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Summary

Research suggests that cash-cropping is associated with deforestation. We use three-year data (2000-2002) from 493 households to estimate the association between cash-cropping rice and deforestation. Doubling the area sown with rice is associated with a 26-30% increase of the area of forest cleared next cropping season. We simulate the changes required to reach 1US$/person/day income with cash from rice. We find that within 10 years 1) deforestation would triple, 2) work requirements would exceed household's labor availability, and 3) fallows duration would decrease two-fold. Avoiding growing deforestation due to cash-cropping by smallholders requires increasing productivity, diversification of income sources, or both.

Key words: Latin America, Bolivia, deforestation, cash crop, poverty alleviation, farm technology.

1. Introduction

The awareness of the many services provided by tropical forest (Costanza et al. 1997) and the rapid increase in tropical deforestation has put forest at the center stage of the agenda for developers, conservationists, and policy-makers. Researchers have studied many of the factors influencing deforestation, such as the opening of new roads (Chomitz & Gray 1996; Reid 2001), land property right issues (Deacon 1999; Alston et al. 2000; Godoy et al. 2001), the spread of industrial cash cropping (McMorrow & Talip 2001), and slash-and-burn agriculture, cattle ranching, and logging activities (Hecht & Cockburn 1989; Palm et al. 2005). Researchers have found that the various factors that cause deforestation are woven together in a complex net of interactions (Angelsen & Kaimowitz 1999). Furthermore, authors find that the causes of deforestation could, in turn, result from deforestation.

Because of the complexity of the issue, the variability across sites, and the lack of reliable empirical information, there is little consensus on an overall mechanism to explain deforestation (Kaimowitz & Angelsen 1998). But the lack of empirical information is one of the main drawbacks on research on deforestation. Kaimowitz and Angelsen (1998) reviewed 146 econometric models explaining deforestation and found that 24% were based on simulations and 23% draw on analytical models, i.e. theoretical mathematic equations including no empirical data. Furthermore, among the 53% of the studies based on empirical data, 38 drew on secondary, national-level data. Only nine of the models reviewed (or 6% of the total) used household-level empirical data. The authors suggest that future studies of the causes of deforestation should focus on either household or regional-level data, because studies without a strong micro-level empirical base are of little value: "*There is no substitute for careful, quantitative micro-level empirical research, and the volume of such studies is not impressive. Plausible theoretical mechanisms are often found to be of little empirical relevance*" (Kaimowitz & Angelsen 1998: p. 99).

This study has two parts. In the first part, we draw on household data from Tsimane' Amerindians, a horticultural and foraging society in the Bolivian Amazon, to assess how cash cropping by smallholders affects the clearance of neotropical forests. We study clearance of fallow and old-growth forest because previous research suggests that fallow forests harbor substantial biological diversity (Finegan 1996; Silver et al. 1996; Smith et al. 1999), but we pay special attention to old-growth forests. In the second part of the paper, we use the same data to simulate the consequences of having the rural poor cash crop their way out of poverty. We focus on the consequences for the total area of forest clearance, for household labor requirements, and for fallow duration. We pay special attention to fallow duration because previous research suggest that increased land scarcity reduces the fallow period (Coomes et al., 2000).

This work contributes to the debate on the causes of deforestation in several ways. First, we use household-level data which, according to Kaimowitz and Angelsen (1998) is of great value and still relatively rare. Second, we document deforestation by indigenous peoples. Indigenous peoples do not account for a large share of deforestation, but this share could grow as indigenous people become more integrated into the market economy (Godoy 2001) or in response to population growth (Picchi 1991). Third, we contribute to the debate on the effects of agricultural technology innovations on deforestation. The results of the simulations help formulate recommendations on the type of technologies needed to reconcile development and conservation of tropical forests.

2. Cash cropping, farm technologies, and deforestation.

There are many studies addressing the various causes of deforestation, but the number of studies focusing on the effect of cash cropping on deforestation using primary data is limited. This empirical literature often studies the impact of cash cropping on deforestation through the introduction of new farm technologies (McMorrow & Talip 2001; Angelsen & Kaimowitz 2001; Pendleton & Howe 2004).

Part of the literature focusing on the effect of cash cropping on deforestation concurs that cash cropping increases deforestation. For example, in a study in Thailand, Dearden (1995) found that the intensification of cash cropping of cabbage increased deforestation because cabbage has a low value compare with opium, which it was replacing. In a household-level study in Cameroon, Mertens and colleagues (2000) found that deforestation increased as the marketing of food crops increased in response to economic crisis. Other researchers, however, suggest that cash cropping does not necessarily leads to increasing deforestation. For example, Tungittiplakorn and Dearden (2002) also found that intensification of cash cropping cabbage and carnations in Thailand reduced pressure on forest because the new cash crops required less land than traditional crops, and therefore allowed more people per unit of land. Similarly, Perz (2004) found that raising rural incomes through agricultural diversity in forest frontier regions was not necessarily related to a reduction of forest cover.

Part of the debate on the effects of cash cropping on clearance of tropical forest relates to the use of new farm technologies for cash cropping. While the common assumption is that technological improvements would decrease deforestation because an improvement in agricultural technology (in terms of production per unit of area) would reduce farmer's need to keep clearing new lands (Holden 1993; Jones et al. 1995; Palm et al. 2005), empirical data often shows that new agricultural technologies relate to more environmental degradation and deforestation (Humphries 1993; Marquette 1998; Godoy 2001). For example in a study on the changes among Yucatec Maya farmers from traditional shifting milpa agriculture to intensive horticultural production for the Mexican market, Humphries (1993) found that the process of agricultural intensification involved an increasingly sedentary production which has heightened reliance on the use of chemicals with negative consequences for the environment. In a study in the Ecuadorian Amazon, Marquette (1998) found that improvement in human welfare of settlers in the agricultural frontier was related to economic activities that increased the area of land cleared. A third group of authors suggest that technological improvements might produce ambiguous results, depending on the type of technology (Angelsen & Kaimowitz 2001). For example, Pichón and colleagues (2002) found that in the Ecuadorian Amazon, farmers in agricultural frontiers adopted a low-intensity clearing land use strategy centering in coffee production, which generates less forest clearing. However, farmers who could afford it, specialized in cattle raising, an activity that generated more income, but was related to less forest cover.

In sum, the question on the impact of cash cropping on deforestation and the role that the introduction of new farm technologies might play in this relation, remains open.

3. Materials and Method.

3.1. Tsimane’ agriculture

Tsimane’ Amerindians live in the lowlands of Bolivia, mostly along the Maniqui and Apere rivers. Detailed ethnographies of the Tsimane’ can be found in recent dissertations and books (Chicchon 1992; Ellis 1996; Reyes-García 2001; Byron 2003; Daillant 2003; Huanca 2005).

