Developing legume shade trees for Sustainable coffee production in Puerto Rico

Final Report for LS04-162

Project Type: Research and Education
Funds awarded in 2004: $195,298.00
Projected End Date: 12/31/2008
Region: Southern
State: Puerto Rico
Principal Investigator:

Eduardo Schröder
University of Puerto Rico

Project Information

Abstract:

Coffee production in Puerto Rico is located in the central mountain region, mostly on acid, highly erodible soils. To improve sustainable production of high quality coffee, we collected soil, weather, and biomass production potential for the whole island and generated the first coffee agro ecological map. Traditional farms producing shaded coffee in 20 municipalities were surveyed. In each farm, tree species were identified and data georeferenciated with GPS and GIS. Soils of the coffee region were characterized. Nitrogen mineralization potential was measured, and with litter fall data, balance of N supplied for coffee estimated. Field sampling was performed to evaluate different sources of N fixation and the microbial soil population structure. Finally, the potential of more than 28 species of fast-growing nitrogen fixing trees was evaluated in two representative soils, with and without pH and nutrient supplements.

Tables, figures or graphs mentioned in this report
are on file in the Southern SARE office.
Contact Sue Blum at 770-229-3350 or
sueblum@uga.edu for a hard copy.

Project Objectives:

Objective 1. Survey present coffee production systems used by farmers in Puerto Rico

Objective 2. Evaluate the potential value of fast-growing nitrogen-fixing trees for the production of shade coffee.

Objective 1. During the project, the fieldwork data analysis and final writing for this objective has been completed by Mr. Miguel Arango (MS student). Using the amount of coffee produced by municipality, the 20 highest coffee producing municipalities were selected for field sampling. Combing the number of farms with shaded coffee with the map of coffee production area, coffee growers were located and interviewed. Each farm was sampled (1,000 sq meters plots) up to 5 acres or 2 plots for larger farms. In each plot, tree species were identified, measured for diameter at breast high (DBH) and tree high estimated. Plots were georeferenciated with GPS, and located in a GIS map, to correlate with soil map and altitude. Climatic data, potential plant growth estimates and soil characteristics were combined to produce a coffee agro-ecozoning map.

Objective 2: The amount of N recycled by litter fall was evaluated at three locations, where plots at sun-grown, shaded and a nearby forest were established. As expected, shaded coffee added more N to the soil, although forest litter was generally even larger. Laboratory and field soil samples were used to measure N mineralization and nitrification. The results also confirm that soil under shaded legume trees provides more nitrate for coffee.
Initial estimates of field biological N fixation by soil, leaves and lichens appear low, but natural 15N enrichment data demonstrate that Inga vera is fixing N2 under field conditions.
Seeds of the available 30 nitrogen-fixing species were evaluated in greenhouse experiments in two representative soils. Plant height and dry weight, nodule number and weight, and nitrogenase activity (ARA) were measured. The best species were: Enterolobium cyclocarpum, Albizia lebbeck and Inga spectabilis among the Mimosoideae, and Erythrina variegata, Clitoria fairchildiana and Pterocrapus officinalis among the Papilinoideae species. Results were included in Manuel Santana's MS thesis.

Another greenhouse experiment obtained a similar ranking, and it suggests that most tropical legume trees tested do not respond to lime and fertilizers.

Introduction:

Coffee originated from dense forests in the Ethiopian highlands, where it grows under the shade of a thick canopy. The Spaniards introduced the crop to Puerto Rico in the 17th century from Haiti. Of the three major crops at the beginning of the 20th century (coffee, sugarcane, and tobacco), only coffee survives as a major crop today. Traditionally, it was grown at low densities under shade in the Western and Central uplands. With its ideal climate, Puerto Rico is famous for producing some of the highest quality coffee beans in the world.
However, since the 1960's, public policy (PR Department of Agriculture) has tried to substitute the traditional agricultural practice of producing coffee under the shade of trees with an open (sun) system, having higher plant density and intensive use of fertilizers and agrochemicals. Recently, this practice has been criticized since production not only declines after a few years, but also there are numerous negative environmental problems (soil erosion, water pollution, loss of plant and wildlife diversity). In spite of that, traditional farmers maintain shade-produced coffee, and some new sustainable agriculture-minded farmers are re-introducing shade trees.
An ecosystem approach to sustainable management needs to consider ecological processes and minimize environmental impacts. This approach must be developed on a crop-by-crop basis.
There is insufficient scientific research conducted in the Caribbean and Puerto Rico regarding the best species of shrubs and trees to use in a multilayer, protective cover for coffee production. Further studies should be designed to test the effects of substrate quality and macroclimate on long-term decomposition and nutrient release dynamics, such as envisioned by the Long Term Ecological Research (LTER/NSF).
Nitrogen fertilizer is used for coffee growth. However, its use depends on economic considerations and the existence of effective infrastructure for fertilizer production

and distribution. Because the maximum-recorded N fertilizer use-efficiency is only 50% and the increasing problem of environmental pollution of water from fertilizers, the use of Biological N Fixation (BNF) is both an economically and environmentally sound practice. Although fertilizers and soil uptake can supply most of the coffee plant requirements, the exploitation of soil N reserves is not sustainable. The use of N-fixing trees for shade results in the elimination or significant reduction of chemical fertilizer application.

