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Slash-and-burn cultivation practice and agricultural input demand and output supply

AWUDU ABDULAI*
Department of Food Economics and Consumption Studies, University of Kiel, Olshausenstrasse 40, 24118 Kiel, Germany

CLAUDIA R. BINDER
Institute for Human-Environment Systems, Swiss Federal Institute of Technology, ETH Zentrum, HAD G 12 Haldenbachstr. 44 8092 Zürich

ABSTRACT. This study uses an endogenous switching-regression model to examine the impact of slash-and-burn cultivation practice on the application of commercial fertilizer and pesticides, as well as yields and net returns. The empirical evidence of the study indicates that cross-section analysis of the impact of technology adoption on input demand and output supply should take into consideration sample selection, and also examine the impact separately for adopters and non-adopters. The results show that education, access to credit, land rights, and visits by extension agents reduce the probability of farmers adopting slash-and-burn farm practices. Environmental variables, such as soil quality and plot slope, do not impact on the adoption decision, but affect output supply of both adopters and non-adopters of slash-and-burn technology.

1. Introduction

Slash-and-burn technology is most commonly practiced as shifting cultivation, in which flash burning and short-term mixed intercropping follow partial clearing of vegetation (Houghton *et al.*, 1985). Slash-and-burn agriculture generally produces relatively low levels of food and encourages deforestation, as well as global CO_2 emission (Tinker *et al.*, 1996; Schuck *et al.*, 2002). Fire is often responsible for large nutrient losses due to particulate movement off the field and volatilization during the fire. Nutrients may also be lost by soil run-off, which is the process of downward moving of soil caused by water flow and gravity forces. Soil run-off is normally enhanced by disappearance of vegetative cover and surface litter following

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* Corresponding author: Tel: +49-431-880 4426. Fax: +49-431-880 7308. E-mail: aabdula@food-econ.uni-kiel.de

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the burn (Rodenburg *et al*., 2003). Otherwise, plant nutrients have to be added to maintain yields or farmers have to clear new plots, contributing to deforestation (Juo and Manu, 1996; Kleinman *et al*., 1995; Barrett, 1999). Shifted cultivators are currently being blamed for 60 per cent of tropical forest loss (Colchester and Lohman, 1993).

As argued by Schuck *et al*. (2002), the ability to replace degraded land with freshly cleared forest means that the person who originally cleared the forest may not bear the full costs of slash-and-burn agriculture. Such costs therefore tend to be borne by the society. Hence, for the individual farmer, in particular, landless farmers without land titles, the perceived benefits of practicing slash-and-burn agriculture may outweigh the perceived social costs of the technology.

Farmers practice slash-and-burn agriculture for a variety of reasons. Poor farmers normally view the technology as a low-cost way for cultivating their land (Ketterings *et al*., 2002). Ketterings *et al*. (1999) found that small-scale rubber producers perceive several advantages when adopting this technology, such as positive fertilizer effect of burned ash (increased levels of Ca, Mg, P, and K in the ash), soil structure improvement, and reduced weed competition and reduced occurrence of pests and diseases. Other explanations for the adoption of slash-and-burn technology range from increased population pressure (Adesina *et al*., 2000; Jones and O'Neill, 1992), land tenure (Larson and Bromley, 1990), government policies (Deacon, 1995) and price risk (Barrett, 1999). Using a non-separable household model of subsistence agricultural production, Holden (1993) show that farmers in northern Zambia used slash-and-burn cultivation for economic reasons. A study by Schuck *et al*. (2002) on Cameroon revealed that farmers' choice not to use slash-and-burn technology could be supported by extension education, if combined with land reform. That is, farmers with security of tenure are more likely to adopt alternative technologies than farmers without land title.

Although a number of studies have examined the determinants of slash-and-burn technology adoption decisions, to the best of our knowledge no study has investigated the adoption decision and its impact on other management decisions, such as input demand and output supply. However, the environmental impacts of slash-and-burn (e.g., reduced weed competition, fertilizer effect) indicate that the adoption of slash-and-burn cultivation is likely to be interrelated with farmers' decisions on fertilizer and pesticide application and might also affect crop yields and net returns. Thus, estimation of input demand and output supply in areas where slash-and-burn is widely practiced, without accounting for the farmers' decision to adopt this technology, might lead to biased estimates and misleading policy recommendations. As pointed out by Feder *et al*. (1985), if technologies are interrelated, biases in the analysis might occur if the adoption of one technology is not considered in the context of the other.

The main objective of this study is to examine the factors that influence farmers' decision to practice slash-and-burn technology, and then to analyze the impact of this decision on their demand for farm inputs and output supply, using plot-level data from the region of San Dionisio, Nicaragua. Slash-and-burn is a commonly used method for land clearing and field preparation in the study area. As in many parts of the developing world, slash-and-burn agriculture appears to be of great concern to environmentalists and policy makers in Nicaragua. Available estimates by the World Resource Institute indicate that between 1980 and 1995 about 1.7 million hectares of forested land were lost by slash-and-burn farming, commercial timber cutting and forest fires, leading to an annual loss of 113,000 hectares in the country (World Resource Institute, 1999). Recent estimates for our study area, which is located in the Region IV (departments of Matagalpa and Jinotega) indicate that the average annual soil loss – partly from soil erosion resulting from deforestation – is around 125 tons/ha for staple crops (Pfister, 2003). Policy measures are therefore being sought to reduce practices that contribute to deforestation. Given that farmers' attributes often influence their adoption decisions, a better understanding of this relationship should aid policy makers in creating improved policies to discourage farmers from slash-and-burn agriculture and help them improve farm yields and productivity.