Tsimane’ are hunters and horticulturalists who practice slash-and-burn agriculture to cultivate upland rice, maize, manioc, and plantains as main staples. They also plant a variety of crops of smaller importance, such as sugar cane, peanuts, sweet potatoes, ahipa, and citrus (Piland 1991; Huanca 1999; Vadez et al. 2003). Although Tsimane’ remain foragers and depend on forest resources, they are becoming increasingly dependent on farming. Farm products represent more than 50% of Tsimane’ cash income (Reyes-García 2001).

The Tsimane’ gather and farm their own land. Tsimane’ land legally belongs to the ethnic group. In a typical village, houses are scattered around the school, and households usually farm around the village in a radius of about 2km, giving around 1250 hectares of land available per village. The land availability per household is directly linked to the number of household living in the village. We found that villages varied from 10 to 70 households, giving a land availability of 18 to 125 ha per household.

Tsimane’ farming is extensive and oriented to household consumption and sale. People usually abandon the plots after one or two cultivation cycles to clear another plot. In a recent study we show that the market economy is influencing Tsimane’ traditional farming practices, but not always in the expected direction. Unlike previous studies with

Amerindians that suggest that integration to the market stimulates specialization on a few crops (Godoy 2001), we found that Tsimane' integration to the market economy does not decrease the diversity of crops grown (Vadez et al. 2004). Households more integrated into the market cultivate larger areas with rice, a finding that is consistent with rice becoming a crop in high demand in the region and in the household economy of the Tsimane'.

3.2. The importance of rice

In Bolivia, the domestic demand for rice exceeds the domestic supply (Comisión Europea 2000). The same situation occurs in the local market place, where the rice supplied by local producers, either Tsimane' or colonists farmers, does not match demand. Part of the rice consumed in the region is brought from other producing areas, such as the department of Santa Cruz, or from abroad. Since rice demand is higher than the supply, there are strong incentives to increase rice production locally.

Jesuit missionaries introduced rice into the Tsimane' territory over 300 years ago (Perez-Diez 1983) and it has become a major income source for Tsimane' households nowadays (Vadez et al. 2004). In the 1950s, missionaries introduced improved rice varieties in the area together with manual sowing machines, technologies that are now widely used by the Tsimane'. Later, colonist farmers introduced herbicides and pesticides for use in rice farming, but even today few Tsimane' use those chemical inputs.

Tsimane' usually open farm plots between July and November, sow rice between August and December, and harvest rice during the rainy season, between January and

April. Rice is both a staple and a cash crop and is cultivated on 60-80% of the surface of newly opened fields (Vadez et al. 2004), depending on the degree of household's integration to the market economy. Tsimane' sell rice and other farm products in the town of San Borja (population ~19,000) but they also sell them to itinerant traders who ply the main rivers of the area.

Insufficient rice supplies in San Borja, seasonally drive up the price of rice in the local market town (Figure 1). For example, the price of rice in the local market was 0.28 US$/kg shortly after harvest in March 2002, and about double (0.48 US$/kg) before the following harvest in January 2003. However, Tsimane' farmers do not take advantage of price fluctuations and sell most of their production in the few months following the harvest, when prices are at their lowest.

INSERT FIGURE 1 ABOUT HERE

3.3. Sample and data collection

We collected information from the same households in 2000, 2001, and 2002. The total sample size was 715 households, among which 174 were interviewed during the three years, and 493 were interviewed at least two consecutive years. The surveys used a random sub-sample of 8-12 household per village. In this paper, we use only data from households for which we have repeated observations for at least two consecutive years. This sample selection allows us to partially abate biases from possible reverse causality and endogeneity, by regressing deforestation at time n+1 against explanatory variables occurring at time n. The procedure represents a considerable improvement over earlier studies of deforestation that typically rely on cross-sectional information.

To estimate the area of forest cleared, we asked the male household head to report the area of all plots from old-growth or fallow forest own by the household during the last farming cycle and the type of forest cleared. Self-reported estimates match closely the area cleared (Vadez et al. 2003). We proxied rice cultivation by asking the male household head about the area sown with rice. All measures of rice area in the surveys reflected the rice area sown in the previous cropping season. We did not proxy rice cultivation with cash earnings from the sale of rice because rice sale volumes fluctuate over the year and the three surveys took place at different time (2000: June-September, 2001: March-May, 2002: March-May).

To estimate household cash income, we asked the male household head to report all the sources of income from sale, barter, and wage labor earned by all the adults in the household during the two weeks before the day of the interview. We collected data on sale of farm and forest products disaggregated by product. We estimate household consumption of farm goods by asking the female household head about the total amount of rice, cassava, and maize consumed in the household during the week before the interview. We interviewed the village main authority to gather information on village road access and walking time to the nearest market town. Table 1 contains definition and summary statistics of the variables used in the regression analysis. Later we discuss how we deal with possible biases from omitted variables.

INSERT TABLE 1 ABOUT HERE

3.4. Focus groups

We used focus groups in 2001 and 2002 to gather information about the different work and technology inputs needed to study the cultivation of rice. To capture variation in rice management, natural resource endowments, and farming skills, we carried out focus groups in half of the villages taking part in the study (n=18), at different distances from the town of San Borja. We arrived to the villages the day before and informed people about the upcoming meeting. We held focus groups with women and men together in the school building. We asked villagers to tell us about the number of work days needed to carry out the different tasks of rice cultivation. We wrote answers once villagers reached a consensus. When groups disagreed, we took the mean of the different responses. We also asked people to estimate yields of a standard variety of rice. For technical inputs, we asked the time needed to fell trees with a chainsaw, to spread pesticide, and to sow rice with a manual sowing machine in a rice field of one hectare. Data on the cost of chemical inputs was obtained from stores in the town of San Borja.

3.5. The estimation model

In the first part of the next section we estimate how cash cropping rice by smallholders affects deforestation, while controlling for other competing drivers of deforestation related to integration to the market, i.e. road access, distance to closest market town, cash income, and market dependence. By market dependence we mean the share of household consumption in total household income that comes from one's own farm plots, so that:

Market dependence = Cash income / (cash income + consumption value of rice, maize and cassava)

We estimate the following model:

[1] $Y_{hvn+1} = a + bX_{hvn} + dT_{hvn} + fC1_{j} + g\,C2_{n} + h_{ihjn}$

Where Y is the area deforested by household *h*, in village *v*, in year *n+1*. X is the area sown with rice of household *h*, in village *v* the previous year, *n*. T is a vector of variables typically related to integration to the market (i.e., road access, distance to closest market town, cash income, and market dependence) of household *h*, in village *v*, in year *n*. C1 is a set of dummy variables used to control for village fixed effects and C2 is a set of dummies for the years to control for the confounding role of weather or year-to-year variation. To control for the effect of household size on deforestation, we used the household values of area sown with rice and area cleared divided by the number of adult equivalents per household. The error term, h, captures exogenous shocks to deforestation (e.g., weather or prices).