Long-term sustainability of agricultural systems must relay, as much as possible, on the use and effective management of farm internal resources, with an emphasis on devising strategies for legume cultivation that optimize N2 fixation, conserve soil N, and augment the pool of soil N for non-leguminous crops such as coffee (Zhang and Smith, 2002). BNF by tropical legume shrubs and trees can be a major source of N for coffee production when optimally integrated in the overstory. This type of agroforestry system also promotes biodiversity.

Tropical soils (like those in the mountainous region of Puerto Rico) present a challenge to maximum BNF because of their acidity, and adequate combinations of legume and N-fixing bacteria are necessary to provide maximum benefits for the sustainable production of coffee under shade. More research is needed to recommend the best combinations and management practices for this particular agroforestry system.

The international price for coffee is at a historic low, and the future perspectives are not favorable, since several countries have overstocks and are selling coffee at extremely low prices. Coffee production in Puerto Rico cannot compete with these international prices and other measures such as improvement in quality and crop diversification need to be considered. Intercropping coffee with other crops is one possible option to increase productivity. Because soil conservation is a requisite, trees must play a significant role in this multiple cropping option. Besides offering shade, several N-fixing trees produce excellent wood, and a few species produce fruit. Although a large proportion of coffee in Puerto Rico is still produced under shade (Monroig-Inglés, 2001), yields are low, and more research is needed to improve sustainable production. Therefore, the introduction of new trees and shrubs for sustainable coffee production in Puerto Rico should be evaluated.

An additional benefit of integrating more trees into the present coffee production agro environment is that they will also act as sinks for carbon sequestration, a much-needed environmental positive measure. Forests represent a large sink for CO2 sequestration and the growth of N-fixing trees is not limited by soil fertility constraints. Significant contributions to soil C pools are mediated by roots, and their roots symbionts (mycorrhizae and rhizobia) respond to elevated atmospheric CO2 (Treseder et al., 2003). Improvement in the soil quality (soil organic matter) under shaded coffee is also expected (Doran et al, 1996).

LITERATURE REVIEW

Coffee can be cultivated as a monocrop under sunny conditions or mixed with other species, as one of the classical agroforestry systems (shade). Since new planted coffee will not start to produce until its third year, farmers usually plant a cash crop (such as beans or plantains) intercropped, until coffee achieves its full size. The system is, therefore, very complex, and research usually centers on a specific topic or objective. Unfortunately, there is a cheap coffee glut in the international market, and farmers are starting to increase quality and enhance value (organic coffee, gourmet, etc.) to generate more income.

Most of the research conducted on coffee under shade has been done in Mexico and Costa Rica. In Puerto Rico, since the 60’s and following published results (Abruña et al., 1965 and 1966, and Vicente Chandler et al., 1984) farmers began to grow coffee without a shade canopy.

In 1978, the government of Puerto Rico started to implement a plan to increase coffee production, by a so-called “modernization” of the industry. The plan was based on sun-grown coffee, heavy fertilization and liming, high inputs of herbicides and chemical control, and gathering grain in plastic nets (Vicente-Chandler et al., 1968, Vicente-Chandler et al., 1969, and Vicente-Chandler et al., 1969). The use of plastic nets to harvest was never widely adopted, but the area sown with unshaded coffee expanded, because traditional shaded coffee had low yields. Excess shade from not pruned overstory was one of the causes.

In recent years, worldwide increases in coffee production caused a drastic reduction in the price of coffee paid to the farmer. A large proportion of this coffee is of very low quality, although special and organic coffees still maintain reasonable prices. Local production is unaffected by the international price (the government imports around 100,000 quintals at low price and pays the farmer a higher price), better quality coffee could maintain the industry and even permit exportation of a small amount). Still, many old coffee farms have been abandoned in the Cordillera Central of Puerto Rico. Although secondary forests develop on abandoned farms, particularly in shaded plantations, only a few native species become common (Marcano-Vega et al., 2002).