This study employs an endogenous switching-regression model to analyse the impact of slash-and-burn agriculture on both the application of commercial fertilizer and pesticides, as well as crop yields and net returns. The data used in the study contain detailed geographic and soil information, cropping history, as well as information on the socioeconomic characteristics of the household and farm, allowing us to control for many potentially confounding factors.[1]

The paper is structured as follows: in the second section we introduce the theoretical framework used in the analysis; this is followed by a description of the data used. The empirical results are presented in the fourth section. The final section presents some concluding remarks.

2. The theoretical framework

Slash-and-burn is a commonly used land-clearing and field preparation method in Nicaragua. Slashing of secondary forest and post-productive agro forests or plantations, is followed by a primary burn. The remaining fuel is normally piled and set on fire a second time. Crop residues are either collected, piled and burned, or they are burned directly after drying. Eberlin (1998) asserts that farmers in Nicaragua commonly practice one of three dominant cultivation methods. These include slash-and-burn of forest to cultivate maize and beans; monocropping, where farmers cultivate a cash crop such as coffee, sugar cane, or cotton; and multicropping, where permanently cropped fields produce crops such as bananas, beans, maize sugarcane, or soya. The crops produced under the monocropping system are generally meant for export or cash sale, and are the most profitable.

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[1] It has been shown that environmental aspects may also play a role in the farmers' adoption decisions. Sherlund *et al.* (2002) found that technical inefficiencies were overestimated when environmental variables were excluded from the analysis. In addition, they state that production decisions appropriate in a specific environmental condition might be inappropriate in another. However, only a few studies have included specific environmental plot conditions in their empirical analysis.

On the other hand, slash-and-burn agriculture appears to be less profitable, but attractive for the landless because of the lower entry costs (Schuck *et al.*, 2002). It is, however, significant to mention that the profitability of slash-and-burn practice relative to other farming methods cannot be generalized to other parts of the developing world. For example, Holden's (1993) work on subsistence agriculture in northern Zambia shows that there were sound economic reasons to use slash-and-burn production methods.[2] The multicropping is an intermediate between monocropping and slash-and-burn agriculture, representing a mix between cash and subsistence production.

Given that the focus of the study is to examine the factors that influence the practice of slash-and-burn agriculture with a specific focus on slash-and-burn as a field preparation method and the impact of this practice on the input demand, output supply and net returns of farmers, we assume that farmers choose between slash-and-burn technology and the other cultivation practices. Moreover, the data set employed shows that farmers who practiced slash-and-burn were not engaged in the other farming practices, allowing us to model the decision-making process, such that farmers either choose to adopt slash-and-burn or practice multicropping/monocropping.[3]

Given the above assumptions, it may be assumed that, in deciding whether to adopt slash-and-burn technology, the producer weighs up the expected utility of wealth from adoption represented as $U_A^*(\pi)$ and the expected utility of wealth from non-adoption represented as $U_N^*(\pi)$, and adoption occurs if $U_A^*(\pi) > U_N^*(\pi)$. This is under the assumption that farmers are risk neutral and that net farm returns (π) represent wealth. The parameters of this decision are usually not observable, but can be represented by a latent variable $U(\pi) = 1$ if $U_A^*(\pi) > U_N^*(\pi)$ and $U(\pi) = 0$, if $U_A^*(\pi) \leq U_N^*(\pi)$. Dropping other subscripts for expositional purposes, utility of adoption can be related to a set of explanatory variables, Z as follows

$$U(\pi) = \delta' Z_i + \varepsilon_i \tag{1}$$

where δ is a vector of parameters and ε is an error term with mean zero and variance σ_ε^2. The error term includes measurement error and factors unobserved by the researcher but known to the farmer. Variables in Z include farm size, education, soil quality, and other socioeconomic and resource characteristics of the farm. Policy variables that affect utility or profitability may also be included in the vector Z. Equation (1) and $U_i^*(\pi)$ may also be expressed as

$$\Pr(U = 1) = \Pr(U_A^*(\pi) > U_N^*(\pi)) = \Pr(\varepsilon_i > -\delta' Z_i) = 1 - F(-\delta' Z_i) \tag{2}$$

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[2] The results of Holden's (1993) work reveal that maize-fertilizer technology that was introduced into the area was unable to replace the slash-and-burn cultivation technology because of the economic incentives.

[3] As pointed out by an anonymous reviewer, the multinomial logit model would be the appropriate model to use, if farmers engaged in either two or all three farming practices.

where F is the cumulative distribution function for ε. Assumptions about the functional form of F result in different models. Here we employ the probit model, which assumes a normal distribution.[4]

As argued earlier, the choice of a production technology often impacts on other decisions, such as the input demand and output supply. To link the adoption decision process to the input demand and output supply decision making, assume as in the previous section that farmers are risk neutral and maximize expected net returns, instead of expected utility. This may be expressed as[5]

$$\max_w E[PQ(W, Z) - R'W] \tag{3}$$

where E is the expectation operator conditional on information currently available to farmers; P is output price; Q is the expected output level; W is a column vector of inputs; Z is, as indicated earlier, a vector of household endowments and characteristics such as farm size, education, soil quality and other socioeconomic and resource characteristics; and R is a column vector of input prices.

Net returns can be expressed as a function of the variable inputs, the output price, the household endowments and characteristics, and the technology d, i.e. slash-and-burn technology or the other alternatives in the following relationship

$$\pi = \pi(R, d, P, Z) \tag{4}$$

Starting with any well-specified normalized profit function, direct application of the Hotteling Lemma to equation (3) yields the corresponding input demand and output supply equations

$$\frac{\partial \pi(P, R)}{\partial R_i} = -W_i^* \qquad \text{for all } i \tag{5}$$

$$\frac{\partial \pi(P, R)}{\partial P_i} = Q_i^* \qquad \text{for all } i \tag{6}$$

where W^* and Q^* are the optimal input demand and output supply levels, respectively. The explicit input demand and output supply functions in

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[4] The other common distributional assumption, that is ε is logistic, generates the logit model. Estimates with the logit model done to check the importance of this assumption to our results were essentially the same as the results presented here.

