CHARCOAL PRODUCTION AND AGRICULTURAL EXPANSION INTO THE PERUVIAN AMAZON RAINFOREST: A HOUSEHOLD ECONOMIC ANALYSIS

By

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ABSTRACT

CHARCOAL PRODUCTION AND AGRICULTURAL EXPANSION INTO THE PERUVIAN AMAZON RAINFOREST: A HOUSEHOLD ECONOMIC ANALYSIS

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Agricultural expansion has traditionally led colonization of the Amazonian rainforest. Recently, pioneer farmers in the forest margins around Pucallpa, Peru, have been changing their production decisions and altering the deforestation process. In response to a government policy to protect forests in another region of the country, pioneer farmers have begun to add charcoal production to their activities. A recursive, dynamic optimization model analyzes how the incorporation of charcoal production by a representative pioneer farm would affect household net returns and the rate of deforestation. The model predicts that after 10 years, a net revenue maximizing pioneer farmer would increase household earnings and reduce forest conversion by producing charcoal. A sensitivity analysis predicts that farmers would allocate most of any additional labor to charcoal production, reinforcing the conservation effect. However, the long-term effects of charcoal production upon rainforest conversion will depend upon how extra earnings are reinvested, a decision that is beyond the scope of this model.

DEDICATION

A las personas más importantes en mi vida:

Malena, Camila y José María, mi pequeña gran familia

Emilio y Ana, mis padres

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1. Introduction

As in many tropical countries, agricultural expansion has been a primary cause of deforestation in the Peruvian Amazon, especially in the area of Pucallpa (IIAP 1996, Fujisaka 1997, Labarta 1998, Yanggen 2000). Although agriculture continues to expand, charcoal production in the forest margins of Pucallpa is changing the deforestation process. Before 1995, charcoal production was not a financially feasible activity for pioneer farmers, who typically sell some timber but mainly convert primary forests to agricultural uses. The absence of markets, high transport costs and the abundance of other forest income sources discouraged charcoal production. Nevertheless, reduced charcoal supplies from northern coastal forests have increased the value of many Amazonian tree species. The production of high-quality Amazonian charcoal, while economically beneficial to farmers in the short term, is changing the longer term forest-agriculture dynamics of the region.

Strong national demand for charcoal is met by limited supply. The high-quality charcoal from selected Amazonian species provides a superior fuel with excellent heat output and can withstand rough transport without pulverizing. Restaurants serving barbecued meat in the coastal cities of Peru constitute a large market that demands this type of charcoal thereby creating high and stable market prices. Traditionally, this demand was met from the northern dry forest of the country. However, overexploitation led to a government prohibition of forest extraction in the region (INRENA 1993). This policy constrained the charcoal supply and therefore raised its market price. A direct consequence of this policy is the recent wave of charcoal production from a few timber species from the virgin Amazon forest.

This “new” activity among Pucallpa pioneer farmers increased annual charcoal production in the area from less than 1,000 metric tons (mt) in the 1980s to more than 11,000 mt in 1998, accounting for around 80% of national charcoal production in Peru (Figure 1). The incorporation of this new activity at an early stage of the forest colonization process raises an important question: Do the financial incentives of charcoal production cause pioneer farmers to increase or to reduce cutting of the primary rainforest? Underlying this question are issues of government policy, farm management strategies, and the resulting impacts upon human welfare and forest cover.

The objective of this research is to analyze potential changes in the traditional forest conversion process and household welfare in response to increased charcoal production. To achieve this general objective, the paper develops conceptual and empirical models to analyze farm and forest management decisions in the pioneer settler context. An optimization model of a representative pioneer farm common to the forest margins near Pucallpa, Peru, serves as a case study.

The paper first provides brief background about deforestation in the Peruvian Amazon. Section 3 develops a conceptual model for understanding the dynamic process of charcoal integration into a farmer’s production options. Section 4 develops an empirical optimization model to simulate behavior by a representative pioneer farmer. Section 5 presents the results of the empirical model, which are discussed in section 6. Finally, section 7 summarizes policy implications and conclusions.

2. Deforestation in the Peruvian Amazon

As agricultural colonization of forest areas has increased, deforestation in the Peruvian Amazon has become a major concern (Fujisaka 1997, Labarta 1998, Yanggen 2000). According to Peruvian statistics, 261,000 ha are deforested annually. By 2000 deforestation was expected to have reached 12.7 percent of the Peruvian Amazon. Of this total, agriculture accounts for 80% of land conversion (INRENA 1994).

The expansion of agriculture in the Peruvian Amazon is driven by demographic patterns at the national level. From 1981 to 1993 the population of the Amazon region grew at an annual rate of 5.3% (INEI 1993). Much of the population growth comes from immigrant pioneer farmers. In-migration results from push factors, like poverty and land scarcity in other parts of the country (Riesco 1993). It also results from the pull factors, such as road development, timber extraction, and coca production (Labarta 1998, Yanggen 2000, White et al. 2001b).

Colonization of the forest margins typically follows a pattern with different development stages. According to Richards (1997), the process starts at the pioneer stage when loggers extract all commercially valuable timber. Since few species are harvested, much of the forest is left intact. Loggers then abandon the area but leave access roads for others to enter the remaining forest. Soon after, pioneer farmers arrive and convert the remaining forest to other uses, concentrating on subsistence food production for the household (Labarta 1997, Barbier and Burgess 2001). In a second stage, markets begin to emerge as road and communication infrastructure improve. For agricultural production, farmers begin to use fallowed land in addition to continued clearing of forest. In a final third stage, farmers become more completely integrated into markets. Here primary forest is scarce and the use of fallow and the establishment of pasture become more important. This paper focuses on the pioneer stage, which has received less attention in the economic literature.

Pioneer farmers enter the forest in search of economic returns. Slash and burn agriculture is a logical land use strategy given the abundance of land, rapidly depleting nutrients and labor scarcity (Ruthenberg 1980, White et al 2000). This land use system involves cutting and burning forest for the planting of crops. After a period of cultivation, the parcel is abandoned and a new area is cleared for a new agricultural cycle. Agronomically, use of slash and burn agriculture reflects the poor quality of most Amazonian soils (Goodland and Irwin 1975, Sanchez 1976). The main crops produced by the pioneers are rice, maize, cassava and plantain (Labarta 1998).

The area near Pucallpa in the western Amazon is representative of this colonization process. The city is located on the Ucayali River, a major tributary of the Amazon. Settlers began arriving in the area in large numbers during the 1940s after the government constructed a road linking Pucallpa and the capital, Lima. Land use in Pucallpa is heterogeneous. The amount of forest that remains on farms correlates closely to the number of years since the land was settled. In more recently inhabited areas, 59% of the farmland is still in forest, while in more mature regions, forest cover decreases to 40% (Fujisaka 1997, White et al. 2000)

Average total rainfall in Pucallpa is approximately 1700mm with a bi-modal pattern of wet months of February-April and October-December, and dry months of May-September and January. The mean annual temperature is 25 ^{o} C. Soil constraints in the area include low cation exchange capacity, soil acidity, high aluminum saturation and low nutrient stocks (particularly phosphorus, nitrogen and calcium). Invasive weeds constitute another factor (Fujisaka et al 2000).

The dynamics of forest margins of Pucallpa began to change in 1995, when the area became an important source of charcoal for urban markets (Malleaux 2001). However so far, other virgin forest areas in the Peruvian Amazon with the same natural conditions have not been part of this charcoal "boom". Among all towns in the Peruvian Amazon, Pucallpa has the best transportation links to the rest of the country. It is also the closest Amazon city to Lima, the capital of Peru with over 8 million inhabitants (a third of the Peru's population).

Although for many years the production conditions in the Amazon for high quality charcoal were excellent, farmers did not initially find this activity attractive for a number of reasons. First, few tree species have ideal characteristics for producing high quality charcoal. Second, production requires relatively large investments in capital and labor. For example, species that are well suited for charcoal like Tahuari (*Tabebuia serratifolia*) or Shihuahuaco (*Coumarouna odorata*) have high wood density that makes cutting difficult. Third, local and regional markets for the high quality charcoal were poorly developed because high transport costs made it difficult to compete with coastal forests nearer to urban markets that could provide similar quality charcoal. To illustrate the rudimentary nature of the local market, in 1995 charcoal had a single price for all types (no quality differentiation), around 5-6 soles[1] per charcoal bag (MINAG 2001).

Wood from the dry northern forest of Peru traditionally supplied the charcoal demands of Lima and other urban markets. Transport from this area was inexpensive and easier. For example, while trucking of a bag of charcoal from Pucallpa to Lima cost between 12 and 14 soles (0.20 soles per kilo) in 1995, moving the same bag from the northern forest to Lima cost between 6 and 7 soles (0.10 soles per kilo). Also, transportation from Pucallpa to Lima is subject to road interruptions for long periods. By contrast, the Pan-American Highway that connects Lima with forest in the northern Departments of Piura and Tumbes allows a consistent year-round charcoal supply. The favorable characteristics of the northern forest led to an overexploitation of the resource. By the early 1990's more than 10,000 hectares were lost every year due to charcoal production. To stop the depletion of the increasingly threatened dry forest, in 1993 the government enacted Law # 27308 that prohibited the production, transportation and commercialization of any firewood or charcoal from the northern forest (INRENA 1993).

After the governmental prohibition, the continued demand for high quality charcoal rapidly changed the market conditions in the area around Pucallpa. The new policy strengthened incentives to produce charcoal from rainforest trees. As a result, the "farm gate" price for this special charcoal tripled to 15-18 soles per bag in the late 1990's (MINAG 2001).

[1] After 2000 the exchange rate stabilized around 1 US$ = 3.5 Peruvian soles

3. Conceptual framework and general model formulation

The household production approach offers a useful conceptual framework for combining farmer production and consumption decisions (Singh et al 1986). Under this approach we develop a model to represent a pioneer household entering into a new area in the forest looking to maximize their utility. In this model household utility in defined as:

$$U = U(X_a, X_o, \ell) \quad (1)$$

We assume that households derive utility from consumption of agricultural goods (X_a), consumption of other goods (X_o) and leisure (ℓ). Other goods include products purchased off-farm or collected from the forest. Utility will be maximized subject to standard household production functions with corresponding resource constraints (land, labor, capital), and a full income constraint (Strauss 1986).

