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Agroforestry Adoption in the Calakmul Biosphere Reserve, Campeche, Mexico

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Since farmers engage in a complex, dynamic process of learning-by-doing, evaluating economic incentives, and assessing risks in deciding whether to adopt agroforestry systems, a multi-pronged research approach is required for a complete analysis of adoption potential and to develop effective technological and institutional interventions. A case study is presented for using multiple approaches to analyse the potential for reforestation and improving livelihoods of small farmers through the adoption of agroforestry systems in the Calakmul Biosphere Reserve in Campeche, Mexico. Specifically, the results from a participatory research project are combined with revealed preference analysis of a household survey to analyse past adoption decisions and preferences, identify limitations, test and evaluate alternatives, and evaluate methods for risk reduction. The participatory research trials suggest that continuous intercropping and line cleaning are equally effective for tree growth, while continuous cropping during the first years offers the additional advantage of early returns to investments through crop production. Farmer participation in the research process, planning of production systems, and annual evaluations, assisted farmers and researchers in identifying limitations, testing and evaluating alternatives, and improving the viability and sustainability of systems. The revealed preference analysis provides insights as to which households are most likely to initially adopt agroforestry systems developed through the participatory research trials. In general, households that originated from the Yucatan Peninsula with more education, more experience both in age of the head of household and technical and project experience, higher incomes, and those that had cleared more forestland were more likely to have experimented with agroforestry systems in the past.

Keywords: Participatory research, revealed preference analysis, risk intercropping

INTRODUCTION

In recent decades, many tropical developing countries have implemented reforestation programs in response to the environmental and economic problems caused by excessive deforestation (Godoy 1992, Utting 1993). To maximise the social and environmental benefits of forests even when returns to small farmers are low, these reforestation programs have typically relied on financial incentives or subsidies to encourage small farmers to invest in activities that produce only long-term financial benefits (Ascher 1995). Even with financial incentives, however, reforestation programs directed at small farmers in Central America have often produced low participation rates and uncertain long-term results (Thacher *et al.* 1997). These authors found that small farmers in Costa Rica adopt reforestation schemes primarily for the alternative short-term benefits the household derives from participation in the incentive programs rather than long-term economic production. Others have found that incorporating annual crops through agroforestry systems may encourage additional participation in reforestation programs by increasing early returns (Haggar *et al.* 2003). Inappropriate project design and top-down management approaches, however, have limited the success of many agroforestry projects in Central American countries (Fischer and Vasseur 2002).

Adoption of agricultural innovations (including agroforestry) has long been recognised as a complex process (Feder *et al.* 1985, Hayami and Ruttan 1985). Furthermore, adopting a new technology is essentially a dynamic process of learning through observation and experimentation as farmers learn about optimal management through their own and neighbours' experiences (Foster and Rosenzweig 1995, Cameron 1999). Since farmers adopt innovations when clear economic incentives are present and associated risks are manageable, understanding current and historic patterns of adoption and economic incentives are required to develop effective technological and institutional interventions (Scherr 1995). Hence, analysing the adoption potential for agroforestry requires a multi-faceted research approach that includes an examination of past adoption practices, understanding results of current farmer experimentation ('learning by doing'), and analysing farmers preferences for dealing with economic and agronomic risk.

This paper reports research performed for the International Centre for Research in Agroforestry (ICRAF) to analyse the potential of agroforestry for enhancing reforestation and improving livelihoods of small farmers in the Calakmul Biosphere Reserve in Campeche, Mexico. The objective is to provide a case study for using multiple approaches to understand the potential for agroforestry adoption. Specifically, we combine the results from a participatory research project (Haggar *et al.* 2001) with revealed preference analysis of a household survey to develop information to assist continuing efforts to develop sustainable agroforestry systems for the southern Yucatan Peninsula of Mexico. Through participatory research with a small group of farmers, we examine current preferences while identifying limitations, testing and evaluating alternatives, and reducing risk and uncertainty by improving the viability and sustainability of agroforestry systems. The revealed preference analysis of past adoption behavior contributes insights concerning the segments of the population most and least likely to adopt agroforestry and where best to invest scarce project resources.

After describing the study site in the next section followed by an overview of agroforestry adoption theory, we present results from participatory agroforestry research trials with nine farmers to improve the design and evaluate the viability of agroforestry alternatives for fruit and timber tree planting in Calakmul. Then, we analyse factors associated with agroforestry adoption using data from a 1998 household survey of 176 smallholders in the Calakmul region. The paper concludes with a discussion of applying these results to agroforestry development projects in the Yucatan Peninsula of Mexico.

THE STUDY SITE

This research was conducted in the buffer zone of the 723,000 ha (1.7 M ac) Calakmul Biosphere Reserve in southeastern Campeche, Mexico (Figure 1). Contiguous with the Maya Biosphere Reserve in Guatemala, the Calakmul Biosphere Reserve was created in 1989 to protect the last great frontier to which Mexicans continue to migrate in search of land for farming (SEMARNAP 2000).[1] Twenty five years ago, Calakmul was hampered by poor road access which, combined with the paucity of rainfall and groundwater, limited settlement. Since the 1970s, however, immigration to the region has surged with the construction and improvement of roads to the area.