[5] We thank an anonymous reviewer for suggesting this framework to us. It is, however, significant to note that small farm resource allocation will usually not follow the dictates of conventional profit maximization under a variety of market imperfections. In particular, labor markets may not function well, since family and hired labor are unlikely to be perfect substitutes. This could either arise from supervisory problems or seasonal sales constraints in local markets. As a result of these reasons, the opportunity cost of family labor is unlikely to equal an exogenous market wage. As demonstrated by Singh *et al.* (1986), a theoretically complete approach to small farm production would require simultaneous treatment of production and consumption choices of the farm household (see also Abdulai and Regmi, 2000).

reduced forms for a variable input and output supply, as well as net returns, are then given as

$$W = W(R, d, P, Z) \tag{7}$$

$$Q = Q(R, d, P, Z) \tag{8}$$

Equations (7) and (8) indicate that input demand and output supply are both influenced by the technology choice, suggesting that these relationships need to be taken into consideration in estimating input demand and output supply functions. For expositional purposes, let $Y = X'\beta + \varepsilon$ represent the relationship between the decision variable Y (such as input demand and output supply), and X represent a vector of household endowments and characteristics (such as farm size, education, soil quality and other socioeconomic and resource characteristics, as well as farm input prices).

In a switching-regression approach, separate equations are usually specified for adopters and non-adopters of a technology in order to capture the differential response of the two farm types. In the present analysis, such a specification takes the following form

$$\begin{aligned} Y_A &= X'\beta_A + \varepsilon_A \quad \text{if } U = 1 \\ Y_N &= X'\beta_N + \varepsilon_N \quad \text{if } U = 0 \end{aligned} \tag{9}$$

The variable Y_A is a decision variable, such as pesticide demand, when the technology is adopted, and Y_N represents demand without adoption. Given that the choice of technology is endogenous in the above specification, ordinary least square (OLS) estimates of the parameters in equation (9) will suffer from sample selection bias. Thus, the error terms in equation (9), conditional on the sample selection criterion, have non-zero expected values (Lee, 1982; Maddala, 1983).

Sample selectivity is treated as a missing-variable problem in Lee's (1982) approach. A joint-normal distribution is posited for the error terms with the following variance–covariance structure

$$Cov(\varepsilon_A, \varepsilon_N, \varepsilon) = \begin{bmatrix} \sigma_A^2 & \sigma_{AN} & \sigma_{AB} \\ \sigma_{AN} & \sigma_N^2 & \sigma_{NB} \\ \sigma_{AB} & \sigma_{NB} & \sigma^2 \end{bmatrix} \tag{10}$$

where $\text{var}(\varepsilon_A) = \sigma_A^2$, $\text{var}(\varepsilon_N) = \sigma_N^2$, $\text{var}(\varepsilon) = \sigma^2$, $\text{cov}(\varepsilon_A, \varepsilon_N) = \sigma_{AN}$, $\text{cov}(\varepsilon_A, \varepsilon) = \sigma_{AB}$, $\text{cov}(\varepsilon_N, \varepsilon) = \sigma_{NB}$. Conditional expectations of ε_A and ε_N are then given as (Johnson and Kotz, 1970)

$$E(\varepsilon_A | U = 1) = E(\varepsilon_A | \varepsilon > -Z'\delta) = \sigma_{AB} \frac{\phi(Z'\delta/\sigma)}{\Phi(Z'\delta/\sigma)} \equiv \sigma_{AB}\lambda_A \tag{11}$$

$$E(\varepsilon_N | U = 0) = E(\varepsilon_N | \varepsilon \leq -Z'\delta) = \sigma_{NB} \frac{-\phi(Z'\delta/\sigma)}{1 - \Phi(Z'\delta/\sigma)} \equiv \sigma_{NB}\lambda_N \tag{12}$$

where ϕ and Φ are the probability density and cumulative distribution function of the standard normal distribution, respectively. The ratio of ϕ and Φ evaluated at $Z'\delta$ is referred to as the inverse Mills ratio (selectivity terms). The selectivity terms, λ_A and λ_N, can be considered as missing variables in equation (9). If suitable instruments can be found for these variables, they can be included in the specification given in equation (9) to obtain consistent estimates with OLS.

The estimation proceeds in two stages. The first step involves a probit regression to determine the probability of adoption. The estimates are then used to estimate the selectivity terms λ_A and λ_N according to the definitions in equations (11) and (12). The second stage of the estimation process incorporates the selectivity terms in the multiple regression given in equation (9), resulting in the following equations

$$\begin{aligned} Y_A &= X'\beta_A + \sigma_{AB}\lambda_A + \mu_A \quad \text{if } U = 1 \\ Y_N &= X'\beta_N + \sigma_{NB}\lambda_N + \mu_N \quad \text{if } U = 0 \end{aligned} \tag{13}$$

These equations are then estimated by OLS. The coefficients of the variables λ_A and λ_N provide estimates of the covariance terms σ_{AB} and σ_{NB}, respectively. In particular, if the covariance terms are nonzero, then OLS estimates of equation (9) would be biased as a result of sample selection. The new residuals μ_A and μ_N in (13) have conditional means of zero but are heteroscedastic, so that a weighting procedure is required to obtain efficient parameter estimates. The method proposed by Lee and Trost (1978) is used, since it always yields positive values for $\hat{\sigma}_A^2$ and $\hat{\sigma}_N^2$. In addition, the standard error correction presented in Lee *et al.* (1980) is employed to account for the fact that the selectivity terms in (13) were estimated from the first stage equation. Since the structure of the model estimated is recursive, identification requires that there be at least one variable in the vector Z in equation (1) that does not appear in X in equation (13).

