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Land-use system modeling and analysis of shaded cacao production in Belize

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Abstract

Shaded cacao (*Theobroma cacao*) cultivation is a tropical land-use that has potential to reduce pressure on the forest and provide additional income to smallholder growers. A land-use system (LUS) model was formulated to represent the economic returns derived from shaded cacao production practiced by smallholders in the Toledo district of Belize. Sixty scenarios were tested to elicit response of net-present-value (NPV), returns to labor, and annual returns to land (ARTL) to individual changes in 10 system parameters. Further scenarios tested the combined interactions between hardwood shade tree type, planting density, time to harvest hardwoods, cacao cultivation practice, and expected output. As a modeling exercise, LUS analysis highlights system components that government agencies, donors, NGOs, extension agents, and smallholders should target with policies, agri-silviculture projects, and further research. Results identify more favorable credit, labor-saving technology, better shade-management practices, grafting, and incorporating non-hardwood shade trees and laurel (*Cordia alliadora*) as interventions that could improve cacao financial performance and encourage adoption. At present, the model cannot predict whether smallholders would respond to recommendations and invest in shaded cacao cultivation in lieu of alternative agricultural land-uses or off-farm employment.

Introduction

The environment, economic growth, and poverty intertwine as a triangle of factors causing and resulting from deforestation in Central and South America (Vosti and Reardon 1997). One view of the relationship is that farmers degrade the environment to improve their welfare (Vosti et al. 2001). For example, frontier emigrants slash-and-burn forest to increase their income (Jaramillo and Kelly 1999), with increasing population accelerating forest conversion (Ostuka and Place 2001). Smallholders in the Toledo district in Belize currently face declining fallow periods for shifting cultivation practices (Levasseur and Oliver 2000) and are gradually abandoning more diverse, long-term forest fallows characteristic of 'traditional' Maya agriculture (Steinberg 1998). New policies, management practices, and agro-ecologic research must promote land-use systems (LUS) that can provide goods and services to sustain and improve the livelihoods of rural smallholders.

An agroforestry system such as shade-grown cacao (*Theobroma cacao*) is one alternative land use to slash-and-burn agriculture and is recommended for sustainable development in the humid tropics (Johns 1999). Although cacao has also been linked to deforestation (Ruf 1998), the link depends on certain conditions such as the suitability of cleared land for cacao, property rights, labor availability, and whether farmers capture forest rents by planting cacao or substituting other shifting cultivation practices (Vosti et al. 2003). Because cacao is shade-tolerant and can grow under a canopy of trees maintained, regenerated, or replanted from the traditional tropical forest (Beer et al. 1998), its inclusion as a component of a forest agro-ecosystem can maintain biodiversity and ecological services provided by the native forest (Glor et al. 2001; Johns 1999; Rice and Greenberg 2000). Shade grown cacao can also provide food, shelter, and material resources for local human needs. Shade-less production does not preserve these services (Laird et al. 1996, p. 96).

To be sustainable, the LUS must also provide smallholders with financial returns that match or exceed their other investment opportunities. Land, labor, purchased inputs, costs, outputs, sale prices, and timing for each production factor shape the overall financial return. A LUS model specifies all factors in matrix form over the lifespan of the land use to explicitly and quantifiably represent a smallholder's land-use activities (Vosti et al. 2000). LUS analysis can then explore socioeconomic implications for a wide range of scenarios, including changing cultivation practices, inputs, exogenous variables, individual and combinations of these parameters. Scenario testing enriches information available to those seeking to promote a LUS. For example, smallholders, project managers, policymakers, researchers, extension agents, or donors can quickly assess what market, land tenure, or credit policies, silvilculture practices, or research initiatives (when implemented) will most significantly improve smallholder income.

This paper presents a LUS model of shaded cacao production practiced predominately by Maya smallholders in the Toledo district of Belize. We report individual sensitivity analysis for 10 LUS variables and combined sensitivity analysis for both (i) mahogany shade tree planting density versus time to harvest shade trees and (ii) cacao cultivation practice versus yield. From the results, we identify policy, silviculture, and research options that show potential to improve smallholder incomes and encourage LUS adoption.

Background

The Toledo Maya Cultural Council (TMCC) and Toledo Alcalde Association (TAA) (1997), Levasseur and Oliver (2000), Sams (2001), Steinberg (2002), Emch (2003), and others describe various aspects of cacao agroforestry in the Southern region of Belize. Kekchi and Mopan Maya smallholders are the main groups presently cultivating cacao. Plots range from a few trees to 6 ha. Smallholders also cultivate corn (*Zea mays,* main season and second season *matahambre*), rice (*Oryza sativa*), vegetables, red kidney beans and black beans (*Phaseolus spp.*). A growing market for organic, fair trade cacao beans has existed in Toledo since 1992 and been supported by Green and Blacks (G and B), an international chocolate marketer. However, supply response has been very weak with output amounting to less that 15% of the quantity G and B desires.