To deal with possible biases from omitted variables, we included village dummies in the regression model. The procedure should allow us to control for the confounding role of village-level attributes, such as access to markets, or village endowments, such as soil fertility. We did not have enough degrees of freedom to run a household fixed-effect model, so the estimated parameters we present might be biased by unobserved household attributes that affect both rice cultivation and deforestation. For example, some households might have access to farm technologies, credit, and labor help that would affect both how much rice they cultivate and how much forest they clear. We run regressions with clustering of households by villages because households are nested in villages and because households from a same village are more likely to be similar in their patterns of deforestation than households from different villages. Clustering is necessary because the units of observation, the households, are not independent of one another but clustered in natural units (villages). Clustering affects the estimated standard errors, making them more conservative, but does not affect the estimated slope coefficient.

3.6. The simulation model

In the second part of the results section, we explore the consequences of Tsimane' trying to exit poverty by increasing the production of rice. First, we estimate the amount of forest a household needed to cultivate with rice to reach 1US$/person/day (poverty line). Second, we asses whether households would be able to meet the additional labor requirements of increased cash cropping and the possible role of farm technologies to ease household labor constraints. Third, we explore the consequences of the increase in area cleared on fallow duration. We simulate five scenarios:

(i) *Subsistence* scenario is a baseline scenario used for comparison. Households keep up with current area clearing to meet their needs. We adjust for a demographic increase of 4.76%/year (Reyes-García 2001).

(ii) *Poverty Line + Traditional Practice* scenario: Households choose to reach the poverty line using traditional farming practices to cultivate rice.

(iii) *Poverty Line + Farm Technology* scenario: Households choose to reach the poverty line with new farm technologies (i.e., herbicides and chainsaws).

(iv) *Poverty Line + Rice Price Increase* scenario: same as (i) but rice price increases by 3%/year.

(v) *Poverty Line + Encroachment* scenario: Same as (i) but encroachment represents an increase in the number of households per village of 3%/year. We assume that encroachers follow the same deforestation patterns as Tsimane' households who choose to reach the poverty line.

Appendixes A and B contain the assumptions, formulas, and empirical data used for the simulation of the five scenarios. Although most of the parameters used are based on empirical data, various assumptions that we make may not fully mimic future reality. For instance, household split over time or may migrate out of the area, or may diversify their income resources by pursuing non-farm occupations. Or education may lower the rate of demographic increase. However, we kept the assumptions simple to make the simulation easy and open to further exploration. Our estimates are conservative because we simulated the changes that would occur to reach the poverty threshold of only 1 US$/person/day, but people would probably aspire to go beyond this bare minimum line.

4. Results

4.1. Rice micro-economy

During 2000, 2001, and 2002 households earned US$ 13.2, 9.9, and 6.8 from rice in the two weeks prior to the interview, equivalent to about 26%, 21%, and 23% of their total cash income (Table 2). We found large variation between households regarding their involvement in rice trade. For 50% of households, rice represented 0%, 7% and 14.7% of their income in 2000, 2001 and 2002. At the other extreme, for 10% of the households, rice represented 82%, 58% and 53% of their total income in 2000, 2001, and 2002. Variation in rice trade and the fact that households that cultivate large areas with rice also sell much rice (Vadez et al. 2004) gives us an ideal setting to estimate the relation between rice cultivation and deforestation.

INSERT TABLE 2 ABOUT HERE

We first used data from focus groups to asses the various cost (in labor and money) incurred under the traditional method of cultivating rice, that is without modern inputs. We found that one hectare of rice requires about 101.9 person-days of work from field opening to rice harvest (Table 3). Participants estimated an average yield of 1540 kg/ha, which would give a gross income of 176 US$/ha (1 kg of rice= 0.114 US$). We divided the gross income by labor input, to calculate the return on labor investment for rice: each day allocated to rice production provides an average wage of 1.72 US$/day, about 66% of the local daily average wage for unskilled labor in the area, such as working on cattle ranches and in logging concessions. Daily wages in these occupations vary by season but average 2.60 US$/day. Participants estimated that a typical adult can dedicate at most 170 days/year to cultivate rice, since rice does not grow all year long and people have other activities. Assuming that a typical household is composed of three adults (Reyes-García, 2001), every household would have at its disposal about 510 days-person available to cultivate rice every year.

INSERT TABLE 3 ABOUT HERE

We used the same focus groups to assess how modern technology would affect work inputs to cultivate rice, with a particular attention to: (i) the use of chain saws to fell trees, (ii) the use of manual sowing machines, and (iii) the use of herbicides to replace manual weeding. The chainsaw work was estimated at two days/ha to fell all trees and would cost 21.84 US$/ha. The cost of using a manual sowing machines is 0.05 US$/ha. Spraying herbicides would cost 9.87 US$/ha. Total input costs for using the three technologies is 31.76 US$/ha, which decreases the income per hectare by about 18%, from 176 US$/ha with traditional practice to 144.24 US$/ha with modern technology. The use of modern technology increased by 70% the returns to labor investment, from 1.72 US$/day with traditional practice to 2.94 US$/day with modern technology by reducing work input by 52%, from 101.9 work person-days to 49.1 work person-days (Table 3). So, the use of modern farm technologies largely decreases the work requirement to cultivate rice while it increases the return to labor investment almost to the level of the local unskilled wage labor.

4.2. Regressions

4.2.1. Rice cash cropping

We used expression [1] to estimate the relation between the area of rice sown one year and the total area cleared the following year. Using untransformed data, we found that the area of rice sown in year *n* bore a highly significant relation with the total area deforested in year *n+1*. An additional hectare of rice planted was associated with 0.30 more hectares deforested in the subsequent year (Table 4). Results were similar whether using village and year dummies or not. We re-estimated expression [1] taking the logarithm of total area deforested and area planted with rice to obtain elasticity coefficients (i.e., the percentage change in the dependent variable from a percentage change in the explanatory variables). We found that the area planted with rice bears a significant positive association with the area deforested. A two-fold increase in the area cultivated with rice correlated with a 26-27% increase in the total area deforested by a household during the following cropping season (Table 4). Results were similar when using village and year dummies.

INSERT TABLE 4 ABOUT HERE

To assess whether rice cultivation is also associated with greater deforestation of old-growth forest, we re-estimated expression [1] using clearance of old-growth forest, instead of total area cleared, as a dependent variable. For this estimation, we used a tobit regression since the dependent variable was censored at zero, because 48% of households did not clear old growth forest. The area sown with rice in year *n* was associated with a significant increase in the clearing of old-growth forest the following year (Table 5). An additional hectare cultivated with rice was associated with a 0.17 and 0.18 hectare increase in the clearing of old-growth forest. The lower estimate is for a regression controlling for village fixed effects and for year and the higher estimate comes from a regression without such controls.

INSERT TABLE 5 ABOUT HERE

We also took the logarithm of old-growth forest and rice area and ran the same regressions to obtain elasticity coefficients. We found that the area sown with rice (in logarithms) bore a highly significant relation with the deforestation of old-growth forest in the next cropping season. A doubling in the area of rice was associated with a 26% increase in the clearing of old-growth forest in the regression using dummy variables to control for village and year. In the regression with no such control, a doubling in the rice area was associated with a 28% increase in the deforestation of old-growth forest (Table 5). Since many households did not clear old-growth forest, we added +1 to the dependent variable. The regressions retained their significance but elasticity coefficients were much lower than in the tobit regressions, i.e. 0.032 (sd=0.009; p<0.002) in the regression using dummy variables to control for village, and 0.030 (sd=0.009; p<0.02) in the regression using no such controls.

