Environmental and Economic Aspects on Agro-forestry and Agricultural Systems in Chiapas, Mexico

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ABSTRACT

Since traditional cost-benefit analysis does not include environmental variables in consideration, the concept of emergy was used to measure all direct and indirect energy to produce a product. In emergy analysis, environmental, social and economic variables are included and indexes are calculated for comparison for several systems. In this paper, emergy and financial ratios are used to determine the sustainability of agro-forestry and agricultural systems in Chiapas, Mexico. Emergy and economic analysis are calculated for: 1) 400 hectares in forest extraction, 2) 1 hectare in shaded coffee cultivation, and 3) 1 hectare for industrialized sugar cane production.

Wood extraction from tropical forests is the system with less dependence on external inputs (purchased/free=0.41) and with a high profitability (net revenue/cost=1.93). Industrialized sugar cane production is one of the most productive activities in the region (net revenue/cost=1.5). Coffee cultivated under the shade is a sustainable agroforestry system because it maintains part of the original forest. However, the use of chemical on coffee production makes coffee economically unattractive. (net revenue/cost=0.47).

INTRODUCTION

Agro-forestry and agro-industrial systems need to be evaluated using both a emergy and financial basis to give a better perspective of sustainability in the long term. To evaluate these systems the investment and environmental loading ratios are used to determine the environmental and economic aspects of agro-forestry and agricultural systems in Chiapas, Mexico. The net revenue/cost is used as a financial indicator of the profitability of the system. Although coffee grown in full sun yields around 3,450 kg per hectare, the shade coffee is important function for conservation of forest cover.

SYSTEMS DESCRIPTION

Agro-forestry System

The system consists of 400 hectares of highland tropical rain forest located at Felipe Angeles, Cintalapa, Chiapas, Mexico. The characteristic species found in this tropical region are: *Nectandra globosa, Brosimum alicastum, Hyperbaena mexicana, Persea schiedeana, Guarea chichon*. The climate is warm and humid with abundant rains in summer. The mean annual temperature and precipitation are 24.4^{o}C and 1,833.6 mm, respectively. There is a steep topography with slopes that oscillate from 10 to 45%.

The extraction system consists mainly on the use of wood forest resources of tropical species, such as: *Platymiscium dimorphandrum, Cedrella odorata, Guarea glabra, and Brosimum alicastrum*, among others. The trees to be cut must have a minimum diameter breast height of 45 cm. No more than 35% of standing trees with this diameter can be cut in one cycle. The four hundred hectares were divided in 12 stands of 33.33 hectares, with a cutting cycle of every 12 years. Based on a previous inventory, it was determined that with these extraction quotas, the system can be sustainable at the long term (Borja et al., 2001).

Shaded Coffee Cultivation System

Thirty percent of the coffee grown in Mexico is cultivated in Chiapas. However, this year, the profitability of coffee production has been low because the international markets are saturated. Selected for the study was a hectare of fertilized shade coffee located in the

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municipality of La Concordia, Chiapas, Mexico. The area and crop is representative of many regions of the state. The farming system that was chosen for this study is locally know as "especializado" which is a monoculture of Arabic coffea. The characteristics are: 1) high yield, 2) densities bigger than 1,200 plants per hectare, 3) specialized shade, 4) two to three fertilizations per year, and 5) systematic prunning (Zavala García et al., 2001). This coffee is cultivated preferably in a warm, humid climate with abundant rains and grows best between 500 and 1,500 meters above sea level. The plants that provide shade for this coffee are: *Acacia virginalis, Cajanus indicus, Paternal inga, Inga edulis, Eugenia jambos,* among others. The useful life of a coffee plant varies between the 15 and 25 years depending on the conservation and farming systems. The production average per hectare of coffee is 563.5 kg.

Sugar Cane Industrialized Cultivation System

Sugar cane is one of the most important agro-industrial systems cultivated in the central region of Chiapas. Values used in this study correspond to averaged data of 3,686 hectares of sugar cane for the varieties Mex-57473 and Mex-69290 (Castillejos Núñez et al., 2001). Sugar cane is cultivated in the municipalities of Venustiano Carranza and Las Rosas, Chiapas, Mexico, at mean elevation of 600 meters above sea level. The climate is warm and humid and has an annual mean temperature of 25.3ºC and annual mean precipitation is 1,218 mm with most rain during the summer. Vegetation is scarce since previously tropical rain forest has been replaced by savanna vegetation. Dams and irrigation systems have been built to provide water to the fields during the dry seasons. In 1999, 3,500 m3 of water were supplied through distribution channels. It is estimated that 50% of distributed water is lost due to deficiency and bad operation of the irrigation system. Sugar cane production has been increased from 50 tons per hectare up to 130 tons by using improved technologies. The mean annual productions is of 95 tons for hectare.