The dynamic nature of the forest colonization process allows us to assume that farmers derive utility every year. As described by Walker (2003), this process can be divided in two main periods. In his model, Walker described a period of land creation (land clearing) and a period of land rotation. The main difference between the two periods is the possibility of using fallowed land that becomes an important source of farm production in the second stage. Period n states the time when fallowed land becomes available. Thus the maximization problem can be written as:

$$\underset{X_{at},X_{ot},\ell_t}{MAX}\, U = \sum_{t=0}^{n} \beta^t U(X_{at}, X_{ot}, \ell_t) + \sum_{t=n+1}^{\infty} \beta^t U(X_{at}, X_{ot}, \ell_t) \qquad (2)$$

Where β^t is the discount factor for time t

For this research, the first period represents the pure pioneer stage of the colonization. In this stage, land consists of virgin forest from which selected high-value timber has been removed. Such forest can be converted into agricultural land by slash and burn techniques. The pioneer period will end around years 8 or 10, when farmers start to combine the use of forest and fallowed area (Labarta 1998). As pioneer farmers are the focus in this research, the model will concentrate the analysis in the first 10 years of the agricultural development of the forest (n=10). For simplicity, it will exclude the second stage. Production of high quality charcoal in the second stage is less likely, because local farmers tend to maintain the remaining forest after converting a majority of their forested land in the previous 10 years of farming (Fujisaka 1997, Labarta 1998, Smith et al 1999).

Forest colonization follows a path of agricultural expansion in which farmer's resources are initially devoted to slash and burn agriculture, some small-scale forest exploitation, and off-farm work. Agricultural production functions in this model are defined according to the type of crops being planted each year. Newly cleared land (A_o) can be cropped for up to two years. In the first year, farmers mainly establish rice or maize, while cassava and plantain are typically second year crops. Each year, farmers may concentrate on clearing only new land for growing first-year crops or may cultivate second-year crops on available land (A_a) that was cleared the year before ($A_{at} \leq A_{ot-1}$). As fallow is not available during the pioneer stage, second year crop production depends on the farmer's decision about clearing new land in the previous year. Thus, agricultural production functions differ according to prior land cover:

$$X_{1t} = X_{1t}(L_{at}, A_{ot}(L_{ot}), K_{1t}) \tag{3}$$

$$X_{2t} = X_{2t}(L_{at}, A_{at}(L_{ot-1}), K_{2t}) \tag{4}$$

First year crop production in year t (X_{1t}) depends on the use of labor for agricultural activities that year (L_{at}) the new land cleared that year (A_{ot}), and a small fixed amount of capital (K_{1t}) that farmers invest in specific inputs (e.g. machete, hatchet) for year t. The area of new land cleared in time t (A_{ot}) is determined by the amount of labor allocated to land clearing during that period (L_{ot}). As stated in (4), second year crop production in year t depends on agricultural labor use, available agricultural land in period t (A_{at}), and a small amount of capital (K_{2t}). Although farmers can choose not to grow second year crops, the availability of agricultural land in time t depends on labor allocated to land clearing in time t-1.

The incorporation of charcoal into the production process adds another household production function:

$$C_t = C_t(L_{ct}, L_{mt}(D), I_t, K_{ct}) \tag{5}$$

L_{ct} is the labor allocated to charcoal production in time t, I_t is the farm endowment of trees required for charcoal production that exist each year and K_{ct} the small amount of capital needed in this activity in the same year. The other variables reflect specific production processes. Since trees are usually far from roads, the bags of charcoal need to be transported to the nearest road. But given the characteristics of the forest and the scarcity of heavy machinery, transportation requires manual labor (L_m). This extra labor or transportation cost is defined by a distance function D which depends on tree density. For simplicity, the model assumes a homogeneous distribution of trees required for charcoal production and defines the following linear distance function:

$$D = \alpha d \qquad (6)$$

This function depends on a fixed parameter of workdays needed per kilometer (α) and on the distance in kilometers between the trees and the nearest roads (d). The younger the farm, the lower the distance the pioneers need to transport charcoal (Angelsen 1999).

Early in the colonization process, land clearing is traditionally accomplished during the dry season (June-August) and agricultural activities occur during the remainder of the year. Adding charcoal production affects this temporal distribution of labor. The main period for this new activity is also during the dry season, introducing labor competition between land clearing and charcoal production (Figure 2). The constraints for labor allocation during the dry season (L_d) and the remaining (rainy[2]) season (L_r) can be written as:

$$L_{ot} + L_{ct} + L_{mt} \leq \overline{L_{dt}} \quad (7)$$

$$L_{at} \leq \overline{L_{rt}} \quad (8)$$

Maximization of the household utility during the pioneer stage can be solved using two different alternative approaches that are based on different assumptions about market integration. A large discussion in the literature has been whether farmers' production decisions are affected by their consumption decisions or whether production and consumption decisions are independent and separable (Singh et al 1986, Benjamin 1992). When farmers face efficient output and input markets, and use homogeneous inputs, farmers' decisions can be represented in a separable model. Production decisions can be analyzed independently of the household preferences that determine their consumption. On the other hand, the existence of market imperfections (such as missing labor or credit markets) can necessitate representing farmers' decisions in a non-separable model where farmers jointly determine household production and consumption (Strauss 1986, De Janvry 1991). Non-separable models can be related to the traditional Chayanov household model which implies a trade-off between disutility of work and utility of income (Ellis 1993).

[2] Although February has almost no rain, most of the remaining season has regular rain

In the Peruvian Amazon, rural labor markets are not completely developed. Although some labor transactions occur, the marginal value product of labor seems to deviate from the market wage, implying that production and consumption decisions are non-separable. As described by Benjamin (1992), what is happening is that the marginal value product of labor is equating to a shadow wage that depends on household characteristics and other utility-related variables. White et al (2005) provided evidence that Peruvian Amazon farmers may have shadow wages higher than market wages during some periods of the agricultural year.

Solving the maximization problem for non-separable decisions presents computational difficulties. However, highlighting the endogeneity of the shadow wage, and the consumption decisions that affect this shadow wage, the problem can still be solved with a recursive system conditional on the shadow wage (Strauss 1986). Although real farmers maximize utility, considering household subsistence and resource constraints, this paper focuses the analysis on the production side using constrained maximization of net returns as an analytically tractable proxy for unobservable utility maximization. This approach will focus on the financial incentives that farmers are face from different production alternatives (Angelsen 1995).

Now the problem becomes to maximize the present value of net returns over the pioneer stage (10 years), subject to farm resource constraints. Net returns during the pioneer stage can be split in two periods: the first year and the remaining years. During year 1, pioneers face a "one-plot problem". At this period there is no available cleared land, so farmers make decisions considering net revenues of first year crops (X_{11}), discounted net revenues from second year crops that they would have in the same plot in year 2 (X_{22}) and year 1 net revenues from charcoal production. Beginning in year 2, farmers face a "two-plot" problem because they can grow first year crops, second year crops or a combination of both in the same period. Discounted net returns for the first year can be defined as:

$$\pi_1 = P_1 X_{11}(.) + \beta P_2 X_{22}(.) + P_{c1} C_1(.) - W_m (L_{a1} + L_{a2} + L_{01} + L_{c1} + L_{m1}) - K_1 \quad (9)$$

For the rest of the pioneer stage net revenues can be defined as:

$$\pi_r = \sum_{t=2}^{n} \beta^t \{P_1 X_{1t}(.) + P_2 X_{2t}(.) + P_{ct} C_t(.) - W_m (L_{at} + L_{at} + L_{0t} + L_{ct} + L_{mt}) - K_t \quad (10)$$

In general farm net returns are discounted by factor β^t. P_1, P_2 and P_c are the farm gate prices for first year crops, second year crops and charcoal respectively, while W_m is the labor wage in the local market. Farm revenues are determined by the output prices and quantity produced in the agricultural and charcoal sectors. Production costs are determined by the total labor cost on farm (during both dry and rainy season) that includes the extra transportation cost of the charcoal production, and the working capital required for both production processes.

Assuming L_a, L_o, L_c, and L_m as the choice variables, given the key role of labor and tree capital in the Peruvian Amazon (White et al 2005), and that working capital is negligible on pioneer farms, the Lagrangean can be formulated as:

$$\underset{L_{at},L_{ot},L_{ct},L_{mt}}{MAX} .\pi = \pi_1 + \pi_r + \lambda_{1t}(L_{dt} - L_{ot} - L_{ct} - \alpha d) + \lambda_2(L_{rt} - L_{at}) + \lambda_{3t}(A_{at} - A_{ot-1}) \qquad (11)$$

λ_1, λ_2 and λ_3 are the Lagrange multipliers for the labor and land constraints. Both λ_1 and λ_2 when added to the local market wage determine the shadow wages during the dry season and the rainy season respectively. These shadow wages depend on production and household characteristics.

With only primary forest (F_t), deforestation can be defined as any conversion to agricultural use. As individual tree cutting is assumed only to degenerate the forest, deforestation is determined mainly for the land opened each year for agricultural purposes. The dynamic of forest conversion can be defined as:

$$F_{t+1} = F_t - A_{ot} \qquad (12)$$

Solving (11), the first order conditions after year 1 and after rearranging terms are:

$$P_1 \frac{\partial X_{1t}}{\partial L_{at}} + P_2 \frac{\partial X_{2t}}{\partial L_{at}} = (W_m + \gamma_2) = W_r^* \qquad (13)$$

$$P_1 \frac{\partial X_{1t}}{\partial A_{ot}} \frac{\partial A_{ot}}{\partial L_{ot}} + P_2 \frac{\partial X_{1t+1}}{\partial A_{at+1}} \frac{\partial A_{at+1}}{\partial L_{ot}} = (W_m + \gamma_1) = W_d^* \qquad (14)$$

$$P_c \frac{\partial C_t}{\partial L_{ct}} = (W_m + \gamma_1) = W_d^* \qquad (15)$$

$$P_c \alpha \frac{\partial C_t}{\partial d} = (W_m + \gamma_1) = W_d^* \qquad (16)$$

$$L_{dt} = L_{ot} + L_{ct} + \alpha d \qquad (17)$$

$$L_{rt} \geq L_{at} \qquad (18)$$

$$A_{ot-1} \geq A_{at} \qquad (19)$$

This equation system leads to useful economic interpretations of farm management tradeoffs. For the ordinary agricultural activities (13), the traditional optimality condition holds. The value of the marginal product of labor devoted to agricultural activities (first year and second year crops) should equate to the opportunity cost of the labor in any time period t, given by the shadow wage during the rainy season ($W^*_r = W_m + \gamma_2$)[3]

Labor allocation during the dry season has different characteristics. According to equation 14, the value of the marginal product of labor has a direct effect during the current season, but an indirect effect over the next season. Any unit of labor allocated to clearing the forest will generate a direct impact on first year crop production at time t and

[3] Although it is beyond the scope of this paper shadow wages may vary during the rainy agricultural season, depending on feasible farm activities. The shadow wages could equate the market wage if there is labor availability (γ_2=0) or could be greater than market wage if the labor constraint during the dry period is binding (γ_2>0). See White et al (2005) for further explanation.

will also generate a positive marginal effect on second year crop production at time t+1. This effect should equal the shadow wage during the dry season, which is expected to be higher than the market wage due to high labor demand in this period from different farm activities ($W^*_d = W_m + \gamma_1$).

