Enhancing the Sustainability of Smallholder Crop-Livestock Systems in the Yucatán Peninsula

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Balance Statement

Low stature tropical forests, such as found on the Yucatán Peninsula, Mexico, are globally a threatened ecosystem, largely due to human habitation and development of agricultural activities. The virtual abandonment of sisal production surrounding Mérida has facilitated the regeneration of large areas of secondary forest. These forests provide multiple services, including carbon sequestration and biodiversity. At a more local scale, the forests are the principal agricultural resource for smallholder farmers. The farmers practice what is called 'slash and burn' agriculture, known locally as *milpa*, whereby a portion of forest is slashed, burned, cropped for 2 years and then returned to forest fallow. Increasing population density and uncertain land tenure have shortened the fallow period from more than 25 years to less than 10 years. Shorter fallow periods ultimately deplete soil nutrients, decrease crop yields and thus result in additional land clearing to meet human food needs. Rural poverty continues unabated in Yucatán state, and the reality is that the *milpa* system will in the foreseeable future continue to be a significant form of land-use for the rural poor.

Ownership of sheep by smallholder farmers is becoming increasingly common due to strong demand for mutton in Mexico City. Small livestock, particularly sheep, have the potential to sustain and enhance the productivity of the milpa system through increased cycling of soil nutrients, potentially increasing the length of the forest fallow. The proposed study will assess and model the interactions between cropping, sheep production, farmer incomes, and the natural resources, to enhance the sustainability of these mixed cropping-livestock systems. Multiple forest use practices involve synergies and trade-offs between environmental, production and economic goals. It is critical that our understanding of these interactions is increased, to improve the well-being of farm households in the region and ensure the preservation of the natural resources.

Project Summary

Glossary

<u>Slash and Burn Agriculture</u> – A method of cultivation used by farmers in many tropical parts of the world. Areas of the forest are burned and cleared for planting; the ash provides some fertilization, and the plot is relatively free of weeds. After several years of cultivation, fertility declines and the land is abandoned and returned to forest.

<u>Mixed Farming Systems</u> – Farming systems where livestock rearing and crop cultivation are, to a greater or lesser extent, integrated components of one farming system. Outputs from one enterprise (e.g. manure, crop straws) are inputs for another.

Hair Sheep – Sheep that do not grow wool and are produced for meat. Breeds such as 'Pelibuey' and 'Barbados Blackbelly' are adapted to the heat, humidity, parasites and low feed quality of the tropics.

System dynamics – System dynamics is a thinking and modelling approach that emphasizes the role that the structure of a system (its stocks, flows and feedback processes) determine the evolution of a problematic behaviour over time. Based on concepts from the theory of nonlinear dynamics and feedback control developed in physics and engineering, system dynamics emphasizes how problems often arise from feedback processes—circular causality—rather than simple one-way causal relationships. System dynamics modelling has been applied to assess numerous problems in natural resources, economics, and business.

Purpose

Problems:

- A lack of employment opportunities for rural people in the Yucatán Peninsula is associated with widespread poverty and malnutrition.
- There exist seemingly competing goals for forest use, including agriculture, livestock production, and preservation for biodiversity.
- Smallholder sheep farming is a recent but expanding agricultural enterprise, however, little is known about the potential positive interactions between sheep farming, household economics, crop production and the environment.

Solutions:

- The necessary first step is an increased understanding of the elements and behavior of the system, including identifying interactions between farming activities and the environment.
- In other areas of the world where slash and burn agriculture is dominant there is a focus on intensifying production so that less forest needs to be cleared. Intensification of agriculture in the Yucatán Peninsula through appropriate incorporation of small livestock has the potential to decrease the land needed for agricultural production.
- Complementarities between cropping and livestock, particularly in the areas of nutrient recycling, suggest that livestock such as sheep can sustain and enhance agricultural production systems.

Plan

Six farms will be chosen, three solely cropping farms, and three mixed cropping and sheep producing farms. Operations on the farm will be closely monitored, and samples of soils and plants will be collected and analyzed. Using this information, a model describing nutrient flows in and out of the farm and between components of the farm will be constructed; for example, nutrients from sheep manure decompose and fertilize the soil for crops. The model will have a number of applications. First, there is a range of farmer practices that will have different affects on nutrient cycling. For example, what does a sheep farmer do with accumulated manure, and if it is applied to crops or forage, what would be the optimum timing? In addition to increasing understanding of observed conditions, a simulation model allows us to ask 'what if' questions and run scenarios to identify sustainable management strategies.