Smallholder cacao yields range widely and may be due to different production practices and stand ages. For example, many smallholders harvest existing cacao stands that were established in the 1980s to meet expected demands of the Hershey Corporation. These stands show succession from multiple shade and hardwood tree species. Shade is managed to various degrees. Yields range from low values of 70 kg ha^{-1} for no management (foraging) (Levasseur and Oliver 2000) to more than 1,000 kg ha^{-1} for intensive pruning and shade management. Other smallholders are reclaiming former plantation areas or combining foraging with selective forest cutting to introduce new cacao seedlings. More recently, farmers have cut grids into existing forest to establish cacao under the remaining canopy. Establishment also involves planting hardwood shade trees such as mahogany (*Swietenia macrophylla*) and fruit trees. Cacao seedlings are established in a nursery and transplanted to cut areas after 5 months. Smallholders weed and prune in cut areas during the period before cacao trees start to bear. With shade management, cacao yields can increase over the first decade, and thereafter stabilize. Cacao plants can produce for 30 to 80 years (Stevenson 1987), however, yields decline in the later years.

Smallholders harvest cacao by hand over a six-month period, ferment pods in wooden boxes or on the ground covered with banana leaves, and dry beans on zinc racks or concrete floors. Smallholders transport dried cacao beans to Punta Gorda and sell them to the Toledo Cooperative Growers Association (TCGA) for \$US 1.55 kg^{-1} (US \$1 = BZ \$2.00, in 2002). TCGA resells the cacao to G and B. The cacao price floor is fixed and the quantity G and B will buy is set under a five-year rolling contract. G and B pays TCGA a minimum of \$US 1.95 kg^{-1} and agrees to buys all cacao up to 227 tonnes (Nesbitt, pers. comm., 2002)[1]. The price includes fair trade and organic price premiums of $US 0.15 kg^{-1} and $US 0.20 kg^{-1} respectively. Part of the organic certification requires smallholders to plant at least 8 hardwood shade trees per hectare (Sams 2001). The organic premium reflects consumer health concerns, beliefs, and is intended to provide growers an incentive to maintain the biodiversity associated with an intact shade canopy (Sams 2001).

Land in the Toledo district is designated as either nationally or privately owned, Maya reservation, protected area, or forest reserve. A large portion of private land is foreign-owned. It is difficult to convert other types of holdings into private ownership. Therefore, most occupancy is based on leased or non-leased national land that is essentially unmanaged. Where leases do exist, rents do not reflect the value of land on the open market and may be as low as $US 3 ha^{-1} yr^{-1}. The Maya reservation system is not widely recognized by the government and does not convey tenure rights for past (or current) occupation. Given these circumstances, smallholders do not typically pay for the land they cultivate; although many have reported that they are willing to pay a rental fee lease land guarantee occupancy rights (Levasseur and Oliver 2000).

Cacao LUS practices in Toledo are rapidly evolving. Several organizations and a few farmers are experimenting with grafting cacao trees, pruning to better manage shade, and planting alternative shade trees species such as laurel (*Cordia alliadora*). Paving the Southern Highway into Toledo and possibly westward through to Guatemala will also likely have profound consequences on input availabilities, markets access, cultivation practices, and land tenure. LUS modeling and analysis can help identify the likely financial implications of these and other scenarios to further inform research and policies.

Methods

Prices and required quantities for each activity associated with shaded cacao production were tabulated by year over three lifecycles of the LUS as a series of linked matrices in an Excel workbook. Dependencies were created in the workbook to link LUS summary parameter values (Table 1) to entries in the annual activity matrices and onto output indicators of financial performance. This model setup treats the summary parameters as 'switches' so that financial performance can be easily calculated for (i) the base case, or (ii) any number of scenarios where parameter values are changed (sensitivity analysis).

Base case

A base case for organic, shaded cacao production in the Toledo district was developed to represent the selective cutting of trees to establish cacao within standing forest (Table 1). Base case parameter values were drawn from cost of production estimates developed with extension agents and farmers in 1998 and 2002. Labor wages, cacao yields, cultivation practices, and purchased input prices were updated in Fall 2002 from interviews with 33 cacao smallholders and 27 other key informants. The cacao growers surveyed live in four villages in the main cacao-growing region and were a subset of a larger 120-farmer-household survey. Informants live in Toledo and work for the Ministry of Agriculture, Fisheries and Cooperatives (MAFC), TCGA, Toledo Maya Cultural Council, village council members and Alcaldes. These organizations regulate, manage, or are encouraging cacao production in Belize.

We use a family labor wage of $US 5 day^{-1} to represent an average, local, Toledo district labor wage (half the national minimum wage of $US 10 day^{-1}). In actuality, this wage varies from family to family and is experiencing upward pressures. A land rental rate of $US 0 ha^{-1} year^{-1} was used based on the existing land tenure situation. Farmer sale price for cacao was split into a base price of $US 1.35 kg^{-1} and organic price premium of $US 0.20 kg^{-1}. Mahogany tree production, discount rate, and hardwood planting density of 8 trees ha^{-1} were compiled from reports by Browder et al (1996), IMF (2001, p.77), and Sams (2001). A 40-year hardwood tree rotation time was chosen to represent the time required to raise and harvest mahogany (Browder et al. 1996; Mayhew and Newton 1998). Mahogany sale price represents the value of standing timber where the buyer bears harvest costs.