In sum, the area cultivated with rice on year *n* is associated positively with the amount of area cleared by the household in year *n+1*, even after controlling for village fixed effects and year of the survey. Results suggest that the observed association between cash cropping and deforestation does not reflect village attributes or time variant aspects. Rather, deforestation probably has more to do with household characteristics.

4.2.2. Other variables of integration to the market.

We estimate the correlation between deforestation and two village-level variables: walking time to the nearest market town and road access for vehicles. Walking time to the nearest market town bore no significant associations with deforestation, neither when using total area cleared (p<0.31) nor when using the logarithm of old-growth forest cleared (p<0.12) (Table 5). Permanent road access to the market town had no significant relation with total or old-growth forest deforestation in any of the regressions.

We then looked at two other household-level proxies for integration to the market: household cash income and household market dependence. In the regression with raw data for total deforestation as a dependent variable, there was no significant association between cash income in year *n* and total area cleared in year *n+1* (column 1 and 2, Table 4). In the regression using logarithm data and no dummy variables to control for village and year fixed effects, there was a significant association between cash income and total deforestation (column 4, Table 4). In the tobit regression with clearing of old-growth forest without controlling for village and year fixed effects (column 2, Table 5), we found a significant relation between cash income and clearing of old-growth forest. In the regressions using logarithm data of old-growth forest, there was no significant association between cash income and clearing of old-growth forest (column 3 and 4, Table 5).

Household's market dependence in year *n* bore no significant association with total deforestation in year *n+1* (Table 4). The explanatory variable had only a weak association with the level of deforestation of old-growth forest in the regression using the logarithm of old-growth forest, and without using dummy variable to control for year and village fixed effects ($p<0.05$). A doubling in the degree of market dependence then was associated with 56% more deforestation of old-growth forest (column 4, Table 5).

In sum, among the various explanatory variables for deforestation, the cultivation of rice in year *n* was the one bearing the most effect on the amount of area cleared in the year *n+1*. The finding supports the intuition that there may be strong incentives for rice production in the study area.

4.3. Can poor rural households cash crop themselves out of poverty?

We have seen that Tsimane' households obtained on average 21-26% of their cash earnings through the sale of rice and that 25% of all the households obtained up to 40-50% of their cash income through rice. Since rice is in high demand on the local market and does not meet local demand, and since Tsimane' income per capita is only 0.90 US$/person/day (Godoy et al., 2002), below the 1US$/person/day poverty line defined by the World Bank, it is reasonable to assume that Tsimane' would rely on the sale of rice as a major way to increase income. Next we simulate what would happen to land and labor requirements and to fallow duration if Tsimane' decide to cash crop rice to reach the poverty line.

4.3.1. Enough land to go beyond the poverty line?

Keeping up with current needs and simply adjusting to demographic increase, the *subsistence* scenario, a typical Tsimane' household would need to clear 2.4 ha within 10 years and about 3.8 ha within 20 years, which represents a 60% and 160% increase in the current level of deforestation (Fig. 2a). Under the *Poverty Line + Traditional Practice* scenario, a typical Tsimane' household would need to clear 4.9 ha within 10 years, or over three times more than they currently cut. Within 20 years, Tsimane' households would need to clear 7.9 ha, over five times more than they currently cut (Figure 2a). Forest clearance under the *Poverty Line + Farm Technology* scenario is fairly similar to the *Poverty Line + Traditional Practice* scenario.

The simulation shows that simply adjusting to demographic increases with current needs would require large increases in the amount of area cleared to sow rice. For that reason, we explore a scenario where an increase in the price of rice would raise the gross income per hectare. Under the *Poverty Line + Rice Price Increase* scenario, forest clearance would be 3.1 ha in year 0, about twice as high as the current level of forest cleared by households. It would then decrease to 2.8 ha within 10 years, about equal than the *subsistence* scenario, and then to 2.5 ha within 20 years, lower than clearance in the *subsistence* scenario, but still 66% higher than clearance at time 0 in the *subsistence* scenario.

INSERT FIGURE 2 ABOUT HERE

4.3.2. Enough work to meet the poverty line?

Since reaching poverty line would require large increase in the area sown with rice, the option that Tsimane' households meet the poverty threshold through rice cultivation may become primarily a matter of work availability. We found that in the *subsistence* scenario, households would have sufficient labor availability for the next 20 years, when they will need 387 person-days/household to meet labor requirements. In the *Poverty Line + Traditional Practice* scenario, a typical household would need 316 days to reach the poverty line in year 0, i.e. 163 more days than under the *subsistence* scenario. A household will need 503 days within 10 years to reach the poverty line (Figure 2b). After 10 years, households choosing to reach the poverty line with no technology input would not be able to meet the labor requirements. In contrast, under the *Poverty Line + Farm Technology* scenario, the labor requirement would be very close to the labor requirement of the subsistence scenario. Households would need 169 person-days of work in year 0, only 16 more days than under subsistence, and 269 persons-days within 10 years, only 26 more days than under subsistence, but 230 days less than in the *Poverty Line + Traditional Practice* scenario. Even after 20 years, the *Poverty Line + Farm Technology* scenario would remain largely below the 510 person-day ceiling of available labor per household.

Although the use of simple farm technologies may help households meet the labor requirements of reaching 1 US$/person/day, the work demand increases over time and would end up imposing a binding constraint on households. In the *Poverty Line + Rice Price Increase* scenario, the labor requirement would decrease over time because forest clearance needed to reach the poverty line would also decrease (Figure 2a). Under that scenario, in years 0, 10, and 20 a household would need 316, 287, and 254 days-person of work to reach the poverty line.

4.3.3. Fallow duration to reach the poverty line

If poor households want to reach the poverty line by selling rice, the fallow duration will be linked to the number of households in the village. We assume a typical village size of 35 households and a fallow period of at least 11 years to allow secondary forest re-growth and to avoid land degradation (Metzger 2002). We compare the fallow duration under different scenarios to this benchmark using the same simulations as in the previous sections. Then, we add a simulation for the *Poverty Line + Traditional Practice* scenario in a small village of 15 households. We also consider the case of encroachment by colonists, equivalent to a 3%/year increase in the number of households in the village (Appendix B).

With current land availability and a household clearance of 1.5 ha/year, the fallow duration is about 24 years in a village of 35 households. Under the *subsistence* scenario, the fallow duration would decrease to about 9.5 years within 20 years in a typical large village of 35 households. Under the *Poverty Line + Traditional Practice*, the fallow duration would decrease to 11.6 years in year 0, about two-fold reduction compared with the subsistence scenario, and to 7.3 years within 10 years, below the 11 years minimum fallow period to prevent land degradation. Under the *Poverty Line + Farm Technology* scenario, the fallow duration would decrease to 10.4 years in year 0 and to 6.5 years within 10 years, below the 11 years fallow period, and about the same than the *Poverty*

Line + Traditional Practice scenario. By contrast, under the *Poverty Line + Traditional Practice* scenario in a small village of 15 households, the fallow duration would be 27.0 years in year 0, it would decrease to 17.0 years within 10 years, and to 10.6 years within 20 years.

