Agroforest Syst (2008) 73:23–36
DOI 10.1007/s10457-008-9105-x

Adoption potential of fruit-tree-based agroforestry on small farms in the subtropical highlands

J. G. Bellow · R. F. Hudson · P. K. R. Nair

Received: 29 September 2005 / Accepted: 26 January 2008 / Published online: 10 February 2008

Abstract Worldwide, fruit-tree-based agroforestry systems have been only modestly studied, although they are common on smallholder farms. Such systems based on apple *(Malus* spp.), peach *(Prunus* spp.), and pear *(Pyrus* spp.) are common in northwest Guatemala as low intensity homegardens and are known to increase total farm productivity in communities where farm size is a limiting factor. This study investigated the potential for adoption of fruit-tree-based agroforestry by resource-limited farmers using ethnographic investigation and linear programming simulations of farm activities at the household level. Two communities with differing demographics, infrastructure, and access to regional markets were selected based on the presence of extensive fruit-tree-based agroforestry. The influences of family size, land holdings, and tree and crop yields on the optimal adoption levels of fruit trees were evaluated through a comparative study of the varying social and physical infrastructure present in the two communities. Fruit-tree-based agroforestry was potentially more attractive to relatively prosperous families or those with larger land holdings. Improvements in fruit-tree productivity and interspecies competition were of greater importance where family land holdings were smaller. The inability of families to produce sufficient food to meet annual needs, poor fruit quality, and lack of market infrastructure were identified as constraints that limit adoption. The complementarity of production with the dominant maize (*Zea mays*) crop, home consumption of fruit, and the potential to generate additional cash on limited land holdings were identified as factors promoting adoption of fruit-tree-based agroforestry.

Keywords Farming systems · Guatemala · Homegardens · Linear programming · Livelihoods · Mixed cropping · Orchard · Pyrus

J. G. Bellow (✉)
Center for Ocean-Atmosphere Prediction Studies, Florida State University, 2035 E. Paul Dirac Drive, R.M. Johnson Bldg. – Rm. 227, Tallahassee, FL 32310, USA
e-mail: bellow@coaps.fsu.edu

R. F. Hudson
Florida Center for Reading Research, Florida State University, Tallahassee, FL 32310, USA

P. K. R. Nair
School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611, USA

Introduction

Fruit-tree-based agroforestry involves intentional, simultaneous association of annual or perennial crops with perennial fruit-producing trees on the same farm unit. Because of the relatively short juvenile (pre-production) phase of fruit trees, high market value of their products, and the contribution of fruits to household dietary needs, fruit-tree-based agroforestry enjoys high popularity among resource-limited producers worldwide (Bellow 2004). Most examples of fruit-tree-based agroforestry have developed over long periods of time in response to interactions between agroecological conditions, plant diversity, and farmer resources and needs. Because of this, the system performance at any given location will depend to a great extent on several site-specific features. Nevertheless, the system performance also follows some general characteristics such as their potential benefits and limitations that are applicable over wider regions. An understanding of such general characteristics of these systems is helpful for adaptation and extension of the system to other highland areas with similar production environments.

In the highlands of western Guatemala, a majority of inhabitants rely, at least partially, on their crop yields for subsistence. Although farmers are aware of potentially more remunerative crops, maize (*Zea mays*) is the preferred crop because it comprises the dietary basis of survival and other sources of cash for maize purchases are highly risk-laden. Maize, potato (*Solanum tuberosum*), wheat (*Triticum aestivum*), and cool season vegetables were previously identified as principal types of farm production within the greater region of the *altiplano* (Immink and Alarcon 1993). The production of maize, rather than vegetable crops which had higher returns per area, was preferred by farmers with the smallest areas of land and highlights the importance of risk avoidance to farmers with limited land for production who may not be food secure.

The highlands of Guatemala share many similarities with other highly-populated subtropical highland areas of the world. As in areas such as Nepal and East Africa, the area suitable and available for cropping is low, frequently <0.5 ha per farm (Instituto Nacional de Estadisticas 1994). A substantial portion of agricultural resources in these small and fragmented landholdings is dedicated to crops for domestic consumption. As in areas such as Upper Mgeta, Tanzania (Delobel et al. 1991), fruit trees are popular among farmers and often numerous on individual farms. However, similar market, infrastructure, and product quality limitations constrain commercial agricultural activity (Delobel et al. 1991; Tsongo 1993). In spite of the limitations imposed by poor infrastructure, these regions have the distinction of experiencing temperate climates in tropical to subtropical latitudes that provide the potential to supply deciduous subtropical and temperate fruits to neighboring regions and earn much-needed income for producers. While smallholder farmers in these highland areas are often called "subsistence farmers," it is important to recognize that Guatemalan farm families survive within a cash-based economy, and that off-farm cash-earning endeavors are critical to the indigenous producers (Smith 1989). As with many smallholders in subtropical highlands, they pursue a broad range of activities, and consequently the time available to them to produce subsistence crops can be limited (Mahat 1987; Mulk et al. 1992; Storck et al. 1991). Given these similarities of the region to other subtropical smallholder farming areas, we believe that an examination of the adoption potential of fruit-tree based agroforestry in the Guatemalan highlands will provide an insight into issues facing resource-limited producers in other mountainous farming ecosystems.

Adoption failure can often be traced to social or economic factors that influence the attractiveness of the new recommendations to potential adopters (Byerlee et al. 1981) rather than intrinsic failures of the technology to perform as anticipated. Because of this common problem in technology transfer, it is critical to better understand crop selection, resource allocation, and management by low-input smallholder farmers. Linear programming (LP) has been successfully used to evaluate the adoption potential of agroforestry technologies among smallholder farmers in a variety of locations. Both socioeconomic characteristics of potential adopters (Mudhara et al. 2003) and the influence of broader scale economic policies (Kaya et al. 2000) have been examined. LP has been effective for planning at small farm and watershed to landscape scales (Garcia de Ceca et al. 1991; Kapp 1998; Knapp and Sadorsky 2000; Nasendi et al. 1996; Njiti 1988; Wirodidjojo 1989), and for identifying management strategies worthy of additional study (Wojtkowski 1990). Farm activities simulation permits the examination and evaluation of agroforestry technologies ex-situ and pre-transfer evaluation and adaptive modification that may increase adoption or help prioritize groups and regions where adoption is most likely.