Equations 15 and 16 describe the optimality conditions for labor allocation to charcoal production during the same dry season. On one hand, the value of the marginal product of labor for charcoal production should equate to the shadow wage during the dry season, but on the other hand, this shadow wage should also be equal to the marginal transport cost (expressed in labor units) incurred during charcoal production. Combining (15) and (16), it can be inferred that the maximum distance that a pioneer farmer will travel for producing charcoal is determined by the point where the value of the marginal product of labor allocated to charcoal production is completely offset by the marginal transport cost required for carrying out the charcoal bags produced. At this point, the farmer will no longer perceive an incentive to continue expanding the charcoal production.

Equations (17), (18) and (19) complete the first order conditions, highlighting the resource limitations that farmers are facing when developing production processes. The dynamic interdependence of farmer decisions will determine the production path and therefore the household deforestation path over the years.

Attractive financial returns to charcoal production on time t compete with agricultural benefits during two periods. During the first period, the competition between charcoal production and opening land for first year crops could be partially alleviated by substituting first year crop production with second year crop production (which does not require labor resources during the dry season). However, the foregone benefits of second year crops in time t+1 will partially offset charcoal benefits realized in time t. If no forest is converted to agricultural land in year t, then no second year crop production will be possible in time t+1, raising the competition for scarce labor resources during the dry season in time t+1. Maintaining a high level of charcoal production implies lower household deforestation, but it necessarily entails strong financial incentives to reduce agricultural production. Completely avoiding deforestation would be very difficult because it seems that there is no product or alternative forest use that can provide such high returns to labor during the dry season.

The challenge is to predict the impact of introducing charcoal production and how the charcoal production alternative will affect the use of the forest resources around Pucallpa. The empirical analysis that follows tries to model this process.

4. A recursive multi-period programming model

A recursive multi-period linear programming model incorporates all possible cropping systems in the area, as well as different charcoal production processes. The objective function is the maximization of the sum of discounted household net income generated from the different enterprises, during the 10-year pioneer stage of forest colonization (Smith et al 1999). Following other studies, the analysis employs a 10% discount rate (White et al 2000, Vosti et al 2001).

The model introduces monthly labor requirements for every crop enterprise and for the existing charcoal production processes in the area (see Table 1). This leads to corresponding labor constraints during the dry season (June-August) and for the rainy season (September-May) (Table 2).

The isolated conditions in the area make it costly for pioneers to buy subsistence crops due to high transport cost. In addition, the non-separability characteristics of farmers' decisions discussed in conceptual model makes subsistence consumption to influence farmers' production decision. This feature is incorporated in the empirical model imposing minimum subsistence crop production constraint. For household home consumption requirements, the model explicitly imposes the constraint that the farm has to produce annually at least 1000 kg of rice, 500 kg of maize, 5000 kg of cassava and 100 bunches of plantain[4] (Table 2). While rice, plantain and cassava are clearly subsistence

[4] These consumption levels are high and are intended to satisfy the consumption of a family of more than 5 members plus feeding day laborers working at the farm.

crops, maize and cassava are also produced for feeding small animals (like chickens and pigs).

The model assumes a typical household with three permanent working members. This implies a labor endowment of 75 man-days per month. Hiring extra workers is difficult for most of the year because of the remoteness of forest margins.

This model is discretely dynamic and recursive because each year's production decisions generate new stocks of virgin forest, agricultural land and desirable trees, that become the initial conditions for the next year. A pioneer could use last year's opened land or clear new land for farming. However, the model recognizes the difference between both types of land. In fact, the main crops demanding the best soils (rice or maize) must be established only on newly cleared land, as suggested by previous studies (Fujisaka 1997, Labarta 1998). Other crops, like cassava and plantain, are preferred for planting on the second year land. However, the availability of land for second year crops does not necessarily imply that the farmer is going to establish them. The structure of the model allows labor allocation decisions to depend on previous land use decisions and on the expectation about future periods (Table 2 and Figure 3).

Model parameters are built using existing data that the International Center for Tropical Agriculture (CIAT) and other research institutes have been collecting from pioneer and other types of farmers in the Peruvian Amazon during recent years (White et al 2001b). This information comes from 80 farmers (see Table 1 for details) and is consistent with other studies that used farm level data to analyze agricultural activities (Fujisaka 1997, Smith et al 1999) and charcoal production (Coomes and Burt 2001, Hofstad 2001) in the Amazon and other tropical areas. The model is developed in an Excel 2000 spreadsheet.

The model develops two scenarios. The first scenario considers only a traditional agricultural expansion. Here a representative farmer decides each year how much labor to allocate between opening new land and farming new and old land, in order to maximize discounted net returns. New land required each year under this scenario determines the deforestation path at the household level.

The second scenario incorporates charcoal production as an alternative within the traditional agricultural expansion of the forest margins. The location effect of trees is incorporated by assuming linearity in the distance function and therefore in the extra labor required for transporting charcoal bags. Specifically, the model assumes no transport cost for the first two years, the need of 8 extra man-days for carrying out the filled bags of charcoal during years 3 and 4, 16 extra man-days for year 5 and 6, 24 man-days for years 7 and 8 and 32 extra man-days for years 9 and 10[5].

Model results offer key elements for understanding the current changes in the deforestation process around Pucallpa (Table 2). Returns to labor over a time horizon of 10 years are calculated, along with the total net returns of the representative farms.

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[5] This assumption is based on interviews of pioneers in the area. They reported enough trees for charcoal production during the first two years and that they have to walk an additional km every two years to continue producing charcoal. They estimated that on average for every km they need 8 extra man-days for carrying the charcoal bags.

General net returns under different scenarios provide a good understanding about variation in the economic incentives that farmers face under alternative production options. The other important output of the model is the area of primary forest cleared each year, which ultimately determines the household deforestation path. Although the model does not consider the option of returning to fallowed areas, the results give a general picture of land use distribution on the representative farm during the 7th year, when the first fallowed land will start to be available. This is important for knowing farm conditions when intensification of agricultural and forested land becomes an alternative.

A sensitivity analysis considers changes to household deforestation and net returns after relaxing key assumptions and constraints of the model. The first alternative scenario allows farmers to buy subsistence crops in the market by eliminating the constraints of minimal agricultural production. The second and the third scenarios modify the tree density for charcoal production. One case considers that the natural tree endowment is rich enough to avoid extra labor for transporting the charcoal bags. The other scenario represents a farmer that would need to carry out the charcoal bags another 2 km each year, which requires extra 8 man days for each 100 charcoal sacks. The fourth scenario models the sensitivity of results to changes in the charcoal price (10% and 50% price decrease). Finally the fifth scenario simulates a household whose charcoal sales permit hiring 12.5 extra man-days during each of the three months of the dry season. Given that the model compares annual activities, the sensitivity analysis excluded different discount rate scenarios. These scenarios will only reduce or proportionally increase farm returns, they will not change deforestation levels.

5. Results

The model predicts that at the end of the pioneer stage of forest colonization, a farm producing charcoal will reduce household deforestation from 21.8 ha to 18.1 ha compared to a farm following the exclusive agricultural path (Table 3). Furthermore, the deforestation path under the charcoal scenario lies always below the deforestation path of the exclusive agricultural expansion scenario (Figure 4). After year 7, when it is expected to have the first fallowed land available for agriculture, the model predicts a deforestation of 12.5 ha under the charcoal scenario and 15.4 ha under the agriculture scenario.

Behind the cumulative deforestation path, the predicted annual deforestation shows a different behavior between both scenarios (Figure 5). The agriculture scenario shows that after the first three years, the level of land cleared annually remains stable, slightly above 2 ha. The charcoal scenario shows two different periods of land clearing. Up to year 6, annual land cleared remains stable slightly above 1.5 ha, but during next four years this scenario shows a biennial pattern. Another difference between both periods in the charcoal scenario is the average annual charcoal production that decreases from 75 bags of charcoal between years 1 to 6, to 53 bags in years 7 to 10. Although land clearing differs between the two scenarios, the total agricultural land that includes new and existing land for second year crops shows a similar trend between both scenarios (Figure 6)

Charcoal production also generates a great effect upon household net returns. In general, household net returns are always greater under the charcoal scenario (Figure 7). At the end of 10 years the charcoal scenario achieves 17% higher discounted net returns than the purely agricultural scenario. Charcoal not only offsets the forgone agricultural benefits for reducing this activity (2,563 soles), but also generates an additional 2,667 soles (Table 3).

The evolution of net returns within the charcoal scenario has two components. Net returns from charcoal peak in the second year (1172 soles) but then show a decreasing trend over the years (Figure 9). However, net returns from agricultural activity compensate for the decreasing path of charcoal net returns by increasing consistently, achieving a level similar to the agriculture scenario after year 8 (Figure 8).

The two scenarios also show different returns to labor that result in consistently higher values in the charcoal scenario (Figure 10). On average, for every man-day consisting of 8 hours work, the representative farmer in the charcoal scenario earns 16.1 soles[6] while the farmer concentrating exclusively on agricultural expansion earns only 14.6 soles. But the 10% discount factor reduces both values to 14.0 and 13.1 soles, respectively. These returns are greater than the local daily wage (10 soles).

During the pioneer stage, on average, the model predicts different shadow wages for both scenarios. In the agricultural scenario, January and May (the main months for harvesting first year crops and second year crops, respectively) show the highest shadow values of labor (Table 3). In the charcoal scenario, July, the month when charcoal production and land clearing compete for labor, has by far the highest shadow wage (Table 3). But the

[6] 1 US$ = 3.5 soles

average shadow wages over 10 years, hide important trends. There is a decreasing trend during July for the charcoal scenario (Figure 11), a more or less stable trend during January for both scenarios (Figure 12) and an increasing trend during May in both scenarios (Figure 13).

Regarding the shadow price of the subsistence production requirements, the results show that only maize presents a binding constraint. However, imposing this constraint makes the farm net revenues to decrease by only 0.18 soles per each extra kilo of maize produced. The farm gate price of maize in the area is 0.30 soles, making cheaper to produce the maize (Table 3).

Net returns increments under the charcoal scenario in combination with the decrease in forested land cleared and the similar level of land cropped makes the returns to land higher under the charcoal scenario (Table 3). Clearing less forest under the charcoal scenario produces almost 30% more returns per ha to land than clearing more forest under the agriculture scenario (Table 3).

