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Home Garden Production and Energetic Sustainability in Calakmul, Campeche, Mexico

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Abstract Energy flows were studied for the 2002–2003 agricultural cycle in four households for which agriculture is part of a diversified survival strategy and four that practice agriculture as a business. Home garden inputs and outputs were measured monthly. Quantified inputs were: household labour, household agro-system production, and purchased external renewable and non-renewable energy. Outputs measured were: sales, family and animal foods. While both strategies had similar indicators in biomass and energy production, vegetable richness, and soil quality, household garden function and sustainability differed between subsistence and commercial householders. Subsistence gardens complemented family diet and contributed to household system resiliency. They relied heavily on renewable energy sources from within their agro-system. Gardens in commercial households reduced fruit tree area and increased animal husbandry for the market. They depended more on purchased non-renewable energy sources and were less sustainable and much less energy efficient than traditional gardens.

Keywords Backyard agriculture · Energy flows · Smallholder strategies · Tropical agriculture · Yucatan

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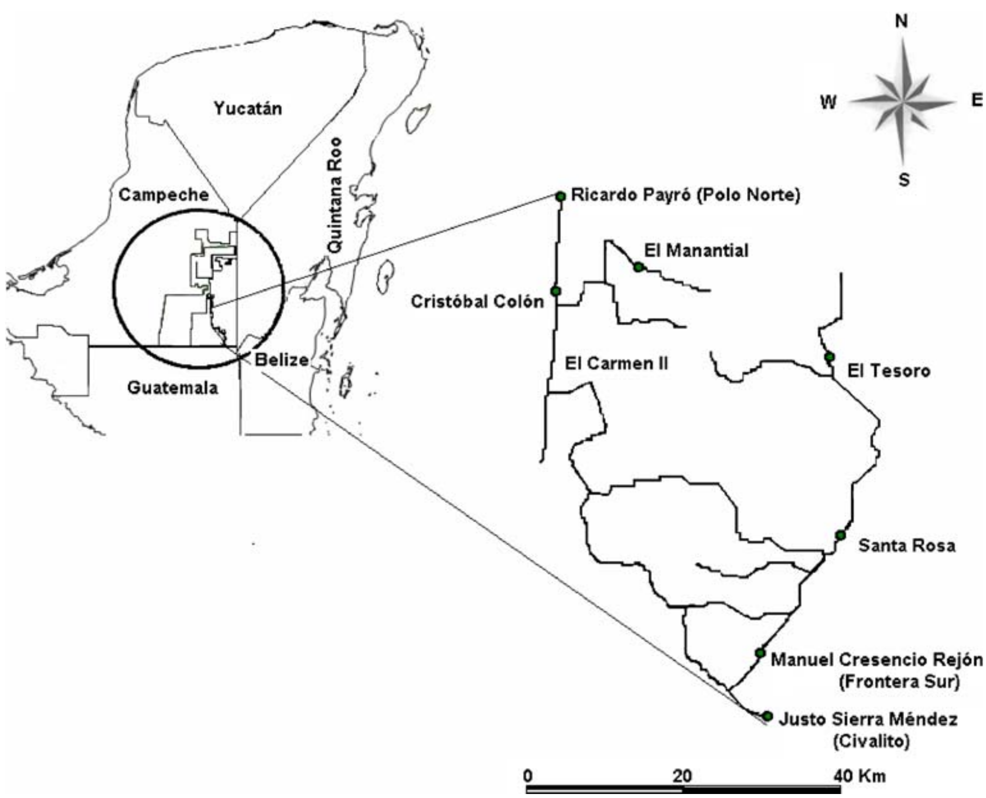
Introduction

Tropical home gardens are ecologically sustainable systems that not only generate important household savings on food, medicine and spice expenditures (Sanyal 1985; MacDicken 1990; Torquebiau 1992), but provide subsistence agriculturalists with a supplementary income and improve the nutritional quality of the families' diet (Immink *et al.* 1981; Niñez 1985b; Soemarwoto *et al*. 1985; Immink 1990; Nair 1997). They offer productive opportunities (MacDicken 1990), and their food products provide badly needed energy, protein, minerals and vitamins to low-income peasant households (Niñez 1985b).

These gardens have formed an essential part of peasant household agricultural systems in Latin America since pre-Columbian times (Stavrakis 1978; Nations and Komes 1983; Budowski 1990; Zuria and Gates 2006), and there have been many studies describing their botanical composition, nutrient cycling and component structures (De Clerk and Negreros-Castillo 2000). Less is known, however, of their ecological relationships with the household system and the surrounding environment (Nair 1997, 2001), and particularly little is known of the intricate relationships to the other components that sustain the smallholder strategy (Immink 1990; Torquebiau 1992). This is especially troubling where the transition from subsistence household agriculture to household commercial agriculture may not only be changing the home gardens structure and function, but also the intra-household dynamics of production, consumption and resource constraints that make home gardens part of a sustainable agricultural strategy (Immink 1990; Shajaat Ali 2005).