Under the *Poverty Line + Rice Price Increase* in a village of 35 households, the fallow duration would be about 11.6 years in year 0, it would increase to 12.7 years within 10 years, and to 14.3 years within 20 years. Under the *Poverty Line + Encroachment* scenario, the fallow duration would dramatically decrease over time and would be only 5.4 years within 10 years and about 2.5 years within 20 years.

5. Discussion and conclusions

Cash cropping rice one year correlated with the total area cleared by the household the following cropping season. Every additional hectare cultivated with rice in year *n* was associated with 0.26-0.30 more hectares deforested in year *n+1*, and with 0.17-0.28 more hectares of old-growth forest cleared in year *n+1*. Though the increase is so far modest, the fact that cash cropping has a significant effect on the clearing of old-growth forest, available only in distant villages, suggests that cash cropping rice is expanding to remote areas of the tropical forest. The high demand for rice in the local market and the importance of rice in household’s economy suggests that rice is likely to fuel more deforestation in coming years. We found no association between the level of deforestation and having all-year road access to the villages. We found a weak correlation between the walking time to the nearest market and the amount of deforestation. In fact, certain villages do have all year long road access by vehicle, but cannot rely on a regular transportation service on these roads to sell rice.

Our simulations show that if people try to exit poverty by intensifying cash cropping the environment and the household's time allocation are likely to suffer. Reaching the poverty line of 1 US$/person/day by cash cropping rice would require doubling in the area of forest cleared per household. If one adds demographic increase, the level of deforestation would triple in a decade. Two possible options to alleviate the pressure on land for the Tsimane' would be an increase in the price of rice, or to substitute rice with another, more profitable cash crop.

Reaching the poverty line would also induce important changes in the household's time allocation because expanding rice crops would require additional work. We estimate that within 10 years, households without access to new farm technology that face a high growth in population would not be able to provide the work needed to reach the poverty line. Labor-saving technological improvements could ease the labor constraints, but only temporarily because even under such a scenario the demographic increase will soon overwhelm the benefits of technological improvements.

Reaching the poverty line by cash cropping rice will also reduce the duration of the fallow, in agreement with previous work (Coomes et al., 2000), especially in large villages facing land scarcity, and more so if outside encroachment occurs. Land constraint will eventually also affect households in small villages. Land-saving technological improvement might ease the constraints.

Although rice cash cropping is currently having only modest impacts on the level of forest area cleared, the socio-economic context in which poor rural households live –

the desire to increase welfare, the high demand for farm products, and the demographic increase - suggest that cash cropping rice might increase, and deforestation along with it. In light of the low returns to labor input of rice and the high demand for land to cultivate rice, the reconciliation of forest conservation and economic development requires new alternatives. We conclude with three recommendations to help reconciliate forest conservation and economic development related to cash cropping by small holders.

First, an increase in the price of rice would increase the profitability per hectare and decrease the amount of forest to reach the poverty line, and would have direct effects on the labor requirement and fallow duration. An increase in the price of rice would benefit the economy of smallholders, but would lower the real income of poor urban households that buy rice. An alternative option is to find a more profitable cash crop. Research is needed to explore potential high profitability market crops.

Second, the large labor demand of rice cultivation would boost the use of the locally available farm technologies to reduce labor, namely chainsaw and herbicides. The use of chemicals in farming have risks for users and for the environment, but they seems unavoidable. Extension work is needed to help farmers use those technologies in appropriate ways.

Third, herbicides and chain saws are labor-saving technologies but they do not increase the productivity of rice. Agriculture research and extension in the area are neededs to increase the productivity of rice. An area of research is to find a sustainable way of intensifying the production of cash crops on the same land. Nitrogen being the most limiting edaphic factor for crop production (Sinclair and Vadez 2002), the use of legumes that fix nitrogen might provide a sustainable way of increasing agricultural production. Work is needed to find and introduce such legumes, as they need to be marketable, and adopted by the population.

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Table 1

Description and summary statistics of the variables measured in surveys (2000-2002).

Variable	**Definition**	**Mean**	**Sd**	**Obs.**
Dependent				
Total clearing	Total area cleared per households, in hectares	0.266	0.273	493
Old-growth forest clearing	Area of old-growth forest cleared per household, in hectares	0.120	0.204	463
Explanatory				
Rice area	Total area planted with rice per household, in hectares	0.222	0.201	469
Walking time	Time to the nearest market town, in hours	9.85	10.22	470
Road access	Accessibility throughout the year to the village with motor vehicle (0=no access; 1=access)	0.39	0.49	470
Cash income	Total household income in past two weeks from sales, barter, and wage labor, in US$.	0.032	0.061	472
Market dependence	Ratio of cash income/(cash income + consumption value of rice + maize + cassava)	0.313	0.304	466

Table 2

Rice in the Tsimane' economy (2000-2002). Data are mean ± standard deviation.

	2000	**2001**	**2002**
Rice income[a]	13.2±32.9	9.9±21.5	6.8±14.1
Household earnings[b]	44.5±57.1	43.9±74.3	29.7±35.6
Rice % of total earnings	25.9±33.5	21.3±26.3	22.6±25.1
Percentile			
25	0	0	0
50	0	7	15
75	51	41	40
90	82	58	53
Nº Observations	511	378	331
Time survey	July-September	March-April	February-April

[a] Sum of rice transactions in cash and in kind, in US$ for past two weeks.

[b] Sum of sales and wage labor, in US$ for past two weeks.

Table 3

Summary statistic for labor inputs in rice cultivation and other economic parameters.

Data are the mean (± sd) of data collected on focus groups on 18 villages.

Activities	**Rice, traditional**	**Rice, modern**
Field preparation		
Slashing (days/ha)	14.1±5.4	14.1±5.4
Felling (days/ha)	22.9±5.9	0
Burning-Cleaning (days/ha)	4.3±5.6	4.3±5.6
Crop management		
Sowing (days/ha)	11.7±5.1	2.3±1.0
Weeding (days/ha)	23.2±8.0	2 [a]
Harvesting (days/ha)	26.4±4.5	26.4±4.5
Technology inputs		
Chainsaw [b] (US$/ha)	0	17.84
Sowing machine[c] (US$/ha)	0	0.05
Herbicide[d] (US$/ha)	0	9.87
Economic parameters		
Yield (kg/ha)	1540±241	1540±241
Total work (days/ha)	101.9	49.1
Total input (US$/ha)	0	31.76
Net income (US$/ha)	176	144.24
Productivity of work (US$/day)	1.72	2.94

[a] Data estimated from information with Tsimane' key informants.