Mixed systems of maize (*Zea mays*), broad bean (*Vicia faba*), common bean (*Phaseolus vulgaris*), and apple (*Malus* spp.), plum and peach (*Prunus* spp.) and pear (*Pyrus* spp.) are common in the study region. Intercropping or mixed cropping in small plots has potential to increase total yields above those of monocropping using the same resource base (Bellow 2004) and land equivalency ratios (LER) >1.0 have previously been demonstrated for the maize-broad bean association (Li et al. 1999), yet no studies have incorporated alternative cropping patterns into assessment of adoption potential of fruit-tree-based agroforestry by highland farmers in this region.

This study is based on the premise that farmers in mountainous land-scarce situations can directly benefit by incorporating fruit trees into an agricultural landscape with few other trees. Worldwide, fruit trees enjoy great popularity among subsistence farmers and provide tangible benefits in short time frames, yet knowledge of critical factors that can lead to adoption of these systems as a land management alternative in subtropical highlands is not available. The existing fruit-tree-based systems, as practiced in western Guatemala at elevations between 2500 and 3000 m above sea level, provide the setting for an excellent case study of this issue. Thus the objective of this investigation was to assess the potential for adoption of fruit-tree-based agroforestry by smallholder farmers in an area similar in many respects to other highly-populated subtropical highland regions. We hypothesized that fruit-tree-based agroforestry would be of interest to smallholder farmers, but that potential differences in adoption rates could be explained by socioeconomic differences.

Methods and materials

Site description

This study was conducted in two departments in the western highlands of Guatemala chosen for their similarity to other subtropical highland areas and the presence of fruit-tree-based agroforestry systems. The departments are characterized by limited infrastructure, little or no education and health facilities, and high population density, ranging from over 300 to nearly 900 persons km^{-2}. Total land area available for cropping is low, such that the average farm-holding size is <1.0 ha. The indigenous Mayan population is not food-secure throughout the year and often migrates seasonally to find work. Market access for crops is limited by poor infrastructure and the majority of land held by smallholders is allocated to crops that are consumed on-farm. The steeply sloping lands, ranging from 900 to 4000 m above sea level, are primarily in forest or agricultural production and occupied primarily by small farms. Soils on low sloping lands are deep and well drained; however, they are considered to be of low productivity due to continuous cultivation (Gramajo 1993). Irrigation infrastructure is limited with most agriculture in the region being rainfed.

Two communities located at approximately 2600 m above sea level were selected for the study based on the historical presence of fruit-tree-based cropping systems. Cabrican is the most northerly community in the department of Quetzaltenango. Roads into the municipality are steep, unpaved, and difficult-to-pass during the rainy season. The community of Chuculjulup is near the departmental capital of Totonicapan and has easy access to the main paved highway. The majority of land is dedicated to the cultivation of maize, whether as a sole crop or as intercrops with other annuals or perennials. Land holdings are small and fragmented with cultivation realized entirely by manual labor. Soil fertility is augmented by the application of locally collected forest leaf litter, bedding and dung from livestock, or through the application of chemical fertilizers (N-P_2O_5-K_2O: 15-15-15, 20-20-0, or 45-0-0). Most farm families appear to operate on a cash basis and neither community has formal banking or credit institutions. Like rural families in many parts of the developing world, family wealth is often maintained in livestock, food surplus on the farm, and through informal credit between neighbors and relatives. Fruit-tree-based agroforestry is extensive in Chuculjulup and Cabrican in comparison to many surrounding areas, yet anecdotal evidence showed obvious differences between farms over small spatial scales. Therefore, systematic data collection was necessary in order to gather representative data on crop choices and management regimes.

Data collection

Sondeos

Ethnographic information on farm families in the two communities was gathered using national and municipal census data, published technical reports, field observations, semi-structured interviews, and an informal survey at the end of the study period. Semi-structured interviews or *sondeos* (Hildebrand 1986) were conducted with key informants from 15 self-selected households per community and from ad hoc focus groups. Key informants were self-selected to the extent that they were willing to spend substantial time discussing their farm activities and family characteristics. Households were not randomly chosen as it was assumed desirable to have good spatial coverage within the community even though stratification was not possible due to self-selection. At least three separate visits were made to each household during the initial *sondeo* process. During the *sondeos*, family size and gender distribution, land holdings, crop practices and animal husbandry were characterized and the presence and variety of fruit trees were noted. One of the visits included an examination of the families' closest field and/or orchard and a discussion of the performance and management of the crops. *Sondeos* were conducted as much as possible with a male-female interview team. Data collected during the *sondeos* were used to parameterize and guide structural formation of the farming simulation model.

Market surveys

Prices of farm products were collected from farmers and market surveys in both communities. Potential seasonal fluctuations in product value were quantified by monthly visits to the two markets most frequented by the communities. Due to differences in product quality and vendor behavior, six vendors were queried and the highest and lowest prices were excluded. Product pricing was very closely linked to the evaluator's perceptions of product quality (size, freshness, and relative absence of pest or disease damage). The remaining prices were averaged quarterly to characterize seasonal values in each community. It remained evident that patronage, familial ties, and bargaining skills often produce substantial variations in market values and ultimately in family market expenditures.

Validation survey

The initial *sondeos* were conducted during the late autumn of 2001 and the spring of 2002, and participants in on-farm yield variability assessments were selected from among those interviewed. It became evident during 2002 that several areas of interest, including household expenditures and management of fruit crops, were inadequately characterized and that further investigation was warranted. In the autumn of 2002, a broader segment of the population in each community was interviewed about their household practices by a two member team to collect similar information as during the *sondeos*.

On-farm yields assessment

Crop yields as reported by families and in informal discussions within the community were highly variable and farmers readily indicated that they did not have mass-based yield information except in the broadest sense. Under common handling practices, dry grain was only shelled incrementally prior to use. In 2001, test plots were established with local varieties and yields were estimated within existing fields. To remove variety effects on these yield estimates, in 2002 farmers were offered San Marceño Mejorado, an improved open-pollinated population of yellow maize, and 15 kg of 15-15-15 fertilizer for self-evaluation. Farmers provided the management they judged appropriate. End-of-season sub-sampling was made on 11 farms in 2001 and 13 in 2002.