Table 4 summarizes the sensitivity analysis. Relaxing the minimum subsistence production constraint slightly increases farm earnings and decreases household deforestation, but reduces July's shadow wage by 13%. The richer endowment in scenario 2 has the biggest effect on all parameters except for farm earnings. It has the lowest level of household deforestation and January's and May's shadow wages, but the highest values for average returns to labor and the shadow wage of July. The poorer tree density scenario (3) makes model parameters respond differently, increasing the household deforestation by 8%, increasing the shadow wages in the harvesting months of January and May and reducing the shadow wage in July.

Reducing charcoal prices mainly reduces household deforestation and increases farm earnings. But while a 10% price reduction (scenario 4) will change very little model parameters, a 50% (scenario 5) price reduction will generate the worst results: the highest household deforestation (but still lower than the original agricultural scenario), the lowest farm net returns and the lowest returns to labor. Shadow wages also suffer big changes (Table 4). The scenario that simulates the possibility of hiring extra labor during the months when farmers sell charcoal (scenario 6) causes no change in deforestation level but the highest level of farm net returns and returns to labor. Shadow wages in January, May and July stay the same as in the original charcoal scenario.

6. Discussion

This analysis shows that even when charcoal production becomes possible, deforestation remains a problem around Pucallpa. At present, colonization of the forest margins provides higher returns to labor than the market wage (Table 3). Hence, farmers do not perceive incentives to refrain from exploiting the primary forest. However, decreasing household deforestation by around 20% and increasing discounted farm earnings by around 17% (Table 3) are not negligible results. The aggregate effect of many pioneers behaving like the modeled representative farmer could represent a win-win situation for the current pioneers and the primary forest in the area. But there is still a need to evaluate whether greater incentives from charcoal production could attract more pioneers and exacerbate land clearing in the forest margins. Over time, a decline in charcoal returns due to rising transport cost as charcoal-quality trees become scarcer seems to constitute a natural protection to reduce incentives for a massive entrance of more pioneers. But the final effect is unknown, and it is beyond the scope of the model.

Vosti et al (2003) pointed out that expected financial returns at the household level could predict which activity would be developed by small farmers in the Brazilian Amazon. In Pucallpa, higher returns to household resources are encouraging pioneers to incorporate charcoal production into their traditionally agricultural land use. This process is affecting farmers' decisions about how to allocate household labor, the key resource affecting deforestation according to many analysts (Shively 2001, Vosti et al 2001, White et al 2005). Model results support this feature by reporting changes in the estimated monthly shadow wages when a representative farmer incorporates charcoal production (Table 3).

Coomes and Burt (2001) also found that farmers around Iquitos (north of Pucallpa) have charcoal as an important source of income. By taking advantage of fallows, Iquitos farmers have integrated charcoal production as a complementary activity to slash and burn agriculture. The expansion of this activity, however, is constrained by low returns to labor that are just slightly higher than the prevailing local wage. This situation has reduced the probability of shifting much labor from agriculture to charcoal production. In Pucallpa the high quality charcoal from virgin forest is producing much higher returns to labor (Table 3). While farmers around Iquitos face a small regional market, farmers around Pucallpa are supplying charcoal to Peru's main urban centers. With no possibility of planting on fallowed land during the first 7 years of the pioneer stage, charcoal production is attractive to local farmers. Even when farmers face lower net returns (e.g. due to more distant trees of charcoal quality or a charcoal price drop of 50%), charcoal production still remains profitable (Table 3).

Charcoal production from virgin forest species is possible only during the dry season (June-August), which coincides with the period of clearing forest for agricultural land. The inherent trade-off between the two activities leads farmers to balance their income between the three-month charcoal activity and the year-round farming activity. Pioneer farmers can considerably increase farm net returns by adding charcoal as an alternative production activity, but the distance effect of the natural location of desirable individual trees generates a decreasing return on these charcoal profits (Figure 8). On the other hand, agriculture provides subsistence crops as well as income during the rainy season, when charcoal cannot be produced. Although subsistence production requirements seem to have little effect upon land clearing decisions (Table 4), eliminating subsistence production constraints causes a slight decrease in household deforestation and a more important increase in farm net returns. These results are consistent with Vosti et al.'s (2003) findings in Brazil when analyzing the feasibility of timber exploitation as an alternative to agricultural expansion. Also, in the Peruvian province of Madre de Dios, Escobal and Aldana (2003) found that the exploitation of Brazil nuts increases farmers' income but does not significantly reduce deforestation. Brazil nuts are a complementary activity for farmers requiring labor during three months of low agricultural activity. By contrast, charcoal around Pucallpa competes with agriculture for available labor, producing changes in labor returns and promoting a labor reallocation that may reduce household deforestation.

According to model results, pioneer farmers who produce charcoal will have a different starting point after 7 years of forest colonization when the first fallows start to become available for replanting. A representative farm producing charcoal may reduce household deforestation by almost 3 ha (to a level of 12.5 ha) and may have accumulated discounted profits by 2,057 soles. A key question is what might the representative farmer going to do with these extra profits? This amount is equivalent to 206 man-days or almost to the full-time work of the household during 3 months. Many studies have shown that market integration improves as farmers pass from the pioneer stage to the emerging market stage (Richards 1997, Smith et al 1999). Are these farmers going to hire extra labor? If so what can they use this labor for? Many studies have stressed the possibility of land use intensification, taking advantage of the presence of secondary forest (Tachibana et. Al

2001, Vosti et al 2001), but others have argued that extra capital can be translated into greater deforestation (Holden et al 1998, Kohlin and Parks 2001). According to our model results, after 7 years charcoal production still seems to be profitable, so additional hired labor could be allocated to produce more charcoal even located farther away. Sensitivity analysis suggests that extra labor hired during the dry season will be allocated mainly to charcoal production without affecting the deforestation rate (Table 4). But the final effect of reinvestment is beyond the scope of the model.

7. Conclusions

Results from a recursive linear programming model of a representative pioneer farm show that under current conditions, deforestation is not likely to stop in the Peruvian Amazon. However its dynamic path and the amount of land cleared may change for farmers who engage in charcoal production. Similarly to Vosti et al (2003) findings when allowing Brazilian farmers small-scale timber extraction, the model results suggested that deforestation may be delayed. A household deforestation reduction of 20% and a farm net returns increase of 17% will definitely create a different starting point of forest availability at the end of the pioneer stage, when the first fallowed land is already available.

Although charcoal production is quite profitable, its profitability decreases as the remaining trees are located farther away from roads. This feature constitutes a natural protection of forest that can offset the high economic incentives of charcoal production and mitigate a massive entrance of new pioneer farmers, assuming no road improvement to facilitate access to the forest margins.

Our results differ from previous similar studies (Coomes and Burt 2001, Escobal and Aldana 2003, Vosti et al 2003) because the analysis concentrates in the pioneer stage of the forest colonization that posses special characteristics and makes the deforestation process at this stage different. Pioneer farmers only cut down virgin forest because secondary forest fallow is not ready to cut until 4-8 years after the cropped land is abandoned, usually after 2 years of crop production (Fujisaka 1997, Labarta 1998, Padoch and De Jong 1991). Previous studies have centered on the intensification-extensification debate (Kaimowitz and Angelsen 1998), but as Tachibana et al (2001) pointed out, this dichotomy does not explain the co-existence of old farms and new farms that becomes a relevant consideration only after pioneer forest colonization. During the pioneer stage, charcoal can only be produced during the dry season and after a long period without rain (usually between June and August). This is the same period when farmers clear the primary forest for agriculture. The analysis here has shown that under these conditions, charcoal production affects not only farm income, but also of household deforestation.

Farm activity at year 7, when the first fallowed land becomes available for farming, has important policy implications. At this time, early deforestation due to high charcoal earnings during early years has started to be partially offset by an increment in the agricultural activity (Figure 8) and a decrease in charcoal profits (Figure 9). Charcoal production from secondary forest is not attractive to pioneer farmers occupying the far forest margins, but land intensification becomes an option. Given the extra accumulated income from charcoal sales, researchers and policy makers will need to provide affordable and sustainable technology options to induce these pioneers to invest these earnings in activities that cause less deforestation. Examples include silvo-pastoral and agroforestry systems.

Further research will be needed in order to overcome the limitations of this study. These limitations include the 10-year time horizon, the absence of other stages of the colonization process (especially when fallow land becomes available for farming), the omission of financial capital accumulation, and the use of linear production and distance functions.

Tables

Table 1. Summary of enterprise budget parameters used in the multi-period model

	Intercropping systems				Rotations		Second year		Large	Low
	Rice/ Cassava	Rice/ Plantain	Maize Cassava	Maize/ Plantain	Rice/ Cassava	Maize/ Cassava	crops Cassava	Plantain	Scale Charcoal	Scale Charcoal
Yields (kg/ha)										
1st crop	1800	1800	1500	1500	2000	1800	12000	450	120**	30**
2nd crop*	12000	450	12000	450	15000	15000				
Prices* **										
1st crop	0.5	0.5	0.3	0.3	0.5	0.3	0.1	3	17	17
2nd crop	0.1	3	0.1	3	0.1	0.1				
Gross benefits	2100	2475	1650	2025	2500	2040	1200	1575	2040	510
Total Cost	1578	1829	1494	1743	1780	1685	739	898	702	365
Net Benefits **(soles)**	522	646	159	282	720	355	461	677	1338	145
Labor use (man-days)										
July	20	20	20	20	20	20	0	0		
August	20	20	20	20	20	20	8	8	51****	25****
September	10	10	10	10	10	10	8	4		
October	0	12	0	12	0	0	8	8		
November	16	8	16	8	8	8	0	12		
December	0	0	0	0	0	0	0	0		
January	29	25	19	19	40	34	8	8		
February	4	8	8	8	4	4	0	0		
March	0	0	0	0	0	0	13	0		
April	20	8	20	8	8	8	14	21		
May	20	22	20	22	23	23	13	13		
June	0	22	0	22	23	23	0	22		

* Plantain production is in bunches per hectare
** Charcoal production in bags of 60 kg per hectare
*** Prices are in `soles per Kg, except for plantain (per bunch) and charcoal (per bag)
***Refers to labor needed per month and could include from 1 to 3 months

Source: Labarta et al 2001, White et al 2001a

Table 2. Model Tableau

Row	Unit	Crop rotations (2)	Intercropping (4)	2nd year crops (2)	Charcoal production (2)	Use labor (10)	use available land (2)	sell crops (8)	sell charcoal (2)	Inequality	RHS
Objective function	Soles	-	-	-	-	-		+	+		
Household labor (10)	man-days	+	+	+	+	-				<	75
Cleared land (6)	ha	+	+							<	1000*
Available land (2)	ha			+			-1			<	Lot-1**
minima										>	1000
Rice (1)	kg	+	+							>	500
Maize (1)	kg	+	+							>	5000
Cassava (1)	kg	+	+	+						>	100
Plantain (1)	bunches		+	+							