The development of a crop-livestock system model will increase our understanding, both through the iterative process of model development and use of the model to test the outcomes of possible farming strategies. The model will be a valuable tool for researchers and agricultural outreach specialists working in the region. In addition the model could be used by researchers and policy makers to predict the effects of potential interventions. Two recent courses in system dynamics at the Universidad Autónoma de Yucatán (UADY) in Mérida have stimulated interest amongst researchers and governmental officials in the application of system dynamics to address regional rural development issues. Policies often create unanticipated side effects, and sometimes attempts to stabilize a system may destabilize it. The proposed model could help avoid the unanticipated consequences of decisions by policy makers with good intentions but limited understanding of the dynamics of the system.

Benefits

The overall goal of this project is to generate information to enhance the sustainability of crop-livestock production systems and improve the well-being of smallholder farmers in rural Yucatán state. This will be accomplished through analysis of the potential for increasing socioeconomic, agricultural and environmental sustainability of rural Yucatán farming practices. Sheep producers are benefiting from the strong demand for mutton, both locally and in the Mexico City market. Because of its accessibility to small producers, sheep production represents a significant development opportunity and a potential means to increase smallholder incomes and reduce poverty.

In addition, there is the potential for great environmental benefits from integrating sheep farming with traditional cropping practices, including improved nutrient recycling and use of cropping by-products for feeding animals. With increasing intensification of agriculture, properly balanced, the pressure on valuable forests can be relieved.

Although the project is focused on the Yucatán Peninsula, the issues are relevant to other parts of Mexico and other tropical regions of the world. The methods that we propose, using system dynamics to link agricultural, economic and environmental outcomes have received only limited application. In a world with increasing population and demand for livestock products, there is need for novel methods that can generate greater understanding of the characteristics and development of environmentally sustainable livestock systems.

Methodology

The objectives of this study are to identify sustainable farming practices through assessment of the dynamic interactions within mixed crop-livestock systems compared to crop only systems, including managed and natural resources. The assessment will include agronomic, environmental and socioeconomic sustainability. To achieve these objectives, a simulation model (or models) with multiple scales and areas of research will aid analysis of the current sheep farming system and allow for prediction of the impact of interventions on key outcomes in the system.

Three villages will be chosen from different locations in the state, and within each village a crop farmer and a mixed crop-livestock (sheep) producer will be chosen, giving a total of six farms. Livestock producers will be chosen to characterize representative management practices. The first focus area will be modelling nutrients, based on the hypothesis that nutrients are a major limitation on production and sustainability in slash and burn agricultural systems. This will involve data collection to estimate the stocks of nutrients in soil, manure, crops and livestock and the nutrient flows as a result of typical farmer practices e.g., fertilization, manure use, grazing crop stubbles, importation of nutrients from 'cut and carry' from the forest, and use of legumes.