Model formulation

A farm simulation-model for the general structure of smallholder agriculture in the two communities was developed using linear programming (LP). The method is well established and provides a good first approximation of a complex process. The model was developed to evaluate family characteristics, land holdings, market opportunities, and their influence on the establishment and maintenance of fruit trees. The model was temporally discrete with three-month periods (February–March–April, May–June–July, August–September–October, and November–December–January) that accurately capture seasonally explicit labor requirements and harvests in the study area. Animal husbandry was further disaggregated for dry (Feb. through Apr.) and wet seasons (May through Jan.).

Farm activities as modeled

Annual crop production, animal husbandry activities and their linkages were characterized and simulated. Consumptive and reproductive characteristics of poultry, swine, sheep, and dairy cattle were included. In the model, animals required fodder or feed that could be obtained through grazing, cut-and-carry operations, and concentrates and/or maize. Labor for animal husbandry was provided from female and adolescent labor, except dry season fodder supplied by male labor. Linkages to cropping were based on the consumption of crop stover, oats, and maize and through organic wastes (*estericol*) used for many cropping combinations. Organic matter for cropping could also be supplied through the allocation of male labor to collecting and applying forest litter, mainly from public lands.

Cropping alternatives included five variations of maize intercropping with climbing beans (*Phaseolus vulgaris*), faba (*Vicia faba*), and squash (*Cucurbita pepo*), monocropped faba bean, potatoes, wheat (*Triticum aestivum*), and oats (*Avena sativa*). For each alternative, quarterly labor requirements were defined. Alternatives required inputs of seed, fertilizers, organic matter, and chemical herbicides and pesticides in varying quantities. Yields were calculated based on the farm area allocated to a particular system. Seed could be purchased or saved from the prior year's production. Fertilizers and chemical inputs were purchased with cash. Seasonal labor, inputs, yields, and market values for apple, peach, and pear were also characterized.

Crop yields could be consumed on-farm by family members or livestock or sold. Modeled crop yields for the two communities were developed from on-farm measurements of maize yields during 2001 (*criollos*) and 2002 (improved population) and from yield expectations stated by farmers for potato, bean, faba, wheat and oats. Because intercropping patterns and yields are extremely variable as an effect of differences in crop percentages, intercropping effects were based on the response seen between the selected maize population and faba bean during on-station trials (Bellow 2004).

Family composition was used to calculate food requirements based on the individual energy contents of the various food items. Daily consumption needs for male and female adults, adolescents, and children were calculated in terms of maize, beans, potatoes, fruit, bread, eggs, meat, and chicken. Consumption could be satisfied through both market purchases and farm production. A linear regression model for each community (Eqs. 1 and 2), where E is estimated weekly expenditures and F_s is family size, was used to estimate additional market cash expenses (sugar, salt, vegetables, oil) per family member that were deducted from cash holdings. Finally, a yearly cash expenditure constraint was stipulated to pay the costs of clothing, utilities, transportation, and miscellaneous expenses.

Total labor availability was calculated based on family composition. Adult males were considered to have 365 work days available or 100% of their time. While this may seem excessive, in practice we observed men who worked on jobs off-farm during one labor day for wages and then one-half day on their own farm within a 24-h period. Females supplied 50% of male labor equivalents owing to their responsibility for reproductive and other activities within the farm household not explicitly modeled. Male and female adolescents contributed 20% of male labor owing to their reduced work capacity and time commitments at school. Children contributed 5% of male labor equivalents, mainly to graze and feed animals. Child, adolescent, and female labor was summed to calculate labor available for female labor activities.

To account for potentially important interactions with cropping systems, the model also included simplified activities related to livestock and crop product marketing and consumption activities, and opportunities for off-farm or non-agrarian livelihood strategies. The model structure is an assumption that the activities are characterized and cross-linked to accurately portray the principal options available to the farmers.

Model objective function, variables, and constraints

The desire to achieve multiple goals was hypothesized for farm families and was incorporated in the simulations. Model constraints stipulated explicitly that families were required to consume nutritionally adequate diets. Adequate cash expenditure to meet common annual expenses such as electricity and clothing was also incorporated as a constraint. The objective function was the maximization of total cash remaining at the end of the twelfth year after family consumption has been met through production and purchases. The sale of farm products and non-agricultural labor were the principal alternatives to meet this goal.

Land area, available cash, and labor availability (both family and hired) are the principal constraints of this model. Additional constraints included limits on starvation and availability of non-agricultural employment. The list of variables included in the initial formulation of the model were the choice and level of crop production, the number and type of livestock, the amount and allocation of family and hired labor, and magnitude of off-farm labor. Off-farm labor activities were disaggregated by gender to represent different activities and pay scales, but earnings were standardized within gender at 250 Q week^{-1} for males and 125 Q week^{-1} for females (1.00 US$ = 7.85 Q). The use of family labor on-farm was partially disaggregated for gender to signify that female labor is generally not available for land preparation, while females can and often do participate in planting, weeding, and harvest activities. Both women and children were considered to contribute labor for animal husbandry.

Simulations

The farm simulation model was explored systematically, and the results shared with key informants. The model was further calibrated based on their feedback to reflect the actual choices made by farmers. For the production and demographic characteristics of each community, feasible combinations of labor availability, farm size, family composition, food security, and household expenses were examined in relation to optimal levels of fruit-tree production. Two alternate scenarios were examined by using community-specific mean crop yields. For each community, examination of principal variables was made while other variables were held constant. Labor availability, calculated as a function of family size and distribution, and agricultural land holdings were evaluated by repeated optimizations, though not all combinations of family- and land-holding- sizes were feasible. Finally, the model was parameterized to represent average families and average farms in each community. The family size and age distribution as well as agricultural and non-agricultural land holdings that were characterized using the community survey instruments were used to define average families for each community as detailed in the results. The effects of tree competitiveness, fruit yields, and farm gate fruit prices on adoption potential of fruit-tree based agroforestry in these two communities were examined.