To study home gardens' system interactions and compare their role in households where agriculture is part of a diversified subsistence strategy to those that have turned it

Fig. 1 Location of the study area



into a business it is necessary to employ an integrated analysis and use a common indicator that will allow us to evaluate capitalist and non-capitalist peasant agricultural production. In this paper we used energy to study subsystems interactions. Energy is used as a common indicator because it allows us to evaluate the economic and ecological dimensions of coupled human environment systems (Odum 1996), and to quantify the effort invested in non-market oriented production (Revelle 1976). While energy flow analysis does not address all issues implied in sustainable development, it has been successfully used by Gliessman (2002) and others (Pimentel and Pimentel 1996; Tellarini *et al.* 1999) to compare the sustainability of different agro-ecosystems because it integrates material and economic flows (Fluck 1991; Odum 1996) in ways that allow us to test the independence, resiliency and environmental impacts of each system. In the case of tropical home gardens, energy flow analysis could also integrate productive, consumption and economic measures that are absent in the empirical data available in the tropical home garden literature (Nair 2001).

The present study quantifies and compares the energetic role of tropical home gardens in households that practice agriculture as part of a diversified subsistence strategy and households for which agriculture is a business in the Maya tropical forests of Southern Mexico. We expected to find home gardens that contributed to the adaptability, sustainability and resiliency of subsistence agriculturalists and were interested in exploring the possibility that as householders change agricultural practices to meet market needs, they also modify their home garden's function.

Study Area

The *municipio*[1] of Calakmul, Campeche, Mexico is located 350 km to the south of the state capital, and houses the Calakmul tropical forest Biosphere Reserve (Fig. 1). It contains a tropical rain forest with a mosaic of vegetation types with different structural appearances that reflect the variation in soils and other biophysical conditions (Turner *et al.* 2001). The region's karst topography is characterized by undulating uplands with elevations ranging from 100 to 350 m above mean sea level and the main soil types are rendzinas (Pérez-Salicrup 2004). A significant difference in total annual rainfall is observed from the south to the north, ranging from approximately 1,400 to 900 mm. Given high evapotranspiration, few permanent sources of surface water, and groundwater sources at depths in excess of 150–200 m, acute shortages of surface water are common toward the end of the dry season. Two main types of seasonal deciduous forest, upland forest (*selva mediana*) and wet land forest (*selva baja indundable*, or *bajo*), cover the area (Pérez-Salicrup 2004). This region has been identified as a

[1] Municipio: the smallest official administrative and territorial unit in Mexico.

hot spot of tropical deforestation, forest fragmentation and biodiversity loss (Turner *et al.* 2004). The forests are a mosaic comprised of old forest which have been heavily exploited for precious woods and secondary forest with a range of ages. The secondary forests are fallow of the slash-and-burn corn production system (*milpa*) which is the mainstay of the families.

The region was populated by colonists from 32 different states of Mexico who began to arrive in the region 30 years ago (Rodríguez 2003). The majority of the settlers originated in Chiapas, Tabasco and Veracruz (Gurri *et al*. 2002). Most of the colonists are peasants who in the past 20 years have developed two distinctive adaptive strategies (Gurri *et al*. 2002). Gurri and colleagues termed these strategies: "Household Subsistence Agricultural Strategy" (HSA) and "Household Commercial Agricultural Strategy" (HCA). Their main cash crop is jalapeño pepper (*Capsicum annum*) and their subsistence crop is maize (*Zea mays*). Other cash land-based options include citrus fruits, squash and grasses sold to the tourist industry of Quintana Roo (Vance *et al*. 2004). Both strategies differ, however, in how they organize to produce (Gurri 2002), in their family structure and household composition (Gurri 2003), in their goals as agricultural producers (Gurri 2006), and also in how they survive the last 2 months before the October harvest when food and other resources are scarce (Alayón and Gurri 2007). To the first strategy, HSA, agriculture is part of a diversified and conservative subsistence strategy that depends on different cultigens that may be harvested throughout the year, agroforestry, hunting, and seasonal labor. Most strategic, productive and distributive decisions are made by the family head, who controls his extended family's labor. The majority of their income is spent on consumer goods and they do not generate savings. For the second strategy, HCA, agriculture is the family business. They invest in agrochemicals, use tractors, hire outside labor to help them during harvest and produce primarily for the market. They generate savings when they sell their jalapeño crop. These savings are used to invest in capital goods, to buy cattle and to open bank accounts. The cattle are sold during the months before the harvest to purchase food and other necessary survival items when resources are scarce. Cattle may also be sold during the jalapeño pepper harvest to pay pickers (Gurri *et al*. 2002).

Materials and Methods

Sample Selection

The data for this study were obtained from eight peasant families that engaged in one of the two types of strategies described above. These families were classified in a previous study carried out by the Adaptability team from El Colegio de la Frontera Sur (ECOSUR) (Gurri *et al.* 2002) and are part of a representative sample of 500 household units from 32 communities in southern Calakmul, Campeche. For this study, three of the 32 communities studied were selected and families that had already been classified were invited to participate. Four of the HSA and four of the HCA families that showed most enthusiasm were chosen; the research was explained in detail and their written consent was obtained. The data were collected between January 2002 and March 2003.

Each household was considered as a unit of analysis and was treated as a system (Speeding 1988). Each families' agro-system was subdivided into three basic subsystems: 1—the local subsistence plot known as *milpa* which combines maize (*Zea mays*) with beans (*Phaseolus vulgaris*), squash (*Cucurbita sp.*) and other cultigens that vary locally, such as sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*); 2—their commercial plot dedicated mostly to the production of jalapeño peppers (*Capsicum annum*) and sometimes to other commercial cultigens cultivated after the peppers have been harvested; and 3—their home garden which combines fruit trees, edible shrubs, herbs, and animals.

Data Collection

Input and output matrices were analyzed for each subsystem, and the system as a whole (Norman 1978; Fluck 1992). In this paper we concentrated on the input and output matrices of both HSA and HCA home gardens and compared them in terms of their diversity, productivity and ecological sustainability. Inputs and outputs for the entire agricultural system were obtained from monthly interviews, and direct measurements.