The signs of the coefficients of the selectivity terms have an economic interpretation. If they have alternate signs, then farmers practice slash-and-burn technology on the basis of their comparative advantage. Thus, those who adopt have above-average returns from adoption, while those who choose not to adopt have above-average returns from non-adoption. On the other hand, if the coefficients of the selectivity terms have the same sign, it indicates hierarchical sorting; that is, adopters have above-average returns whether they adopt or not, but they are better off adopting than not adopting. The non-adopters have below-average returns in either case, but are better off not adopting (Willis and Rosen, 1979).

3. Data and definition of variables

The data used in this study are a sub-sample of a random survey of 188 farm households conducted in 2000 in the catchment area of the Rio Calico in Nicaragua. The municipality is located in the Montañas Altas province, which is characterized by hilly areas and steep slopes. The rainfall pattern in the area is bimodal, with two wet and two dry seasons. Average rainfall ranges between 1000 and 2000 mm per annum. The most prevalent agricultural production units in this region are the minifundia (small plots of land of 0.7–3.5 hectares). The production patterns differ with the location (altitude of the farmland) and the farm size. Almost all farmers produce maize and beans. There are two production cycles in the region:

primera, which is from May to August, and postrera, from September to November/December. A third production cycle, the so-called apante, is possible in regions with more favourable precipitation during December to February/March (Leemann, 2003). In the study region there is a preference for planting maize (and some beans) in the primera, with beans mostly planted in the postrera season. Thus, maize is planted in May after the first rainfall, with the first harvest occurring in early August. The rest of the plant is left on the field to dry, and cut off in September. It is during this period (postrera season) that beans are planted and then harvested either at the end of November or beginning of December (Pfister, 2003). However, if beans are planted in the primera season (May), they are harvested in August. Agriculture is not mechanized and also oxen are rarely seen. Mineral fertilizer is applied only to maize.

Landless farmers who rent land as well as small-scale farmers (< 3.5 ha) plant maize and beans for subsistence purposes only, covering about 50–75 per cent of their needs of maize (Pfister, 2003). They therefore rarely sell their harvest within the region. On the other hand, large-scale farmers with the capacity to store the harvest are able to produce surplus maize for the markets within the region and export to Managua (Pfister, 2003).

The survey was carried out in cooperation with the Universidad Nacional Agraria, Managua, and the Escuela Católica de Agricultura y Ganadería de Estelí. The sample was selected using a stratified random sampling technique. Three geographic strata, differentiated by altitude level, were selected. Within each stratum, coordinates were chosen randomly. The coordinates were located using GPS and, with the help of the local community leaders, the individual farmers were interviewed using a questionnaire. Administration of the questionnaires was carried out by trained enumerators under the supervision of the authors.

The data gathered include detailed information on household characteristics such as labour supply and non-farm activities, access to credit and extension services, household size, age, and education of household head. Farm characteristics include qualitative characterization of the soil, cropping history, input and output prices, and conservation practices used. From the original 188 households in the survey, 127 farmers who cultivated maize were chosen from the two districts based on complete availability of needed information on the household. The two districts are characterized by altitude ranges. District 1 encompasses households cultivating plots at an altitude between 400 and 650 meters above sea level, whereas district 2 consists of farm households cultivating at an altitude between 651 and 900 meters above sea level. In district 1, erosion rates are lower, whereas at higher altitudes, increasingly higher slopes and larger erosion rates are found. Table 1 presents descriptive statistics for the variables used in the empirical analysis. The means, minimum, and maximum values are presented separately for farmers who practiced slash-and-burn and those who did not practice the technology at the time of the survey. The dependent variables include the decision to adopt slash-and-burn technology, the pesticide application rate, nitrogen application rate, crop yield, and net returns. At the time of the survey, 54 per cent of the farmers had practiced slash-and-burn agriculture, with 46 per cent involved in

Table 1. *Definition of variables and summary statistics (A: Adopters; N = 69, NA: Non-adopters; N = 58)*

		Mean		*Min.*		*Max.*	
Variable	*Description*	*A*	*NA*	*A*	*NA*	*A*	*NA*
Dependent Variables							
N Fertilizer	Nitrogen fertilizer application rate (kg/ha)	82	83	0	0	505	553
Pesticide	Pesticide application rate (kg/ha)	12	20	0	0	316	404
Yield	Maize yield (t/ha)	30	39	2.5	1	116	217
Net returns	Revenue minus input costs (C$/ha)[a]	941	974	−7,280	−4,736	8,087	17,561
Explanatory Variables							
Age of head	Age in years of the household head	48	47	22	22	77	75
Education	1 if farmer has an education, zero otherwise	0.54	0.63	0	0	1	1
Household size	Number of people residing in household	6.5	6.9	2	1	12	13
Access to credit	1 if farmer is liquidity-nonconstrained, zero otherwise	0.29	0.64	0	0	1	1
Land title	1 if farmer has a land title, zero otherwise	0.48	0.81	0	0	1	1
Non-farm work	1 if farmer participated in off-farm work, zero otherwise	0.28	0.37	0	0	1	1
Crop income	Gross annual sales C$	9,271	11,974	180	140	160,725	97,362
Silty soil	1, if soil texture is silty or loamy (suelto), zero otherwise	0.58	0.59	0	0	1	1
Clay soil	1, if soil texture is clay-rich (barrialoso), zero otherwise	0.35	0.31	0	0	1	1
Soil depth	1, if depth of A-horizon is greater than or equal to 5 inch, zero otherwise	0.54	0.52	0	0	1	1
Slope	1 if slope greater than or equal to 8%, zero otherwise	0.73	0.71	0	0	1	1
Farm size	Number of ha cultivated	2.29	2.83	0.67	0.86	10.14	20.29
Beans	1 if beans grown in plot the previous season or intercropped, zero otherwise	0.19	0.33	0	0	1	1
Extension	1 if the farmer received visit from an extension agent, zero otherwise	0.32	0.53	0	0	1	1
District	1 if the farmer is located in district 1, zero otherwise	0.62	0.48	0	0	1	1