* This number represents the open access to land regime

** This parameter is updated with land cleared in time t-1

Numbers in parentheses represent number of rows or columns in category

Table 3. Model results: Net returns, household deforestation, labor use, returns to labor and shadow prices over a 10-year horizon under two scenarios

	Only Agriculture	**Agriculture & Charcoal**
Land use (ha.)		
Land cleared after 10 years	21.8	18.1
After 7 years (first fallows available)	15.4	12.5
Total agricultural land during 10 years	41.3	39.0
Net revenues (Peruvian soles)		
Total farm net revenues	23,242	26,690
Total discounted farm net revenues	15,443	18,110
Agricultural net revenues	23,242	19,856
Discounted agricultural net revenues	15,443	12,880
Labor use (man-days)		
Total labor used during 10 years	5041	4501
Labor returns (Peruvian soles/man-day		
Average returns to labor	14.6	16.1
Discounted returns to labor	13.1	14.0
Average Shadow wages		
July	10.0	28.4
January	20.8	18.3
April	12.8	10.0
May	19.0	10.9
Jun	13.0	10.0
Other months	10.0	10.0
Shadow output prices (Peruvian soles/Kg)		
Maize	-0.17	-0.18
Land returns (Peruvian soles/ha.)		
Returns to total agricultural land	563	691
Discounted returns to total agricultural land	374	464
Returns to cleared land	1052	1369
Discounted returns to cleared land	699	919

Table 4. Sensitivity analysis: Changes in model results in alternative scenarios of subsistence production, tree density, charcoal price and labor endowment

	Land cleared after 10 years (ha)	Discounted farm net revenues (Peru soles)	Average returns to labor (Peru soles)	Average July shadow wage (Peru soles)	Average January shadow wage (Peru soles)	Average May shadow wage (Peru soles)
Base scenario Original charcoal scenario in table 2	18.1	18,110	16.1	28.4	18.3	10.9
Scenario 1 No subsistence production constraints	17.7	18,549	16.3	24.8	18.3	10.9
Scenario 2 Richer tree density (lower transport cost)	17.3	18108	16.4	31.0	17.4	10.1
Scenario 3 Poorer tree density (higher transport cost)	19.5	17,462	15.4	22.9	18.8	14.8
Scenario 4 Charcoal price decreases in 10%	18.9	17686	15.7	25.3	19.3	12.1
Scenario 5 Charcoal price decreases in 50%	20.1	15,279	14.6	12.7	19.7	21.2
Scenario 6 Household hires extra 12.5 man-days during dry season (June-August)	18.1	19,776	16.4	28.4	18.3	10.9

Figure 1. Peru: National charcoal production between 1990-2001

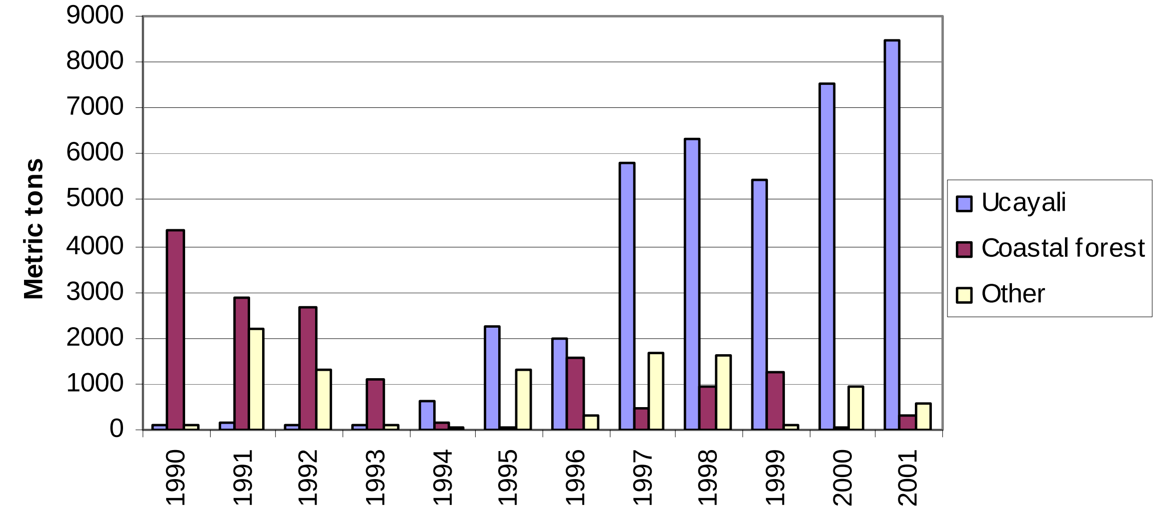
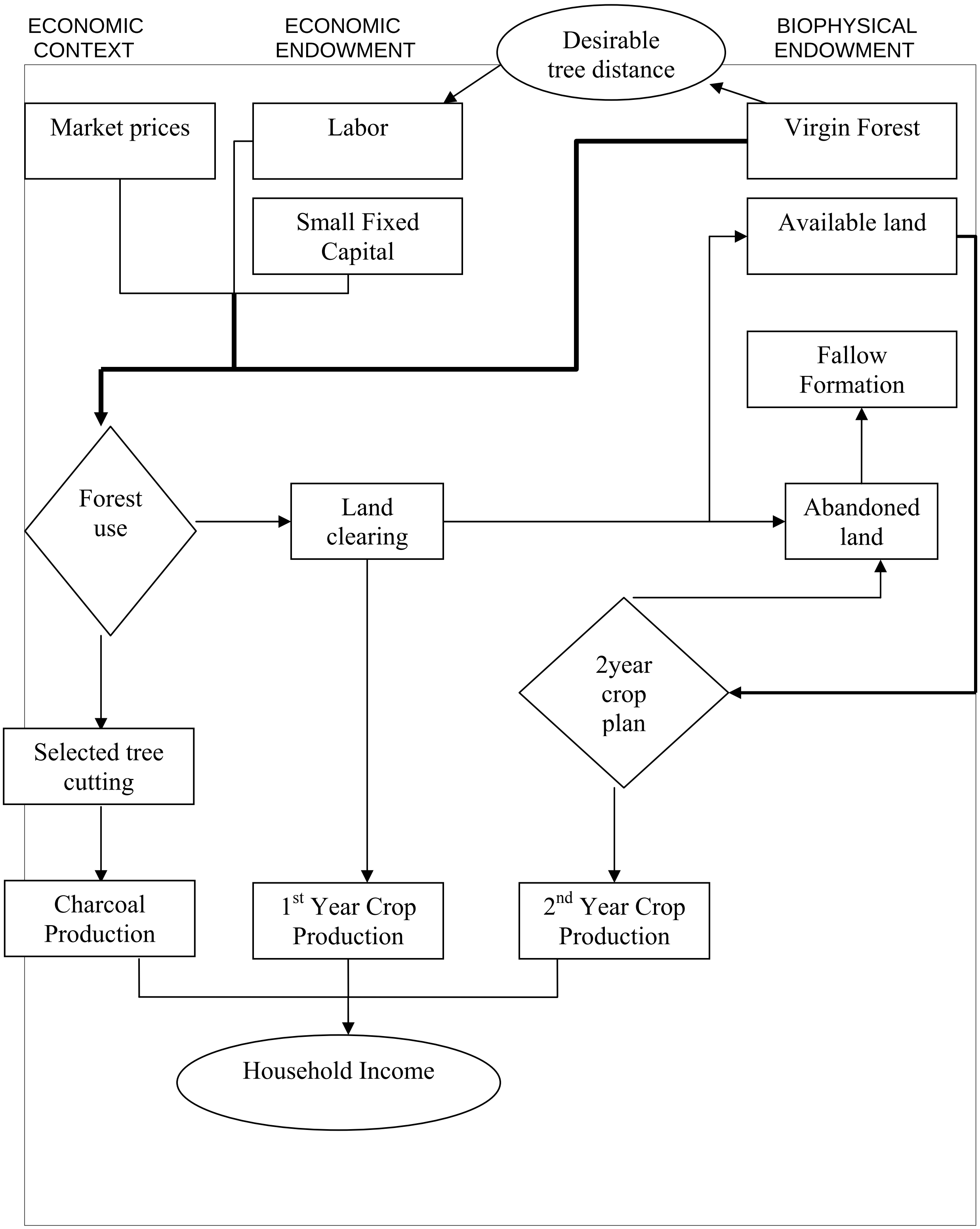


Figure 2. Calendar of agricultural and charcoal production activities

	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Land clearing	■	■	■									
Rice				■	■	■	■	■				
Maize				■	■	■	■	■				
Cassava					■	■	■	■	■	■	■	■
Plantain					■	■	■	■	■	■	■	■
Charcoal	■	■	■									

Figure 3. Recursive multi-period model structure



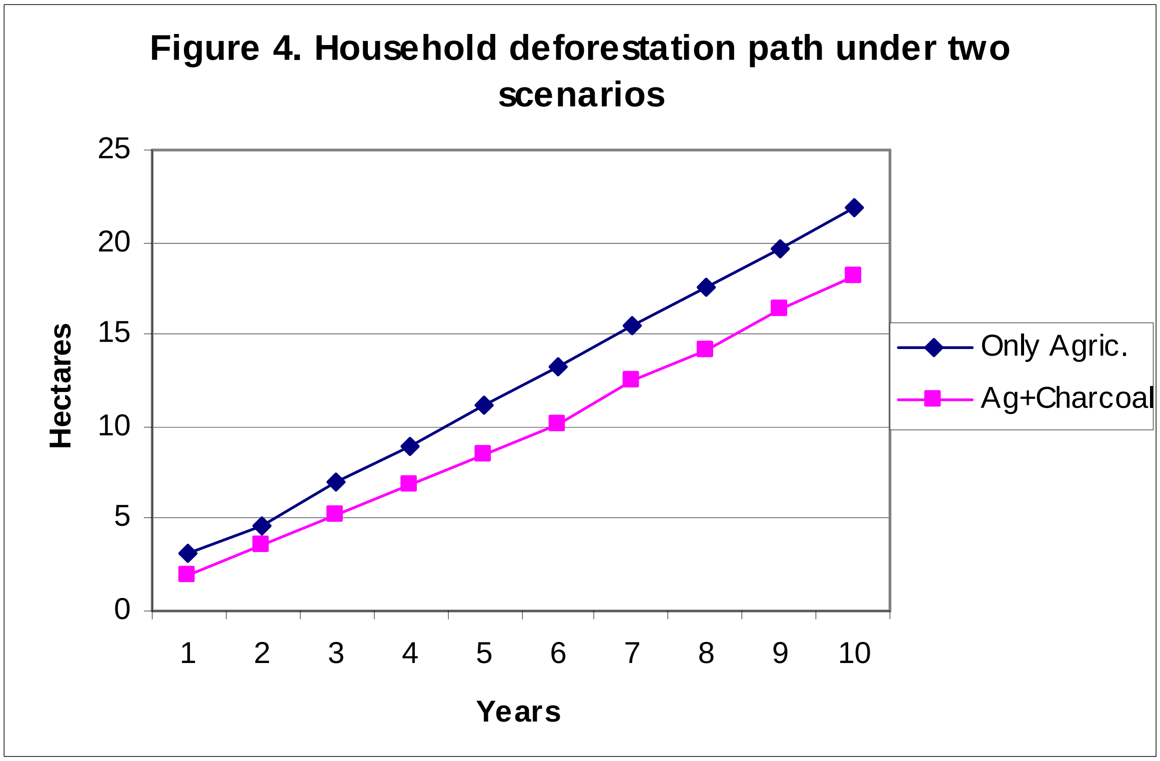


Figure 4. Household deforestation path under two scenarios
Hectares
Years
Only Agric.
Ag+Charcoal
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10