A questionnaire was applied every 30 days for 15 months. Each questionnaire was answered by both male and female household heads. Using local measurement units and product names, household heads were asked to provide information on the type, quantity and cost of all herbicide, insecticide, fungicide, and fertilizers they utilized during the 30 days preceding the interview. They were also asked to list the tools they had employed as well as the plants and animals they reared. Finally they were questioned as to the types of activities they had performed in their home gardens and the time they had invested in each.

To quantify production and inputs, a family member, usually a male adolescent or the female household head were trained to register all garden produce consumed or sold by family members during the 30 days preceding our visit. They were also asked to record every garden item lost, sold, or invested in other household agricultural subsystems and to keep track of any *milpa* or jalapeño field products used in the garden. Finally, once a month the first author made direct vegetable and animal biomass measurements. To measure the biomass contributed by plants in the home garden, all edible fruits were weighed, and litter and herbaceous biomass were measured. Litter was carefully collected from two randomly placed 1 m^2 permanent traps. Litter sampling was done at monthly intervals for 1 year. Litter was classified into different components such as leaf, woody and reproductive parts. A sample of the litter was dried at 60°C in hot air oven and weighed to determine dry matter (DM) concentration, and the dry samples were sent to a laboratory to determine Gross Energy (GE) concentration (AOAC 1980).

To measure home garden herb production five randomly distributed 1 m^2 plots were harvested every 30 days. A sample of the harvested materials was selected to determine their DM contents after drying them in a stove at 60°C. In addition, a compound soil sample was obtained every three months from 15 cm deep cores from each of the 1 m^2 plots. The soil sample was divided in two. The first sample was dried in a stove at 60°C until reaching constant weight to determine percent humidity. The second sample was dried at room temperature and was sent to a laboratory that followed Sheldrick's (1984) protocol to determine Organic Matter (OM), organic Carbon (C_o), total Nitrogen (N_t) and pH concentrations. Edible fruit samples were weighed and total production was estimated multiplying by the amount consumed or sold as reported in each of the monthly questionnaires. Edible fruit dry weight was obtained after drying them in a stove at 70°C. The dry samples were ground with a hammer mill with a 3 mm sieve and sent to a laboratory for GE determination (AOAC 1980).

All animals present in the home garden were counted every 4 months. One randomly chosen animal from each species and each developmental stage present was weighed every 4 months to estimate seasonal changes in total animal biomass. Their cost to the system was estimated by adding the food, medicine and labour energy invested by family members in each animal. Their contribution to the system was obtained from estimating the total amount of meat or eggs utilized by the family and animal deaths were quantified as losses. Finally, the sum of all inputs and outputs was standardized for comparison in Mega Joules per hectare (MJ/ha). It is important to keep in mind that total system's investment in animal growth will be underestimated since only those inputs provided by humans were quantified and backyard animals in Calakmul obtain unknown amounts of their diet while foraging unsupervised in and outside the garden.

Energy Measurement and Flow

A process analysis was used to measure energy flow (Fluck 1992) adding human work contributions (Odum 1996). These were estimated by extrapolating standard energy values, most of them obtained during a previous time allocation analysis (Alayón and Gurri 2005) and others from reference sources (Fluck 1992; Pimentel and Pimentel 1996; Gliessman 2002) on the activities reported by our household informants in our monthly questionnaires (Alayón 2006).

An input–output model was developed following Leontief's (1936) system. Internal and external inputs were measured in Mega Joules (MJ) and divided into renewable (biological or cultural energy) and non-renewable (fossil energy) energy sources (Gliessman 2002), which were further subdivided into: internal renewable energy, external renewable energy, internal non-renewable energy and external non-renewable energy. Outputs, also measured in MJ, were obtained from the sum of: energy invested in family consumption; energy lost to the market, energy consumed by home garden animals,' and non-collected garbage classified as potentially reusable energy.

The system structural and functional indicators of Tellarini *et al.* (1999) were used respectively to characterize and describe the system's efficiency. Input structural indicators were: index of dependence on non-renewable energy sources (IDNRE), and index of overall sustainability (IS). Output structural indicators were: index of immediate removal (IIR), and global index of immediate internal destination (GIID). The functional indicators estimated were: index of gross yield from total input (IGY), index of gross yield from total external input (IGYEI), and index of gross yield from external non-renewable input (IGYNRE) (Table 1).

The data were analyzed with a Mann–Whitney μ test using the statistical package SPSS (ver. 11.5) (Daytham 1999). A larger sample may have allowed us to use t-tests or one-way ANOVAs to test for differences between strategies. Unfortunately, however, the amount of man hours of observation time, and effort invested in data collection throughout the year made a greater sample size unmanageable. A Mann–Whitney μ test converts the raw data into ranks before comparisons are carried out allowing us to ignore assumptions about homogeneity of variances and normality. This procedure will mask real differences between strategies but will reduce the possibility of finding significant results when they don't exist. For this study, sample size was selected under the assumption that the quality of our data would allow us to find significant differences between strategies in spite of the lower resolution power of non-parametric statistics.