The base case also assumes: (i) establishment cultivation with resulting cacao yield increasing up to a maximum of 450 kg ha^{-1} after 9 years, (ii) household members perform all labor tasks, (iii) cacao price (in-

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Table 1. Summary of base case parameter values for shaded cacao production in Belize.

Labor inputs	Wage rate ($US/unit)	Required units
Household labor (Nursery and grove establishment, grove maintence, harvest, processing, and transport	5 $/pers/day	Depend on year and labor productivity
Hired labor	10$/per/day	0 days/lifecycle
Land input	Land rental rate ($US/unit)	Required units
Farm size	0 $/hectare/yr	1 hectares
Purchased inputs	Price ($US/unit)	Required quantity
Seed	$0.13	428 seeds/hectare
Plastic bag	$0.07 $/bag	1 bags/seed
Black soil	$7.50 $/cart	1 carts/hectare
Hardwood tree seedlings	$2.00 $/seedling	8 seedlings/ha
4-gallon water sprayer	$62.50 $/sprayer	1 units
Grove:		
Cutlass	$3.50 $/cutlass	1 units
Non-organic fertilizer: 14-36-12 (N, P, K)	$0.28 $/kg	500 kg/hectare
Lime	$0.06 $/kg	300 kg/hectare
Processing:		
Fermenting box	$2.50 $/box	68 kg cacao/box
10′ zinc rack	$4.88 $/rack	4 racks/hectare
10′ zinc roof	$4.88 $/roof	2 roofs/hectare
Sacks	$0.08 $/sack	45 kg cacao/sack
Transport:		
Public bus to TCGA warehouse	$0.02 $/kg	Depends on cacao harvest
Outputs	Prices ($US/unit)	Production quantity
Year 1 cacao price	$1.35 $/kg dry cacao	Depends on year and yield trend
Mahogany harvest	$315.00 $/m^3 wood	0–2.2 m^3 /tree, depends on harvest year
Other parameters	Value	Unit or description
Discount rate	12%	
Exchange rate	0.5	$US/$BZ
Expected future cacao price trend	1	(1 = stable, 2 = annual % change, 3 = linear, 4 = exponential)
Expected price change		percent
Price ceiling		$US/kg cacao
Organic price premium	$0.20	$US/kg dry cacao (in addition to cacao price
Hardwoods required to get organic price premium	8	trees/ha
Composite input price change	100%	percent
Labor productivity	100%	percent
Length of land tenure	120	years 3 Shade tree harvest/replant cycles
Cultivation practice	5	(1 = foraging every year; 3 = reclaim/establish; 4 = intensively manage shade; 5 = establish; 6 = forage and manage shade; 7 = graft)
Expected cacao yield	2	(1 = forage, 70 kg/ha; 2 = establish, 450 kg/ha by year 9; 3 = intensive shade management, 700 kg/ha by year 9; 4 = forage > establish, 5 = grafting, 450 kg/yr by year 7; 6 = forage with shade management, 450 kg/ha forage every year)
Year of 1st yield	5	0 shock (0 = all, 1 = even, 2 = odd)
Year of first full yield	9	0% percent fall
Hardwood tree management	1	(0 = none, 1 = Mahogany/Cahune/Cedar/Mamey, 2 = add Laurel)
Mahogany trees planted	2	trees/ha
Cahune, cedar, and mamey fruit trees planted	6	trees/ha
Harvest timber and replant all cacao in year	40	
Cacao trees lost because plant hardwoods	16	

clusive of organic premium) is guaranteed over the lifetime of the LUS, (iv) mahogany trees represent 25% of the hardwood trees planted and are harvested at the end of the hardwood rotation cycle with a yield linearly interpolated / extrapolated from growth data presented by Mayhew and Newton (1998, p. 214), and (v) after hardwood harvest, cacao and hardwood trees are planted anew. The model ignores (vi) cacao or hardwood tree mortality, (vii) the value of fruit crops or cahune palm leaves, (viii) the sale or fuel wood value of other shade trees retained after selective cutting, and (ix) the value of other cultural or ecological services provided by hardwood or shade trees.

The base case does not capture variations in production related to market distance, farm size, cacao lifespan, yields, natural disasters, future cacao price trends, mahogany tree planting density, foraging, reclaiming, intensive shade management practices, alternative hardwood species, time to harvest hardwoods, or other exogenous factors. Outputs for theses variations were explored using individual and combined sensitivity analyses.

Financial performance indicators

Based on the annual tabulated benefits and costs, the LUS model returns financial performance indicators for net present value (NPV), returns to labor, and annual returns to land (ARTL).

NPV [\$US in Year 1 ha^{-1}] was calculated by discounting each benefit and cost and dividing by the LUS farm size:

$$\mathrm{NPV} = \frac{\sum_{t=1}^{T} \left[\mathrm{B(t)} - \mathrm{C(t)}\right] \cdot (1+i)^{-(t-1)}}{a}$$

where: B(t) and C(t) are total benefits and costs gained in year *t* [\$ US], T is the length of land-tenure [years], *i* is the interest rate, *a* is the LUS farm size [hectares], and $(1 + i)^{-(t-1)}$ is the discounting factor for year *t*.