Results and discussion

Farming systems characterization

Family size and consumption

Estimates of weekly expenditures indicated that purchases of vegetables, whole grains and pulses (excluding maize) were significantly higher in Chucul julup than in Cabrican while weekly meat and miscellaneous purchases such as spices and oil were greater in Cabrican (Fig. 1). No significant differences were detected in expenditures on breads. Purchase prices for locally available products suggest that prices do not differ significantly throughout the year and did not vary significantly between the two communities (data not shown). Regression equations were developed to estimate market expenditures (*E*) based on family size in both communities (Eq. 1 for Cabrican ($R^2 = 0.12$) and Eq. 2 for Chuculjulup ($R^2 = 0.13$) however, expenditures were highly variable and R^2 values extremely low limiting the usefulness of this approach.

$$E = 76.89 + 8.1F_s \quad (1)$$

$$E = 77.98 + 5.0F_s \quad (2)$$

Maize consumption per household was higher in Cabrican than in Chuculjulup (Table 1). Even though

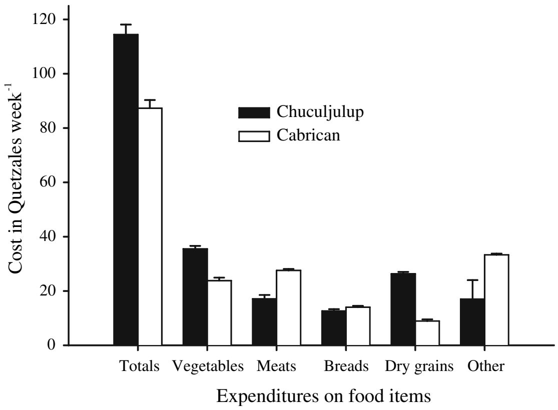

Fig. 1 Weekly purchase expenses for several food frequently purchased by families of two communities in northwest Guatemala. (1.00 $US = 7.85 Q 2002)

some families reported purchasing maize year-around, maize shortfalls most commonly occurred from June to October. In Chuculjulup, 48% of surveyed families reported purchasing maize during the year while only 28% of surveyed families in Cabrican reported maize purchases. The estimated amount of maize purchased during a year was also significantly greater in Chuculjulup (313 kg) than in Cabrican (232 kg). Regression equations were developed to predict daily household maize (M) consumption (kg) where S_f is family size (Eqs. 3 & 4) for Cabrican ($R^2 = 0.32$) and Chuculjulup ($R^2 = 0.42$).

$$M = 0.32 + 0.27S_f \quad (3)$$

$$M = 0.53 + 0.36S_f \quad (4)$$

Larger average family size in Cabrican was reflected in higher reported monthly maize consumption. When family size is smaller, with slightly higher maize yields, it appears to be easier to support survival with smaller land holdings. The importance of extensive versus intensive production in remote, low-resource areas is supported by the finding that families in the more-remote community reported lower maize purchases to augment their on-farm production, which was lower on a per area basis than in Chuculjulup. The low explanatory power of the equations (Eqs. 1 and 2) relating family size to market expenditures is the result of high variation in the actual level of consumption (wealth and/or nutritive status) of the various families as well as variations in the amount that different purchasers will pay for the same item due to patronage or negotiating skills. The inherent difficulties in correctly incorporating non-economic drivers such as aesthetics, religious beliefs, social pressures, cultural or moral values may limit the results of the simulation as family goals diverge from economic optimization.

Table 1 Community and household characteristics of the two communities in western Guatemala

	Cabrican		Chuculjulup	
Population	14,500 (92% Mam)		2,900 (97% Quiché)	
Population Density	330 persons km^{-2}		890 persons km^{-2}	
Functional literacy (%)	73		60	
Educational level				
Pre-elementary (%)	6		32	
Elementary (%)	84		61.3	
High School (%)	9.5		6	
Post-High School (%)	0.5		0.7	
Households	2870 (58% with electric)		501 (93% with electric)	
Data source: Sondeo ($n < 35$) and Survey ($n > 175$)	($n = 31$)	($n = 180$)	($n = 23$)	($n = 233$)
Household size (members in residence)	7.3	6.1	5.1	5.2
Agricultural land (ha)	0.78	0.6	0.22	0.23
Non-agricultural land (ha)	0.52	0.48	0.09	0.12
Weekly food purchases (Q: 1 US $ = 7.85 Q, 2004))	125.0 ns	87.3	113.5 ns	114.4
Household maize consumption (kg month^{-1})	108	100.75	67.6	73.77

Means separation not done for community characteristics. All household means significantly different at $\alpha = 0.05$ unless followed by ns. Means comparisons made within small ($n = 31$, 23) samples (*sondeos*) and within large ($n = 180$, 233) samples (household surveys) using t-test assuming unequal variances

Table 2 Characteristics of the farming systems observed in two highland communities of western Guatemala

Principal crops	Mean crop yields kg ha^{-1}	Percent of observed systems		Labor days ha^{-1} during each quarter			
		Cabrican	Chuculjulup	F–M–A	M–J–J	A–S–O	N–D–J
Maize	5150	28.4	11.2	22.7	90.9	51.1	102.2
Bean	120						
Maize	2950	14.7	0.9	25	90.9	73.9	106.7
bean	120						
faba	90						
squash	15000						
Maize	2950	14.2	0.9	25	90.9	73.9	102.2
bean	120						
faba	90						
Maize	5150	10.6	0.4	22.7	90.9	45.5	102.2
faba	360						
Maize	5660	17.0	84.1	22.7	113.6	22.7	90.9
Faba	790	0.9	0.4	0	96.5	5.7	56.8
Bean		0.0	0	0	96.5	5.7	56.8
Potato 1st	16900	5.0	0	34	223.3	113.5	0
2nd	2570						
3rd	1550						
Wheat	2050	2.3	0.9	0	28.4	9.3	23.6
Oats	1275	6.9	0.4	27.2	0	34.1	0
Fruit trees (sole crop)	4625	0.0	0.9	12.3	12.3	24.5	8.2

Fruit tree variety	Tree crown size m^2	Estimated fresh fruit yields (kg $tree^{-1}$)				
		Yr 3	Yr 5	Yr 7	Yr 9	Yr 11
Pear	9.0	0.5	5.0	10.0	18.5	27.0
Peach	9.0	2.0	10.5	19.0	29.5	40.0
Apple	9.0	0.5	5.0	10.0	18.5	27.0

Doblador is the ear husk of maize and is used to wrap maize-based foods such as *tamales* or cheese. Potatoes reported based on size class. All values for fruit orchards are on the basis of 204 trees ha^{-1} (7.0 × 7.0 m) for 7 year-old trees

Greater land holdings and more diversified production may produce greater resilience in food security, permitting larger family size. This may allow survival of larger families in Cabrican or at least permit smaller families to satisfy many basic needs without access to consistent off-farm income sources. An alternative explanation is that larger families in Cabrican are hungrier or purchase less food than those in Chuculjulup.