[b] Two days wage (7.89 US$/ha), 10 liters of gas (3.95 US$/ha), cost and maintenance (10 US$/ha);

[c] Cost 5.26 US$ and would work for about a 100 ha minimum, that is 0.05 US$/ha;

[d] Chemical inputs: 6.58 US$/ha, plus 3.29 US$ per ha for rental, based on the pump price.

Table 4

Regression with total deforestation, first with raw data (column 1 & 2), and with the logarithm of deforestation and rice area (column 3 & 4). Data are the regression coefficients with standard deviation in brackets. Significance at the 99, 95 and 90% level indicated with ***, **, and *.

Deforestation	**Raw data**		**Logarithm**	
Rice area	0.300*** (0.096)	0.306*** (0.097)	-	-
Log(rice area)	-	-	0.263*** (0.044)	0.276*** (0.040)
Walking time	NA	-0.0017 (0.0013)	NA	-0.0056 (0.0045)
Road access	NA	0.0023 (0.0299)	NA	0.0272 (0.0824)
Cash income	0.211 (0.186)	0.345 (0.157)	0.812 (0.443)	1.166** (0.389)
Market dependence	0.054 (0.078)	0.041 (0.057)	0.087 (0.168)	0.104 (0.132)
Observations	463	463	449	449
R^2	0.14	0.07	0.21	0.12
Dummy variables	Yes	No	Yes	No

NA, non applicable. Variables taken out of regressions using village dummies.

Table 5

Regression with old-growth forest deforestation, first with raw deforestation data (columns 1 & 2), and with the logarithm of old-growth forest and rice area (columns 3 & 4). Data are the regression coefficients with standard deviation in brackets. Significance at the 99, 95 and 90% level indicated with ***, **, and *.

Old-growth forest	**Tobit regression**		**Log of old-growth forest**	
Rice area	0.175**	0.178**	-	-
	(0.076)	(0.077)		
Log(rice area)	-	-	0.256***	0.278***
			(0.076)	(0.074)
Walking time	NA	0.0026	NA	-0.0096
		(0.0016)		(0.0059)
Road access	NA	-0.0056	NA	-0.0025
		(0.0334)		(0.0986)
Cash income	0.225	0.654***	0.295	0.053
	(0.272)	(0.253)	(0.507)	(0.517)
Market dependence	0.071	0.057	0.397	0.564**
	(0.063)	(0.055)	(0.336)	(0.235)
Observations	463	463	259	259
R^2	0.29	0.05	0.32	0.15
Dummy variables	Yes	No	Yes	No

NA, non applicable. Variables taken out of regressions using village dummies.

Figure captions

Figure 1. Retail rice prices in San Borja, Bolivia, in 2002-2003.

Figure 2. Consequences of reaching up to the poverty line with a 4.76% demography increase on: forest clearance per household (Fig. 2a), work required to cultivate (Fig. 2b), fallow duration in situation of varying land availability (Fig. 2c).

Appendix A. Basic calculations and assumptions of simulations

Area cleared under the different scenarios. The additional forest clearance needed in year 0 to reach the 1 US$/person/day (365 US$/person/year) poverty threshold was

[2] $FC_0 = CCR + [(PL-I)*HHC/(RGM*CRPL)]/PRO$

Where FC_0 is the forest cleared in year 0; CCR is the current clearing amount, 1.5ha/hh/year (Vadez et al. 2004); PL is the poverty line (365 US$/person/year); I is the average Tsimane' income per person (cash + consumption), estimated to 332 US$/person/year (Godoy et al. 2002); HHC is the household composition, 6.5 persons/household (this study); PRO is the share of newly opened fields planted with rice, 76% (this study); RGM is the rice gross income, 176 US$/ha with no modern technology input (this study); CRPL is the contribution of rice to meet poverty line, assumed to be 100%.

Then, FC_n the additional forest clearance needed in year n was such as:

$FC_n = FC_0*(1 + DI/100)^n$

[3] $FC_n = [1.5 + [(33)*6.5/RGM]/0.76]* (1 + 4.76/100)^n$

Where DI is the demographic increase, estimated to 4.76% (Reyes-García 2001).

Work needed under different scenarios. From expression [3], we calculated the work required to reach poverty line in year n, such as:

$Work = RLR*FC_n$

[4] $Work = RLR*[1.5 + [(33)*6.5/RGM]/0.76]*(1 + 4.76/100)^n$

Where: RLR, the rice labor requirement varies from 102 days-person/ha (*Poverty Line + Traditional farming*) to 49.1 days-person/ha (*Poverty Line + Farm technology*).

Fallow duration under the different scenarios. From expression [3], we calculated the fallow duration to reach poverty line in year n, such as:

$$\text{Fallow duration} = LA/(VS*FC_n)$$

$$\text{Fallow duration} = LA/(VS*[1.5 + [(33)*6.5/RGM]/0.76]*(1 + DI/100)^{n} \quad [5]$$

Where LA, the land availability per village and is estimated to 1250ha, and VS, the village size varies between 15 households (small villages) and 35 households (large villages).

Appendix B. Summary of the main assumptions made in the different scenarios concerning the area to be cleared per household, the fallow duration, and the labor requirement, to meet poverty line with a 4.76% demographic increase. Main varying parameter is indicated in bold.

Scenarios	**Main assumptions**	
	Area to be cleared and Work	**Fallow**
Subsistence	**$Fn = 1.5*(1+DI/100)^n$** with DI = 4.76%/y	VS = 35 hh
PL + Tradional Practice	**RGM = 176 US$/ha**; DI = 4.76%/y	VS = 35 hh
PL + Farm technology	**RGM = 144 US$/ha**; DI = 4.76%/y	VS = 35 hh
PL + Rice price increase	RGM = 176 US$/ha; DI = 4.76%/y; **Price increase = 3%/y**	VS = 35 hh
PL + Tradional Practice	-	RGM = 176 US$/ha; DI = 4.76%/y; **VS = 15 hh**
PL + Encroachment	-	**VS increase = 3%/year** due to encroachment: $VS_n = 15*(1+3/100)^n$

References

Alston, L, GD Libecap, and B Mueller. Land reform policies, the sources of violent conflict, and implications for deforestation in the Brazilian Amazon. Journal of Environmental Economic Management 39(2). 2000. Pp 162-88.

Angelsen, A and D Kaimowitz. Rethinking the causes of deforestation: lessons from economic models. World Bank Research Observer 14(1). 1999. Pp 73-98.

Angelsen, A and D Kaimowitz. Agricultural Technologies and Tropical Deforestation. Wallingford, Oxford: Center for International Forestry Research. 2001.

Byron, E. Market Integration and Health: The Impact of Markets on the Nutritional Status, Morbidity, and Diet of the Tsimane' Amerindians of Lowland Bolivia. Gainesville: University of Florida. 2003.

Chicchon, A. Chimane Resource Use and Market Involvement in the Beni Biosphere Reserve, Bolivia. Gainesville: University of Florida. 1992.