Many factors indicate that good quality coffee can yield economic benefits and contribute to a sustainable production. In the first place, an agroforestry system in which coffee is produced under the shade of trees, can maintain biodiversity of the ecosystem. For example, fruit set depends on cross-pollinization by bees, and the distance to forest, the variety of trees and number of flowering herbs increases the number of bees’ species that facilitate pollination (Klein et al., 2003). The importance of biodiversity has also been shown by research conducted in Costa Rica in capital-intensive monoculture plantations where all shade trees were eliminated. Perfecto et al. (1997) showed that arthropod biodiversity was lost when samples were collected in coffee monoculture compared to traditional plantations with many species of shade trees. In another study conducted in Southern Mexico (Chiapas), Perfecto et al (2003) compared species richness of birds, butterflies, and ants along a coffee intensification gradient represented by a reduction in the number of species of shade trees and percentage of shade cover in coffee plantations. Although the three taxa responded differently, there was a reduction in species richness along the gradient. Bird species (more mobile) where correlated with distance to forest fragments and not the habitat type. Their results imply that levels of shade and landscape structure are very important for biodiversity conservation. Another study also from Southern Mexico (Peeters et al, 2003) showed that replacement of a diverse shade vegetation of native tree species by the monoculture of Inga significantly reduced firewood products and secondary production (e.g., timber, woods, medicines,) and that coffee production was similar in both plantation types. Neotropical army ants were also studied in Panama in intact moist forest, shade coffee plantations and sun coffee plantations by Roberts et al (2000). Shade coffee plantations provided additional habitat for the ants, which act as critical links between birds and arthropods, providing an easily exploited food resource that would otherwise be unavailable for many birds. Continued conversion of shaded coffee plantations to sun coffee plantations could have negative effects on army ants and associated biodiversity. Ant biodiversity was also reduced in a shaded (Inga) coffee monoculture as compared to traditional polyculture plantation when the distance to the forest increased (Ambrecht and Perfecto, 2003).

In Costa Rica, an agroforestry system that includes very fast-growing trees such as Eucalyptus deglupta is recommended to increase productivity of coffee plantations. Since the benefits could be outweighed by competition for light and soil nutrients, Schaller et al., (2003) studied the factors that regulate the association. They found no evidence of negative effect of the trees on coffee growth, yields, and mineral nutrition. It seems that trees and coffee differ in their roots depth and distribution, resulting in complementary use of soil resources.

Management practices such as deforestation, shifting cultivation, use of very steep lands for cropping, reduced fallow periods and cutting woody perennials for fuel and wood causes erosion problems in tropical soils. Erosion severity depends on soil properties, topography, climate, and use of the land. In Venezuela the government has also promoted changes to the traditional way of cultivating coffee under shade. Ataroff and Monasterios (1997) conducted a study in the State of Merida to analyze the possible consequences of this change on the soil erosion in coffee plantations located on steep slopes. They showed a significant loss of the soil mineral fraction during the first year and that human activities within the plantations increased erosion. Trees provide a solution for wind problems, and although this aspect is not often considered in the Americas, it has been suggested as the agroforestry solution for several countries in Africa such as Tanzania (Stigter et al., 2002).

Soil erosion affects not only land productivity, but also sediments from rivers are transported to the oceans and affect corals. Since reefs are essential for aquatic life, marine productivity is also affected in this chain of events. Appropriate soil erosion control measures, such as the use of multiple-layer plant canopies should be taken in steep slopes such as the mountainous region of Puerto Rico. Data from the U. S. Geological Survey show that lakes capacity has been reduced by sedimentation from 12 to 81 percent of the reservoirs' original storage capacities (Soler-López, L. R., 2002).

Coffee diseases can reduce quality and yield of the crop. Shade affects each disease differently. For example, Fusarium oxysporum causes severe economic losses in coffee, and the use of resistant varieties is the only practical measure to control the disease (Pietro et al., 2003). More research on Integrated Pest Management (IPM) needs to be conducted in shaded coffee agrosystems. Vandermeer et al (2002) studied the role of Azteca ants as potential biological control agents (BCA) in an organic farm in Chiapas, Mexico. Their results indicate that ants have potential as pests through their positive effect on scale insects, but also potential as BCA through their negative effect on potential herbivores. The arrival of coffee seed borer (CSB) in 2007 in Puerto Rico seems to have reduced significantly the 2008 coffee harvest and many farmers are considering abandoning coffee production.

To obtain good prices for coffee, farmers need to improve quality. A study conducted in Costa Rica found that fruit weight and bean size increased significantly when shade intensity was increased from 0% to more than 80% under unprunned Erythrina poeppigiana. The author hypothesizes that shade promotes slower and more balanced filling and uniform ripening of berries, thus yielding a better-quality product than unshaded coffee plants (Muschler, 2001).

To achieve agricultural sustainability, the use of organic manure and biological nitrogen fixation (BNF) is an efficient biological way of managing soil fertility. Such practices could be the main source of N inflow to agroecosystems and thus a substitute to expensive chemical fertilizer use, especially under low-input agriculture. Besides supplying N for coffee, organic manure imparts beneficial effects on physical soil properties (Kadiata et al., 2002).

Significant higher yields of coffee are obtained with adequate NPK fertilization. In coffee plantations with abundance of N fixing trees, organic matter mineralization supplies, enough N (nitrate and ammonium) for plant nutrition, and N fertilization would be both an economic waste and a source of contamination for water. Besides, owing to its sensitivity to available soil mineral N, any N2-fixing legume may be affected in its nodulation and N2 fixation. This effect can be either stimulation or inhibition, depending on the rate as well as the nature of the fertilizer.