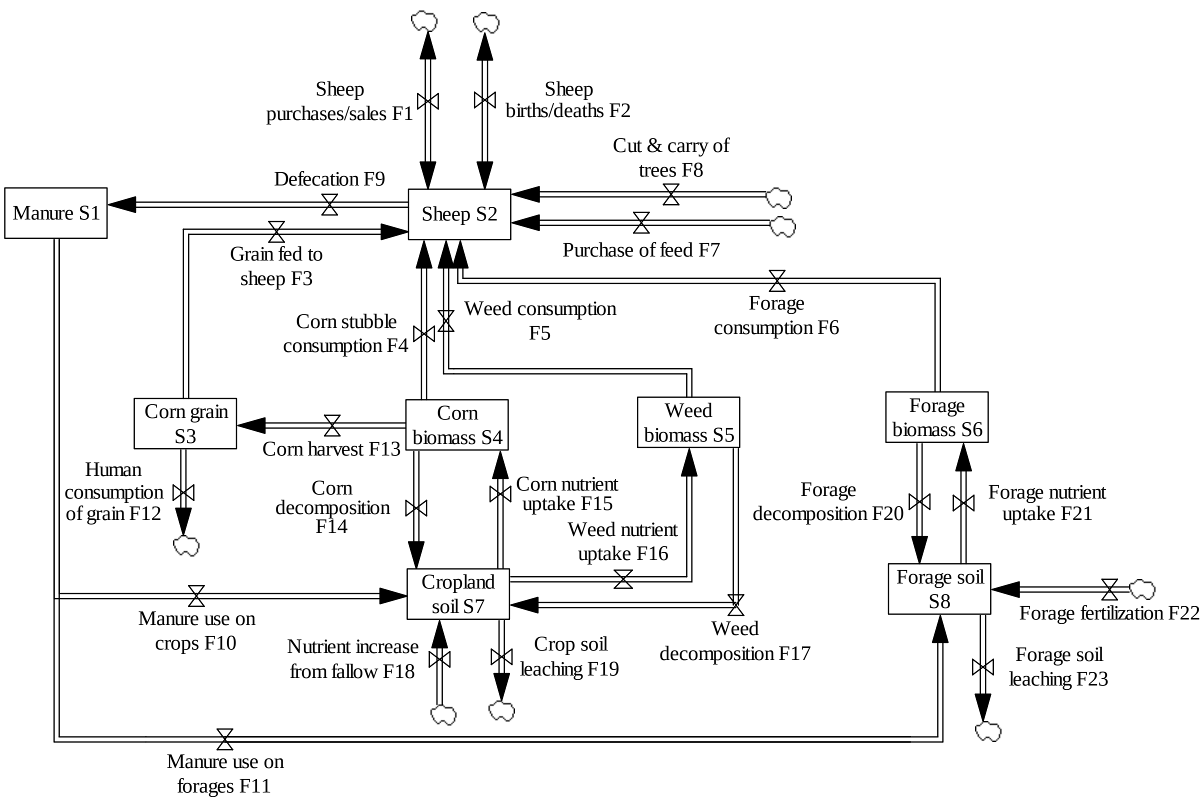


Figure 1 – Stock and flow diagram

Figure 1 shows a simplified stock and flow diagram for nutrients in a mixed farming system. Stocks, represented by boxes, are accumulations of nutrients and are numbered S1-8. Inflows and outflows are represented by pipes with the direction of flow indicated by arrowheads. The rates of flow are controlled by natural processes and human decisions, and are indicated by valves, numbered F1-23. Clouds represent sources and sinks for flows that are not within the boundary of the model.

In figure 1, many of the flows include both nutrients and other characteristics, such as plant biomass, sheep or manure. Specific details on how the data will be collected are as follows:

Soil data – Soil samples will be taken at regular intervals from the cropping and forage soils (S7, S8) and analysed for soil fertility status (pH, organic matter, available nutrients). Field fertilization practices (F22) will be estimated from farmer records. Crop and forage soil leaching (F19, F23) will be based on literature values and adjusted for local soil and rainfall data. Nutrient increase from fallow (F18) will be based on studies conducted in the region.

Plant data – Corn grain yield (S3/F13) will be directly measured at harvest. Levels of human grain consumption (F12) will be obtained through farmer interview. Corn, weed and forage biomass (S4, S5, S6) will be measured at intervals during the growing season. Decomposition rates for corn, weeds and forage (F14, F17, F20) will be estimated from biomass measurements and literature values. Corn, weed and forage nutrient uptake (F15, F16, F21) will be estimated from plant analyses, biomass measurements and literature values.

Manure data – The stock of manure (S1) will be measured periodically, thus enabling an estimation of defecation rates (F9). Farmer records and periodic measurements will be used to calculate manure use on crops and forage (F10, F11).

Sheep data – Sheep numbers and monthly weights will be recorded (S2), as will purchases, sales, births and deaths (F1, F2). All fodder fed to sheep will be measured and analysed, including grain (F3), corn stubble (F4), weeds (F5), forage (F6), purchased feed (F7) and 'cut and carry' of trees from the forest (F8).

Other data - The interaction of other physical and economic characteristics of the farm and farmer will also be modeled, and this will be linked to the nutrient section of the model as deemed appropriate. This will include additional physical and economic variables such as household labor, household member characteristics and off-farm income. The model will be developed using the collected data, supplemented with available data from comparable tropical systems, other available data specific to Yucatán, and data from a recent baseline survey of sheep farming practices (Parsons et al., 2004). This will enable the development of a general model, supported with detailed and specific case studies that will aid in understanding how differing farmer practices affect the system.