Results

Home Garden Characteristics

Households from both strategies had 2,500 m^2 plots divided into a housing area, an area without trees and an area with

Table 1 Agro-Environmental Performance Indicators Measured in Each Home Garden in Calakmul, Campeche (from Tellarini *et al*. 1999)

Performance indicators		
Structural indicators		
Input indicators	Index of dependence on non-renewable energy sources (IDNRE)	It's the ratio of total external non-renewable energy to total energy introduced into the system.
	Index of overall sustainability (IS)	It's the complement of IDNRE and is estimated as 1-IDNRE. It's the ratio of input from internal agricultural energy to total input invested in the system.
Output indicators	Index of immediate removal (IIR)	It's the ratio of energy output destined for consumption to total energy output.
	Global index of immediate internal destination (GIID)	It's the ratio of energy output immediately re-invested into the system to total energy output.
Functional indicators		
Index of gross yield from total input (IGY)		It's the energy obtained (gross or net) per energy unit introduced (from any source) into the system.
Index of gross yield from total external input (IGYEI)		It's the total energy obtained from the system for each external energy unit invested.
Index of gross yield from external no-renewable input (IGYNRE)		It's total energy produced per unit of non-renewable energy introduced into the system.

fruit trees. The HCA housing and fruit tree areas were smaller than in HSA households. On average HCA houses were 50 m^2 smaller than HSA and had fruit tree areas that measured 234 m^2 less (Fig. 2). While this difference affected the abundance and number of fruit and other edible plants present in each garden (see Table 2 for a plant inventory per strategy), differences in vegetable diversity between strategies as measured by the Simpson Index (D) were not significant. Neither were there significant differences in the chemical composition of the soils (Table 3). Soils in both home gardens had similar concentrations of OM, N_t and C_o. Their pH average was 7.5 and they contained similar amounts of moisture.

Home Garden Inputs

On average HCA home gardens invested 31735.48 MJ and HSA 45132.70 MJ. These differences were not significant (Table 4). Significant differences between strategies were found, however, in the distribution of their energy sources. Table 4 shows the results of a Mann Whitney μ test that compares differences in the contribution to total energy

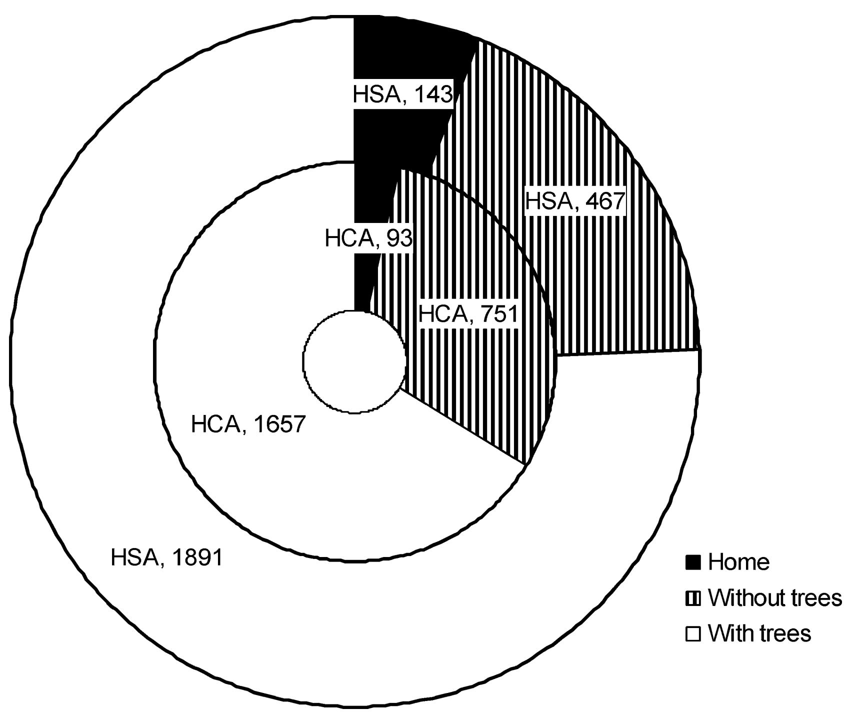


Fig. 2 Home plot area distribution in m^2 per strategies in Calakmul, Campeche, Mexico