Further studies are needed since legume residues (mostly leaf fall), even if they have high N concentration, may still cause a net immobilization of N, since they might decompose slowly during early stages. Materials with high C/N ratio cause strong N immobilization.

Agroforestry systems such as coffee with shade trees, life fences and tree enrichment of fallows are technically, socially, and economically viable and have a C-sequestration potential varying from 17.6 to 176.3 Mg C ha-1. A project to evaluate and monitor the carbon mitigation effect was established in Mexico (De Jong et al., 1997).

To evaluate the effect of shade on yield of coffee, it is necessary to investigate the shade structure. Results from on-farm research conducted in Chiapas, Mexico, showed that shade cover percentage and coffee shade density had significant effects on yields Soto-Pinto et al., 2000). Shade tree cover had a positive effect between 23 and 38% shade cover and yield was the maintained up to 48%. Production may decrease under shade cover >50%. They found a total of 61 shade species with an average density of 260 trees per hectare, the majority of them being indigenous species, used as a source of food, construction material and as firewood.

The shaded coffee agroforestry systems are more efficient in maintaining soil fertility than monocropping systems. Certain shaded coffee plantations have remained productive for many decades but more research on the causal factors is needed. Roskoski (1981) studied the nodulation and N2-fixation of Inga jinicuil in Veracuz, México. She estimated annual nitrogen fixation as approximately 35 kg/ha, since NPK fertilization was used. However, coffee production was 37% higher with I. jinicuil than with I. vera that lacked nodulated roots. Van Kessel and Roskoski (1981 and 1983) estimated that high levels of phosphorus produced maximum nodule biomass but neither magnesium nor molybdenum affected nodulation or acetylene reduction of I. jinicuil seedlings. Favorable effects on soil fertility and crop nutrition have been observed in associations including N2 fixing legume trees (Schroth, G et al., 2001). Somarriba et al (2001) have proposed research trusts on the responses of coffee to shade and competition and socioeconomic analysis of both traditional and new shade-coffee combinations vs. monocultures. Budowski and Russo (1997) discussed the role of N-fixing trees is sustainable agriculture, particularly with examples from Mexico and Costa Rica. Research has involved Leucaena, Alnus acuminata and Erythrina spp. Results with E. poeppingiana indicate considerable benefits to the soil associated crops, and research projects in this area are promising.

In Africa (Burundi), Snoeck (1996) investigated the optimization of BNF for coffee by legumes. From his results, he recommended Leucaena diversifolia for sites over 1500 m and Leucaena leucocephala under 1500 m. More recently, Snoeck et al., (2000) used isotopic techniques to demonstrate nitrogen transfer from legumes to coffee. They showed that N availability for coffee depends on the conditions. When the legume crop can fix more than 20-25% of its needs from BNF, the N transfer is effective from the first year. The importance of BNF has probably being underestimated. An innovative labelling technique to measure 15N recovery (Meyer et al, 2003) suggests that significant rhizodeposition (RD) not identified with visible roots or root fragments occur. The RD can increase the soil nitrogen pools by 40-68 kg ha-1 and represents a significant addition to the soil. Although nitrogen fixation occurs in the leaves of coffee by epiphytic lichens, the amounts provided for coffee growth is very small (Roskoski, 1980). However, the phyllospheric N fixation occurring in shade trees in coffee ecosystems has not been measured.

All factors previously discussed interact in specific sites, therefore the relative importance depends upon site conditions, component selection, below-ground and above-ground characteristics of the tree and coffee variety, and management practices. They have been reviewed by Beer et al (1997), who indicate that economic evaluations are needed to judge the best system. Therefore, we will not

be able to recommend a single “Magic Tree”; it is necessary to use a mix of species. We need to have a list of several species, adapted to different soil and environmental conditions and management practices. This tree biodiversity is also recommended for wildlife conservation. Besides providing shade for coffee, some trees have other uses such as providing fruits, soil conservation; can be used as windbreak and for alley cropping.
In Puerto Rico, public interest in supporting sustainable agriculture is high or increasing.
However, information on NFT is very scarce (mostly botanical aspects) of shade trees. Much more research is needed. A study conducted in Chiapas, Mexico, indicated that farmer knowledge of legumes and the process of BNF were limited, although they had seen root nodules (Grossman, 2003). The situation is possible similar in Puerto Rico, since soil microorganisms, unlike earthworms, cannot be seen directly. Grossman et al, (2005) characterized the diversity of strains isolated from Inga oerstediana, Inga pavonina and an unknown species of Inga and showed they belong to Bradyrhizobium. However, growth nodulation and N fixation seem low during initial growth of Inga oerstediana (Grossman et al., 2006). Since more than 300 species of Inga are known, comparative studies should be performed to select more effective species.