Farm holdings

Farmers' reported land holdings per household were significantly higher in Cabrican than in Chuculjulup for both agricultural and non-agricultural land (Table 1). Analysis of the distribution of farm size showed that most families in Chuculjulup are at the lower end of the range of holdings for agricultural land. A small sample of families from both communities stated that they did not own agricultural lands.

Land allocation

During the *sondeos*, twelve major cropping systems were observed and characterized within the two communities (Table 2). Of these, five were maize-based variants. Sole cropped runner bean was observed only once in Cabrican on wooden supports, and was not investigated further. Fruit trees, wherever present, were usually components of mixed cropping, except in very few instances of pure stands. The distribution of agricultural systems explains the greater allocation of the families' food expenses to vegetables and dry grains in Chuculjulup, and the systems that include legumes or other grains are more prevalent in Cabrican where families are able to produce a greater share of their consumption needs on their farms.

While the observed systems are similar to those described by Immink and Alarcon (1991, 1993), few families in either community were growing wheat or horticultural crops, and potato-based systems were uncommon in Cabrican. Furthermore, among potato planters, the crop occupied less than 20% of their agricultural land. In contrast, Immink and Alarcon (1993) found no more than 50% of farmers engaged in extensive maize production. It is well established that sub-regions of the *altiplano* specialize in crops well suited to the area, i.e., horticultural production in *San Pedro Almalonga* or emphasis on potatoes in *San Marcos*. The differences between the two sets of findings suggest that broader-scale studies may be inadequate for characterization of individual sub-regions or communities.

On-farm yields assessment

Assessment of on-farm maize yields in the two communities shows higher mean maize yields in Chuculjulup (4100 kg ha^{-1}) than in Cabrican (3000 kg ha^{-1}) for local varieties during 2001, which was due to higher yields per stalk and greater total ear mass harvested in Chuculjulup. During 2002, yields were not significantly different between the two communities when a standard improved variety was assessed. When comparing the average performance of local varieties in 2001 (3400 kg ha^{-1}) with the improved variety during 2002 (4500 kg ha^{-1}), the improved variety produced higher grain yields with higher per stalk yields and shelling fraction than the bulked local varieties.

Substantial room remains for increasing maize production in these small homesteads. The maize yield from 0.3 ha planted to locally adapted varieties (900 to 1250 kg) is close to providing a full year's supply of maize for a family of five to six members (roughly 900 to 1300 kg). However, the mean farm sizes in Chuculjulup of 0.21 ha essentially ensures a shortage of farm-produced maize on the order of 60 to 400 kg (1 to 4 months of maize). This need for smallholder farmers to purchase maize late during the production season is a prime indicator of food-insecurity. The yields of an improved local variety (1250 to 1350 kg) on this land area appear to be able to close this gap.

Fruit-tree-management

Management practices and end uses for fruit trees were evaluated separately from annual crops although they frequently occurred in mixed plantings. The percentage of families with fruit trees was higher in Chuculjulup than Cabrican (Table 3) though the percentage who had sold fruit the prior year was similar in both communities. Sale of fruit to brokers was much higher in Chuculjulup, 58.6%, than in Cabrican, 25.1%. Families with fruit trees estimated significantly more trees per family in Cabrican (23.2 trees household^{-1}) than in Chuculjulup (13.3 trees household^{-1}). Apple (*Malus* spp.) was the most common, followed by peach (*Prunus* spp.) with pear (*Pyrus* spp.) a distant third. Families with trees had relatively low levels of the common management practices (Table 4) though they were more commonly stated as part of farmer practices in Cabrican than in Chuculjulup.

Animal husbandry

Farmers in both communities kept a variety of livestock within and around the homestead. Overall,

Table 3 Prevalence of fruit trees in the farming systems of two highland communities of western Guatemala

	Families with >1.0 productive fruit tree (%)	Predominance of three fruit trees (percent of reported trees)			Families selling fruit in 2001 (%)
		Peach	Apple	Pear	
Cabrican ($n = 180$)	83.4	25.7	74.1	0.21	53.0
Chuculjulup ($n = 233$)	90.9	37.5	61.1	1.4	55.0

Percentage of families selling fruit based solely on those with trees. Numerous fruit varieties are contained within species classification

Table 4 Percentage of smallholder farmers who practiced deciduous-fruit-tree management in agroforestry systems on their farmlands in western Guatemala highlands

	Spraying	Pruning	Calcium application	Chemical fertilization	Fruit thinning	Organic matter application
Cabrican ($n = 150$)	7.9 a	51.8 a	50.7 a	2.2 a	5.1 a	55.1 a
Chuculjulup ($n = 211$)	8.3 a	13.7 b	35.6 b	2.0 a	5.4 a	12.7 b

Practice means followed by the same letter not significantly different (t-test with unequal variances, $P < 0.05$)

livestock was a greater factor in the livelihood strategies of Cabrican families than those of Chuculjulup (data not shown). Labor requirements for both genders for animal husbandry were identified through *sondeo* discussions and with key informants who stated that women and children did most of the labor. Gathering dry season fodder was specifically identified as a male task.

Non-agricultural livelihoods

The economic character of non-agricultural activities on a per day basis was developed from conversations during *sondeos* and focus groups. Individuals described a broad range of wage-earning endeavors not directly linked to their agricultural practices. It was clear that the opportunities for wage earning were extremely limited in Cabrican as compared to Chuculjulup. While numerous cottage industries and piecework activities were observed in Chuculjulup households, Cabrican informants were more likely to describe less continuous opportunities such as field work, sand or lime mining, or the lack of any activities at all. Since Chuculjulup is located much closer to a major population center, its greater reliance on off-farm income is most likely due to need (less land and higher population density) as well as greater opportunity (closer to supplies and market).