Chomitz, KM and DA Gray. Roads, land use, and deforestation: A spatial model applied to Belize. World Bank Economic Review 10(3). 1996. Pp 487-512.

Comisión Europea. Mercados agroalimentarios en Bolivia: El caso de arroz, maíz, trigo, y papa. Apuntes técnicos n 4. La Paz: Unidad de Seguridad Alimentaria. 2000. Web:http://europa.eu.int/comm/europeaid/projects/resal/Download/report/mission/bolper/1200tnbol.pdf

Coomes OT, F Grimard, and GJ Burt. Tropical forests and shifting cultivation: secondary forest fallow dynamics among traditional farmers of the Peruvian Amazon. Ecological Economics 32. 2000. Pp 109-124.

Costanza, R, R D'Arge, R de Groot, S Farber, M Grasso, B Hannon, K Limburg, S Naeem, RV O'Neill, J Paruelo, RG Raskin, P Sutton, and M Van den Belk. The value of the world's ecosystem services and natural capital. Nature 387. 1997. Pp 253-60.

Daillant, I. Sens Dessus Dessous. Organization sociale et spatiale des Chimane d'Amazonie boliviane. Nanterre: Societe d'ethnologie. 2003.

Deacon, RT. Deforestation and ownership: Evidence from historical accounts and contemporary data. Land Economics 75(3). 1999. Pp 341-59.

Dearden, P. Development, the environment and social differentiation in northern Thailand. In J Rigg (Ed), Counting the Costs: Environmental Growth and Economic Change. Singapore: ISEAS. 1995. Pp 111-30.

Ellis, R. A Taste for Movement: An Exploration of the Social Ethics of the Tsimane' of Lowland Bolivia. Scotland: St Andrews University. 1996.

Finegan, B. Pattern and process in neotropical secondary rain forest. The first 100 years of succession. Trends in Ecological Evolution 11(3). 1996. Pp 119-24.

Godoy, R. Indians, Markets, and Rainforest. Theory, Methods, Analysis. New York: Columbia University Press. 2001.

Godoy, R, KN Kirby, and D Wilkie. Tenure security, private time preference, and use of natural resources among lowland Bolivian Amerindians. Ecological Economics 38(1). 2001. Pp 105-18.

Godoy, R, H Overman, J Demmer, L Apaza, E Byron, T Huanca, W Leonard, E Perez, V Reyes-García, V Vadez, D Wilkie, A Cubas, K McSweeny, and N Brokaw. Local financial benefits of rain forests: Comparative evidence from Amerindian societies in Bolivia and Honduras. Ecological Economics 40(3). 2002. Pp 397-409.

Hecht, S and A Cockburn. The Fate of the Forest: Developers, Destroyers, and Defenders of the Amazon. New York: Harper Perennia. 1989.

Holden, S. Peasant household modeling: farming systems evolution and sustainability in Northern Zambia. Agricultural Economics 9(3). 1993. Pp 241-67.

Huanca, T. Tsimane' Indigenous Knowledge. Swidden Fallow Management and Conservation. Gainesville: University of Florida. 1999.

Huanca, T. Tsimane' Oral Tradition, Landscape, and Identity in Tropical Forest. La Paz: Campo Iris. 2005.

Humphries, S. The intensification of traditional agriculture among Yucatec Maya farmers: facing up to the dilemma of livelihood sustainability. Human Ecology 21(1). 1993. Pp 87-103.

Jones, D, V Dale, J Beaucamp, M Pedlowsky, and R O'Neill. Farming in Rondonia. Resource and Energy Economics 17(2). 1995. Pp 155-88.

Kaimowitz, D and A Angelsen. Economic Models of Tropical Deforestation, A Review. Bogor: Center for International Forestry Research. 1998.

Marquette, CM. Land Use Patterns Among Small Farmer Settlers in the Northeastern Ecuadorian Amazon. Human Ecology 26(4). 1998. Pp 573-98.

McMorrow, J and AM Talip. Decline of forest area in Sabah, Malaysia: Relationship to state policies, land code and land capability. Global Environmental Change 11. 2001. Pp 217-30.

Mertens, B, WD Sunderlin, O Ndoye, and EF Lambin. Impact of macroeconomic change on deforestation in South Cameroon: Integration of household survey and remotely-sensed data. World Development 28(6). 2000. Pp 983-99.

Metzger, J. Landscape dynamics and equilibrium in areas of slash-and-burn agriculture with short and long fallow period (Bragantina region, NE Brazilian Amazon). Landscape Ecology 17(5). 2002. Pp 419-31.

Palm, CA, SA Vosti, PA Sanchez, and PJ Ericksen. Slash-and-Burn Agriculture: The Search for Alternatives. New York: Columbia University Press. 2005.

Pendleton, LH and LE Howe. Market Integration, Development, and Smallholder Forest Clearance. Land Economics 78(1). 2004. Pp. 1-19.

Pérez-Diez, A. Etnografía de los Chimane del Oriente Boliviano. Buenos Aires: Universidad de Buenos Aires. 1983.

Perz, SG. Are Agricultural Production and Forest Conservation Compatible? Agricultural Diversity, Agricultural Incomes and Primary Forest Cover Among Small Farm Colonists in the Amazon. World Development 32(6). 2004. Pp 957-77.

Picchi, D. The impact of an industrial agricultural project on the Bakairi Indians of Central Brazil. Human Organization 50(1). 1991. Pp 26-38.

Pichón, F, C Marquette, L Murphy, and R Bilsborrow. Endogenous Patterns and Processes of Settler Land Use and Forest Change in the Ecuadorian Amazon. In C Wood & R Porro (eds), Deforestation and Land Use in the Amazon, Gainesville: University of Florida Press. 2002. Pp 241-80.

Piland, R. Traditional Chimane Agriculture and Its Relationship to Soils of the Beni Biosphere Reserve, Bolivia. Gainesville: University of Florida. 1991.

Reid, J. Roads and tropical forests: From white lines to white elephants. In IA Bowles & GT Prickett (eds), Footprints in the Jungle: Natural Resource Industries, Infrastructure, and Biodiversity Conservation. New York: Oxford University Press. 2001. Pp 281-91.

Reyes-García, V. Indigenous People, Ethnobotanical Knowledge, and Market Economy. A Study of the Tsimane' Amerindians, Bolivia. Gainesville: University of Florida. 2001.

Silver, W, S Brown, and A Lugo. Effects of changes in biodiversity on ecosystem function in tropical forest. Conservation Biology 10(1). 1996. Pp 17-24.