Cooperators

- Wigmar González-Muñiz

  Administrator

  Agricultural Experiment Station

  HC-01 Box 4508
  Adjuntas, PR 00601-9717

  (787) 829-0012 (office)

- Luis Mejía

  lmejia@uprm.edu

  Sustainable Agriculture Coordinator

  University of Puerto Rico

  Agricultural Extension Service
  Department of Agricultural Economics
  Mayagüez, PR 00681-9030

  (787) 832-4040 (office)

- Miguel Monroig

  Extension Specialist

  Agricultural Extension Service

  University of Puerto Rico
  PO Box 9030
  Mayagüez, PR 00681

(787) 265-4130 (office)

Research

Materials and methods:

Our general approach is to include agriculture specialists from different areas (horticulture, botany, microbiology, and soils) to participate in the project at different levels (laboratory, greenhouse, and field). To develop a successful sustainable agricultural agroforestry system, interdisciplinary collaboration is indispensable.

Objective 1. A survey was conducted to obtain baseline data about the study area, both by field data collection and evaluation of GIS data, and evaluate their correlation. Traditional (shade) coffee farms were sampled and composition (species, distribution, density, and age) of the trees obtained. Farmers were also interviewed and their opinion on advantages and disadvantages of the different species recorded. Soil and climate data were obtained from the INTERNET maps and databases.
Objective 2. To evaluate nitrogen-fixing species, seeds were planted in pots with soils representative of the coffee region (generally acid) and grown under optimal conditions in the greenhouse. At sampling times (3 and 6 months), plants were evaluated for growth (height), nodulation (by native rhizobia), and nodulated roots incubated with acetylene for an hour before sampling incubated gas for injection in a gas chromatograph (GC), and for measurement of acetylene reduction activity (ARA, Turner and Gibson, 1980).
Since not all legumes can be nodulated by rhizobia, nodulation data (number and biomass) was obtained. After superficial disinfection, nodules were cut and strain isolated for further characterization.
Seeds or vegetative parts from species of the following genera of tropical legumes were evaluated for their N fixation potential, inoculation response, and management alternatives. Other potential uses of legume trees (such as high value timber, Torres and Schröder, 2003) will be studied. The following list of species (Table 1) was selected to assess their N fixation potential under greenhouse conditions.
Table 1. List of NFT evaluated
Scientific name Spanish name English name
Mimosoideae:
Acacia angustissima
Acacia auriculiformis
Acacia mangium
Adenanthera pavonina
Albizia lebbeck
Albizia procera
Anadenanthera peregrina Cojoba
Calliandra houstoniana (ex calotrysus Caliandra
Calliandra surinamensis Caliandra de Surinam Surinam Calliandra
Cojoba arbórea Cojóba, cojóbana
Enterolobium cyclocarpum Guanacaste, oreja de mono Monkey ear
Inga fagifolia Guamá Ponshock
Inga fastuosa Guaba peluda, venezolana
Inga quaternata Guamá venezolano
Inga spectabilis

Inga vera Guaba
Leucaena leucocephala Leucaena Leucaena
Leucaena diversifolia
Lysiloma latisiliqua Dormido
Paraserianthes falcataria Batai
Parkia pedunculata
Pithecellobium carbonarium Carbonero
Pithecellobium dulce Guamá Americano
Samanea saman Dormilón, saman Rain tree
Zapoteca portoricensis

Papilionoideae:
Andira inermis Moca Angelin tree
Clitoria fairchildiana Clitoria (facao)
Dalbergia sissoo (wood) Siso Indian rosewood
Erythrina berteroana Bucayo enano, bucayo sin espinas
Erythrina edulis Chachafruto
Erythrina eggersii Brucayo, Búcar Cock's spur
Erythrina peoppigiana Brucayo, bucayo gigante Bois immortelle
Erythrina variegata Bucayo haitiano, pompón haitiano
Gliricidia sepium Madre de cacao, mata ratón
Flemingia macrophylla Flemingia
Lonchocarpus domingensis Genogeno
L. glaucifolius Geno
Ormosia krugii Palo de matos, palo de peronías
Pongamia pinnata (Milleta; oilseed)
Pterocarpus indicus Terocarpo Indian paddauk
Pterocarpus macrocarpus Terocarpo
Pterocarpus officinalis Palo de pollo
Sesbania grandiflora Báculo, cresta de gallo
--- The potential of a legume tree to grow and fix N depends on the establishment of an effective symbiosis with root (or stem in some cases) producing bacteria. Most tropical soils harbor a diversity of microsymbionts capable of infecting germinating roots of native trees; however, adverse soil and environmental conditions (acid pH, drought, diseases, etc) or when new species are introduced, adequate rhizobia may be lacking, and seed inoculation with selected strains is necessary (Turk et al., 1993). Knowledge of tropical legume tree microsymbionts is limited (Turco and Keyser, 1992). In order to be able to select the best species for shade, we will isolate and characterize (Odee et al., 1997) the bacteria that nodulate seeds planted in representative soils, grown in the greenhouse. Preliminary observations indicate that legume trees in Puerto Rico are nodulated by a diverse group of proteobacteria. The amount of N supplied by leaves (litter fall) was evaluated under sun-grown, shaded coffee, and forests. Replicated plots were established at cooperative farmers' fields (Las Marias, Lares and Jayuya), and the N cycle parameters (N mineralization, nitrification and N2 fixation were measured).