METHODS

Several different tools of analysis were used to address questions of sustainability of productive activities. Emergy analysis of the flows of energy, materials and labor were used to evaluate productive activities. Financial analysis was used to evaluate the economic benefits of productive activities. Information for each system was collected from experts in the region.

Emergy Analysis

The emergy analysis methodology is a top down systems approach and is designed to evaluate the flows of energy and materials of systems in common units that enable one to compare environmental and economic aspects of systems (Brown and Murphy, 1994; Odum, 1996). The first step in each of the emergy analyses was to construct a system diagram to organize thinking and relationships between components and pathways of exchange and resource flow. The second step was to construct an emergy analysis table from the diagram (see Appendix). The emergy flows were aggregated (Figure 1) into environmental inputs (R and N), purchased feedbacks (M and S), and output products (Y). The final step involved calculating several emergy indices (see Figure 1) that related emergy flows of the economy with those of the environment, and allowed for the prediction of economic viability and carrying capacity.

The investment ratio (IR) is the ratio of emergy of purchased inputs (economic inputs) to emergy of free inputs (renewable and nonrenewable) derived from local sources. The name is derived from the fact that it is a ratio of "invested" emergy to resident emergy. The investment ratio is a dimensionless number; the bigger the number the greater the amount of purchased emergy per unit of resident emergy. The environmental loading ratio (ELR) is a measure of potential impact or "loading" a particular development activity can have on its environment (Brown et al., 1992). It is the relationship of purchased emergy (M and S) plus resident nonrenewable emergy (N) to resident renewable emergy (R). This ratio can be used as an indicator of the appropriate level of development of the alternatives. Nearly all productive processes of humanity involve the interaction of nonrenewable resources with renewable sources from the environment. Low ELRs indicate relatively small "loading" on the ecosystem support base, while high ELRs reflect greater potential impact. The ELR, an index of environmental loading, reflects the potential environmental strain or stress of a development when compared to the same ratio for the region.

(Insert figure 1 here; FILE:FIGURE1.CVS)

Footnotes:
R. Free renewable emergy of environmental inputs from such as sun, wind, and rain
N. Free nonrenewable resource emergy from the local environment such as soil, forest, wood, and minerals when used faster than produced
M. Purchased emergy of minerals, fuels, and raw materials brought to an area by the economic system, and
S. Purchased emergy in services and labor, the paid work of people.
Useful Investment Ratios for Evaluating Uses of Resources:

Purchased / free	(Investment ratio, IR)	(M+S) / (R+N)
Nonrenewable / renewable		(N+M) / R
Service / free		S / (N+R)
Service / resource		S / (R+N+M)
Developed / environmental	(Environmental loading ratio, ELR)	(N+M+S) / R

Figure 1. Summary Diagram Showing the Main Flows of Emergy and Materials.

Financial Analysis

The economic appraisal suggested by Kiker and Lynne (1995) consist of the following steps: 1) to establish the socioeconomic boundaries associated with the object under study, 2) to identify the flows of important resources and outputs within and across the boundary, 3) to quantify the flows of resources and outputs within and across the boundary in multiple units, 4) to identify the benefits and costs associated with the alternative, 5) to quantify the monetary benefits and costs, and 6) to compare benefits and costs. The revenue/cost ratio is calculated in monetary terms.