Table 2 Home Garden Plant Inventory per Strategy in Calakmul, Campeche, Mexico

HSA						HCA					
Common name	Scientific name	Absolute freq.	Common name	Scientific name	Absolute freq.	Common name	Scientific name	Absolute freq.	Common name	Scientific name	Absolute freq.
Allspice	*Pimienta dioica*	5	Tropical cedar	*Cedrela mexicana*	3	Aerial yam	*Dioscorea bulbifera*	1	Peanut	*Arachis hypogaea*	1
Aloe	*Aloe vera*	1	Unknown tree	*N/D*	1	Almís	N/D	1	Physic nut	*Jatropha curacas*	1
Avocado	*Persea americana*	2	Xate palm	*Chameadora seifrizii*	1	Aloe	*Aloe vera*	7	Pitahaya	*Hylocercus undatus*	1
Banana	*Musa paradisiaca*	32	Zapote	*Pouteria mammosa*	3	Anotta	*Bixa orellana*[2]	1	Rose	*Rosa sp*	3
Bay cedar	*Guazuma ulmifolia*	1	Total	*n*	151	Avocado	*Persea americana*	4	Rue	*Ruta graveolens*	1
Birch wood	*Bursera simaruba*	2				Banana	*Musa paradisiaca*	13	Sour lemon	*Citrus limonia*	1
Bitter orange	*Citrus aurantium*	2				Bay cedar	*Guazuma ulmifolia*	1	Spiny custard apple	*Annona muricata*	4
Black nightshade	*Solanum americanum*	2				Bitter orange	*Citrus aurantium*	4	Sugar cane	*Saccharum officinarum*	1
Breadnut	*Brosimum alicastrum*	2				Black nightshade	*Solanum americanum*	1	Sweet cassava	*Maranta arundinacea*	1
Buganvila	*Bougainvillea buttiana*	1				Buganvila	*Bougainvillea buttiana*	1	Sweet orange	*Citrus sinensis*	23
Caimito	*Chrysophyllum caimito*	1				Caimito	*Chrysophyllum caimito*	1	Tabacco	*Nicotiana tabacum*	1
Cashew	*Anacardium occidentale*	2				Cashew	*Anacardium occidentale*	1	Teresita flower	*Montanoa grandifolia*	14
Chaya	*Cnidosculus chayamansa*	4				Cassava	*Manihot esculenta*	1	Tiger wood	*Erythrina standleyana*	1
Chayote	*Sechium edule*	4				Castor bean	*Ricinus communis*	1	Tomato	*Licopersicum esculentum*	1
Chili max	*Capsicum annum* var *ariviculare*	3				Chaya	*C nidosculus chayamansa*	1	Tropical almond	*Terminalia cattapa*	1
Chinese rose	*Hibiscus rosa-sinensis*	6				Chayote	*Sechium edule*	4	Tropical cedar	*Cedrela mexicana*	2
Coconut	*Cocos nucífera*	1				Chicozapote	*Manilkara zapota*	1	Unknown tree	*N/D*	1
Corral	N/D	1				Chili max	*Capsicum annum* var *ariviculare*	4	Velvet bean	*Mucuna pruriens*	1
Cotton	*Gossypium hirsutum*	1				Chinese rose	*Hibiscus rosa-sinensis*	1	Total	*n*	168
Custard apple	*Annona purpúrea*	4				Chives	*Allium schoenoprasum*	2			
Dogwood	*Piscidia piscipula*	1				Coconut	*Cocos nucífera*	2			
Flamboyant	*Delonix regia*	1				Cotton	*Gossypium hirsutum*	1			

Guava	*Psidium guajava*	4	Cow okra	*Parmentiera edulis*	1
Guaya Cuban	*Melicoccus bejigatus*	4	Custard apple	*Annona purpúrea*	4
Guaya Native	*Talisia olivaeformis*	1	Dogwood	*Piscidia piscipula*	1
Hogplum	*Spondias mombin*	2	Goose foot	*Chenopodium ambrosoides*	2
King orange	*Citrus nobilis*	2	Guava	*Psidium guajava*	8
Lemon	*Citrus aurintifolia*	2	Guaya Cuban	*Melicoccus bejigatus*	2
Lemongrass	*Cymbopogon citratus*	1	Hogplum	*Spondias mombin*	2
Madrial	*Gliricidia sepium*	2	Huaxim	*Leucaena leucocephala*	1
Mahogany	*Swietenia macrophylla*	2	King orange	*Citrus nobilis*	2
Moon flower	*Datura inoxia*	2	Lemon	*Citrus aurintifolia*	2
Neem	*Azadirachta indica*	1	Lemongrass	*Cymbopogon citratus*	1
Papaya	*Carica papaya*	1	Limon mandarino	*Citrus spp*	1
Passion flower	*Pasiflora coriacea*[2]	8	Madrial	*Gliricidia sepium*	1
Pata de vaca	*Bahuinia divaricata*	1	Maguey	*Agave fourcroydes*	2
Physic nut	*Jatropha curcas*	1	Mahogany	*Swietenia macrophylla*	3
Pitahaya	*Hylocereus undatus*	2	Mango	*Mangífera indica*	4
Rue	*Ruta graveolens*	1	Mexican piper	*Piper auritum*	1
Spiny custard apple	*Annona muricata*	12	Nance	*Byrsonima crassifolia*	3
Sugar cane	*Saccharum officinarum*	1	Nopal	*Opuntia spp*	1
Sweet orange	*Citrus sinensis*	22	Orange cordia tree	*Cordia dodecandra*	1
Tiger wood	*Erythrina standleyana*	2	Papaya	*Carica papaya*	2
Tropical almond	*Terminalia cattapa*	1	Parsley	*Petroselinum sativum*	25

Simpson Index (D): HCA=0.937; HSA=0.917; E.E. 0.05; *t* Student test t=1.991, (P<0.05)=0.09; *N/D* Not determined

Table 3 Soil Characteristics per Strategy in Home Gardens from Calakmul, Campeche, Mexico

Soil components (%)	Strategy HCA (n=12)	HSA (n=12)	E.E.	t-test	P-value
OM	7.23	7.51	0.92	−0.313	P>0.05
N_t	0.59	0.67	0.08	−0.948	P>0.05
C_o	4.19	4.36	0.53	−0.314	P>0.05
pH	7.40	7.50	0.08	−0.937	P>0.05
Moisture	26.20	23.60	3.35	0.746	P>0.05

HCA: Household Commercial Agricultural Strategy; HSA: Household Subsistence Agricultural Strategy; OM: Organic matter; N_t: Total nitrogen; C_o: Total organic carbon; E.E.: Standard error of the difference of the means

made by each energy source per strategy. HCA households employed significantly greater proportions of non-renewable energy than HSA households. The greatest differences, however, were that HSA households invested in their home gardens a greater amount of the renewable energy produced by their own agricultural system, while HCA gardens bought their external renewable energy (Table 4).