The Calakmul region consists of a municipality (Calakmul) comprised of the core bioreserve area, where settlement is prohibited, a buffer zone of 72 communities (15,000 inhabitants) called *ejidos,* and a few privately owned properties (Bosque Modelo de Calakmul 1997). *Ejidos* are communities in which each member family has equal legal rights to the use of communal forest and agricultural land. *Ejidos* typically control a land area ranging in size from 500 to 50,000 ha and have from 10 to 150 members. The allotment for each family's agricultural use varies from 25 to 50 ha, while communal forest areas range from 250 to 25,000 ha per *ejido*.

The study area lies on a limestone platform that underlies the whole of the Yucatan peninsula, much of Belize and part of neighbouring Guatemala. The terrain is relatively flat, punctuated by low hills with elevations ranging from 205 to 270 m above sea level. The most important agricultural soils are: shallow, rocky *lithosols* (5- 20 cm deep); medium deep (10 – 40 cm), often stony, brown *cambisols*; and deep (>30 cm) brown to black *luvisols*. Heavy seasonally inundated *vertisols* are also present but seldom cultivated. Rainfall is unpredictable both in distribution throughout the year and in amount, typically ranging between 800 and 1600 mm per year. A rainfall gradient exists within the zone with more rainfall in the southern sector of Calakmul and a dry season between February and May.

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[1] The Calakmul Biospshere Reserve joined UNESCO's Man and the Biosphere program in 1993.

Figure 1. Map of Calakmul Biosphere Reserve, Yucatan Peninsula, Mexico

Source: Bosque Modelo de Calakmul (1994).

Vegetation is tropical semi-deciduous forest with over 100 species per hectare. The forest structure and species composition are shaped by rainfall, soils, hurricanes and agriculture practices. Typically, the forests of the region are comprised of a mosaic of high-graded old forest and large areas of secondary forests of mixed aged stands. The most abundant tree species are chiclé (*Manilkara zapota*) and breadnut or ramon (*Brosimum alicastrum*) which are valued for latex and leaves for fodder, respectively. The most important commercial timber species are mahogany (*Swietenia macrophylla*) and Spanish cedar (*Cedrela odorata*).

Among the *ejidos* of Calakmul, farmers produce basic grains by a slash and burn agricultural system known locally as *milpa*, in which a field is cleared by cutting and burning the forest. Then, corn (the primary subsistence crop) is planted, usually in association with beans and squash. Typically, the field is cropped for two or three years and then left to fallow for three to 15 years. Families typically have three to five hectares of *milpa* in production each year. Corn yields are highly variable from year to year and from field to field, averaging about 250 kg/ha (2.0 t/ha) (Snook 1996). Production from the *milpa* is complemented by fruit and vegetables grown in home gardens for household use, and pigs and chickens produced for both home use and sale. The principal cash crop is jalapeño chili (*Capsicum annuum*), produced with high levels of fertilisation and insecticides. Chili production is also a driver for deforestation because farmers seek new planting sites with lower incidence of pests and higher soil fertility. Limitations to production are unpredictable and insufficient rainfall, lack of money to invest in improved production techniques, seasonal labour shortages, lack of technical expertise, and poor market access.

The third production area of importance to every rural household is the forest, which is a source of cash crops including honey, timber, *chiclé* latex and construction materials for home use and the local market. Some *ejidos* also plant trees in the forest following logging to meet the legal obligation to replace harvested timber trees. These plantings of millions of mahogany and cedar trees each year in the communal forest areas typically receive little maintenance resulting in low seedling survival rates (Negreros 1997). In *ejidos* that had long since depleted their timber or deforested their land, the only tree plantings have been a few fruit trees (mostly *Citrus spp.)* for home use. As a result, an important goal of small farmers in the Mexican Yucatan Peninsula is to diversify traditional shifting cultivation with tree and livestock production (Avila 1995).

From 1991 to 1996, the Regional Agrosilvopastoral Council of Xpujil (CRASX) implemented an agroforestry project that offered 225 timber trees and 110 fruit trees, free of charge, to each participant who agreed to plant the trees in association with agricultural crops in one hectare agroforestry plots (Snook and Zapata 1998). The objectives were to provide short, medium and long-term production starting with annual crops, followed by fruits and finally timber. Approximately 700 ha were established. This was followed in 1995-97 with a tree planting project concentrating solely on native trees without the fruit tree component. The project provided, free of charge, 21 native tree species to be planted in individual or community managed plots, often in association with crops. Snook and Zapata (1998) reported a high degree of initial interest, with demand for seedlings exceeding supply in some cases. However, problems with tree survival and a lack of markets for citrus products resulted in low returns on labour investments and a decline in investment in plot maintenance.

From the mid 1990s, the International Centre for Research in Agroforestry (ICRAF) began evaluating the potential and limitations to developing agroforestry technologies in Calakmul. Although efforts during the 1990s to promote agroforestry in the region achieved widespread initial acceptance, tree survival and growth rates were highly variable (Sosa 1997, Smid 1999). In many cases, farmers either stopped investing labour in their agroforestry plots or modified the design and management of their agroforestry plots in ways unanticipated by planners (Snook and Zapata 1998, Snook 2004**).** Within two years of establishment, many of the plots established by the CRASX agroforestry project (of mixed fruit trees, timber and crops) had been abandoned due to immigration (10%), complete loss of trees probably due to fires and hurricanes (12%), or because the farmers simply stopped investing labour in their maintenance (15%) (Sosa 1997). Since there are no detailed planting records, the rate of abandonment or loss of the plots established in the reforestation project could not be calculated (Smid 1999).