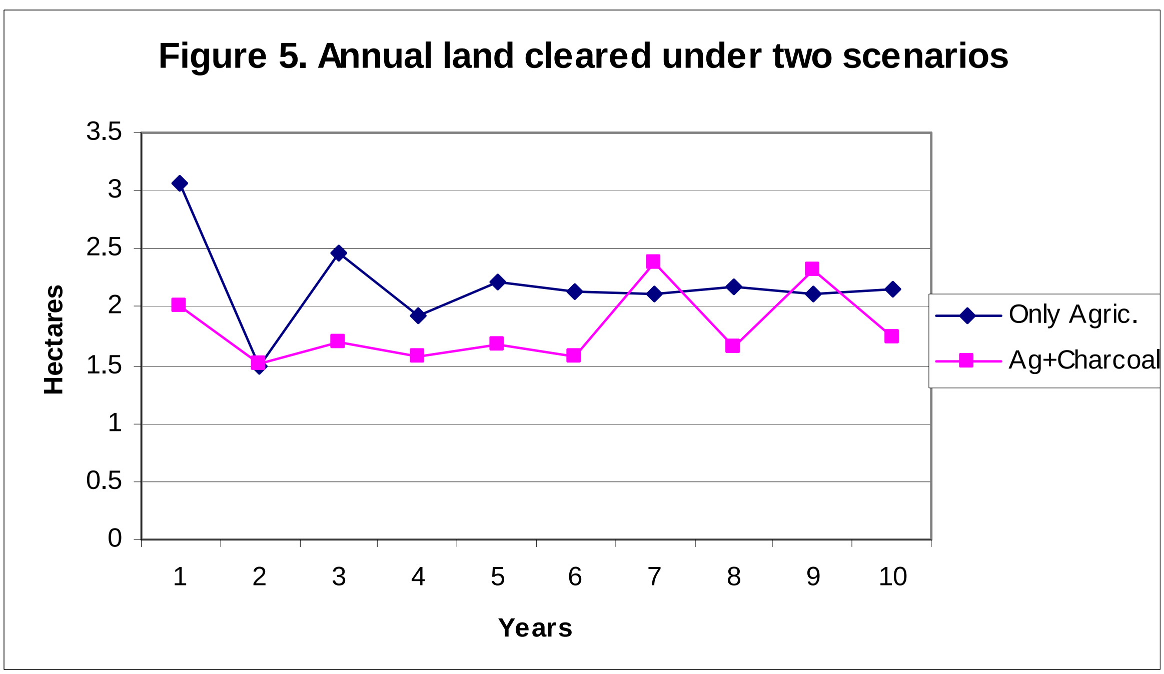


Figure 5. Annual land cleared under two scenarios
Hectares
Years
Only Agric.
Ag+Charcoal
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10

Figure 6. Total agricultural land under two scenarios

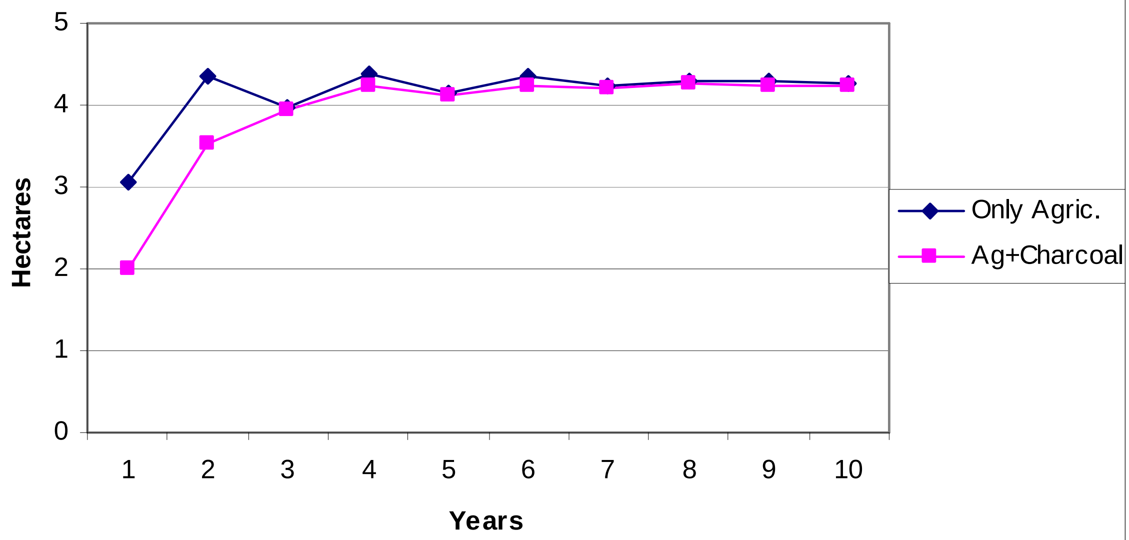


Figure 7. Total Farm earnings under two scenarios

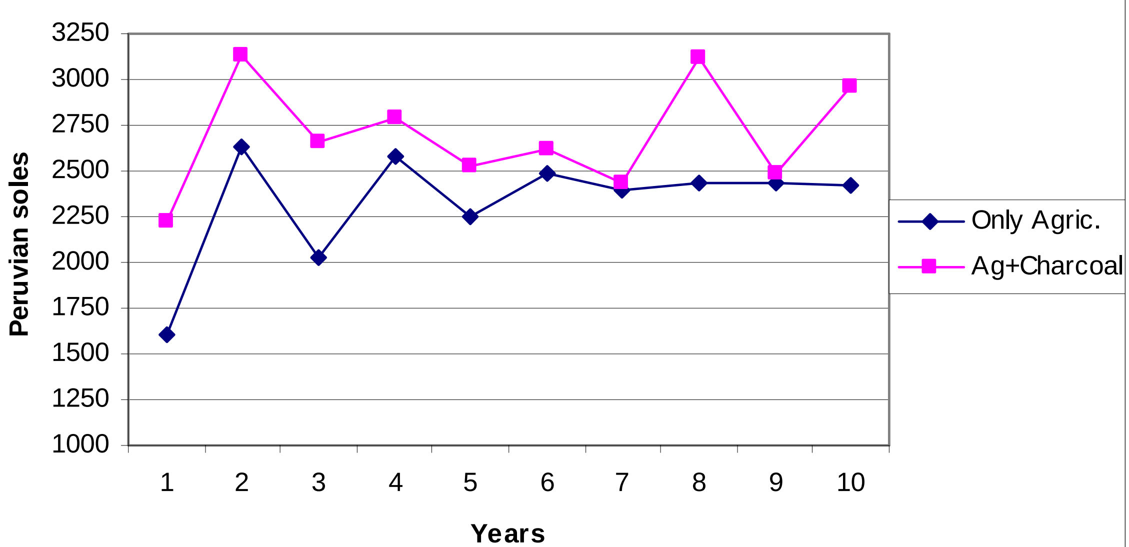


Figure 8. Agricultural earnings under two scenarios

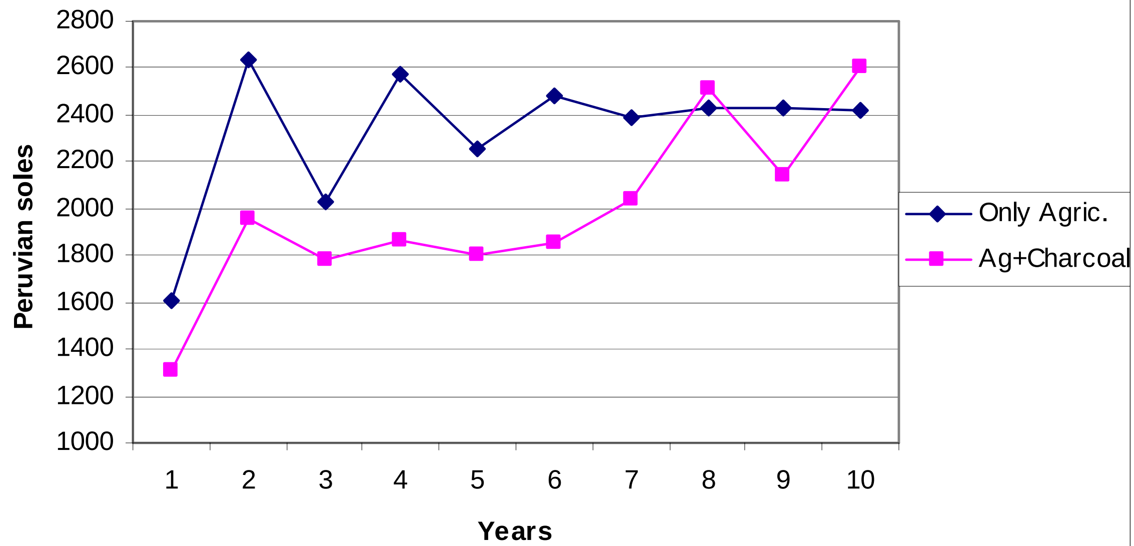
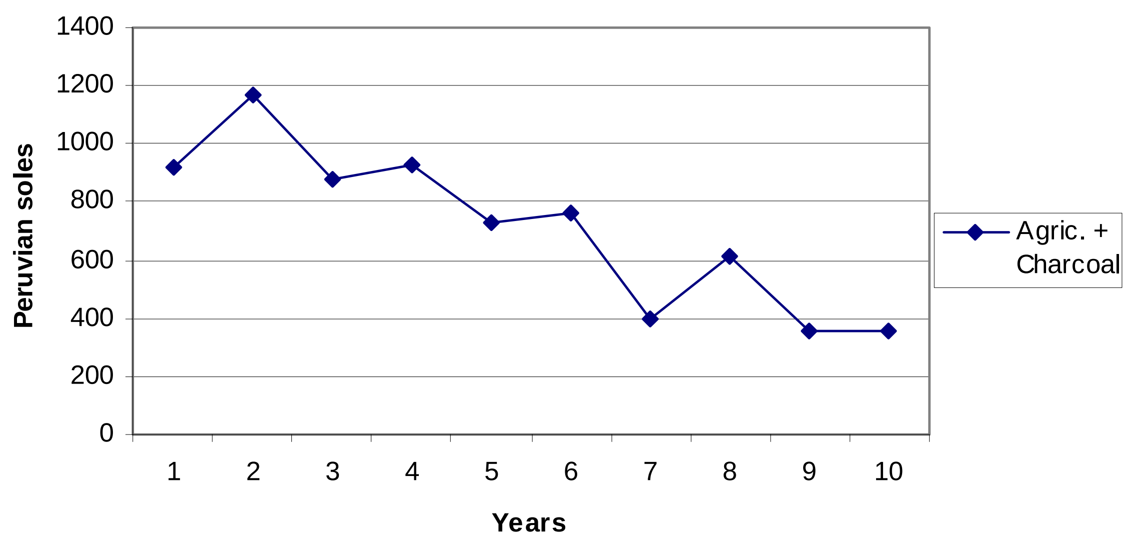