Research results and discussion:

Objective 1.
Using the coffee farmer's database compiled previously, field trips to all larger coffee-producing municipalities and neighborhoods were taken. Over 110 farmers with shaded coffee have been sampled. Results indicate that more than 63 species (IVI, Index of Value Importance) with DBH> 10 cm are present. The predominant species found were Inga vera, Citrus sp., and Andira inermis, with 33.7%, 11.3% and

9.1% of IVI, respectively. The values for basal area (BA) were 36.5%, 5.8% and 7.0% in that order. The correlation between basal area and crown area (CA) was highly significant (r=0.48, P Results are summarized in Table 2.

Table 2. Frequency of shade tree species in the coffee region

SPECIES	RA	RF	RD	IVI	Order
Inga vera*	36.708	20.217	31.271	29.398	1
Andira inermis*	15.344	10.650	11.788	12.594	2
Citrus sp	12.200	14.440	4.862	10.501	3
Inga laurina*	3.783	3.791	8.243	5.272	4
Spathodea campanulata	2.344	4.693	5.810	4.283	5
Persea americana	3.729	5.776	3.285	4.263	6
Guarea guidonia	3.410	5.054	4.320	4.261	7
Artocarpus altilis	3.037	3.610	2.441	3.029	8
Mangifera indica	1.066	2.888	4.439	2.798	9
Tabebuia heterophylla	2.930	3.430	1.855	2.738	10
Cecropia schreberiana	0.693	1.986	1.772	1.484	11
Erythrina poeppigiana*	0.586	1.444	2.261	1.430	12
Inga quaternata*	0.693	0.722	2.748	1.387	13
Gliricidia sepium*	1.119	1.264	1.688	1.357	14
Cedrela odorata	0.693	1.264	1.870	1.275	15

RA: Relative Abundance; RF: Relative Frequency; RD: Relative Dominance;
IVI: Index of Value Importance
* Legume species

The calculated α diversity indexes are shown in Table 3. Compared to tropical forest, they show low biodiversity values.

Table 3. Alfa Biodiversity indexes in shaded coffee in Puerto Rico

		Altitude (ns)				
Index	Total	0-200	2 00-400	400-600	600-800	800-1000
H'	2.46	0.87	1.10	1.09	1.04	0.85
R	66	3.77	4.37	4.23	4.00	3.31
Bulla	0.29	0.04	0.05	0.05	0.05	0.04
E	0.58	0.29	0.32	0.30	0.28	0.26

ns: No significant differences (P>0.05)

Data for climate (Puerto Rico Climate Center) and soils of Puerto Rico (USDA-NRCS) were obtained, digitized and prepared as excel data tables. A map with agroecozones for coffee production was developed by adding optimum ecological layers, soils and appropriate information using ArcGIS (v.9.1). The new map will substitute the present imprecise map of the coffee producing area, and could be used to give more incentives to farmers located in the best zone for coffee production. Management options for farmers (amount of shade, fertilization, tree species, etc) can also be deduced from this map. The information needs to be made available to farmers, planning agencies, extension agents and other scientists. Results were presented at the Sustainable Coffee Forum (May, 2007) and extended abstract published in the proceedings. The potential to produce coffee was evaluated by AEZ, and a map produced (Fig.1).

Figure 1. Coffee AgroEcological Zoning for Puerto Rico
Objective 2.
The two most extensive soils from the coffee region (Los Guineos and Humatas series; Oxisol and Ultisol, respectively) were selected for the greenhouse experiments. They have been analyzed and both are acid and poor in available N. The greenhouse (6 kg of soil/pot) experiment with selected legume tree species was

carried out with a reduced number of species. This objective faced some problems due to the lack of seeds, since:

1) We had to wait for seed production for many local species in order to obtain seed. For some species, we have not been able to locate trees producing, or their fructifying period is unknown. To facilitate future work and seed collection, we prepared tables with species location (GPS) and the period of flowering/seed production for local trees. However, this database is still incomplete since permanent field trips all over Puerto Rico are required to obtain data. Seeds from a few other species were obtained from ECHO (Florida).

2) Some species (mostly of the genus Inga), even when harvested in the most appropriate time, are recalcitrant and don't germinate after 2 weeks even in the best storage condition. Therefore, some of these species were included in the first, smaller experiment. For comparative purposes, seeds of Pithecellobium carbonarum (carbonero) were included as control, and they were included in every planting date. This species shows good shade characteristics, but was recorded as very susceptible to nematodes, at least in one soil. Furthermore growth is extremely slow, at least under the low altitude where our greenhouses are located. We are presently testing the use of stakes for those species (such as Inga) were seed is recalcitrant or not available. The species that were harvested earlier (first experiment with recalcitrant seeds, genus Inga) were analyzed by Kjeldahl to estimate the amount of N fixed. Tables 4 and 5 show the results for the Mimosoideae and Papilionoideae tested species. We were not able to obtain seeds from some species such as Zapoteca portoricensis and Pongamia pinnata. The complete results have been included in Manuel Santana's MS thesis.