AGROFORESTRY ADOPTION THEORY

Based on a review of 120 agriculture and forestry technology adoption studies and 32 agroforestry and related technology adoption studies, Pattanayak *et al*. (2003) identified five categories of factors that explain adoption: market incentives, biophysical conditions, resource endowments, household preferences, and risk. The following discussion is based on Pattanayak *et al.*'s literature review and meta-analysis of agroforestry adoption studies.

Market incentives include factors that explicitly reduce costs or produce higher benefits from technology adoption (e.g. input and output prices, distance to markets and fields, and the perceived potential for increased income with agroforestry). Unfortunately, explicit market data including prices are often lacking in adoption studies due to thin markets, the unavailability of prices or price proxies in subsistence economies, and the geographic and temporal limitations of most studies, which tends to reduce the variability of market prices between respondents.

*S*oil quality, steepness of farm land, and plot size are examples of *biophysical conditions* that have been shown to affect agroforestry adoption. Although recent studies have found adoption to be more likely on steep slopes, the influence of plot size on adoption rates has been ambiguous, perhaps because of the confounding influence of scale economies and resource constraints. Similar ambiguity surrounds the impact of soil quality on adoption, which appears most likely on low (but not too low) quality sites. When soil quality is high farmers usually prefer to limit production to high valued annual crops, whereas farmers' may perceive investing in the poorest soils as pointless.

The third factor, *resource endowments*, concerns the availability of land, labour and capital for farmers to invest in new technologies. Asset holdings and wealth measures including land, labour, livestock and savings have been relatively strong predictors of adoption, producing a consistent and unambiguous positive influence on agroforestry adoption. Farmers that are relatively well-off compared to their neighbours tend to have higher adoption rates.

Risk relates to the market and institutional environment that farmers face in making investment decisions. Examples of short-term risks include fluctuations in commodity prices and rainfall, while long-term risks include tenure insecurity, political insecurity, and the future availability of markets for wood products. Risk has been found to have high statistical power in predicting adoption. The higher the perceived risk associated with a technology the lower the probability of adoption. For example, landowners have consistently proven more likely than tenants to adopt agroforestry. Risk reducing factors such as previous experiences and familiarity with agroforestry and other conservation investment projects and the availability of information disseminated through extension services or community group membership also increase the probability of adoption.

Household preferences reflect a broad category of household specific influences including risk tolerance, intra-household homogeneity, conservation attitude, and patrimony for future generations. Typically, preferences are difficult to measure explicitly and are, therefore, usually proxied with socio-demographic variables such as age, gender and education. Although higher education levels and greater proportion of males in the household have consistently been associated with higher adoption rates, age has usually had little influence on adoption rates.

Using neoclassical economic theory and the insights of past adoption studies, Amacher *et al*. (1993), Pender and Kerr (1998), and Mercer and Pattanayak (2003) developed a theory of agroforestry adoption in which agroforestry is one of many possible joint investments of labour, money and capital available to the farm household as it attempts to enhance its overall well-being or utility. Since the returns to these alternatives occur in the future, households consider the expected stream of income (net of consumption) in choosing between alternate investments to maximise household utility. The expected income streams of alternative investments depend on the household's resource endowments, biophysical conditions of the farmland, market incentives, and risks in the short and long term. Therefore, the household chooses the set of investments that maximise household utility, which is conditioned by household preferences (proxied by socio-demographic variables) and subject to three constraints, namely the household's available time (labour) endowment, expected productivity of investment alternatives and household cash income (including credit).

The Adoption Model

Consider the choice facing household *i* when deciding whether to adopt agroforestry. The household compares its expected net utility (EU_i) with and without adoption of agroforestry and invests in agroforestry if the household expects to be better off (expected utility maximised) by implementing an agroforestry system. A reduced form equation of the relationship between net utility and household and farm variables can be stated as:

$$EU_i = \alpha_I I_i + \alpha_L L_i + \alpha_R R_i + \alpha_Z Z_i + \alpha_H H_i + \varepsilon_i \qquad [1]$$

where EU_i = expected utility of household *i*

I_i = relative importance of agroforestry to household *i*'s income stream
L_i = resource endowments of household *i* (e.g. land, tools, labour)
H_i = characteristics of household *i*
Z_i = biophysical characteristics of the farmlands of household *i*
R_i = risk facing household *i.*
αi = estimated coefficients on independent variables

I_i captures market incentives because net income is a function of explicit and implicit prices of outputs and inputs of the agroforestry process. Since the true expected utility function is unknown, the estimated function is treated as a random variable by including the error term ε_i.

Although EU_i is not directly observable, the researcher can observe the household's adoption decision and define a variable L_{AFi} that indicates whether the household *i* adopts agroforestry ($L_{AFi} = 1$) or not ($L_{AFi} = 0$), so that:

$$L_{AFi} = 0 \; if \; EU_i \leq 0 \quad and \quad L_{AFi} = 1 \; if \; EU_i > 0 \qquad [2]$$

Depending on the assumptions regarding the distribution of the population error term in equation [1], the structural relationship is usually estimated with either probit or logit models assuming a normal (probit) or logistic (logit) distribution for the error term (Maddala 1983). That is,

$$\text{Prob}(L_{AFi} = 1) \quad = \quad \Phi(\alpha_I I + \alpha_L L + \alpha_R R + \alpha_Z Z + \alpha_H H\ ) \qquad [3]$$

where: Φ (.) is the cumulative distribution function; I, *L, R, Z,* and *H* are the explanatory variables in equation [1]; and α is the vector of parameters to be estimated.