Energy input distribution differences between strategies are detailed further in Fig. 3. Both types of households raised Creole hens (*Gallus domesticus*), turkeys (*Meleagris gallopavo*), ducks (*Anas platyrhynchus*), pigs (*Sus scrofa*), and occasionally lambs (*Ovis ovis*). These animals ranged freely and were medicated only when they were obviously sick, yet HCA households invested more on medicine for their animals which may explain why they had higher survival rates (Alayón 2006). As much as 75% of HSA household's animal food was produced within the system, and as much as 42.8% of it came from agricultural by-products. HCA households on the other hand bought as much as 60.9% of their animal food. In addition, HCA peasants invested 770% more non-renewable energy than HSA households in agrochemicals and in the energy cost of the equipment used for garden production. Finally HSA households employed more wood from within their agricultural system for building animal shelters.

Home Garden Outputs

HSA overall energy obtained and the distribution of energy outputs were similar to those obtained by HCA (Table 5). Differences in the distribution of the output's destination between strategies were not statistically significant. Most of the energy produced in both home gardens was reinvested to be used as inputs the following year. Nevertheless, HSA home gardens reused a greater amount than HCA households, and although both strategies consumed a similar proportion of their output, the energy consumed by HSA households was greater in absolute terms, and it represented 10% more of the total energy utilized by humans during this agricultural cycle.

Figure 4 breaks down the information presented in Table 5. HSA gardens produced more litter from trees and herbaceous plants, which will potentially increase soil fertility, than HCA gardens. HSA garden fruit production was greater than that of HCA. Nevertheless, HCA farmers dedicate a much greater proportion of their production to the market (51.5% of their total fruit energy produced vs 39.3% in HSA) so that they sold almost as much fruit energy as HSA households and consumed considerably less. HCA garden animals produced 1193.1 MJ more than HSA animals and HCA households directed as much as 61% of their total animal energy outputs to the market. Because HSA households only sold 52% of their whole animal energy outputs, HSA and HCA household members consumed almost the same amount of energy from their home garden animals (1326.0 HCA vs. 1197.2 HSA). Both strategies separated similar absolute amounts of animal energy to replenish the stock. This energy, however, represented only 16.4% of HCA home garden animal production and as much as 22.8% of HSA's.

Sustainability

Structural and functional indicators used to evaluate differences in sustainability between strategies are presented in Table 6. Significant differences were found in structural

Table 4 Home Garden Energy Inputs Distribution in Mega Joules (MJ) per Strategy in Calakmul, Campeche, Mexico

Input	Strategy HCA (n=4) Mean rank	HCA Percent	HSA (n=4) Mean rank	HSA Percent	M–Wμ	P-value
Non-renewable	6.50	2.94	2.50	0.18	−2.31	P<0.05
External renewable	6.25	40.63	2.75	11.19	−2.02	P<0.05
Internal renewable	2.75	56.43	6.25	88.63	−2.00	P<0.05
Total	3.50	100.00	5.50	100.00	−1.15	P>0.05

M–Wμ: μ Mann–Whitney test; Percentages estimated over total inputs in MJ per household which were: HCA=31,735.48 and HSA=45,132.70

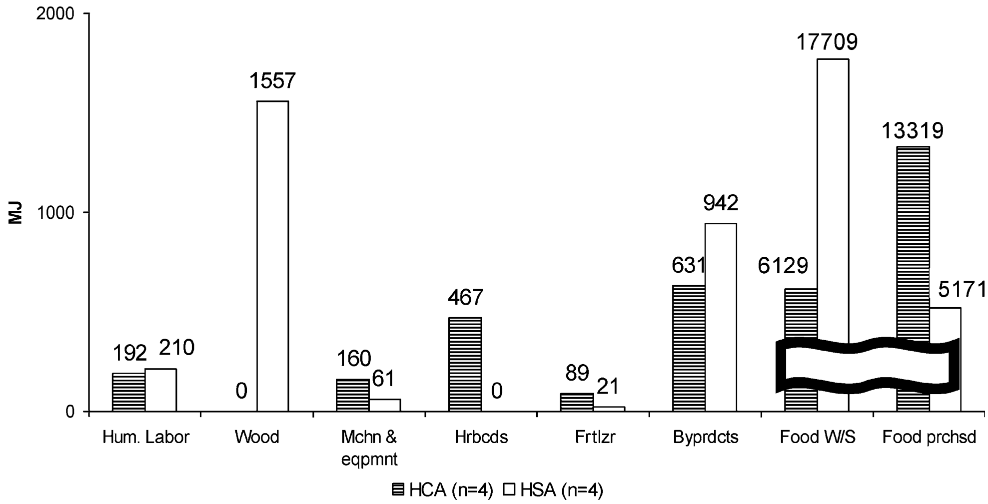


Fig. 3 Energy input distribution in mega joules (MJ) per strategy in home gardens from Calakmul, Campeche, Mexico (Hum. Labor: Human labor; Mchn & eqpmnt: Machines and equipment; Hrbcds: Herbicides; Frtlzr: Fertilizers; Byprdcts: Byproducts; Food W/S: Food produced; Food prchsd: Food purchased)

input indicators. HCA households depended more on non-renewable energy sources so that their index of dependence on non-renewable energy sources (IDNRE) was significantly greater. In addition, because HSA households invested energy produced within their own system, their index of overall sustainability (IS) was significantly greater and their ratio of total external non-renewable energy to total energy introduced into the system (IDNRE) was significantly lower.