The gas chromatograph (used the ARA analysis) purchased with the project funds was extensively used to evaluate N fixation (ethylene production) from greenhouse and field experiments. Growth and N fixation indicated that Enterolobium cyclocarpum, Erythrina variegata, Clitoria fairchildiana and Flemingia macrophylla are top fast-growing N field fixing species. Most legume trees were growing as well in the acid soil as in the limed one, and few responded to mineral supplements. The cumulative N fixation estimates were similar at all locations, and apparently no effects of temperature or soil humidity were detected. Although total N fixed was very low, samples of Inga vera leaves indicated active N fixation by the 15N natural enrichment method.

Soil N mineralization and nitrification studies show that N mineralization and nitrification were higher in the plots were coffee was shaded by Inga vera trees. Litter fall was studied at three different altitudes Jayuya, Lares and Las Marías), each with sun (CSL), shade grown coffee (CSM) and forest (BQS) ecosystems. Results for one year are shown in Table 6. Litter fall was less at the sun-grown coffee plots than at the shade-grown sites, and both generally smaller than litter fall at the close by forests.

Table 6. Amount of litter fall (ton ha-1 y-1) at three locations.

Ecosystem Location Average
Jayuya Lares Las Marías
CSL
CSM
BQS 1.39 a
2.09 b
1.56 ab 1.15 a
1.97 b
2.08 ab 1.65 a
2.37 b
1.86 ab 1.40 a

2.15 b
1.83 b
Media 1.68 a 1.73 a 1.96 b 1.79
*Different letters indicate significant differences (Tukey, $p \leq 0.05$) at one locality.

Other results obtained have been published in papers, thesis and presented at different meetings, and two more M.S. thesis will be completed in the near future. Copies of the publications are included in the attachment, and photos are available at the WEB sites;
http://academic.uprm.edu/eschroder
and
http://www.uprm.edu/cafesostenible
Completed theses are available at the UPRM library and the Department of Agronomy and Soils web address.

Participation Summary

Educational & Outreach Activities

PARTICIPATION SUMMARY:

Education/outreach description:

Arango, M., Santana, M., and Schröder, E.C. 2004. Reintroduction of shade for sustainable coffee production in Puerto Rico. Memorias. Reunión Anual, Sociedad Puertorriqueña de Ciencias Agrícolas (SOPCA), Arroyo, December 3, 2004. p. 49

Brelles-Mariño, G. and Schröder, E. C. 2005. Bacterias beneficiosas para la agricultura. Agrotemas de Puerto Rico 16(8): 4.

Arango, M., Cruz, L., Santana, M. and Schröder, E.C. 2005. Structural analysis and species composition of tree species associated with coffee. Memorias de la Reunión Anual, Sociedad Puertorriqueña de Ciencias Agrícolas (SOPCA). Guaynabo, PR 19 November 2005. p. 7.

Cruz, L. and Schröder, E.C. 2006. Characterization of soil in the Puerto Rico coffee agroecosystem. 42nd. Annual Meeting, Caribbean Food Crops Society. San Juan, PR. P 65.

Arango, M., and Schröder, E. C. 2006. Structural analysis and species composition of tree species associated with coffee in Puerto Rico. 42nd. Annual Meeting, Caribbean Food Crops Society. San Juan, PR. P 27.

Schröder, E.C. 2007. Foro sobre Café Sostenible en Puerto Rico. Proceedings. Mayagüez, UPRM, Department of Agronomy and Soils, May 2007, 47 pp.

López-Rodríguez, G.L., Schröder, E.C., Sotomayor, E.C. and Macchiavelli, R. 2008. Aporte de hojarascas en Agrosistemas de café en Puerto Rico. Sigma Xi XIII Poster Day, Mayagüez, Puerto Rico. April 10th, 2008. P1.

Sotomayor-Ramírez, D., Acosta-Martínez, V., Espinoza, Y., Schröder, E. C., and Amador, J. 2008. Soil Biological Community Structure in Coffee (Coffea arabica L.) Agroecosystems in Puerto Rico. Proceedings, CFCS, 2008. Miami, Florida.

Arango, M. A., Santana, M., Cruz, L. and Schröder, E.C. 2008. Legume trees in the Coffee Agroecosystem of Puerto Rico. In: Biological Nitrogen Fixation: Towards Poverty Alleviation through Sustainable Agriculture. Dakora, F.D., et al Eds. Springer. Proceedings of the 15th Internat. Conf. Nitrogen Fixation. Cape Town, South Africa. P 83-84.

López-Rodríguez, G.L., Schröder, E.C., Sotomayor-Ramírez, D., y Macchiavelli, R. 2008. Mineralización de nitrógeno en suelos bajo agrosistemas de producción de café (Coffea arabica L.) en Puerto Rico. Resúmenes SOPCA, Aguadilla, PR, Noviembre 2008, p 4.