RESEARCH METHOD

Participatory Research

A total of nine immigrant farmers from five communities in Calakmul agreed to participate in establishing trial agroforestry systems with fruit and timber trees. Avila (1995) describes how previous farmer surveys were used to choose tree species for the trials. Fruit trees were purchased from a commercial nursery while timber tree seedlings were grown in local reforestation nurseries. Planting materials of annatto (*Bixa orelana*), habanero chili (*Capsicum sinensis*), pigeon pea (*Cajanus cajan*), velvet bean (*Mucuna prurient*), and jack bean (*Canavalia ensiformis*) were provided on request by the farmers in the second year. Twenty six plots were established in Calakmul in 1996.

Management alternatives for the agroforestry plots were developed through a series of farmer participant workshops. Three tree-type combinations were established: 1) pure fruit trees, 2) fruit trees mixed with timber trees, and 3) pure timber trees. Farmers planted 8 to 10 fruit trees (most used 8) and 1 to 2 timber species (mostly 2) in 26 plots (8 pure fruit, 9 mixed fruit and timber, and 9 pure timber). Pure timber and fruit tree plots consisted of about 40 timber trees or 10 fruit trees per 0.12 ha plot while the mixed timber-fruit plots were planted on 0.25 ha plots. Management strategies of the plots may be classified into three groups:

1. *Continuously intercropped*: perennial and annuals intercropped for three years; over time this management may lead to a multi-strata type agroforestry system.
2. *Open cleaned*: site is cleaned regularly, with only intermittent intercropping usually only in the first year but never allowing woody regrowth; this may be considered similar to a Taungya type agroforestry system.
3. *Line cleaned:* Only the tree rows are cleaned; intercropping in year one is followed by woody regrowth between rows of planted trees; this may lead to an enrichment planting of secondary forest or agroforest.

Following the first year of the project, farmers were interviewed to evaluate their objectives for participating, plot establishment problems, potential solutions, future plans and constraints. At the end of the second year, preference matrices (as described by Ashby (1990)) were applied to evaluate farmer preferences for tree and crop components. Farmers were asked to keep records of labour and inputs used in the establishment and management of their plots; the data were collected and reviewed during bimonthly visits to each farmer. Tree survival, heights and diameter were measured at 3-4 months, 15-16 months and 27-28 months after establishment, and analysed with a mixed ANOVA model using the farm as the random effect and species, soil, rainfall and management as the fixed effects. Multiple means comparisons (*t* and Duncan tests) were used to test for differences between treatments.

Revealed Preference Analysis

Farmers' past preferences for agroforestry adoption were revealed by asking them about their past land-use decisions. It is assumed that farmers who had previously planted trees in their agricultural fields had a preference (at some time in the past) for establishing agroforestry systems. Data were collected in winter of 1998 through personal interviews of a stratified random sample (by ejido) of farmers in the buffer zone of the Calakmul Biosphere Reserve. The final sample consisted of 176 farmers in 15 separate ejidos. Details on field logistics and data gathering are available in Casey *et al*. (1999).

Logistic regression analysis was used to model the various factors that influenced farmers to plant trees on their agricultural lands as follows:

$$\Pr(\text{Adopt}=1) = F(\beta_0 + \beta_i K_i) \qquad [4]$$

where $\Pr(\,)$ = probability that respondent had previously planted trees on farmlands
Adopt = 1 if previously adopted agroforestry, 0 if not;
β_0 = constant;
β_i = coefficients on K_i;
K_i = set of explanatory variables (market incentives, biophysical conditions, resource endowments, household preferences, risk); and
$F(z)$ = $e^z/(1 + e^z)$ is the cumulative logistic distribution.

Independent variables (K_i) included proxies for household preferences (gender, age, education, residence prior to moving to Calakmul, length of residency in Calakmul), market incentives (income, distance to agricultural parcels), resource endowments (farm size, primary forest area, fallow land, previous non-agroforestry tree plantings[2], hectares of forestland cleared), and proxies for risk (previous participation in agriculture or forestry programs, interest in planting more trees on their farms, previous forestry experience).[3]

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[2] Non-agroforestry tree plantings consist of trees planted in areas other than agricultural fields or home gardens, i.e. planting trees in forest areas.

[3] Lack of geographical and temporal variability in the survey prohibited the inclusion of market prices. Unfortunately, questions about soil quality and other biophysical variables were not included in the survey instrument.

RESULTS

Participatory Research

The results from the interviews with the nine participating farmers following the first year of establishment are presented in Table 1. Production for home consumption, diversification of products and ability to harvest crops throughout the year were the most common objectives for establishing agroforestry plots (reported by 66% of participants), followed by legacy (55%) and testing adaptability of plants (44%). Only 22% of participants reported production for sale as an important objective. Drought and pests were the most common problems in establishing the agroforestry plots (each of which were reported by 66% of participants), followed by weed infestations (55%), slow growth (33%) and high tree mortality (22%). Despite only qualified success in the first year, 44% planned to expand their plots the next year with 66% and 55% planning to plant more annual crops and fruit trees, respectively, in their agroforestry trials. Lack of money (55%), labour (44%) and irrigation water (44%) were the most common constraints to farmers achieving their objectives for the agroforestry plots.