The results from this project will be linked with a market-level model being developed to assess the broader economic implications of productivity improvements on smallholder farms. This is an essential step because initial dynamic conceptual modelling of these sheep systems has suggested that the ultimate outcomes for smallholder sheep producers depend on the actions of sheep producers elsewhere in Mexico and on the characteristics of sheep meat demand in the Mexico City market (Nicholson, 2005). Thus, progression from a farm scale model to a broader scale will enable the analysis of the wider implications of interventions and policies.

Time Horizon

Data collection will begin in March 2006 and end in September 2007. This will enable the collection of soil samples before fields are planted and will also allow data collection over two cropping seasons. Sample analysis will begin in June 2006 and data analysis and model development will proceed concurrently.

Results/Application

The proposed work will generate an accounting of nutrient flows and economic characteristics of 3 crop farms and 3 mixed crop-livestock farms in Yucatán. The data will then be used to construct a system dynamics model.

There are a number of reasons for pursuing a dynamic systems modelling approach to this study. Agricultural systems are complex, and have numerous characteristics which render system dynamics modelling techniques appropriate. Analysis of the response of the model to changes in parameters can indicate priority information needs; that is, they can indicate where precise measurements are important to outcomes and where they may be less important. System dynamics models provide a framework within which to assess which interventions in the sheep production system will most benefit smallholder producers in the short and long run. Therefore models can assess the impacts of policy decisions outside the range of parameter values historically observed.

Development of a mixed farming system model will be a knowledge generating process in two ways. First, the iterative process of model development will require careful thought about how the various components of the system interact, resulting in increased understanding of the behaviors of the system. Second, using the model to test the outcomes of farmer decision making will increase learning of those exposed to the model.

A functioning model will be a useful tool for researchers and agricultural outreach specialists working in the region. The results will stimulate discussion and provide focus for future research efforts. In particular, the model will be used in short courses for the TIES initiative (U.S. Mexico Training, Internships, Exchanges and Scholarships), a partnership between Cornell University and UADY, funded by USAID. Previous courses have introduced participants to agricultural systems analysis and the model generated by this project will provide complementary educational benefits to the participants.

In addition to analyzing farmer practices in Yucatán, the model development process will have broader geographical application. By modelling the production effects of actions such as improving animal nutrition, increasing veterinary care, and implementing government grants, we can assess the effects on physical, economic and environmental sustainability of smallholder sheep systems in the region. Thus the model will also be of interest for policy makers to cultivate discussion of the effects of possible interventions and help determine where development money may be best spent.

Review of literature

Increasing Global Livestock Demand - Studies in recent years have indicated that the demand for livestock products, especially in the developing world, is likely to increase dramatically in the next two decades. The expected ‘explosion’ in livestock numbers will be fueled by growing population, rising income, and growing urbanization (LEAD, 2005). These forecasts present both opportunities and challenges. The increase in demand creates opportunity for increased participation of small-scale farmers, potentially alleviating poverty and spurring economic growth (Delgado et al., 1999). In terms of environmental consequences, it has been suggested that increasing livestock numbers and productivity may present an opportunity for enhancing natural resources, through maximizing the positive impacts whilst minimizing the negative (Nicholson et al., 2001). However, increased production can have negative consequences for the environment in certain situations, unless steps are taken to ensure that the natural resource base can be sustained while food production increases (LEAD, 2005). A key question is: how can livestock production increase to meet this demand for livestock products, using methods which the resource base can sustain? Mixed farming systems, where livestock and crops are produced within the same farm unit or in close proximity, should not be overlooked in offering potential for sustainable intensification (meaning greater output per unit of land). Mixed farming systems are extremely important in less developed countries. They produce the largest share of total meat (54%) and milk (90%) and are the main system for smallholder farmers in many less developed countries (LEAD, 2004); indeed two thirds of the world's rural poor rely on mixed crop-livestock systems for their livelihoods (ILRI, 2000).