Returns to labor [\$US day^{-1}] were calculated using the Solver add-in extension to Excel. NPV was highlighted as the Target Cell. The objective was to make the Target Cell equal 0 by changing the labor wage parameter. A constraint for labor wage $>= 0$ was also entered before Excel iteratively searched for the labor rate to satisfy the objective. This operation was possible because workbook dependencies linked cells containing NPV output, yearly activity costs and benefits, and parameter values including the wage rate.

Annual returns to land [\$US ha^{-1} $year^{-1}$] was calculated using the Excel *payment* function:

$$\mathrm{ARTL} = \mathrm{PMT}(\mathrm{i, T, NPV, 0, 1})$$

where i, T, and NPV are as above, 0 specifies a \$0 future annuity value after T years, and 1 specifies beginning-of-period payments. ARTL represents an average, annualized land rental rate – and is the constant, annual payment made at the beginning of each year over the lifetime of the LUS that makes NPV equal returns to land.

Individual sensitivity analysis

Sixty additional scenarios were developed to explore the sensitivity of NPV and ARTL to individual changes in 10 LUS system parameters (Table 2). The first seven parameters were scaled from 50% to 200% of their base case value while all other system parameters were held at their base-case value. Time required to perform all labor activities except transporting dried cacao to TCGA represents generic labor productivity. This productivity is different than the cultivation practice (see combined sensitivity analysis).

Scenarios for the three non-scalable parameters were:

- Mahogany tree planting density. Densities from 0 to 8 trees ha^{-1} were examined maintaining constant the total labor required to clear land to plant trees. Thus, each mahogany tree precluded planting 2 cacao trees. The organic price premium was only paid when the planting density was greater than or equal to 2 trees ha^{-1}.
- Land rental rate was varied from \$US -24 to 24 ha^{-1} $year^{-1}$. The upper bound was chosen as eight times the current governmental land rental rate (where it exists).
- Future cacao price trends considering: (1) stable cacao price of \$US 1.40 kg^{-1} representing the current world market price, (2) 0.62% annual, (3) linear, and (4) exponential growth to a ceiling price of \$US 1.90 kg^{-1} in year 40. The Year 1 price started at \$US 1.35 kg^{-1} for the last three scenarios.

Table 2. Parameter values used in develop 60 scenarios for individual sensitivity analysis of shaded cacao in Belize.

Change in parameter from base case value (%)	Value of scaleable system parameters (42 scenarios)[a]							Value of non-scaleable system parameters (18 scenarios)[d]		
	Discount rate (%)	Labor wage ($US day^{-1})	Change in composite input prices (%)	Time to complete all labor tasks[b] (pers days lifecycle^{-1})	Farm size (ha)	Organic price premium ($US kg^{-1})	Mahogany tree price ($US m^{-3})	Mahogany tree planting density (trees ha^{-1})	Land rental rate ($US ha^{-1} yr^{-1})	Future cacao price trend
50%	6%	$2.50	50%	533	0.5	$0.10	$157.50	0	− $24	(1) Stable world price of $US 1.40/kg every year
70%	8%	$3.50	70%	746	0.7	$0.14	$220.50	1	− $10	(2) 0.6% annual increase
90%	11%	$4.50	90%	959	0.9	$0.18	$283.50	2[c]	− $3	(3) Exponential increase to $US 1.75/kg in Year 40
100%[c]	12%	$5.00	100%	1065	1.0	$0.20	$315.00	3	0[c]	(4) Linear increase to $US 1.75/kg in Year 40
111%	13%	$5.56	111%	1183	1.1	$0.22	$350.00	4	$3	Constant $US 1.35/kg every year[c]
143%	17%	$7.14	143%	1521	1.4	$0.29	$450.00	5	$10	
200%	24%	$10.00	200%	2130	2.0	$0.40	$630.00	6	$24	
								7		
								8		

Notes: [a]42 scenarios developed my making changes to individual parameter while holding all other parameters at base case value; [b]Excludes transporting processed cacao to TCGA warehouse in Punta Gorda Town; [c]Parameter values used for base case; [d]18 additional scenarios developed by making change to individual parameter while holding all quantifiable and other system parameters at base case values.

For each scenario, parameter values were entered into Table 1. Financial performance output was recorded. Then, parameter values for the next scenario were entered. These steps were automated using an Excel Visual Basic macro. Output responses to scaleable parameters were graphed against the percentage change in parameter value. Non-scalable parameter responses were graphed as vertical bars to the right of the scalable parameter traces. This format shows response sensitivity across all parameters tested.

Combined sensitivity analysis for mahogany tree planting density and time to harvest

Forty-five scenarios investigated the interaction between the mahogany tree planting density and the time to harvest mahogany. Densities between 1 and 8 trees ha^{-1} were examined. For each density, time to harvest was varied from 10 to 90 years. All other system parameters were left at their base case values.