Functional indicators showed that modern technology and industrial inputs did not make HCA home garden production more energetically efficient. The index of gross yield from total input (IGY), and index of gross yield from total external input (IGYEI) did not show any significant differences between strategies in energy yield per unit of investment. In addition, the index of gross yield from external non-renewable input (IGYNRE) showed that even though HSA households use less non-renewable energy, they are much more efficient in their use than HCA households. The HSA IGYNRE index value of 375.74 was four times the HCA IGYNRE index value of 78.83 and the differences were significant ($P<0.05$).

Discussion and Conclusions

In general, vegetable and animal biodiversity should be high in tropical home gardens and different structural arrangements and composition promote high fertility and constant soil humidity (Niñez 1985a; Gómez-Pompa *et al.* 1987; Rico-Gray *et al.* 1990; Nair 1997, 2001; De Clerk and Negreros-Castillo 2000). In Calakmul, both HSA and HCA home gardens had high biodiversity, similar concentrations of organic matter (OM), organic carbon (C_o), pH and relative soil humidity. In fact, the chemical characteristics of their soils were similar to those found in red soils, a fertile soil type, found in fallow fields where shifting cultivation has been practiced in Yucatan (Weisbach *et al.* 2002). In these gardens, high humidity was maintained throughout the year and this could have improved the OM availability and the utilization of the C_o and N_t of the soils.

Nevertheless, peasant agriculture is part of a household adaptive strategy and variability in sociocultural adaptations should be reflected in different agricultural practices (Geertz 1963; Loomis 1984; González Jácome 2003). Home gardens are an essential part of household agro-

Table 5 Home Garden Energy Outputs Destination in MJ per Strategy in Calakmul, Campeche, Mexico*

Output	Strategy					
	HCA (n=4)		HSA (n=4)		M–Wμ	P-value
	Mean rank	Percent	Mean rank	Percent		
Market	4.25	18.65	4.75	13.41	−0.28	P>0.05
Internal consumption	4.25	13.06	4.75	14.44	−0.28	P>0.05
Re-investment	4.50	68.29	4.50	72.15	0.00	P>0.05
Total	3.50	100.00	5.50	100.00	−1.15	P>0.05

M–Wμ: μ Mann–Whitney test; *Percentages estimated over total outputs in MJ per household which were: HCA=19643.43 and HSA=28191.05

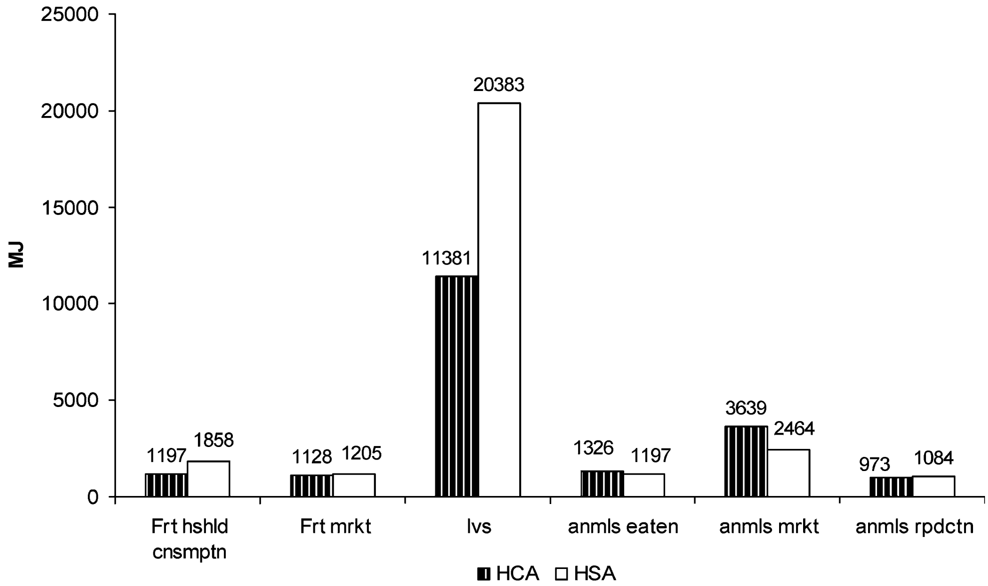


Fig. 4 Energy (MJ) output destination per strategy in home gardens from Calakmul, Campeche, México (Frt hshld cnsmpt: Fruit harvested and consumed by the family; Frt mrkt: Fruit harvested and sold inside and outside of the community; lvs: Litter and forbs; anmls eaten: Meat and egg produced by the animals in home gardens and consumed by the family; anmls mrkt: Meat and egg sold inside and outside the community; anmls rpdctn: Meat and eggs not utilized and invested on the home garden inventory)

systems in the tropics, and they show a wide variety of management practices (Wiersum 1982; Niñez 1985b; Torquebiau 1992). These have been shown to reflect socio-economic conditions, productive orientations, global family strategies and ecological conditions (Wiersum 1982; Sanyal 1985; MacDicken 1990; Méndez *et al*. 2001; González Jácome 2003; Shajaat Ali 2005).