The Decline of Commercial Agriculture in Yucatán - For much of the 20th century, the sisal fiber produced from henequen, (*Agave fourcroydes*) was the foundation of economic activity in the Yucatán Peninsula, Mexico. After World War II, due to surplus production in other parts of the world and the development of synthetic fibers, the market demand for sisal dropped. As a result, in the 1960's many areas of sisal were abandoned, and the decline of what was in essence a monoculture left a wounded agricultural economy, and an underemployed workforce (Sprague et al., 1978). However, due to government intervention, sisal production continued, and in 1970, partly due to a lack of alternatives, 50% of Yucatán's population remained employed in the production and processing of sisal (Mizrahi et al., 1997). The industry finally collapsed in 1992, when the government stopped subsidizing its production (Mizrahi et al., 1997). Partly as a result of the dramatic decline in sisal production, many rural households were left without employment, and no clear options for earning a living from the natural resources available.

Emergence of Sheep Farming - Small ruminants, particularly sheep, have for a long time been present in small numbers in the region. However it is only in the last 10 years that they have emerged in former sisal areas as an agriculture system component of growing importance. Hair sheep have great potential for meat production for a number of reasons. Although they have lower productivity than wool sheep in temperate areas, they have greater fertility (Segura et al., 1996). In addition, they are adept at browsing fibrous biomass and converting it into food, and the entry level of capital investment to purchase animals is less than for cattle. The state government, in recognition of the potential of the industry has helped some (mostly large) producers finance purchases of animals and infrastructure, including watering and housing facilities. A recent study (Parsons et al., 2004) found that 80 percent of the sheep producers in the Yucatán Peninsula are smallholders who combine sheep production with other rural agricultural and non-agricultural activities. In addition, most smallholder producers have little access to extension or government development programs, and have initiated the activity as a response to economic incentives. Sheep producers, including both smallholder farmers and the owners of more substantial sized operations, are benefiting from the strong demand for mutton, both locally and, more significantly, in the Mexico City market. Thus, sheep production has the potential to become a significant part of the economy of the State of Yucatán. Because of its accessibility to small producers, sheep production represents a significant development opportunity and a potential means to increase smallholder incomes and reduce poverty.

Natural Resource Parameters: Climate, soils and vegetation - It is important to consider the natural resources of Yucatán as significant shaping forces of past agricultural systems and the framework upon which future developments will be based. The climate of Yucatán is sub-humid tropical with a rainy season of 6 to 7 months in summer, followed by a 5 to 6 month dry season. Average annual rainfall is approximately 800-1000 mm, with approximately 80% of total precipitation occurring in the rainy season.

The thin soils of the Yucatán Peninsula are formed on Tertiary limestone. They are shallow and extremely stony, with limestone fragments making up a large portion of the soil matrix, thus largely precluding mechanical cultivation. Nutrient availability varies with many factors such as soil type, years of fallow and type of vegetation. Soils are generally slightly alkaline and low in available nutrients, with nitrogen, phosphorus, manganese, iron and zinc of particular concern (Sprague et al., 1978).

Low-stature tropical dry forests are distributed across sizeable areas of the Gulf of Mexico region, including some of the Yucatán Peninsula, particularly the northwest portion (Gonzalez-Iturbe et al., 2002). The tropical dry forests of the Yucatán Peninsula have been used and managed by the Maya people for hundreds of years. Legumes dominate secondary tropical dry forest sites, particularly in early succession, due to their capacity to fix nitrogen, and seed with characteristically hard testa that are resistant to fire and dry periods (Gonzalez-Iturbe et al., 2002).

The decline in sisal production has resulted in abandonment of many cultivated fields. Consequently, the area of tropical dry forest is increasing (Gonzalez-Iturbe et al., 2002). This may be a desirable outcome because such recuperation increases biodiversity, and regeneration of forests is seen as environmentally and aesthetically beneficial. However, viewing the scenario pragmatically, it is logical that landholders will make land-use decisions based on economic opportunities, incentives and constraints. The natural vegetation is becoming an increasingly valuable production resource for livestock, and consideration should be given to how conservation and production goals may be obtained synergistically.