Farm optimizations

Farm size

Differences in land holdings affected the potential response to fruit trees. In the community closest to the capital, increase in the size of the land holdings was associated with a strong increase in the optimal number of fruit trees. In contrast, the response in the remote community was much weaker and occurred only at much higher land holding levels than the equivalent response in the other community (Fig. 2). Here, the smallest land holding that permitted family survival within stipulated constraints was >0.35 ha. In the more economically-integrated community, maize-based cropping leveled off and cash reserves were maximized at 0.53 ha, after which resources were invested in other activities. With such small farm sizes (<0.5 ha), excess family labor is readily available and needed to obtain income from off-farm activities rather than being a limiting constraint to on-farm activities.

Using number of fruit trees established as a measure of adoption, the optimal number of trees was used to gauge the response to scenarios. Fruit-tree-based agroforestry has greater potential in Chuculjulup under current socioeconomic conditions (2002) than in Cabrican, which corresponds well with observations. This could be due to the greater degree of food security of the residents. The greater availability of off-farm

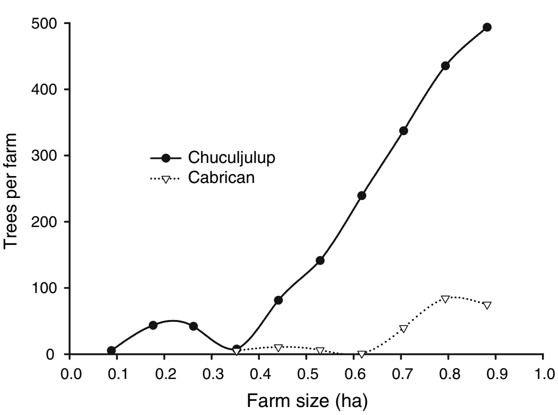

Fig. 2 Simulated effects of agricultural land-holding size on the potential popularity of fruit trees with families of average composition in Chuculjulup and Cabrican

income, smaller family size, and higher maize yields likely offset the limitations posed by smaller land-holdings. The simulations predict that the combination of income and maize yields allows food consumption needs to be met at which point, the adoption of fruit trees is favored as a means to maximize discretionary or year-end cash reserves.

Family composition

Increasing family size, with land holdings held at the community means, had a strong negative effect on the optimal number of fruit trees in both communities. The magnitude of the effect was substantially greater in Cabrican with larger farm sizes and lower maize yields (Fig. 3). Increasing family size was positively related to land allocation to maize-based systems and optimal livestock activities in both communities. In Chuculjulup, larger families produced declines in year-end cash while in contrast, larger families in Cabrican achieved higher year-end cash values.

The simulated negative relationships between optimal numbers of fruit trees and maize production as well as family size illustrate the need to retain higher levels of food security when consumption needs increase. Agricultural potential with the small land holdings is insufficient to fully exploit the labor present in larger families. Based on simulation results, a potential tension between food security within farm households and adoption of fruit-tree-based agroforestry may exist. Higher numbers of fruit trees were predicted where food security is more readily achieved, i.e., where sufficient land exists to grow larger maize fields in spite of low yields or where food consumption is lowered due to small family sizes. A substantial portion of previous research on fruit varieties in the highlands region of Guatemala has emphasized the methods for establishment and management of commercial orchards (Williams et al. 1992; Williams and Vasquez 1990; Vasquez 2000), however the simulation results suggest that intensive plantings will only be popular among farmers where maize yields are high or farmers are not dependent on maize production for cultural and economic survival.

Fruit production characteristics: values, yield, competition

The simulated effects of several possible types of interventions in fruit-tree-based agroforestry indicated that no single approach would be equally successful in all situations. Potential strategies include those that would increase the price farmers received for the fruit they produced or increase the yields of individual trees during their productive period. Simulation of the effects of changes in market values of fruits revealed that when market value was between 90 and 130% of 2003 market values, the number of fruit trees in Chuculjulup increased substantially (Fig. 4). In Cabrican, the optimal number of fruit trees was maximized when fruit values

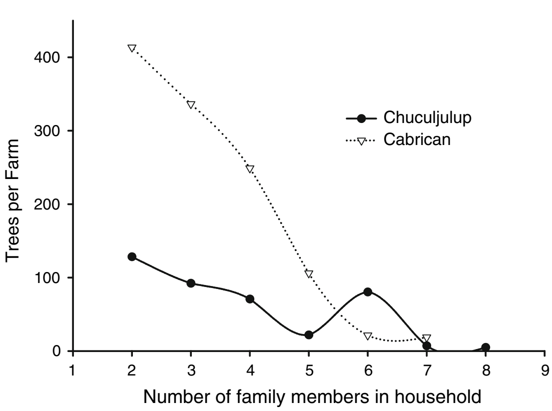

Fig. 3 Influence of family size for farms of average size land holdings on likely adoption and management of deciduous fruit trees in Chuculjulup and Cabrican

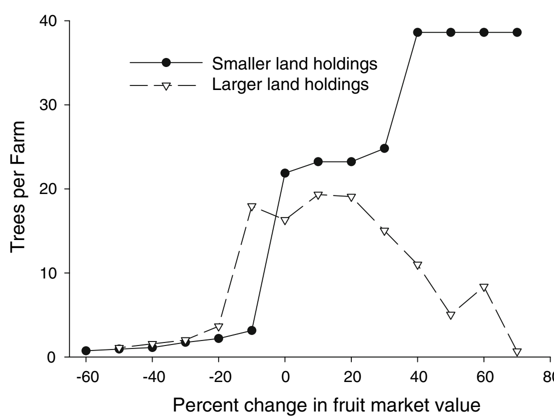

Fig. 4 Simulated market sales and purchase prices affecting potential popularity of fruit-tree-based agroforestry by families with larger (0.75 ha) and smaller (0.25 ha) land holdings

ranged from 90% to 120% of market values. Where opportunities for off-farm income were strongly limited, Cabrican families were predicted to generate needed cash by other means and were unable to adopt fruit-tree-based agroforestry resulting in observed decline in adoption. The effects of fruit tree yields on optimal tree numbers were similar to the effects of variations in fruit values. The simulated potential for intensive fruit production was much greater in Chuculjulup, where optimal tree number was twice as dense when yields were 100% of expected compared to Cabrican (Fig. 5). If yields were increased to 140% of expected, simulated tree establishment per hectare was four times greater in Chuculjulup than Cabrican. Increases in fruit tree yields resulted in declines in the amount of land allocated to other crops in both communities. There was no clear evidence that increases in fruit tree yields would enhance the year-end cash status of families in the seventh year of simulated adoption.