Figure 9. Charcoal earnings during 10 years



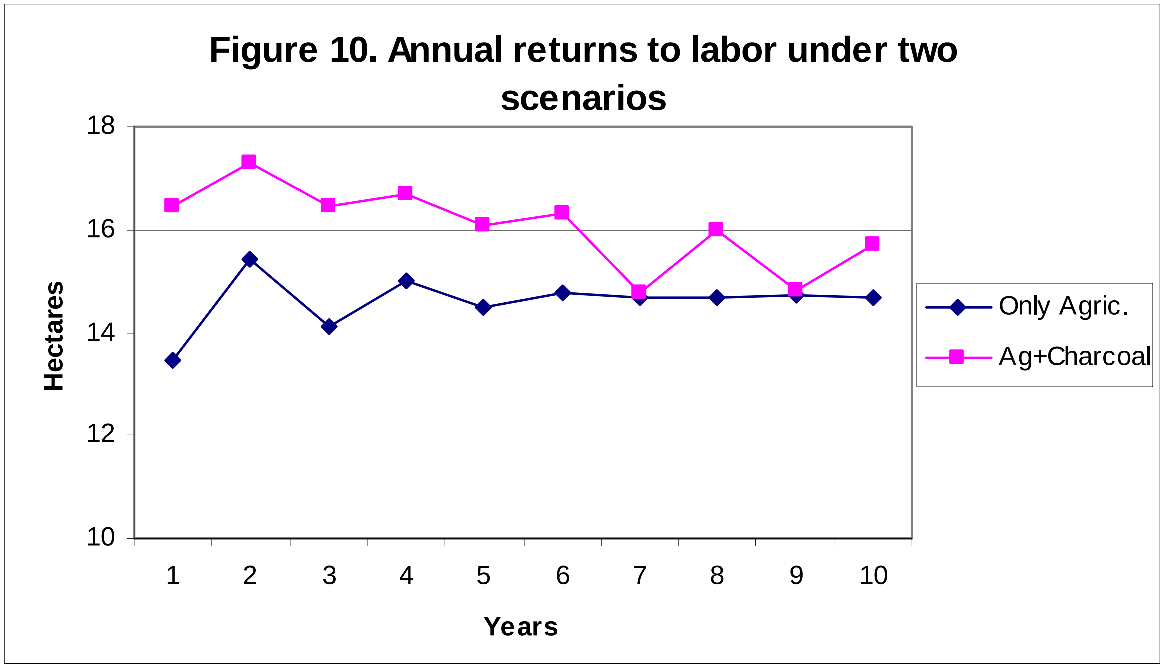


Figure 10. Annual returns to labor under two scenarios
Hectares
18
16
14
12
10
1
2
3
4
5
6
7
8
9
10
Years
Only Agric.
Ag+Charcoal

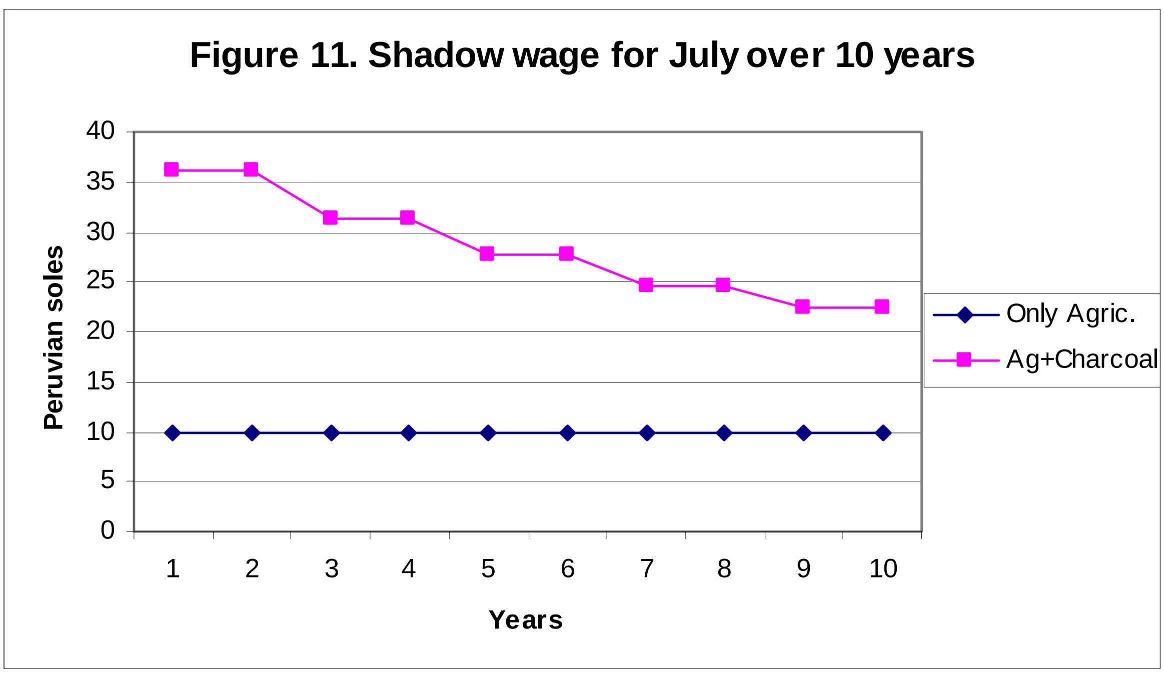


Figure 11. Shadow wage for July over 10 years
Peruvian soles
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
Years
Only Agric.
Ag+Charcoal

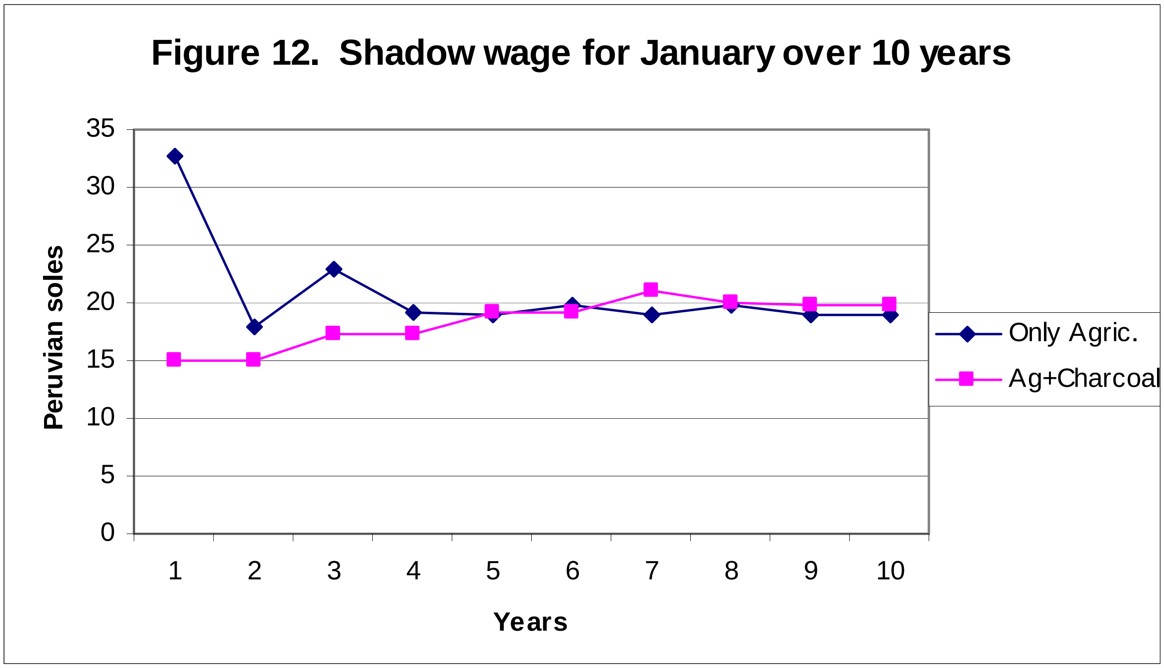


Figure 12. Shadow wage for January over 10 years
Peruvian soles
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
Years
Only Agric.
Ag+Charcoal