Line cleaned plots with intercropping only in the first year were the most common management system (used by 42% of the participant farmers), followed by plots maintained clean with occasional annual intercropping and no woody regrowth between lines (30%) and continuously intercropped throughout the three years (27%). Table 2 reports the relative importance scores for the different tree and annual crops. The staple crop, maize, was the most important intercrop in the first year while additional intercrops were tested in subsequent years. The most preferred annual intercrops were maize (*Zea mays*) and squash (*Curcurbita* spp.), while jack bean was the preferred legume cover crop, and annatto (*Bixa orelana)*, bananas, and plantains (*Musa* spp.) were the preferred perennial crops. Farmers' preferred timber species were broadleaf mahogany (*Swietenia macrophylla*) and shaving-brush tree (*Psuedobombax ellipticum*) (which has a light wood widely exploited for the plywood industry), whereas the preferred fruit trees were nance (*Brysonima crassifolia*), allspice *(Pimienta dioica*) and *sapotilla (Manilkara zapota*).

The average height growth (m/year) and basal diameters (cm) of fruit and timber species by management regime following the second year of establishment are indicated in Table 3. Both timber and fruit tree height growth were significantly greater on continuously cropped sites than on cleaned sites with intermittent cropping, whereas tree diameters were significantly larger on lined-cleaned sites than fully cleaned sites. There were no significant differences for timber or fruit tree survival for the different management strategies.

During the first three years, all systems required a net investment from the farmers (Table 4). In general, systems with fruit trees had higher establishment and maintenance costs than systems with timber trees alone. Management costs were greatest for the cleaned or open system.

Table 1. Objectives, limitations, and future plans of farmer participants establishing agroforestry trial plots in Calakmul, Campeche, Mexico (N = 9)

Concept	Response	Percentage of respondents
Objectives for establishing agroforestry	Home consumption	66
	Sale	22
	Legacy	55
	Diversification of products	66
	Test plant adaptability	44
	Temporal diversification	66
Problems establishing agroforestry	Slow growth	33
	High mortality	22
	Drought	66
	Pests	66
	Weeds	55
	Poor or degraded soil	11
Solutions	Irrigation	11
	Fertilisation	44
	Insecticide application	44
	Weeding	33
	Mulch around trees	22
	Legume cover crops	55
Future plans	Enlarge plots	55
	Plant more fruit trees	55
	Plant more timber trees	22
	Plant annual crops	66
Limitations to implementing plans	Lack of money	55
	Labour/time	44
	No water for irrigation	44

Line cleaned systems required the least investment, but after the production of the first year, no income is generated until the onset of fruit and finally timber production. The net investment was greatest for the open cleaned management systems. Net investment was lower for timber-only systems than those that included fruit trees and lower for continuously cropped systems than line cleaned systems.

Table 2. Preferences for annual crops, legume cover crops, perennial crops, fruit and timber trees of farmers in agroforestry trials in Calakmul, Campeche

Species used in agroforestry trials	Yield (kg/ha)	Preference index[a]
Annual crop		
Jalapeño chili *Capsicum annuum* L.	700-6000	2
Corn *Zea maiz* L.	200-1800	5 [b]
Beans *Phaseolus vulgaris* L.	80-600	4
Squashes *Curcurbita spp.* L.	150-350	5 [b]
Legume cover crop		
Jack bean *Canavalia ensiformis* (L) DC	250-4100	5 [b]
Pigeon pea *Cajanus cajan* (L) Millsp.	125	3
Velvet bean *Mucuna pruriens* DC	150-300	3
Perennial crop		
Annatto *Bixa orelana* L.	n/a	4 [b]
Cassava *Manihot esculenta* Crantz	1000	2
Bananas and plantains *Musa sp.*	n/a	4 [b]
Fruit tree species		
Avocado *Persea americana*Mill.	n/a	3
Star apple *Chrysophyllum cainito* L.	n/a	4
Soursop *Anona muricata* L.	n/a	1
Zapote *Pouteria sapota* (Jacq) H.E. Moore and Stearn	n/a	3
Mango *Mangifera indica* L.	n/a	2
Cashew *Anacardium occidentale* L.	n/a	2
Nance *Brysonima crassifolia* H.B.K.	n/a	6 [b]
Allspice *Pimienta dioica* (L.) Merr	n/a	6 [b]
Tamarind *Tamarindus indica* L.	n/a	5
Sapotilla *Manilkara zapota* (L) P. Royen	n/a	6 [b]
Timber tree species		
Spanish cedar *Cedrela odorata* L.	n/a	2
Big-leaf mahogany *Swietenia macrophylla* King	n/a	5 [b]
Siricote *Cordia dodecandra* A.DC.	n/a	4
Shaving brush tree *Psuedobombax ellipticum* (Kunth) Dugand	n/a	5 [b]

a. Preference scores range from 1 = least preferred to 6 = most preferred and are based on yield, home consumption, marketability, and soil and pest restrictions.

b. These indices indicate preferred tree and crop combinations determined by consensus.

Table 3. Height growth and basal diameter of trees after two years in farmer participatory agroforestry trials in Southern Yucatan Peninsula[a]

Tree type	Height growth (m/year)			Basal diameter (cm)		
	Management system					
	Line cleaned	Completely cleaned	Cropped	Line cleaned	Completely cleaned	Cropped
Fruit	0.39 ab	0.33 b	0.47 a	1.86 a	1.60 b	1.77 ab
Timber	0.69 ab	0.65 b	0.99 a	3.11ab	1.67 b	3.25 a

a. Values with different letters are significantly different ($p< 0.05$).