Combined sensitivity analysis for cacao cultivation practices and expected outputs

Eight additional scenarios investigated the interaction between cacao cultivation practice and expected yield. Parameter changes reflect altering timings and amount of labor inputs and expected outputs. These scenarios are summarized as follows:

- Intensive shade management. Add 8 person-days $year^{-1}$ to intensively manage shade. This activity may boost cacao yields to 700 kg ha^{-1} from base case yields.
- Grafting. Base case establishment, but add 9 days of labor in the first year to graft existing cacao shoots onto seedlings in a nursery. Replant grafted shoots after two years. Agronomic research is ongoing; results show potential to shorten by up to 2 years the time to when cacao trees start producing harvestable pods.
- Foraging with no shade management. Harvest existing stands with no labor inputs for establishing cacao or managing shade. This scenario gives low yields of 70 kg ha^{-1} and treats establishment as a sunk cost.
- Foraging with shade management. Add 15 person-days $year^{-1}$ labor input to manage shade in addition to forage harvesting. This activity could boost yields to 450 kg ha^{-1}.
- Reclaiming. Continue foraging existing stands in the near term, but devote half the amount of base-case labor inputs to re-establish and improve the existing stand. This investment would preserve foraging yields in the short term, and transition to base case yield of 450 kg ha^{-1} in the long term.
- System shocks. Establishment production considering that pest, price, or other factors beyond smallholder control reduce cacao revenue (yield or price) every 2nd year by 50%. This scenario tests susceptibility to recurrent shocks.
- Add laurel (64 trees ha^{-1}). Establishment production adding approximately 2.5 days of labor to clear additional land to plant 64 laurel trees per hectare. This scenario represents an additive laurel shade tree treatment and assumes (i) an additional input cost of $US 2 per laurel seedling, (ii) a 10-year laurel growth function described by Ramirez et al. (2001), (iii) that laurel growth doubles by year 20, (iv) shade trees (laurel and mahogany) are harvested after twenty years, and (v) laurel trees can be sold for $US 130 m^{-3}.
- Add laurel (160 trees ha^{-1}). The additive laurel treatment described above increasing planting density to 160 trees per hectare. Input labor and laurel growth are scaled accordingly.

Table 3. Indicators of financial performance for base case of shaded cacao production in Belize.

Financial indicator	$ US	$ BZ
Net present value ($/hectare)	$ 1,503.30	$ 3,006.61
Returns to labor ($/day)	$ 7.58	$ 15.16
Annual returns to land ($/hectare/yr)	$ 162.82	$ 325.64
Break even year	10	

Results

Financial performance for base case

Financial performance indicators for the base case show NPV is positive, ARTL is approximately $US 160 per hectare per year, and returns to labor are greater than the local labor wage but less than the national labor wage (Table 3). The LUS does not break even until after year 10. Purchased inputs represent 21% of gross expenditures. Other costs are entirely for labor.

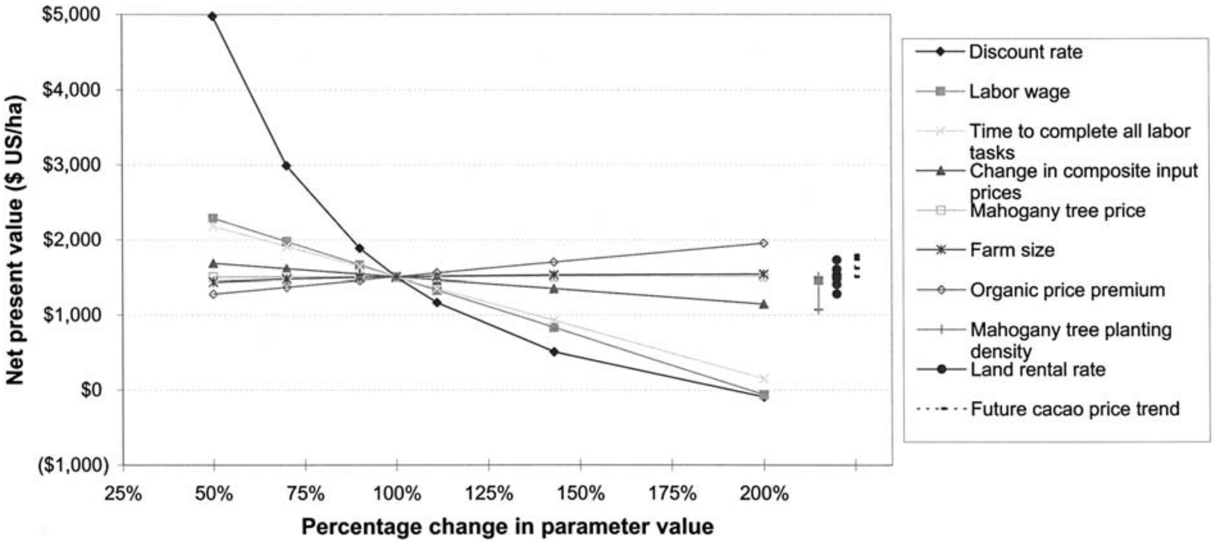

Figure 1. Sensitivity of Net Present Value to individual changes in parameters for shaded cacao in Belize.