Increases in effective tree competition across the entire resource pool, simulated by increasing the area in which associated crops yielded poorly, resulted in declines in the optimal number of trees per family. Farmers with smaller holdings were affected when tree competition reached nominal levels (indicated by the arrow in Fig. 6). Where farm holdings are larger, there was no simulated response to increasing competition until tree competitive area had reached 20 m^2.

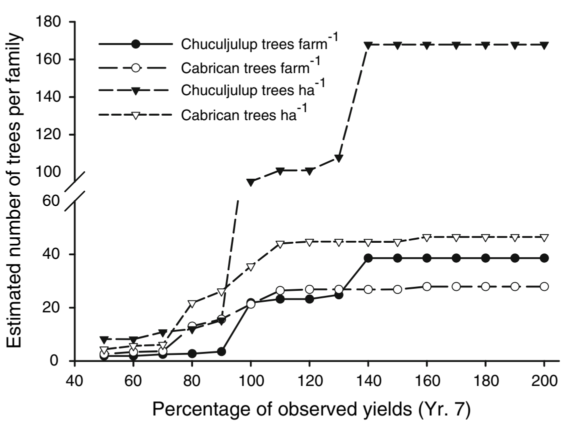

Fig. 5 Importance of fruit yield levels on likely popularity of deciduous fruit trees as an agroforestry technology among average farm families in two highland communities of western Guatemala

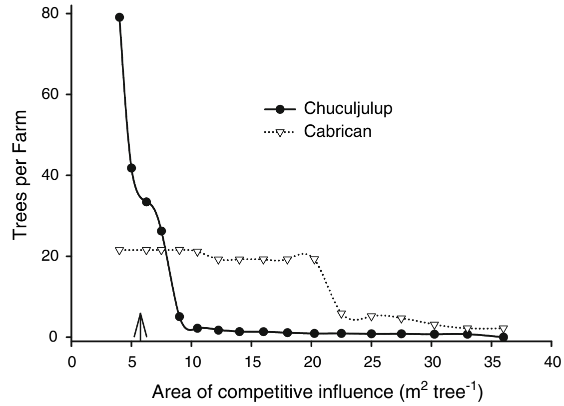

Fig. 6 Tree-crop competition as a factor influencing the rates of tree establishment and management by families representing average conditions in two highland communities. The arrow indicates the nominal value for seven-year-old trees

Conclusions about the adoption potential of fruit-tree based agroforestry

Analysis of the socioeconomic status of potential adopters showed that particular circumstances such as seasonal food shortages, low crop yields, or large family sizes may limit levels of adoption of fruit-tree-based agroforestry. It is possible that the length of juvenile phase (time between establishment and initial returns) of fruit trees negatively influences families that have food security concerns or are less economically secure. The characterization of the two communities revealed deeper differences that may explain differing levels of adoption in the subtropical highland areas of the world. The community still dependent on subsistence agriculture to meet the needs of many of its inhabitants showed considerably less adoption than the community with greater integration into the market economy. Simulation modeling of farmer options for resource allocation and production alternatives indicated that principal crop yields rather than land holdings were a critical issue and that fruit-tree-based agroforestry would be very popular where subsistence needs could be satisfied. Food security, when defined as having the necessary food on hand rather than simply the means to procure food if available, is unlikely to be enhanced through fruit-tree-based agroforestry. The findings suggest that adoption of this technology is enhanced where other factors contribute to enhancing the security of the family in tandem.

For many highland farmers in the region, maize cultivation is not purely an economic or food security endeavor but contains spiritual or moral connotations that may drive otherwise uneconomical activities. In the current study, this was modeled as a constraint that 80% of household maize consumption be produced on-farm which prohibited excessive speculation in cash crops and may be responsible for the simulated negative relation between family size and fruit production. It is likely that in the absence of this cultural norm, fruit-tree-based agroforestry might enjoy greater adoption as has been seen anecdotally among Latino farmers.

The study showed that fruit-tree-based agroforestry is not likely to be scale neutral in its effects. Larger, economically stable families are more likely to be adopters compared with more marginal households. This highlights the need for a coordinated and holistic team approach to the small farmer's fields with emphasis on increasing annual crop yields as a strategy for augmenting overall productivity through species diversification and fruit-tree-integration on farmlands.

Adoption-limiting factors

Adoption of mixed cropping requires sufficient flexibility by the producer to accept changes in the percentage of the total yields coming from an individual component. This limits adoption where an annual crop is critical to food security and is in limited supply. When available land or crop yields present a constraint to farm productivity, it is possible that some families will not or cannot adopt the technology since doing so would reduce crop yields to a small and unacceptable level. In spite of the biological and economic superiority of the fruit-tree-based systems over annual crop systems, the risk inherent in producing and marketing a perishable commodity in an infrastructure-limited region reduces its overall attractiveness. Based on these observations and findings, it is recommended that development activities that promote fruit-tree-based agroforestry or intend to enhance small farm fruit production in marginal highland areas should be integrated with efforts to enhance the productivity of the associated or principal crops. Limited availability of quality planting materials and lack of information on appropriate management are additional potential limitations to adoption not directly addressed by this study.

In spite of the above shortcomings, fruit trees were overwhelmingly popular among farmers in both communities and potential for adoption is high if the other constraints are managed. More than half the families with trees were engaged at some level in the marketing of their fruit and families produce large amounts of fruit for their own consumption with the concomitant improvement in their quality of life. The fruit harvest in the region occurred mainly during the interval between the final hilling of maize and its harvest, thus complementing well the labor requirements of maize cropping. The income that can be earned from fruit sales through any of the available market channels comes at a time when families are most likely to have run short of maize from the prior year's harvest and need to purchase food for daily consumption.

The temperate climate of subtropical highlands permits deciduous fruit to be grown and marketed locally as well as in surrounding regions. The development of more equitable support mechanisms and infrastructure could enhance farmers' ability to benefit from this form of agricultural intensification. There is little potential for the expansion of deciduous fruit exports to temperate regions; however, current farmer practices fill a valuable niche, and the failure to support and encourage this form of land use can only have negative consequences for rural producers.