Table 4. Patterns of investment and production per hectare in Mexican pesos (US$1.0 equals approximately N$8.5, 1998) for agroforestry plots during the first three years after planting[a,b]

Production system	Average labour used (days/ha)	Discounted costs (N$/ha)	Discounted value of production (N$/ha)
Plots with fruit trees or fruit and timber trees			
Continuously cropped	134	5082	3066
Open cleaned occasionally cropped	248	9695	1637
Line cleaned, cropped only 1st year	110	4239	632
Plots with only timber trees			
Continuously cropped	138	3,560	2,250
Open cleaned, occasionally cropped	221	7753	2478
Line cleaned, cropped only 1st year	105	2854	574

[a] Means are given for each production system. Daily wage rate varied between N$25 and N$30 over the three years.

[b] Note that this table only includes production of annual crops during the first three years following adoption before the trees add to production value. Results are likely to vary in subsequent years when perennial crops, and fruit and timber trees begin to produce.

Revealed Preference Analysis

Descriptive statistics for the variables from the 1998 household survey are provided in Table 5. On average, the age of the household head was 38 years, households had 4 children living at home, and the annual household income was US$1,510. Only 29% of farmer respondents had completed primary school, while only 11% had finished secondary school. The typical household had lived in Calakmul for 11 years, with 94% of respondents having immigrated to Calakmul from outside the state of Campeche. The average landholding was 48.2 ha, of which 39.7 ha was originally under primary forest cover and 8.72 ha under secondary fallow. Farmers had cleared an average 9.9 ha of forests resulting in an average of 27.6 ha per household currently under forest cover, 19 ha under fallow, and 4.8 ha in *milpa.* Since joining the *ejido*, 67% of respondents had established an average of 1.27 ha of non-agroforestry tree plantings. However, only 31% reported establishing agroforestry systems; average plot size was 1.15 ha. About 47% of respondents had previous experience with an agricultural or forestry development project, and 79% reported an interest in participating in future agroforestry development projects.

Table 5. Descriptive statistics for Calakmul household survey (N=176)

Continuous variables	Mean	Standard deviation	Range
Age of farmer (years)	38.31	13.76	16-74
Total farm income (US$/year)	$1510	$1638	$0-8477
Timber income (US$/year)	$ 118	$ 486	$0-5332
Length of residency in Calakmul (years)	10.97	6.33	0.3-36
Distance to fields from house (km)	2.81	2.22	0-10
Farm size (ha)	48.16	25.25	0-120
Non-agroforestry tree plantings (ha)	1.27	2.54	0-15
Amount of fallow land (ha)	18.98	11.68	0-60
Forestland (ha)	27.60	24.19	0-95
Forestland harvested (ha)	9.92	11.05	0-50

Categorical variables	‘Yes’		‘No’	
	Count	Percent	Count	Percent
Agroforestry adopter (1= yes; 0 = no)	55	31%	121	69%
Secondary Education (1= yes; 0 = no)	19	11%	157	89%
Native of Yucatan Peninsula (1= yes; 0 = no)	11	6%	165	94%
Forestry experience (1= yes; 0 = no)	8	4%	168	96%
Previous project experience (1= yes; 0 = no)	82	47%	94	53%
Interest in planting more trees (1= yes; 0 = no)	140	79%	36	21%

Table 6 presents the results of the maximum likelihood estimation of the logit regression model. The dependent variable – whether or not the farmer had established an agroforestry system – is regressed against the list of explanatory variables in Table 5. The χ^2 statistic and psuedo R^2 suggest that the estimated model fits the data reasonably well, with 73.86% of all responses predicted correctly.

In Table 6 statistical significance of variables is identified by the *p*-value (probability value) reported in column 3. Four variables are significant at or below the 5% level *(native from the Yucatan Peninsula, distance to fields, previous project experience, and interest in planting more trees*). *Total farm income, non-agroforestry tree plantings, amount of forestland,* and *age of household head* are significant at the 6-10% level. Thus, *household preferences* (age, interest in more tree planting, and native of Yucatan Peninsula), *resource endowments* (forestland, non-agroforestry tree plantings), *market incentives* (distance to fields, income), and *risk and uncertainty* (previous project and forestry experience) all have statistically significant impacts on adoption. *Biophysical* conditions are also likely to have a strong effect on adoption but, unfortunately, were not available for the current analysis.

Table 6. Maximum likelihood estimate of logit regression model of agroforestry adoption in Campeche, Mexico (N = 176)[a]

Variable	Coefficient	*p*-value	Odds ratio
Constant	-2.314	0.04	---
Age of farmer (years)	0.024	0.10	1.025
Education (1= secondary; 0 = no secondary education)	0.982	0.14	2.67
Native of Yucatan Peninsula (1 = yes; 0 = no)	2.58	0.01	13.204
Length of residency (years)	-0.106	0.77	0.989
Total farm income (last 12 months)	0.00003	0.10	1.000
Timber income (last 12 months)	-0.00014	0.24	1.000
Distance to fields (km)	-0.249	0.02	0.779
Non-agroforestry tree plantings (hectares)	-0.155	0.06	0.856
Interest in planting more trees (1= yes; 0 = no)	1.21	0.03	3.354
Forestry experience (1= yes; 0 = no)	0.586	0.16	1.797
Previous project experience (1= yes; 0 = no)	0.971	0.01	2.642
Fallow land (hectares)	-0.026	0.20	0.974
Forestland (hectares)	-0.019	0.08	0.981
Forestland harvested (hectares)	0.0289	0.20	1.029
χ^2 (14) statistic	44.42		
prob > χ^2	0.0001		
Pseudo R^2	0.2032		
Percent correctly predicted	73.86		

[a] Dependent variable Adopt = 1 if established an agroforestry system and Adopt = 0 if not.