Individual sensitivity analysis

Individual parameter changes show NPV [\$US ha^{-1}] is (Figure 1):

1. Most sensitive to the discount rate. This factor has the steepest slope.
2. Very sensitive to labor wage and time to complete all labor tasks. These factors have steep slopes.
3. Less sensitive to composite input prices and organic price premium. These factors have smaller slopes than the factors discussed previously,
4. Slightly sensitive to hardwood tree planting density, land rental rate, and future price trends, and
5. Insensitive to farm size and mahogany tree sale price.

NPV appears insensitive to mahogany tree sale price because the benefit is realized forty years in the future and heavily discounted compared to other LUS costs and benefits that are born in the more near term. ARTL responses reinforce the observations noted above for NPV (results not shown).

Plotting NPV and ARTL versus mahogany tree planting density shows that LUS performance is optimized when two mahogany trees per hectare are planted (Figure 2). The jump in NPV from one to two trees per hectare shows the influence of the 'organic price premium'. Planting additional mahogany trees is not profitable. It is better to invest additional labor to cut forest to establish cacao.

Combined sensitivity analysis

The LUS shows a diminishing NPV as the time to harvest mahogany is extended (Figure 3). The point of zero additional return (flat line) is after 30 or 50 years. The analysis shows that a mahogany tree planting density of two trees ha^{-1} is still optimal for all tenure lengths.

Results for cacao cultivation practices and expected yields show a steady financial improvement for NPV when moving from establishment, to intensive shade management, to establishment with grafting (Figure 4). Returns to labor drops slightly for intensive shade management. Forage harvesting in existing cacao stands shows the highest returns to labor, but lowest NPV. Foragers who invest additional labor to manage shade can boost NPV, but lower their returns to labor. Managing shade appears to yield a slightly better financial return than reclaiming and expanding production. Facing recurrent shocks that reduce revenues, the LUS still shows positive financial return. Planting laurel can increase NPV compared to the base case, but does not significantly change returns to labor.

Discussion

Base case results show that smallholders can earn positive financial profits for establishing cacao. Sensitivity analysis shows how profits may respond to

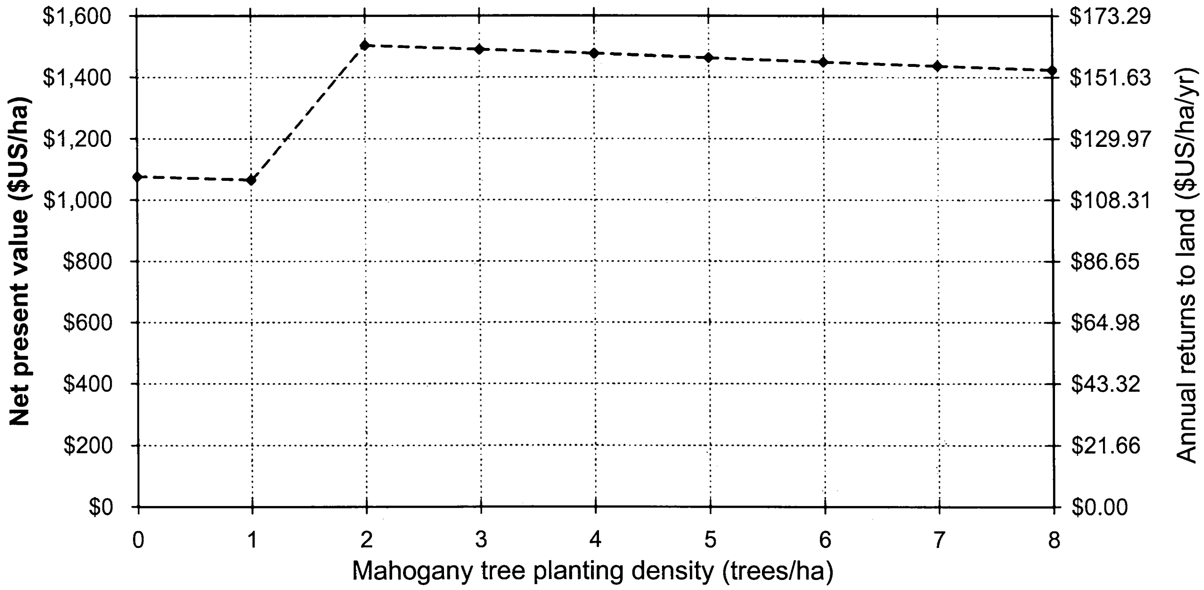

Figure 2. Responses to mahogany tree planting density for shaded cacao in Belize.