Traditional Milpa Agriculture - Natural resource constraints have necessitated the development of suitable agricultural practices that depend on moisture from the rainy season. Traditional agriculture in the region is based on maize mixed with squash (*Cucurbita* spp.) and beans, such as ‘ib’ (*Phaseolus lunatus*) and ‘xpelón’ (*Vigna unguiculate*). Farming involves using slash and burn *milpa* techniques, where a small area of 0.5 to 2.5 ha is cleared by hand and burnt, thereby obtaining nutrients released from slashed vegetation for growth of the planted crops. Traditionally, species are planted together as a mixture of seeds at the beginning of the rainy season, and weeds and pests are controlled manually. Generally a two to three year cultivation period is followed by a ten to twenty year (or longer) period of forest fallow (Kessler, 1990). The increasing population density and limited land allocation has forced farmers, predominantly of Mayan heritage in small villages, to shorten fallow periods, creating areas of young vegetation and practically eliminating old growth forests. This also has important implications for the viability of farming, as shorter fallows reduce nutrient availability and increase the burden of weeds. Indeed, reported average maize yields of approximately 750 kg/ha are significantly below the national average yield of 2 t/ha. Weed infestation is reported to be common, resulting in increased chemical use and consequent reduction in companion planting of squash and beans (Caamal-Maldonado et al., 2001).

Intensifying Agriculture - As a response to the problems of traditional crop cultivation, alternative cropping systems have been promoted, with the objective of offering more sustainable crop production options. The ‘intensive milpa system’ (Lopez-Forment, 1998) involves adding animal manure to the soil, using improved open-pollinated varieties of corn, and planting the inter-row with the fast growing legume velvetbean (*Mucuna pruriens*). The idea is to increase nutrient recycling and reduce weed competition, so that the same land can be cropped for years without the need to slash a new field. Currently few farmers are using the system, one reason being that farmers don’t enjoy consuming the velvetbean (J. J. Jimenez-Osornio, personal communication). There is a growing realization amongst researchers of the potential of livestock to enhance the intensive milpa system. A recent study showed that addition of velvetbean to the diet of growing sheep in Yucatán improved animal weight gains (Castillo-Caamal et al., 2003). Thus there are many complementarities between livestock and an intensive cropping system, the result of which may also reduce the impact on the surrounding forested areas. There are more opportunities to mitigate the negative and enhance the positive impacts of livestock on the environment in mixed systems than in specialized systems (LEAD, 2005). In addition there are advantages from spreading income and risks over both crops and livestock production with flexibility to adjust crop/livestock ratio to economic needs and opportunities. Thus understanding, quantifying, and modeling of the physical and economic dynamics of the cropping-livestock-forest agroecosystem are the objectives of the proposed project.

Literature Cited

Caamal-Maldonado, J.A., J.J. Jimenez-Osornio, A. Torres-Barragan, and A.L. Anaya. 2001. The use of allelopathic legume cover and mulch species for weed control in cropping systems. *Agronomy Journal* 93:27-36.

Castillo-Caamal, J.B., J.J. Jimenez-Osornio, A. Lopez-Perez, W. Aguilar-Cordero, and A.M. Castillo-Caamal. 2003. Feeding Mucuna beans to small ruminants of Mayan farmers in the Yucatán peninsula, Mexico. *Tropical and Subtropical Agroecosystems* 1:113-117.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020: The Next Food Revolution. Washington, DC: International Food Policy Research Institute. [Food, Agriculture and the Environment Discussion Paper 28].

Gonzalez-Iturbe, J.A., I. Olmsted, and F. Tun-Dzul. 2002. Tropical dry forest recovery after long term Henequen (sisal, *Agave fourcroydes* Lem.) plantation in northern Yucatán, Mexico. *Forest Ecology and Management* 167:67-82.

ILRI. 2000. *Livestock strategy to 2010: Making the livestock revolution work for the poor*. ILRI (International Livestock Research Institute), Nairobi, Kenya. 112 pp.

Kessler, C.D.J. 1990. An Agronomic Evaluation of Jackbean *Canavalia ensiformis* in Yucatán Mexico i. Plant Density. *Experimental Agriculture* 26:11-22.

LEAD (Livestock, Environment and Development Initiative). 2005. *Livestock and environment toolbox.* FAO, Rome, Italy. Accessed March 2005. http://www.fao.org/lead/toolbox

Lopez-Forment, I. S. 1998. *Changes in Diversity in the Process of Milpa Intensification in the Henequen Zone in Yucatán, Mexico*. Meeting of the Latin American Studies Association, Chicago, Illinois.

Mizrahi, A., J.M. Ramos-Prado, and J.J. Jimenez-Osornio. 1997. Composition, structure, and management potential of secondary dry tropical vegetation in two abandoned henequen plantations of Yucatán, Mexico. *Forest Ecology and Management* 96:273-282.

Nicholson, C. F., R. W. Blake, R. S. Reid and J. Schelhas. 2001. Environmental impacts of livestock in the developing world. *Environment* 43: 7-17.