Note: [a] At the time of the survey, 12C$ = 1US$.

monocropping or intercropping, implying that 54 per cent adopted slash-and-burn technology. Nitrogen input was computed as the sum of the nitrogen component of each fertilizer type, including urea. The average pesticide and nitrogen fertilizer use for farmers who practiced slash-and-burn was 12.0 kg/ha and 82.0 kg/ha, respectively. The corresponding figures for the group of farmers who did not practice slash-and-burn use were 20.0 kg/ha and 83.0 kg/ha, respectively. As shown in table 1, yields were measured in kg/ha, while net returns were computed as revenue from maize crop minus input costs (input costs include pesticides, fertilizer, labour, and land rent). The presented statistics indicate slight differences in average yields between the group of farmers who practiced slash-and-burn and those who did not practice the technology. As argued by Holden (2001), soils are sometimes more fertile after slash-and-burn than will be the case for those that are continuously cropped, contributing to higher yields on crops following slash-and burn. The education variable also shows that farmers who did not practice slash-and-burn agriculture were on average more educated.

The independent variables used include farm and household characteristics, cropping history, geographic location, and soil quality. Household characteristics include household size, age and education of household head, access to credit, participation in non-farm work, access to extension services, as well as land title to the land cultivated. Households have an average size of seven persons, with the household head being on average 47 years old. They differ considerably in the size of land owned, the size of plots cultivated, the amount of inputs applied, and labour utilized. A dummy variable is included to indicate the cultivation of beans either in the previous period or intercropped with maize, since this could influence the demand for nitrogen fertilizer and yields. Four variables are used to describe the characteristics of the farmed plot and its soil quality. They include plot slope and depth of the A-Horizon (soil depth), as well as dummy variables indicating whether soils are silty or not, and whether soils are clay or not (Burpee and Turcios, 1997).

The ability to acquire and process information and to conceptualize the results of alternative effects of adopting technological improvements is also enhanced by education. This permits a more critical evaluation of the productive characteristics and costs of adopting technologies, enabling farmers to distinguish more easily those improvements whose adoption provides an opportunity for net economic gain from those that do not. If this hypothesis is correct, farmers who have more schooling and information will be better informed about the existence and general performance of different technologies, will make more accurate assessments of differences in farm-level performance, and will make more efficient adoption decisions (Huffman, 2001). The inclusion of the agricultural education component in the Nicaragua-Agricultural Technology programme recognizes the role that knowledge plays in adopting appropriate agricultural technologies to raise productivity (World Bank, 2000).

In many developing countries, access to credit normally contributes to increased farm productivity by helping farmers overcome financial constraints for the purchase of higher quality variable inputs, such as fertilizer, pesticides, or new technological packages such as high-yielding seeds. If a farmer fails to purchase fertilizer or pesticides for his standing crop, output loss may be irretrievable. Credit, therefore, can help to increase crop yields, while credit constraints decrease crop yields by limiting the adoption of high-yielding varieties and the acquisition of information needed for increased productivity. Given that slash-and-burn technology has low entry costs, it may be more attractive for farmers without land rights. Hence, farmers without land title are more likely to adopt the technology than those with land titles.

The practice of slash-and-burn farming may also be influenced by visits of agricultural extension workers to farmers. In most developing countries, agricultural extension tends to be a major source of information on technological improvements in the agricultural sector. Although the information provided by extension workers may not be totally objective with respect to information on expected performance, it is most likely that they serve as an important source of information on how and when to use a technology. It is therefore hypothesized that farmers who are visited by extension agents will be more aware about the ecological costs of slash-and-burn, and as such will be less likely to adopt.

The practice of slash-and-burn cultivation may result in differential use of inputs such as pesticide and nitrogen fertilizer. For instance, if slash-and-burn results in a clear soil fertility gradient, the farmer may adjust his crop choice or fertilizer input strategy (Rodenburg *et al.*, 2003). As noted by Ketterings *et al.* (1999), slash-and-burn cultivation reduces competition by weeds and occurrence of pests. The practice of slash-and-burn may therefore lead to reduced demand for pesticides.

Given that about 95 per cent of the nitrogen content in the residues is transported to the atmosphere during the burning process, it may appear logical to hypothesize that farmers practicing slash-and-burn cultivation may use more nitrogen fertilizer than the non-adopters. However, if the slash-and-burn field does not follow an extremely short fallow period, the soils are usually more fertile than land under continuous cropping, resulting in less demand for nitrogen fertilizer. The potential impact of slash-and-burn cultivation on the demand for nitrogen fertilizer is therefore ambiguous.

