions of their land to the crop. It follows that those farmers with greater non-maize income

sources might be among the first to purchase herbicides and give up the struggle to save their mucuna plots, returning to the traditional system of cultivation. Conversely, more dedicated farmers, those who grow maize for profit, may be more likely to care for their aboneras and keep them free of weeds.

[98] The importance of over-application can be established only anecdotally, although it is logically consistent with the emergence of *rottboellia*. Moreover, all three major herbicides in use on the coast can cause damage to *mucuna*.

[99] Survey work indicated that maize-*mucuna* farmers were in fact more likely to burn in preparation for wet season maize and that, despite general awareness of other sustainable technologies, fewer than five percent of farmers use live barriers and/or contouring, ideal companion technologies for *mucuna* in that they hold the soil and minimize nutrient run-off. That only 15% of current and former adopters have ever used *mucuna* with a crop other than maize suggests incomplete comprehension of nitrogen fixation, which can increase yields not only of maize but of most crops grown on the North Coast. Moreover, the widespread over-application of herbicides alleged by extensionists working with *mucuna* seems to indicate inadequate understanding of system maintenance, as does the widespread failure of farmers to reseed their *aboneras* yearly.

[100] Fujisaka, *ibid*.

[101] In addition, *mucuna* is not particularly good for carbon sequestration. Replacing woody species with *mucuna* may still leave a net carbon loss that is a key problem of deforestation (Fernandes, personal communication).