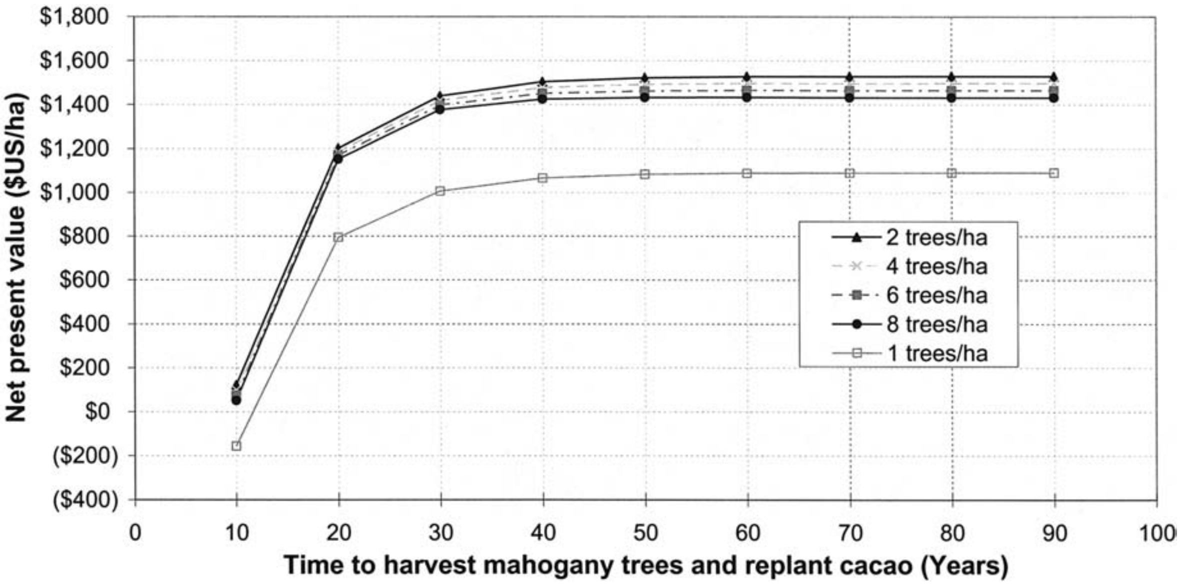

Figure 3. Combined sensitivity to mahogany tree planting density and time to harvest hardwoods for shaded cacao production in Belize.

changes in numerous parameter values. The strongest responses – exhibited by the steepest slopes, tallest bars, or largest changes – identify system components that policy-making, programs, and further research should target to improve smallholder income. We discuss interventions in each of these areas.

Policy recommendations

Credit

NPV shows a strong and non-linear response to the discount rate. As the discount rate decreases, NPV increases 2- to 3-fold. This result suggests that low interest credit made available to invest in cacao production could encourage cacao adoption.

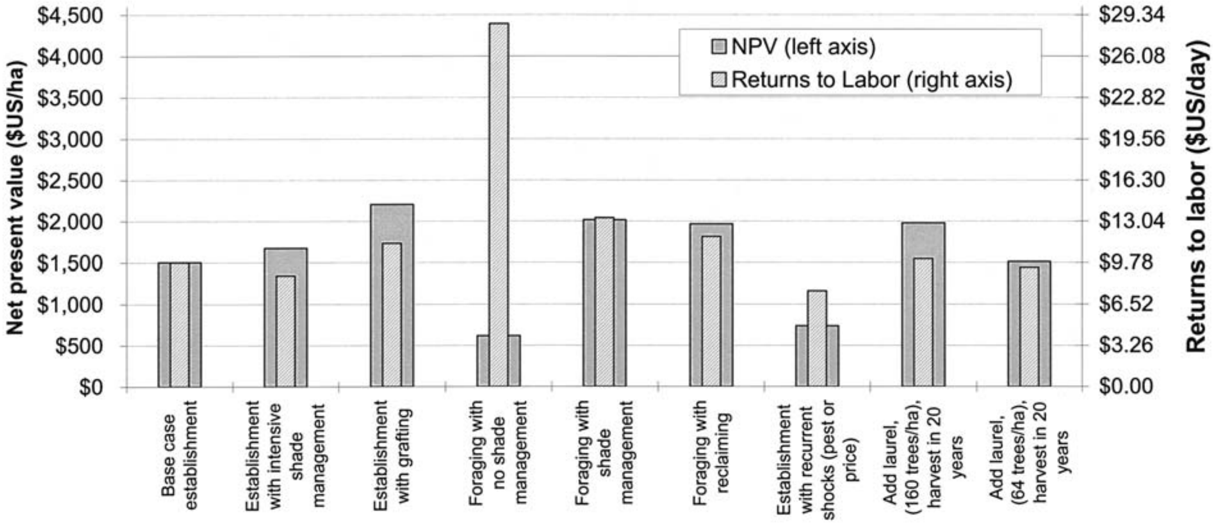

Figure 4. Combined sensitivity to cacao cultivation and expected outputs for shaded production in Belize.

Labor-saving technology and practices
NPV response is strongly sensitive to time to complete all labor tasks. Using labor saving technology and practices to reduce the time needed to cut selected areas of the forest, establish cacao, and manage shade could also improve LUS profitability.

Price policy
NPV responses to cacao price trends are less sensitive. The organic price premium enhances smallholder income, but the effect is less important than other factors. These results identify potential to develop a stronger cacao price support related to the social and ecological services provided by shade grown cacao, for example, carbon sequestration, biodiversity, soil, and watershed protection (Beer et al. 1998; Macilwain 1998; Vosti et al. 2001), and tree products like thatch and palm oils. To be significant, the price supports must compare with or be greater than current organic price incentives. Developing a price support mechanism will require quantifying ecological services provided by cacao and implementing policies that deliver service benefits to smallholders. Once implemented, additional payments to smallholders can be incorporated into the LUS model as additional line items in the activity matrices.