4. Empirical results

The switching-regression model was estimated using the Limdep statistical package. Estimates of the probit model of slash-and-burn technology adoption are reported in table 2. The marginal effects measure the change in the probability of adoption given a one-unit change in the explanatory variable. They are obtained by multiplying the coefficient estimates $\hat{\beta}$ by $\phi(\hat{\beta}'Z)$ at the mean values of Z (Maddala, 1983). To measure the performance of the model, the McFadden R^2 and the log-likelihood are reported. This is calculated as $R^2 = 1 - L_\Omega/L_\omega$, where L_Ω is the unrestricted maximum log-likelihood and L_ω is the restricted maximum log-likelihood with all slope

Table 2. *Probit model of slash-and-burn technology adoption*

Variable	*Coefficent*	*t-value*	*Marginal effects*
Constant	0.4852	0.321	–
Age of head	−0.2421	−1.314	−0.107
Education	−0.3736	−1.836	−0.164
Household size	−0.0381	−1.295	−0.017
Access to credit	−0.3521**	−2.373	−0.155
Wage rate	0.2863**	2.295	0.1261
Fertilizer price	−0.1972	−1.487	−0.3944
Pesticide price	0.2114*	1.962	0.4228
Land title	−0.2678*	−1.709	−0.117
Non-farm income	−0.2364**	−2.247	−0.104
Crop income	−0.072**	−2.452	−0.032
Silty soil	−0.0814	−1.096	−0.036
Clay soil	0.0493	1.327	0.022
Soil depth	0.0276	1.578	0.012
Slope	−0.0041	−1.029	−0.002
Farm size	0.0205	1.327	0.062
Beans	−0.2637*	−1.916	−0.116
Extension	−0.3298**	−2.503	−0.145
Farm size* extension	−0.1256*	−1.772	–
District	0.3515	1.190	0.155
McFadden R^2	0.318		
Log likelihood	−262.57		
Correct predictions	78%		

Notes: Coefficients followed by * and ** indicate significance at the 10% and 5% level, respectively.

coefficients set equal to zero (Amemiya, 1981). The percentage of correct predictions is calculated as the total number of predictions as a percentage of the number of observations. The model correctly predicts the choice of slash-and-burn technology for 78 per cent of the sample.

The farm size variable was positive, but not statistically significant, indicating that the number of acres cultivated does not influence the practice of slash-and-burn agriculture. The negative and significant coefficients of the variables for education and extension indicate that farmers who receive extension visits and who are educated are less likely to adopt slash-and-burn technology. Similarly, the negative coefficient for the variable representing access to credit suggests that the probability of adopting the technology is higher for farmers who face credit constraints. A multiplicative interaction term was also included to measure the separate impact of extension on the effect of farm size on adoption of slash-and-burn cultivation. The negative coefficient suggests that amongst farmers who received extension visits, farmers of larger farms are less likely to practice slash-and-burn cultivation. Farmers who had land rights or land titles also had a lower probability of adopting the technology. These results are in agreement with the finding by Schuck *et al*. (2002) who found that land ownership and access to extension services played a significant role in reducing slash-and-burn practices, while cultivating large acreages encouraged the technology.

Soil characteristics, age of the household head, and geographic location did not appear to significantly influence the pattern of adoption of slash-and-burn. However, having access to non-farm income was significantly correlated with non-adoption, implying that farmers who earn additional income from non-farm sources are less likely to practice slash-and-burn agriculture.

The results of the second stage analysis of the switching-regression model are presented in tables 3 and 4. Table 3 reports the estimates for nitrogen fertilizer and pesticide demand, while table 4 presents the estimates for yield and net returns. As mentioned earlier, identification of the model requires that there be at least one variable in the adoption equation that does not appear in the input demand, output supply, and net returns equations. Farm income and the interaction between farm size and extension variables were used as identifying instruments in estimating the fertilizer and pesticide application, as well as the yield and net returns equations. The inverse Mill's ratio (selectivity terms) for adopters was significant in all the estimations for adopters, but not significant for non-adopters, even at the 10 per cent level. This finding suggests that adoption of slash-and-burn technology may not have the same effect on the non-adopters, should they decide to adopt. Furthermore, the significance of the inverse Mill's ratio for adopters indicates that sample selection bias would have resulted if the input demand, output supply, and net returns equations had been estimated without taking into account the decision to adopt slash-and-burn technology.

The estimates of the input demand equations show that for the entire sample, slash-and-burn technology increases nitrogen fertilizer application for larger farms. For the sample as a whole, the practice of slash-and-burn technology increases the average nitrogen fertilizer application rate by 11.3 kg/ha for each additional hectare. However, farm size does not appear to significantly affect the application rate of nitrogen fertilizer for farmers who choose a different cultivation practice. Pesticide application also seems to be influenced differently by farm size, depending on whether slash-and-burn technology was adopted or not. Without slash-and-burn, each additional hectare increases pesticide application by 3.1 kg/ha. The estimates also indicate that either intercropping with a legume (beans) or planting beans in the previous season appear to significantly reduce the demand for nitrogen fertilizer for both adopters and non-adopters. Specifically, planting beans with maize or planting it in the previous season reduces the average commercial fertilizer application rate by 13.9 kg/ha for non-adopters, but by only 6.3 kg/ha for adopters of slash-and-burn technology. These findings suggest that farmers include at least to some extent technology or management choices, such as adopting slash-and-burn technology or intercropping in their input demand decisions. This is in line with our initial hypothesis that the environmental impacts of the

Table 3. *Switching regression model of nitrogen fertilizer and pesticide application*