In subsistence shifting agriculture home garden production complements the family's diet, helps protect the family when the main crops fail, and it generates some monetary income throughout the year (Wiersum 1982; Niñez 1985a; Immink 1990; MacDicken 1990; Méndez *et al*. 2001). Commitment to agriculture as a business, however, is accompanied by changes in garden structure and function. These changes affect the home garden's energy flow throughout the entire household agricultural system. Home gardens in subsistence agricultural households are occupied by plants that complement the basic foods obtained from their agricultural plots (Jiménez-Osornio *et al.* 1999; Méndez *et al*. 2001; Shajaat Ali 2005). In Calakmul, the surface area dedicated to fruit and other edible plants and total biodiversity tended to be greater in HSA than in HCA gardens. Like other slash-and-burn agriculturalists, the biodiversity of HSA home gardens is an important nutritional complement to their global strategy (Geertz 1963; Niñez 1985a; Okafor and Fernandes 1987; McC Netting 1993; Herrera 1994; Asfaw and Nigatu 1995; De Clerk and Negreros-Castillo 2000). Their production contributes directly to the diet by introducing seasonal and nutrient variety and producing savings in food investment reducing the uncertainty of tropical dry agriculture (Torquebiau 1992).

In Ethiopia (Asfaw and Nigatu 1995); Colombia (Pinton 1985), Nigeria (Okafor and Fernandes 1987); Nicaragua (Méndez *et al*. 2001), Bangladesh (Shajaat Ali 2005), and the Yucatan Peninsula (Gómez-Pompa *et al*. 1987; Rico-Gray *et al*. 1990; Herrera 1994; Ruenes and Jiménez-Osornio 1997; Jiménez-Osornio *et al*. 1999; De Clerk and Negreros-Castillo 2000) subsistence home garden production depends on biodiversity management through the integration of byproducts from other household agricultural subsystems. Thus, the biodiversity required by subsistence home gardens favors energy exchange between traditional subsistence gardens and other elements of the household's agricultural system. In Calakmul, HSA gardens depend on greater energy interaction between the household agricultural subsystems than HCA households. More agricultural byproducts from other parts of the system are incorporated into garden production mainly as animal feed and fertilizers than in HCA home gardens and more of their biomass production is recycled into energy for family members and animal husbandry. This management is combined with a smaller investment on non-renewable and external renew-

Table 6 Structural and Functional Indicators of Sustainability per Strategy in Home Gardens from Calakmul, Campeche, Mexico

Indicator	Strategy			
	HCA (n=4)	HSA (n=4)	M–Wμ	P-value
Structural				
IDNRE	0.029	0.002	−2.370	P<0.05
IS	0.971	0.998	−2.370	P<0.05
IIR	0.186	0.134	−0.290	P>0.05
GIID	0.814	0.866	−0.280	P>0.05
Functional				
IGY	1.950	7.740	−1.440	P>0.05
IGYNRE	78.730	375.740	−2.310	P<0.05
IGYEI	2.070	8.290	−1.440	P>0.05

M–Wμ: μ Mann–Whitney test

able energy sources making HSA home gardens more sustainable than HCA and four times more efficient. Similar differences in energy efficiency between productive gardens were observed by Shajaat Ali (2005) in Bangladesh, Pinton (1985) in Colombia, and Peyre *et al.* (2006) in India where efficiency was diminished by an increased dependence on external inputs and a greater use of non-renewable energy sources.

The productive decisions of households whose business is agriculture are regulated by the market. Their profitable home gardens sacrifice the subsistence components that make traditional home gardens an essential part of traditional agricultural strategies. Commercial households have fewer nutritious plants in their home gardens and dedicate a smaller area for cultivation. Peasants who shifted to commercial agriculture in response to bigger markets and greater labor opportunities increased their garden animal husbandry, particularly chickens and small ruminants that can be easily sold (Padoch *et al*. 1985; Pinton 1985; Niñez 1985a; Immink 1990). Commercial agriculture increased their dependence on wage labor and their external energy inputs in veterinary products, animal feed, and food for the family (Niñez 1985a,b; Padoch *et al.* 1985).

As expected in Calakmul HCA home garden production followed this pattern. Unlike their HSA counter parts, HCA households hardly used any of their own agricultural byproducts or labor and depended more on their ability to buy animal foods, agrochemicals and equipment. As much as 76.3% of their energy sold came from home garden animals in comparison to the 67.1% of HSA households. Nevertheless, because HSA gardens are more productive both strategies sold similar amounts of energy, although the amount sold may have represented important cash differences that favor HCA households. The emphasis on animal production for the market has also been observed amongst rural colonists of urban origin in the tropical forests of Colombia (Pinton 1985; Sanyal 1985). In Calakmul, all HSA migrants came from agricultural households in their home towns, but many HCA migrants came from urban areas (Rodríguez 2003).

Finally, these findings confirm that rural traditional agroecosystem management of natural resources, social capital and their economy is rational (McC Netting 1993; Nielsen *et al*. 2006). HSA household gardens in Calakmul, like traditional agricultural systems elsewhere (Norman 1978; Wiersum 1982; Pinton 1985; Soemarwoto *et al*. 1985; Gliessman 2002), are more efficient, more productive, less dependent on outside sources beyond their control than their commercial counterparts and are an integrated element of a much more sustainable agricultural system. HCA migrants like peasants who make a shift towards market oriented intensive systems (Naylor 1996; Pimentel and Pimentel 1996; Pimentel *et al*. 1999; Altieri 2002) depend more on outside labour, non-renewable energy sources and external renewable energy that decrease their efficiency and productivity.

Like other commercial agriculturalists, HCA households must adapt locally to global demands. To do this they transformed traditional home gardens from an integral part of a household's agricultural system that increased its sustainability and resiliency to an almost autonomous money-making element as unsustainable and vulnerable to outside forces as the rest of their system. Unfortunately, to compete in a global market, peasants will consciously ignore the limits imposed by local ecological conditions compromising the sustainability of their own survival system.

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