Nicholson, C. F. 2005. Description of the Yucatán Sheep Sector Model. Department of Applied Economics and Management, Cornell University. [mimeo]

Parsons, D., R.W. Blake, C. F. Nicholson, J. H. Cherney and A. G. Ríos. 2004. Encuesta para Productores Pequeños y Comerciales de Ovinos en el Estado de Yucatán. Universidad Autónoma de Yucatán and Cornell University. [mimeo]

Segura, J.C., L. Sarmiento, and O. Rojas. 1996. Productivity of Pelibuey and Blackbelly ewes in Mexico under extensive management. *Small Ruminant Research* 21:57-62.

Sprague, M.A., W.J. Hanna, and W.E. Chappell. 1978. Alternatives to a monoculture of henequen in Yucatán: the agriculture, climate, soil, and weed control. *Interciencia* 3:285-290.

Personnel

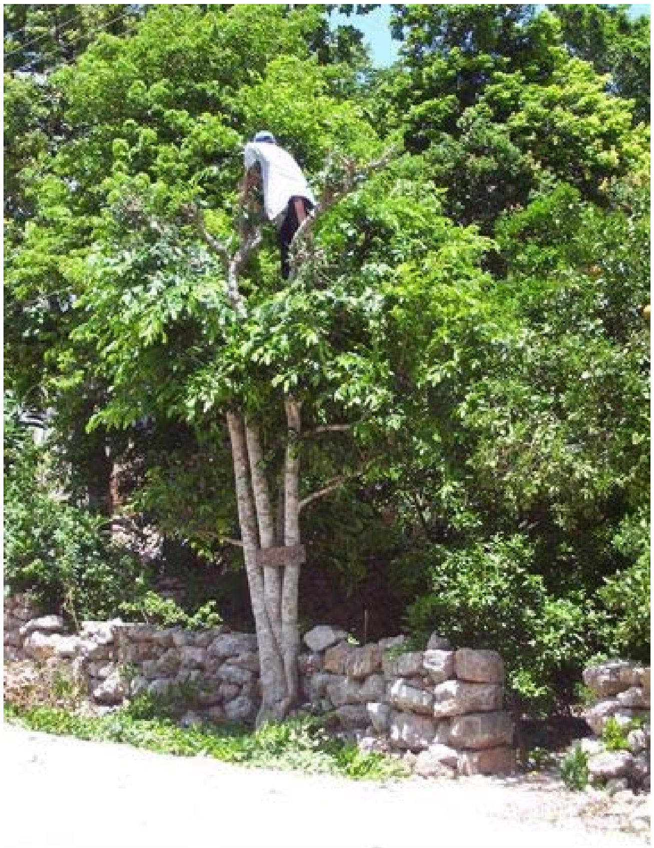
Personnel	Field	Role	Time
David Parsons, Graduate Student	Agronomy	D. Parsons is a Cornell University graduate student. He will be based in Mérida for the duration of the project and will be responsible for co-ordinating the project, sample collection, and data analysis, including model development.	100%
Jerry Cherney, E.V. Baker Professor of Agriculture	Agronomy Forage quality	J. Cherney will provide expertise in agronomy and forage quality. J. Cherney's forage quality lab will be available for sample analysis	10%
Robert Blake, Professor of Animal Science	International animal science	R. Blake is the Principal Investigator for the TIES project, a collaboration between Cornell & UADY, and will provide guidance to the project.	10%
Charles Nicholson, Senior Research Associate, Applied Economics and Management	Economics System Dynamics	C. Nicholson will provide expertise in simulation modelling and economic data collection and analysis.	10%
Guillermo Ríos, Lecturer in small ruminant production	Sheep production and nutrition	G. Ríos is based in Mérida and will provide logistical support for the project. G. Ríos also has invaluable knowledge of the area, sheep farming practices and local producers.	20%

Supporting materials
The following photos were taken by D. Parsons during a 2004 baseline survey of Yucatán sheep farming practices:


A smallholder mixed crop and sheep farm south of Mérida.


Demonstrating to producers how to determine the age of sheep.

A selection of leguminous shrubs cut from the forest and transported to the backyard for feeding to sheep.



Harvesting ramón (*Brosimum alicastrum*), a native plant and high quality sheep feed.