	N fertilizer application		*Pesticide application*	
Variable	*Non-adopters*	*Adopters*	*Non-adopters*	*Adopters*
Constant	1.028	1.273**	2.316**	1.942**
	(1.665)	(2.021)	(2.804)	(2.435)
Age of head	4.267	2.259	−5.238**	−3.028
	(1.204)	(1.162)	(2.419)	(1.537)
Education	9.471	12.174**	7.821*	4.372
	(1.563)	(2.168)	(1.709)	(1.425)
Household size	−0.157	−0.876	−0.143	0.293
	(1.402)	(0.982)	(1.366)	(1.016)
Access to credit	8.014**	12.569**	4.4128*	3.247*
	(2.173)	(2.422)	(1.796)	(1.918)
Wage rate	−4.2561	−2.7082	−1.9351	−2.0849
	(1.269)	(0.974)	(0.833)	(1.625)
Fertilizer price	−5.3844**	−6.1936	−2.0374	−1.9332
	(3.207)	(2.947)	(1.206)	(1.174)
Pesticide price	−1.6290	−2.7034	−3.8332**	−4.261**
	(0.753)	(1.428)	(2.455)	(2.158)
Land title	5.828*	6.610	−0.252	0.782
	(1.961)	(1.572)	(0.617)	(0.895)
Non-farm income	4.226*	0.529	7.664**	5.3072*
	(1.849)	(1.632)	(2.153)	(1.861)
Silty soil	0.065	−0.113*	−3.260	4.872
	(1.138)	(1.746)	(0.832)	(1.469)
Clay soil	0.137	0.357	0.138	−0.0723
	(1.568)	(1.268)	(1.557)	(1.481)
Soil depth	−0.203**	−0.325**	−0.223	0.208
	(2.354)	(2.474)	(1.654)	(1.446)
Slope	0.728	0.116	0.671	0.825
	(1.519)	(1.053)	(1.362)	(1.247)
Farm size	5.136	11.328**	3.142**	4.911**
	(1.454)	(2.117)	(2.283)	(2.462)
Beans	−13.871**	−6.252	0.149	−0.273
	(2.309)	(1.916)	(1.286)	(0.869)
Extension	8.012*	9.858**	0.172**	0.354
	(1.965)	(2.307)	(2.293)	(1.108)
District	0.137	0.479	0.895	−0.722
	(1.342)	(1.168)	(1.385)	(1.955)
Selectivity terms	−0.382	−0.587**	0.274	−0.413**
	(1.276)	(2.423)	(1.382)	(2.966)
Adjusted R^2	0.40	0.44	0.49	0.46

Note: Absolute *t*-values in parentheses. Coefficients followed by * and ** indicate significance at the 10% and 5% level, respectively.

slash-and-burn technology, such as weed control and nitrogen losses, influence farmers' input demand.

Another interesting result is that of the education variable. While education exerts a positive influence on the nitrogen fertilizer application rate for adopters, it does not significantly influence the demand for nitrogen

Table 4. *Switching regression model of maize yield and net returns*

	Maize yield		*Net return*	
Variable	*Non-adopters*	*Adopters*	*Non-adopters*	*Adopters*
Constant	0.896**	1.152**	2.218**	1.883*
	(2.217)	(2.426)	(2.077)	(1.766)
Age of Head	0.129*	0.153	0.269**	1.295
	(1.872)	(1.572)	(2.375)	(1.368)
Education	0.258**	−0.121	7.672**	−8.466
	(2.403)	(0.867)	(2.315)	(0.429)
Household size	0.162	0.326	−6.147	−4.263
	(0.548)	(1.277)	(1.261)	(0.757)
Access to credit	0.235*	0.389**	−5.223	7.124*
	(1.946)	(2.411)	(1.292)	(1.878)
Wage rate	−0.483	−0.526*	−4.336**	−5.128**
	(1.452)	(1.671)	(2.491)	−(2.267)
Fertilizer price	−0.622**	−0.499**	−3.862**	−4.253**
	(2.359)	(2.618)	(3.015)	(2.867)
Pesticide price	−0.376*	−0.392**	−2.928**	−3.472**
	(1.803)	(2.058)	(2.462)	(2.104))
Land title	0.473**	0.524	12.736*	−7.327
	(2.218)	(1.579)	(1.812)	(1.293)
Non-farm income	0.626*	0.565	0.498**	0.446*
	(1.937)	(1.461)	(2.104)	(1.897)
Silty soil	0.128	−0.147	0.0586	−0.092
	(1.468)	(1.273)	(1.347)	(0.537)
Clay soil	0.572**	0.514**	6.246*	8.934**
	(2.254)	(2.429)	(1.679)	(2.582)
Soil depth	0.283	0.180	0.636	0.125
	(1.586)	(1.259)	(1.142)	(1.472)
Slope	−0.384	−0.627	−3.291	−2.806
	(1.614)	(1.406)	(1.573)	(1.398)
Farm size	−0.7132*	0.3079	−12.897*	−3.8221
	(2.017)	(1.005)	(2.162)	(1.124)
Beans	2.762**	3.618	8.2536**	4.0769
	(2.317)	(1.036)	(2.274)	(1.302)
Extension	0.5358*	0.2420	10.529**	−8.892
	(1.956)	(1.273)	(2.403)	(1.052)
Selectivity terms	0.462	0.372**	0.487	0.421**
	(1.538)	(2.359)	(1.246)	(2.640)
Adjusted R^2	0.37	0.41	0.47	0.51

Note: Absolute *t*-values in parentheses. Coefficients followed by * and ** indicate significance at the 10% and 5% level, respectively.

fertilizer of non-adopters. The positive and significant effect of the credit variable for fertilizer application appears to support the notion that credit permits farmers to overcome financial constraints to purchase and apply optimal levels of inputs.

The fertilizer price has the expected significant and negative effect on fertilizer use, while pesticide price tends to exert a significant and negative impact on pesticide use, suggesting that an increase in the prevailing prices of these inputs will result in a reduction in their use in maize production in the prevailing locations. The estimates of the wage rate variable indicate that labour use is a net complement of fertilizer and pesticide inputs.

For the maize yield and net returns equations, the estimated coefficients of the farm size variables were statistically different between the adopters and non-adopters. Without adoption of slash-and-burn technology, larger farm size is associated with lower yields and net returns. Each additional hectare reduces the average yield by almost 713 kg/ha, and net returns by almost 12.9 C$/ha (12C$ = 1US$). This finding appears to support the inverse farm size–productivity relationship, which posits that small farms are more productive than large farms, even when the specification accounts for differences in other inputs' use (Binswanger *et al.*, 1995). But farm size does not appear to explain differences in yields and net returns when the technology is adopted. Similarly, the estimated coefficients for the education variables appeared to be statistically different for adopters and non-adopters. Without slash-and-burn technology, additional schooling contributes to higher yields and net returns. Education increases average yields by 258 kg/ha and net returns by 7.7 C$/ha. However, education is not significant in explaining the differences in yield and net returns among adopters of the technology.