Andújar, F., Schröder, E.C., Sotomayor-Ramírez, D., y Kolterman, D. Crecimiento y nodulación de leguminosas arbóreas para sombra de café en un Ultisol enmendado con cal y nutrients en Puerto Rico. Resúmenes SOPCA, Aguadilla, PR, Noviembre 2008, p 43.

Avilés-Vázquez, I., Schröder, E.C., and van Bloem, S. 2008. Fijación Biológica de nitrógeno en hojarasca bajo agroecosistemas de café (Coffea arabica L.). Resúmenes SOPCA, Aguadilla, PR, Noviembre 2008, p 44.

Schröder, E.C., Cruz, L., and Arango, M.A. 2008. Production potential of coffee in Puerto Rico by agro-ecological zoning. International Congress on Tropical Agriculture, held at the Hyatt Hotel in Port of Spain, Trinidad. December, 2008.

Thesis (M.S.) produced in this project:

Arango, Miguel A., 2007 Zonificación agroecológica del café en Puerto Rico y análisis
estructural y de composición de especies arbóreas presentes en el agro ecosistema cafetero.
Santana, Manuel, 2007. Fijación biológica de nitrógeno por leguminosas arbóreas para
sombra de café en Puerto Rico.
López, Glenny L. 2008. Mineralización de nitrógeno en suelos bajo agrosistemas de
producción de café (Coffea arabica L.) en Puerto Rico.
Andújar, Feliciano A. 2009. (In process)
Avilés, Ixia, 2009. (In process).

Presentations:

Marzo 2, 2006. Conference: Fijación simbiótica de Nitrógeno en siembras de café bajo sombra. Universidad Interamericana de Puerto Rico, Programa de Ciencias Ambientales. Ponce, Puerto Rico.
January 25, 2007. Oral presentation. Legume trees in the Coffee Agroecosystem of Puerto Rico. In: Biological Nitrogen Fixation: Towards Poverty Alleviation through Sustainable Agriculture. 15th Internat. Conf. Nitrogen Fixation. Cape Town, South Africa.
April 11, 2008. Proyecto de Arboles de Sombra para Café. 1.er Foro de Conservación en
los Agroecosistemas. UPR-Utuado,
December 2, 2008. Production potential of coffee in Puerto Rico by agro-ecological zoning. International Congress on Tropical Agriculture, held at the Hyatt Hotel in Port of Spain, Trinidad.
Yearly exhibits of the coffee and shade tree project were also established during the popular “Five Days with our Land” (5 Dias con Nuestra Tierra), organized by the students of the College of Agricultural Sciences (from 2005 to 2008).

Project Outcomes

Project outcomes:

Results of the coffee farms surveys indicated that although legume trees are abundant, species diversity is very low and other species should be included to improve biodiversity ecosystem services and resilience. The PR Department of Agriculture should modify its present recommendations to required shade in future plantations, avoiding damaging forest clearing, restrict economic subsidies to those farmers in the most adequate zones for coffee and reduce fertilizer recommendations. New species of fast-growing and highly effective in N fixation legumes such as E. variegata, C. fairchildiana, and F. macrophylla should be propagated at coffee nurseries and supplied to coffee farmers.

Economic Analysis

Economic analysis was not included in the objectives, and the results are not amendable to make economic recommendations. Although coffee yields were higher under intensively managed sun-grown coffee farms, inputs of fertilizers, pesticides and labor were evidently also higher.
Adoption of shade for more coffee farms might reduce yields, but long-term, sustainable coffee production will increase coffee quality and provide environmental services that must be estimated in future research projects and ecozoning planning at regional level.

Farmer Adoption

Agricultural scientists, agronomists and farmers are slowly accepting the need to change from sun-grown to shade-grown coffee in Puerto Rico. Approximately 10-12 farms made plans with the program “Partners for Fish and Wildlife” and have introduced several species of trees in the coffee plantations, but few species are legumes. We have supplied a few legume trees to farmers, but a large and permanent organization (Department of Agriculture, US Fish and Wildlife Service) needs to support legume tree production at nursery level and design plans for farmer adoption. In our field surveys, we found that shade is often used in excess, and we would recommend farmers to prune trees regularly (at least once a year).

Recommendations:

Areas needing additional study

The extent of shade was not considered in the present project, and future measurements of photo synthetically active radiation (PAR) should be taken and correlated with coffee yields for each site. Evaluation of the environmental impacts (particularly on soil erosion and water contamination) of coffee sun-grown systems and shaded plantations are necessary to provide economic estimates of environmental services provided by the more sustainable agro-ecosystems. Nutrient cycling data and carbon sequestration potential on both management systems are also necessary.
The best species of woody legumes selected in the present project should be tested for adaptation in the field at different altitudes to identify those to be recommended for specific areas in Puerto Rico. Similarly, the species introduced into coffee plantations by the USFWS in the past few years should be evaluated for their performance.
Long-term research should also be conducted on the effect of climate changes, not only for coffee growing areas (that can migrate to higher altitudes), but also for other crops.