Most signs for independent variables are intuitively credible, with higher probabilities of adoption being positively correlated with age, education, income, forestry experience, previous agricultural or forestry project experience, forest area harvested, interest in more tree planting, and originating from the Yucatan Peninsula. The greater the distance that farmers have to walk to their fields, the larger the farmer's forestland area and fallow land area, and the more hectares in non-agroforestry tree plantings, the less likely are the farmers to adopt agroforestry.

The effects of the independent variables on the logit or log odds of adopting agroforestry are reported as odds ratios in column 4 of Table 6. Odds ratios (calculated as e^{β}) represent the amounts by which the odds favouring adoption (y = 1) are multiplied for each one-unit increase in that independent variable, assuming that levels of all other independent variables remain constant. The variables that have the greatest impact on adoption probabilities are *originating from the Yucatan Peninsula, education, forestry experience, previous project experience,* and *interest in planting more trees.* Farmers with some secondary education, previous forestry experience, previous project experience, and interest in more tree planting are 2.6, 2.6, and 3.4 times as likely to have adopted agroforestry, respectively. In contrast, respondents originating from the Yucatan Peninsula are 13.2 times as likely to have adopted agroforestry. Odds ratios for all other variables range from 0.777 (distance to fields) to 1.026 (forestland harvested).

DISCUSSION

The most common management system established by the farmers in the participatory agroforestry trials – completely cleaned with limited intercropping – had the lowest net production value. These systems also had the lowest growth rates of fruit and timber trees and the highest maintenance costs. Maintenance costs were lowest in the line cleaned plots, and tree growth was equal to or higher than cleaned sites and not significantly different from intercropped sites. Many of the farmer participants were unable to fulfill their plans to intercrop between the lines of trees, and in many cases, the intercrops failed. This was the most common scenario leading to a clean but un-cropped management of the agroforestry plots. Some farmers reported that restrictions on burning (imposed to protect tree seedlings) created serious problems for maintaining the plots and preparing for annual crops. Because only the annual crops had entered production at year 3 and trees had yet to generate income, comparing productivity or profits is premature. However, it is notable that when plots are completely cleared but not successfully diversified, labour investments contribute to high net economic loss in the early years.

One of the reasons farmers were interested in agroforestry was the low agronomic potential of their lands. As a result, farmers developed the following three strategies for annual production to justify their investments in maintaining the plots:

1. planting high value crops, e.g. jalapeño chili, in small, intensively managed areas on patches of the best soils;
2. planting legumes (e.g. jack beans) as cover crops to dominate the weeds; and
3. planting perennial crops (e.g. annatto, cassava and bananas) that have low maintenance costs after establishment.

Farmers were still experimenting with high value crops in the final year of the study. Legume cover crops required a great deal of labour to establish in the weedy conditions during the first year but facilitated cropping in subsequent years. Perennial crops were successfully established by some farmers, but had not yet begun to produce during the study period.

Results from the participatory research trials suggest that continuous intercropping produces the largest combined benefits for the first three years in terms of tree growth and early returns to investments through crop production. Nevertheless, if intercropping (of perennials, legume cover, or high valued annual crops) proves unsustainable due to poor site conditions, line-cleaning systems are the next best alternative because they reduce maintenance costs and produce higher growth rates of most tree species. In addition, overall production value did not appear to be the sole objective of participating farmers, who were also concerned with increasing family consumption, product diversity and increased patrimony. A definitive evaluation of the viability and adoptability of different systems should also consider these factors, an area for further research.

The revealed preference analysis provides insights as to which households are most likely to adopt agroforestry systems developed through the participatory research trials. In general, households that originated from the Yucatan Peninsula with more education, more experience both in age of the head of household and technical and project experience, higher incomes, and those that had cleared more forestland were more likely to have experimented with agroforestry systems in the past. In contrast, those households with higher incomes from timber during the past year, more non-agroforestry tree plantings, and larger areas of fallow land and forestland were less likely to have experimented with agroforestry in the past.

The odds ratio analysis suggests that education levels, experience, and immigrant status are the strongest predictors of past adoption. The impact of immigrant status on adoption suggests that the peoples of the Yucatan Peninsula (states of Yucatan, Quintana Roo and Campeche) share a knowledge base of the local soils, plants and climate, and generally adopt a modified version of the indigenous natural resource management system common throughout the peninsula. This diversified production system is well-adapted to local soils and unpredictable climate and typically includes utilising forest and secondary forest regrowth for timber and non-timber forest products, small livestock in a diversified home garden, and the *milpa*. In contrast, immigrants from other parts of Mexico bring a knowledge base and associated natural resource management practices developed and adapted in different climatic and soil conditions. For the most part, they also come from areas where the forestry sector is absent or negligible. Having little knowledge of local species and production techniques, these settlers are poorly positioned to take up innovative tree-based systems.