Property rights also appear to be explaining yield and net returns differences among non-adopters of slash-and-burn technology. Farmers with land titles obtained 473 kg/ha more yield and an average of 12.7 C$/ha higher net returns than farmers without land titles, supporting the notion that increased individualization of rights improves farmers' abilities to reap returns from investments on land.[6]

As expected, soil characteristics such as texture and slope also tend to influence crop yield and net returns. Soil texture generally exerts a positive influence on yields and net returns. On the other hand, slope exerts a negative influence, *albeit* statistically insignificant at conventional levels, suggesting that nitrogen losses occurring through erosion processes at steeper slopes are probably not compensated through fertilizer use. In the long run, this might lead to soil degradation and further decreases in yield.[7] Indeed such a trend has already been observed for some regions, where agricultural activities have been carried out for more than 50 years (Burpee and Turcios, 1997). The significant influence of soil variables on yields and net returns suggests that biases in the estimations of yields and net returns are likely to occur, if environmental variables are omitted. This finding is in line with the argument put forward by Sherlund *et al.* (2002) that omission of environmental production conditions, that intuitively affect both output

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[6] Increased individualization of rights may also improve the credit worthiness of the farmer and enhance his chances of receiving formal credit. Both of these demand- and supply-side effects interact to increase investments in land and input use, which in turn lead to greater land productivity.

[7] For a detailed discussion on the link between soil depth, erosion, and productivity, see also Taylor and Young (1986).

and inputs subject to farmer control, leads to biased estimates of parameters describing the production function.

Farmers' access to credit appears to positively and significantly influence yields and net returns, with the impact on yields and net returns being more pronounced with adoption than without adoption. The positive and significant relationship between access to credit and yields is consistent with the work of Carter (1989) which shows a positive association between credit and input use and farm productivity in Nicaragua. The productivity impact of the recent effort by the government – with the support of the World Bank – to improve farmers' access to credit would be positive if implemented successfully.

The effects of intercropping with beans and visits by extension agents on yields and net returns were also more significant for non-adopters than for adopters. Specifically, the estimated coefficients of the extension education variables were statistically different between the adoption and non-adoption equations, suggesting that access to extension services is making farmers more aware of the higher yields and net returns to be achieved through other production methods. Farmers who received extension visits obtained yields of 536 kg/ha and net returns of 10.53 C$/ha more than farmers who received no extension visits. However, access to extension services does not significantly affect yields and net returns when slash-and-burn is practiced.

5. Concluding remarks

This study examined the impact of slash-and-burn agriculture on the application of commercial fertilizer and pesticides, as well as yields and net return. The empirical evidence of the study indicates that cross-section analysis of the impact of technology adoption on input demand and output supply should take into consideration sample selection, and also examine the impact separately for adopters and non-adopters. The results show that education, land rights, access to credit and visits by extension agents reduce the probability of farmers practicing slash-and-burn agriculture.

Estimates of the input demand and output supply equations indicate that the impact of farm size on fertilizer and pesticide application is different for adopters and non-adopters of slash-and-burn technology. Without adoption of slash-and-burn technology, a larger farm size is associated with lower yields and net returns but farm size does not appear to explain differences in yields and net returns when the technology is adopted. The estimated coefficients for the education variables also appeared statistically different for adopters and non-adopters of the technology. Education exerted a positive and significant impact on yields and net returns for those farmers who did not practice slash-and-burn, but did not significantly explain the differences in yield and net returns among adopters of the technology. Soil characteristics play a significant role with respect to yields and net returns for both adopters and non-adopters, suggesting that soil quality should be included when estimating yield and net returns functions. However, soil characteristics do not impact significantly on input demand decisions of farmers, implying that land and liquidity constraints, as well as access to extension services, dominate farmers' decisions.

A major policy implication arising from the results of this study is that efforts to move farmers away from slash-and-burn cultivation should focus on resource poor households cultivating on steep slopes, in order to help minimize erosion and nutrient losses. These are mostly households that have relatively low levels of education and face liquidity constraints. Extension services and basic education programs should go hand in hand to support farmers in moving away from slash-and-burn cultivation by providing them with information relating to the negative aspects of the technology and building the capacity to understand and successfully apply new cultivation techniques. On the other hand, liquidity constraints and lack of property rights could push asset-poor households to engage in this farming practice. Under such conditions, slash-and-burn cultivation could be mitigated by land redistribution and secured property rights, as well as by improving the access of liquidity constrained farmers to credit facilities.

The current effort by the government to improve access to land (and to titles) for the poor therefore appears to be in the right direction to increase their ability to accumulate assets and opportunities for accessing credit markets and other services. In addition to this effort, education of poor and illiterate farmers should not be ignored. Besides supporting farmers to move away from the slash-and-burn technology, improving education could also lead to a better and more efficient use of inputs.

Another policy issue relates to the improvement of productivity and net returns. The results showed that farmers who practiced slash-and-burn and were not credit constrained were more productive and achieved higher net returns, while those who did not practice the technology and were not credit constrained obtained higher yields. These findings are probably due to the fact that farmers without liquidity problems are in a better position to acquire and apply higher levels of productivity-enhancing inputs. This suggests that streamlining the acquisition of credit among farmers may contribute to improving productivity and net returns. It is, however, worth mentioning that allocating public resources to farmers on political grounds may not help the poor farmers gain access to credit. The open access credit policy initiated by the Sandinistan government in 1979 and still being pursued appears to be in the right direction.

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