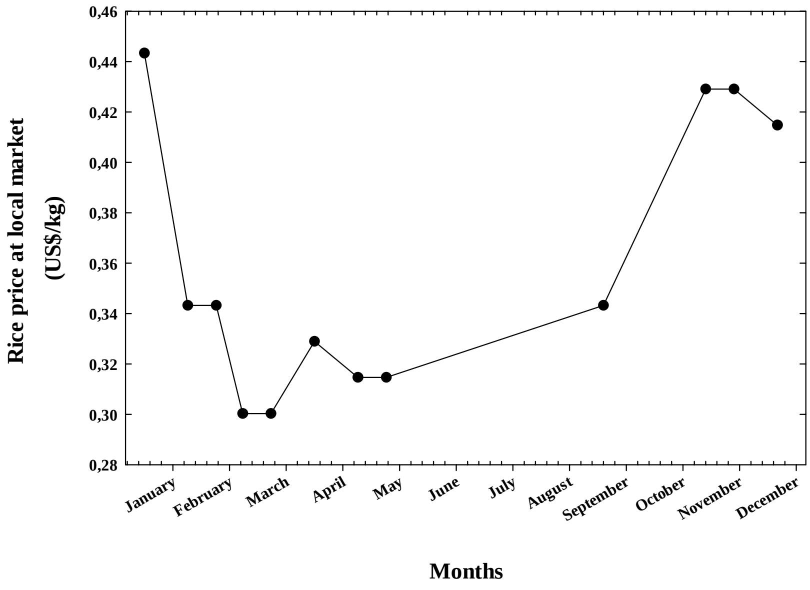
Sinclair, TR and V Vadez. Physiological traits for crop yield improvement in low N and P environment. Plant Soil 245(1). 2002. Pp 1-15.

Smith, J, P van de Kop, K Reategui, I Lombardi, C Sabogal, and A Diaz. Dynamics of secondary forests in slash-and-burn farming: interactions among land use types in the Peruvian Amazon. Agriculture, Ecosystems, & Environment 76(2-3). 1999. Pp 85-98.

Tungittiplakorn, W and P Dearden. Biodiversity conservation and cash crop development in northern Thailand. Biodiversity and Conservation 11. 2002. Pp 2007-25.

Vadez, V, V Reyes-García, L Apaza, E Byron, T Huanca, W Leonard, E Perez, and D Wilkie. Does integration to the market threaten agricultural diversity? Panel and cross-sectional evidence from a horticultural-foraging society in the Bolivian Amazon. Human Ecology 32(5). 2004. Pp 635-46.

Vadez, V, V Reyes-García, R Godoy, L Williams, L Apaza, E Byron, T Huanca, W Leonard, E Perez, and D Wilkie. Validity of self-reports to measure deforestation: Evidence from the Bolivian lowlands. Field Methods 15(3). 2003. Pp 289-304.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Rice price at local market (US$/kg)
January
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April
May
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September
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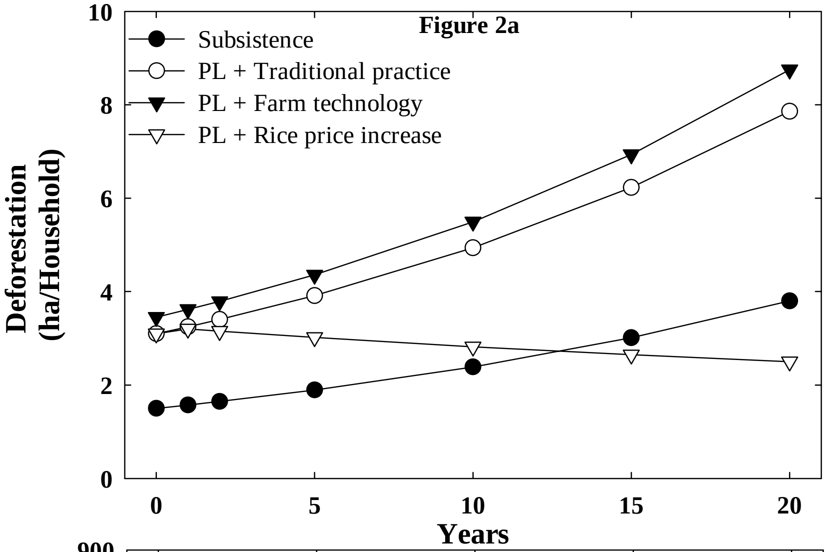
November
December
Months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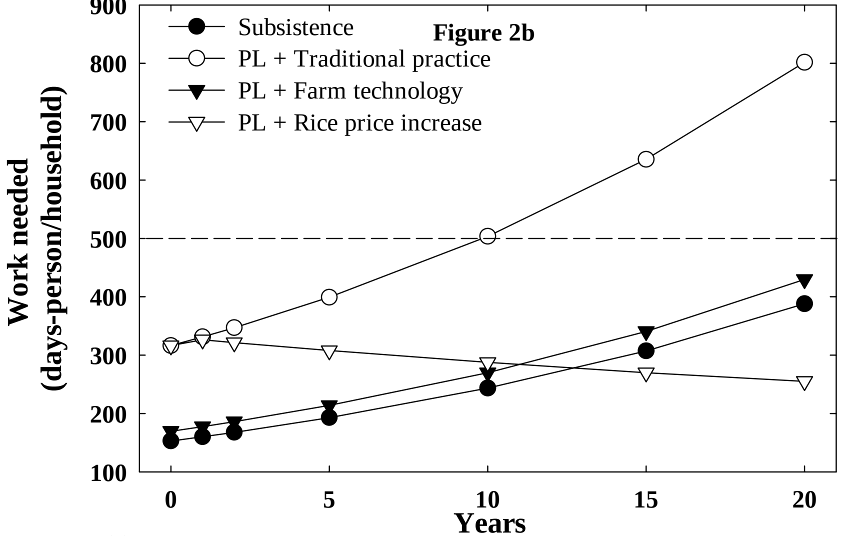
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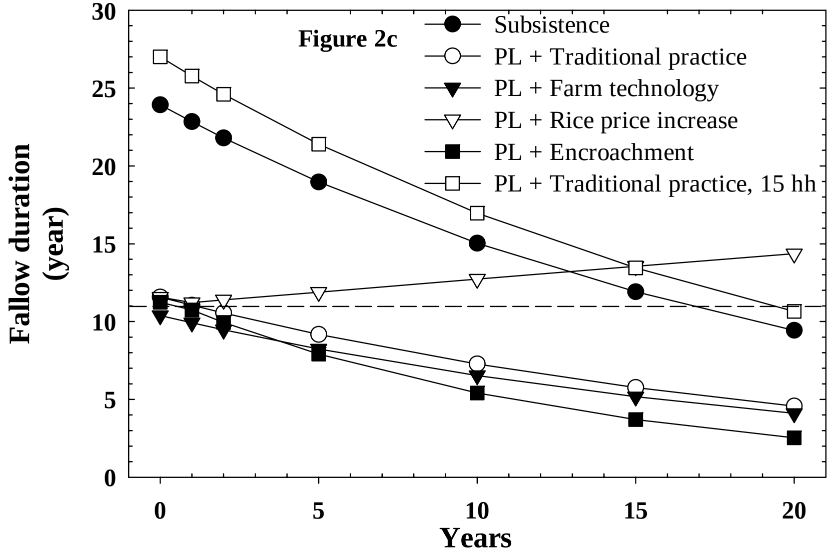
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