Findings of this study suggest several ways for future agroforestry development projects in the Calakmul Biosphere Reserve to improve on past project experience. If technicians and agroforesters work with farmers in a participatory process to identify objectives (for individuals and groups) and take into account how farmers adapt the systems over time, systems can be fine-tuned to be more attractive and viable and increase the probability of adoption. Farmers initially responded well to the previous projects that provided free tree seedlings but little technical assistance. Although abandonment was common due to frustrations with lack of early income and high maintenance costs, many farmers adapted the agroforestry systems to suit their own particular limitations and needs, to minimise labour costs and to increase system diversity and returns to labour.

The farmers who participated in the participatory research trials were all immigrants from outside the Yucatan Peninsula. The revealed preference analysis suggests they are likely to be slow adopters. However, participants also tended to be literate community leaders with experience of development projects, who had cleared relatively large forest areas. Nevertheless, the low proportion of farmers who achieved the most economically productive continuously cropped system (not including tree production in later years) may be a reflection of a lower level of knowledge of viable crop management options. It also reflects the importance of implementing agroforestry systems through participatory methods that allow both farmers and agronomists or foresters to learn the viable crop and management options that meet farmers' individual needs and capacities to implement new systems.

Critical technical education and advice for future projects should include facilitating the development and fine-tuning of continuous intercropping systems, because these appear to produce the greatest benefits in terms of tree growth and returns to investment through crop production in the initial years. In addition, farmers should be encouraged to manage the tree plantings with a line-cleaning system that reduces maintenance costs while having similar results as continuous inter-cropping on early growth of most tree species. In the past, this management technique by farmers has been criticised by technical staff, who tried to persuade farmers to maintain their fields clear of regrowth.

Equally important is choice of species and availability of planting materials. Ensuring that tree species are both priority species for the farmer and well adapted to the agricultural environment should improve establishment success and farmers' motivations to sustain management. Farmers preferred production systems that combined fruit and timber trees with perennial, annual or cover crops. Unfortunately, the lack of planting material adapted to site conditions for the intercrops resulted in lost opportunities for early returns to the rather large cost of establishment and was likely a major cause for reducing investments in weeding soon after establishment in previous projects.

The revealed preference analysis suggests that projects may maximise the potential for early success by initially concentrating scarce project resources on those farmers most likely to adopt and maintain the systems. Implementation by less experienced farmers should be initiated through participatory processes that enable farmers to test and evaluate the new production system with which they are experimenting. Therefore, outreach efforts early in a project cycle might concentrate on *ejidos* characterised by older and more highly educated farmers from the Yucatan Peninsula with previous project experience, larger amounts of cleared forest, fewer forest resources, and agricultural fields in close proximity to housing. Following success with these farmers, extension efforts could then concentrate on *ejidos* characterised by lower educational levels and a larger proportion of immigrants from outside of the Yucatan Peninsula.

CONCLUSIONS

While tree-planting projects in the Calakmul Biosphere Reserve during the 1990s attracted high initial interest among farmers, benefits from these projects were not well measured or documented. However, at the outset of the agroforestry projects in Calakmul, a standardised system design that required high maintenance costs resulted in farmers adopting unprofitable systems (especially in the crucial early years) and quickly abandoning them. To improve on this history, the farmers and technicians in Calakmul began to adapt agroforestry and reforestation efforts, and ICRAF initiated several research projects to examine how to increase adoption potential and success for future agroforestry development projects in the region. One project utilised farmer participants to establish trials of alternative systems, while the other surveyed households to analyse past adoption behaviour. Farmer participation in the research process, planning of production systems, and annual evaluations facilitated farmers and researchers in identifying limitations, testing and evaluating alternatives, and improving the viability and sustainability of systems. This was especially useful for working with immigrant farmers as an experiential learning approach to developing capability in novel production systems. The traditional household survey allowed researchers to develop insights of segments of the population most and least likely to adopt agroforestry systems and where to best invest scarce project resources early in the project cycle.

Although general recommendations can be made to farmers concerning the most viable systems (e.g. continuous inter-cropping or line-cleaning systems rather than the open-clean management systems[4]), recommendations for specific farmers depend on the biophysical condition of the farm, the farmer's capacity to invest in high-risk technologies, and local preferences for different product combinations and other benefits. Meeting these conditions and increasing the likelihood of sustained adoption requires intensive and continuing technical assistance, education and advice as well as the active participation of the farmers in identifying attractive and viable alternatives.

Because intensive technical assistance is expensive, projects should utilise the results from revealed preference analyses of household survey data to direct scarce project resources at communities and farmers with a high likelihood of adoption and success. Demonstrated successes in those communities will reduce the risks associated with adoption and improve the chances of widespread success in promoting productive and sustainable systems throughout the region. Where immigrant communities with less knowledge of local production options are the target group, training and participatory learning processes will be especially important for developing farmer experience in novel production systems. The agroforestry plots of farmers participating in this study have subsequently been used by government development projects as demonstrations of locally-adapted production systems for training technicians and farmers.

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[4] Continuous inter-cropping requires that perennial and annuals are intercropped for three years. In the line-cleaning system, only the tree rows are cleaned, with intercropping in year one followed by woody regrowth between the rows of planted trees. Under the open-clean management system, the site is cleaned (weeded) regularly, with only intermittent intercropping usually only in the first year but never allowing woody regrowth.

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