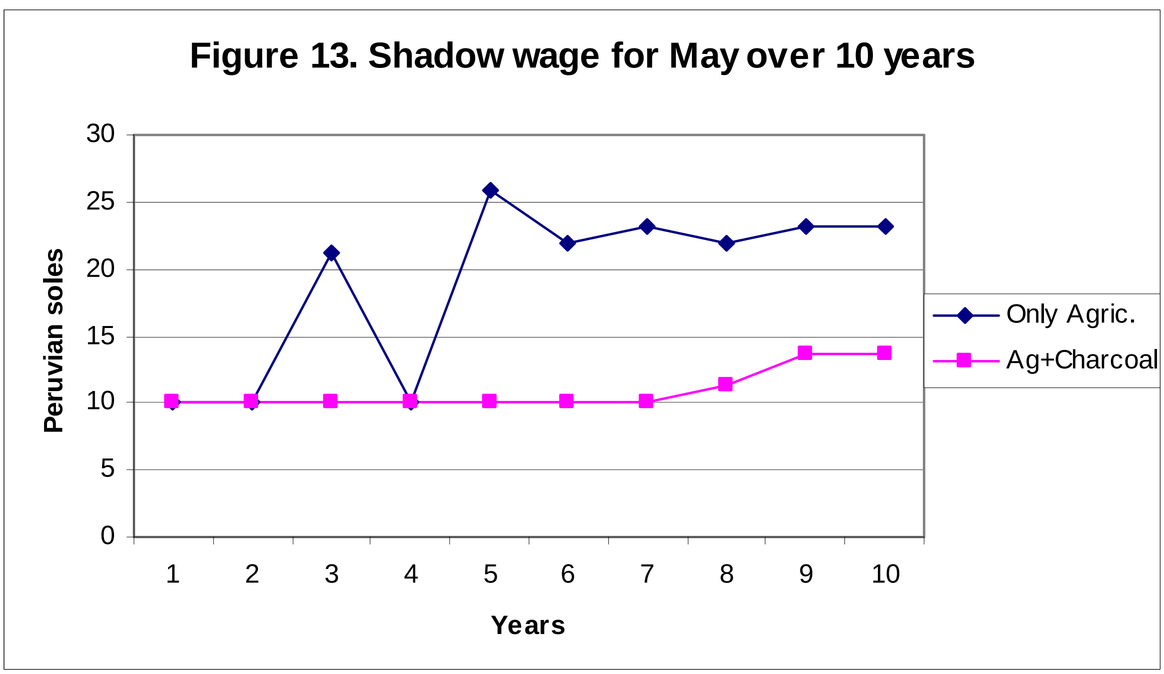


Figure 13. Shadow wage for May over 10 years
Peruvian soles
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
Years
Only Agric.
Ag+Charcoal

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Appendices

Subsystem 1 Rice-cassava(Rotation)

	Crops	**Yields (kg/ha)**	**Price (soles)**	**Revenue (S/ha)**
Crop1	Rice	2000	0.5	1000
Crop2	Cassava	15000	0.1	1500
System				2500

Inputs cost/ ha	Rice	Cassava	0	Cost
Seed	20	0	0	20
Fertilizer	0	0	0	0
Herbicide	40	0	0	40
Insecticide	0	0	0	0
Tools	0	0	0	0
				60

Labor (man-days/ ha)	Rice	Cassava	Cost
Preparation	40	8	480
Sowing	10	8	180
Weeding	8	8	160
Harvesting	22	36	580
Transport	6	10	160
	86	70	**1560**

Wage **10**

Tools	Price	Quantity	Cost
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	254	127
Sprayer	20	1	20
Total			160

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation	20	20					8						
Sowing			10				4	4					
Weeding					8					8			
Harvesting							22				18	18	
Transport							6				5	5	
	20	20	10	0	8	0	40	4	0	8	23	23	**156**

Subsystem 2 Rice-cassava(Intercropping)

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Rice	1800	0.5	900
Crop2	Cassava	12000	0.1	1200
System				2100

Inputs cost/ ha	Rice	Cassava	0	Cost
Seed	20	0	0	20
Fertilizer	0	0	0	0
Herbicide	40	0	0	40
Insecticide	0	0	0	0
Tools	0	0	0	0
				60

Labor (man-days/ ha)	Rice	Cassava	Cost	
Preparation	40		400	**Wage**
Sowing	10	8	180	**10**
Weeding	8	8	160	
Harvesting	20	32	520	
Transport	4	8	120	
	82	56	**1380**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	207	104
Sprayer	20	1	20
Total			137

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation	20	20											
Sowing			10		8								
Weeding					8		4	4					
Harvesting							20			16	16		
Drying													
Transport							5			4	4		
	20	20	10	0	16	0	29	4	0	20	20	0	**139**

Subsystem 3 Rice-plantain(Intercropping)

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Rice	1800	0.5	900
Crop2	Plantain	450	3.5	1575
System				2475

Inputs cost/ ha	Rice	Plantain	0	Cost
Seed	20	175	0	195
Fertilizer	0	0	0	0
Herbicide	40	0	0	40
Insecticide	0	0	0	0
Tools	0	0	0	0
				235

Labor (man-days/ ha)	Rice	Plantain	Cost	
Preparation	40	8	480	**Wage**
Sowing	10	4	140	**10**
Weeding	8	16	240	
Harvesting	20	36	560	
Transport	4	8	120	
	82	72	**1540**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	42	21
Sprayer	20	1	20
Total			54

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation	20	20		8									
Sowing			10	4									
Weeding					8			8		8			
Harvesting							20				18	18	
Drying													
Transport							5				4	4	
	20	20	10	12	8	0	25	8	0	8	22	22	**155**

Subsystem 4 Maize-cassava(Rotation)

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Maize	1800	0.3	540
Crop2	Cassava	15000	0.1	1500
System				2040

Inputs cost/ ha	Maize	Cassava	0	Cost
Seed	27	0	0	27
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				27

Labor (man-days/ ha)	Maize	Cassava	Cost	
Preparation	40	8	480	**Wage**
Sowing	10	8	180	**10**
Weeding	8	8	160	
Harvesting	17	36	530	
Transport	5	10	150	
	80	70	**1500**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	250	125
Sprayer	20	1	20
Total			158

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation	20	20					8						
Sowing			10				4	4					
Weeding					8					8			
Harvesting							17				18	18	
Transport							5				5	5	
	20	20	10	0	8	0	34	4	0	8	23	23	**150**

Subsystem 5 Maize-cassava(Intercropping)

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Maiz	1500	0.3	450
Crop2	Cassava	12000	0.1	1200
System				1650

Inputs cost/ ha	Maize	Cassava	0	Cost
Seed	27	0	0	27
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				27

Labor (man-days/ ha)	Maiz	Cassava	Cost	
Preparation	40		400	**Wage**
Sowing	10	8	180	**10**
Weeding	8	8	160	
Harvesting	15	32	470	
Transport	4	8	120	
	77	56	**1330**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	201	101
Sprayer	20	1	20
Total			134

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation	20	20											
Sowing			10		8								
Weeding					8			8					
Harvesting							15			16	16		
Transport							4			4	4		
	20	20	10	0	16	0	19	8	0	20	20	0	**133**

Subsystem 6 Rice-plantain(Intercropping)

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Maiz	1500	0.3	450
Crop2	Plantain	450	3.5	1575
System				2025

Inputs cost/ ha	Maize	Plantain	0	Cost
Seed	27	175	0	202
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				202

Labor (man-days/ ha)	Maiz	Plantain	Cost	
Preparation	40	8	480	**Wage**
Sowing	10	4	140	**10**
Weeding	8	16	240	
Harvesting	15	36	510	
Transport	4	8	120	
	77	72	**1490**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	36	18
Sprayer	20	1	20
Total			51

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation	20	20		8									
Sowing			10	4									
Weeding					8			8		8			
Harvesting							15				18	18	
Transport							4				4	4	
	20	20	10	12	8	0	19	8	0	8	22	22	**149**

Subsystem 7 2nd year cassava rotation

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Cassava	12000	0.1	1200
Crop2				0
System				1200

Inputs cost/ ha	Cassava	0	0	Cost
Seed	0	0	0	0
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				0

Labor (man-days/ ha)	Cassava	0	Cost	
Preparation	8		80	**Wage**
Sowing	8		80	**10**
Weeding	8		80	
Harvesting	32		320	
Transport	8		80	
	64	0	**640**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch	20	0.25	5
Bags	0.5	171	86
Sprayer			0
Total			99

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation		8											
Sowing			8										
Weeding				8			8						
Harvesting									11	11	11		
Transport									3	2	3		
	0	8	8	8	0	0	8	0	14	13	14	0	**72**

Subsystem 8 2nd year plantain rotation

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Plantain	450	3.5	1575
Crop2				0
System				1575

Inputs cost/ ha	Plantain	0	0	Cost
Seed	0	0	0	0
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				0

Labor (man-days/ ha)	Plantain	0	Cost	
Preparation	8		80	**Wage**
Sowing	4		40	**10**
Weeding	24		240	
Harvesting	36		360	
Transport	12		120	
	84	0	**840**	

Tools	Price	Quantity	Value
Machete	8	1	8
Hatch			0
Bags			0
Sprayer			0
Total			8

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Preparation		8											
Sowing			4										
Weeding				8	12		8			8			
Harvesting										12	12	12	
Transport										4	4	4	
	0	8	4	8	12	0	8	0	0	24	16	16	**96**

Subsystem 9 Low-intensity charcoal production in July

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Charcoal	30	17	510
Crop2				0
System				510

Inputs cost/ ha	Charcoal	0	0	Cost
Seed	0	0	0	0
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				0

Labor (man-days/ ha)	Charcoal	0	Cost
Tree cutting	2		20
Tree skidding	2		20
Kiln prep	2		20
Kiln cover	3		30
Guarding	8		80
Bagging	5		50
Transport	3		30
	25	0	**250**

Wage
10

Tools	Price	Quantity	Value
Fuel	5	5	25
Oil	2	1	2
Chainsaw	50	1	50
Bags	1	30	30
Machete	8	1	8
total			115

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	June	
Tree cutting	2												
Tree skidding	2												
Kiln prep	2												
Kiln cover	3												
Guarding	8												
Bagging	5												
Transport	3												
	25	0	0	0	0	0	0	0	0	0	0	0	**25**

Subsystem 10 Large-Intensity charcoal production in July

	Crops	Yields (kg/ha)	Price (soles)	Revenue (S/ha)
Crop1	Charcoal	120	17	2040
Crop2				0
System				2040

Inputs cost/ ha	Charcoal	0	0	Cost
Seed	0	0	0	0
Fertilizer	0	0	0	0
Herbicide	0	0	0	0
Insecticide	0	0	0	0
Tools	0	0	0	0
				0

Labor (man-days/ ha)	Charcoal	0	Cost
Tree cutting	3		30
Tree skidding	6		60
Kiln prep	5		50
Kiln cover	5		50
Guarding	8		80
Bagging	12		120
Transport	12		120
	51	0	**510**

Wage
10

Tools	Price	Quantity	Value
Fuel	5	10	50
Oil	2	2	4
Chainsaw	50	2	100
Bags	1	30	30
Machete	8	1	8
total			192

Labor calendar (man-days /ha)

	July	August	September	October	November	December	January	February	March	April	May	Jun	
Tree cutting	3												
Tree skidding	6												
Kiln prep	5												
Kiln cover	5												
Guarding	8												
Bagging	12												
Transport	12												
	51	0	0	0	0	0	0	0	0	0	0	0	**51**