Land Tenure
ARTL results are well above existing land rental rates and indicate that even with land rental payments as high as $US 188 ha^{-1} yr^{-1}, establishing cacao onto additional land may be profitable for smallholders. However, land tenure is uncertain in Toledo. Policy reforms would need to help smallholders access land markets to own or lease land. Reforms would need to guarantee occupancy rights for up to 50 years.

Silvicultural practice and project recommendations

Shade management
Investing additional labor to intensively manage shade shows opportunity to improve LUS financial returns over the establishment base case. The investment does slightly diminish returns to labor, indicating smallholders may prefer to hire labor to intensively manage shade. Managing shade or reclaiming additional stands are both viable labor investments compared to foraging existing stands. These results indicate that organizations should encourage intensifying management in existing stands.

Mahogany establishment
NPV is insensitive to mahogany sale prices and planting cacao trees appears more profitable than planting mahogany trees. The G and B contract requirement seems to establish a financially optimal planting density of two mahogany trees per hectare. Thus, growers and organizations should devote little time to marketing mahogany and only plant mahogany to the extent required by the G and B contract.

Farm size and location for adoption
NPV is insensitive to farm size and indicates that the LUS shows no economies of scale. Also, returns to labor for cacao production are less than national (off-farm) labor wage rates. These results suggest smallholder constraints on land, labor, and cash resources will largely determine the scale of cacao cultivation. Therefore, adoption programs should promote cacao in areas where land and labor-for hire are more readily available and off-farm employment options are limited.

Research recommendations

Grafting
The grafting cultivation and output scenario showed the largest improvement to NPV and returns to labor. Smallholders may significantly benefit from research and extension that brings grafting practices from the research station to the field.

Best shade management practices
Results for generic labor productivity and shade management cultivation-output scenarios show that NPV is highly sensitive to labor practices. These results point to benefits for identifying best shade management practices that minimize labor inputs while maximizing cacao yields. Researchers should consult with the highest-yield cacao growers and extend best management practices to other smallholders.

Alternative shade tree species
Results for the additive laurel scenarios showed that laurel planting densities greater than 64 trees per hectare have potential to increase NPV. These results suggest that growers may benefit from (i) research that identifies faster-growing shade trees that require shorter time to harvest and (ii) extension that shows how to incorporate those species into the LUS. Alternative shade species could also include fruit, nut, or spice trees that generate annual outputs over the lifetime of the LUS (Duguma et al. 2001).

Shock management
The cacao LUS shows ability to provide income even when recurrent shocks from pests or prices reduce output revenues. However, the revenue drop compared to the base case is significant and may highlight risks associated with cultivating cacao. The scenario did not consider investing additional labor or purchased inputs to mitigate or respond to shocks or other natural disasters like floods or hurricanes. Further research should examine the financial viability of potential responses. And, once probabilities, consequences of, and responses to shocks are known, further LUS analysis could inform policies aimed at protecting cacao smallholders against shocks.

Modeling limitations

LUS modeling results and analysis can guide recommendations for policies, silvicultural practices, and research initiatives to improve smallholder incomes. As with any modeling exercise, the accuracy of results depend on the validity of the underlying assumptions. Grafting, shade tree management, and incorporating laurel represent the forefront of fast-changing cacao production practices in Toledo; further work should confirm the assumptions regarding input labor and output yields underlying these modeling scenarios. When available, updated parameter values can be re-entered in the LUS model.

Improved financial returns are necessary, but not sufficient reasons to encourage smallholder adoption. Adoption requires smallholders to invest land, labor, and cash in recommended activities. Given smallholders' other land-use and off-farm activities, it is not known what resources smallholders have to invest in cacao or how investments compare to alternative investments available to smallholders such as other crops, animals, or off-farm employment.

For example, extremely high returns to labor for the foraging scenario may explain the weak cacao supply response seen to date in Toledo. Compared to foraging, the base case establishment and shade management scenarios increase NPV but reduce returns to labor. Smallholders will not invest in establishment or shade management if their time is constrained, they do not have the ability to hire additional help, or if growing another crop provides a higher return to labor. Cacao LUS modeling and analysis cannot resolve these outcomes. Resolution requires a farm-household model that incorporates family cash, time, and land constraints, and optimizes smallholder choices across all land-use alternatives (Vosti et al. 2001). This analysis remains as an important area of further work.

Conclusions

A LUS model was developed to represent financial returns for shade-grown cacao in Belize. The modeling and sensitivity analysis highlight key LUS components that government agencies, donors, development projects, and smallholders should target for policy-making, agri-silviculture projects, and further research. Results show that more favorable credit rates, labor saving technology, and intensive shade management have the strongest potential to increase smallholder incomes. If implemented, grafting technology, best shade management practices, and adding laurel or annual shade tree crops such as fruits, nuts, or spices also show potential to significantly improve smallholder income. The model does not consider land, time, and cash constraints nor compare cacao investments to alternative investment options. Further farm-household analysis is required to predict whether smallholders will respond to cacao recommendations in lieu of alternative slash-and-burn land-uses or off-farm employment.

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