Many of the socioeconomic factors that influenced the predicted adoption rates, such as market limitations, low subsistence crop yields, regional niche opportunities for production, and farmer desires for diversified diets and food security are not unique to the Guatemalan highlands. Overall, this study provides support for further research of fruit-tree-based agroforestry and a recommendation to promote its use among smallholders in highland tropical and subtropical environments. Research designed to increase the food security of smallholder farmers should focus on the development and validation of management techniques in concert with and intended for limited resource production scenarios where the fruit trees will be grown in mixtures with annual crops.

Acknowledgments The authors are deeply indebted to the families of Chuculjulup and Cabrican, Guatemala for their contributions and the personnel of ICTA, in Quetzaltenango for their support and collaboration. The principal author was supported by an E.T. York Presidential Fellowship, University of Florida, and by a Bowen fellowship from the National Security Education Program. The study was also supported by a USDA/Initiative for Future Agricultural and Food Systems CSREES grant to the University of Florida (Center for Subtropical Agriculture), Gainesville, FL., USA.

References

Bellow J (2004) Fruit-tree-based agroforestry in the western highlands of Guatemala. Dissertation, University of Florida, Gainesville, FL, USA

Byerlee D, Biggs S, Collinson M, Harrington L, Martinez J, Moscardi E, Winkelmann D (1981) On-farm research to develop technologies appropriate to farmers. I.A.A.E. occasional paper – Int Assoc Agric Econ 2:170–177

Delobel T, Evers G, Maerere A (1991) Position and functions of deciduous fruit trees in the farming systems at Upper Mgeta, Uluguru Mountains, Tanzania. Acta Hort 270:91–102

Garcia de Ceca J, Gebremedhin K, Jarvis P (1991) A decision support system for planning agroforestry systems. For Ecol Manag 45:199–206

Gramajo S (1993) Autogestion comunitaria de recursos naturales, estudio de caso en Totonicapan. FLACSO programa, Guatemala City, Guatemala, 109 pp

Hildebrand P (1986) The sondeo: a team rapid survey approach. In: Hildebrand P (ed) Perspectives on farming research and extension. Lynne Rienner Publishing, Bolder, Colorado, 167 pp

Immink M, Alarcon J (1991) Household food security, nutrition and crop diversification among smallholder farmers in the highlands of Guatemala. Ecol Food Nutrition 25:287–307

Immink M, Alarcon J (1993) Household income, food availability, and commercial crop production by small-holder farmers in the western highlands of Guatemala. Econ Dev Cult Change 41:319–342

INE (Instituto Nacional de Estadisticas) (1994) Departmento de Totonicapan, caracteristicas generales de poblacion y habitacion. Instituto Nacional de Estadisticas, Guatemala, Guatemala, 125 pp

Kapp G (1998) Financial evaluation tools for smallholder forestry: a methodological comparison of two forms of cost-benefit analysis and optimization. Int Tree Crops J 9:233–246

Kaya B, Hildebrand P, Nair PKR (2000) Modeling changes in farming systems with the adoption of improved fallows in southern Mali. Agrofor Sys 66:51–68

Knapp K, Sadorsky P (2000) Economics of agroforestry production in irrigated agriculture. J Agric Res Econ 25:286–306

Li L, Yang S, Li X, Zhang F, Christie P, Li L, Yang SC, Li XL, Zhang FS (1999) Interspecific complementary and competitive interactions between intercropped maize and faba bean. Plant Soil 212:105–114

Mahat T (1987) Forestry farming linkages in the mountains. ICIMOD (International Centre for Integrated Mountain Development) Occasional Paper. No. 7, 47 pp

Mudhara M, Hildebrand P, Nair PKR (2003) Potential for adoption of *Sesbania sesban* improved fallows in Zimbabwe: a linear programming-based case study of small-scale farmers. Agrofor Sys 59:307–315

Mulk M, Jodha N, Banskota M, Partap T (1992) Diversity of farming systems and farmers' strategies in the mountain valley of Chitral, Pakistan. In: Jodha N, Banskota M (eds) Sustainable mountain agriculture. V. 2: farmer's strategies and innovative approaches. Intermediate Technology Publications, London, pp 477–496

Nasendi B, Hasanudin Nugroho I, Mulyaningrum Karyono O, Tryono Murod A, Sipayung W (1996) Analysis of industrial plantation forest model development with a mosaic system using a linear programming modeling approach: a proposed model for the Padang Lawas area, North Sumatra. Buletin Penelitian Hasil Hutan 14:291–307

Njiti C (1988) Development of a goal programming model for land use planning with emphasis on wood for energy production in the Republic of Cameroon. Dissertation Abstracts International: Humanities-and-Social-Sciences. Southern Illinois University, 150 pp

Smith C (1989) Survival strategies among petty commodity producers in Guatemala. Int Labor Rev 128:791–813

Storck H, Emana B, Adenew B, Borowiecki A, Hawariat S (1991) Farming systems and farm management practices of smallholders in the Hararghe highlands – a baseline survey. Farming Sys Res Econ Trop 11:195

Tsongo N (1993) The impact of the introduction of an innovation on the development of peasant farms in the mountainous zones of Kivu (Zaire). Tropicultura 11:11–15

Vasquez J (2000) El Manzano (*Malus pumila*) y recomendaciones para el cultivo en Guatemala. Instituto de Ciencia y Tecnologia Agricolas, Guatemala, 112 pp

Williams W, Vasquez J (1990) El Cultivo de Pera. Programa de Desarrollo Agricola, MAGA-AID, 16 pp

Williams W, Cifuentes S, del Aguila V, Perez R (1992) Rejuvenation of a peach orchard in the highlands of Guatemala through integrated management. Trop Agric 69:341–346

Wirodidjojo S (1989) Application linear programming model for watershed management planning. Duta Rimba 15:3–17, 24–29, 107–108

Wojtkowski P (1990) Bioeconomic simulation of agroforestry systems: an application to southeast Bahia, Brasil. Dissertation Abstracts International: Humanities and Social Sciences. Thesis, University of Georgia, 117 pp