RESULTS AND DISCUSSION

The wood extraction system used in the tropical rain forest has a purchased to free ratio of 0.41 (Table 1) indicating its minimum dependence on external inputs such as chemicals, machinery or imported services. Seventy percent of its total emergy comes from the rain ($251x10^{15}$ sej/yr, Table 2). For a long term sustainability, all the area under forest is required and the wood extraction quota of 28.3 m^3 per hectare per year should not be surpassed (Borja et al., 2001). This system is the most profitable of the three analyzed systems, indicated by the net revenue/cost ratio of 1.93. This means that for each dollar that local people invest, they make USD1.93 as net profit. The corn shifting cultivation system was even more profitable (net revenue/cost=2.32) than the forest extraction system with less required area for cultivation. However, the corn cultivation system requires cutting the forest and fallow lands are allowed to regenerate only for five years with succession forest. To conserve tropical rain forest results more convenient the forest extraction system; however, at present, it has been observed (Borja et al., 2001; Guillén Trujillo, 1998) that this system is not sustainable for the following reasons: 1) increasing colonization pressures, 2) diminishing tropical forests for corn cultivation with chemical and cattle grazing, and 3) surpassing wood extraction quotas by local people due to cash needed, corruption with wood companies and lack of law enforcement by local and federal authorities.

On the opposite side, industrialized systems depend mainly on external sources (M and S), such as materials, machinery, fertilizers, etc; and services brought to the local areas, instead of free renewable and nonrenewable resources (R and N). The industrialized sugar cane system had a purchased to free ratio of 16.26 indicating its strong dependence on external inputs, mainly fertilizers (9.8E15 sej/year) accounting for 34 percent of its total emergy (Table 3). Although at the present it is one of the most productive activities (net revenue/cost=1.5), the main disadvantage of promoting this system is that tropical rain forest has to be completely cut.

(Insert Table 1 here; FILE:TABLE1HUGO.WPS)

A system that can be considered in an intermediate point of forest substitution and forest conservation is coffee planted under shade. This system depends on the partially maintained forest for its cultivation as opposed to coffee planted in completely open areas. Coffee planted under shade usually substitutes around 50 percent of the original tropical rain forest, maintaining part of the biodiversity of native ecosystems. Trees that provide good shade and fix nitrogen are planted, maintaining a forest cover. Organic coffee cultivation is usually proposed by conservation organizations as a system to be managed in the transition zone between protected areas and agricultural fields. However, the system analyzed in this study is a very common system, that uses chemicals with a high purchased to free ratio (9.35, Table 1 and 4), making local people vulnerable to external markets.

Furthermore, labor requirements for coffee shaded cultivation are very high, compared to the other productive systems, because of 1) shade management, 2) sloping conditions of cultivating plots (commonly bigger than 45%), 3) coffee plants maintenance, and 4) production activities such as cutting, washing, drying, etc. The service to free, and the service to resource ratios of 6.01 and 1.39, respectively, indicate the strong contribution of labor accounting for almost sixty percent of the total emergy.

Presently, due to the low price of coffee at the international market, the intensive labor required for production and the lack of mechanisms for small farmers to add value to the coffee production; coffee cultivation using chemicals is not a good economic alternative. This is indicated by a low net revenue/cost ratio of 0.47 compared to the other productive activities with ratios greater than one. The state government has been giving subsidies to small farmers to overcome the economic crisis. Unfortunately, one of the immediate effects of the lack of profitability in the shaded coffee cultivation , as it has been observed in some regions of Chiapas, is that people are switching their coffee plots into other less sustainable uses of land such as corn cultivation or cattle grazing, impacting dramatically the conservation of tropical rain forest. Further studies should address the sustainability of organic coffee cultivation under shade to evaluate its profitability.

In additional to the three systems (forest extraction, coffee and sugar cane production) analysed in this work, two other traditional cultivation systems, previously evaluated by Guillén Trujillo (1998), are included for comparison purposes: 1) corn shifting cultivation in 12.5 hectares (2.5 hectares cultivated per year with a rotation cycle of 5 years), and 2) a one hectare corn cultivation using chemical fertilizers (see Table 1).

Overall, the purchased to free ratio and the environmental loading ratio (developed/environment) increase as systems import resources from external markets. The systems with ratios lower than one are those that depend mainly on free renewable resources such as corn shifting cultivation and forest extraction from tropical rain forest.

CONCLUSIONS

Wood extraction from tropical forests is the system with less dependence on external inputs and with a high profitability. However, its long term sustainability is threatened by shrinking tropical rain forest and wood over-exploitation. The analyzed system (400 hectares) should be maintained within an extraction quota of 28.3 m3 / hectare/year and assure that it is not surpassed.

Industrialized sugar cane production is one of the most economically productive activities analysed in this study. However, this system has a strong external dependence and substitutes native ecosystems.

Coffee cultivated under shade is a sustainable agroforestry system because it maintains part of the original forest. However, coffee planted using chemicals is not economically attractive (net revenue/cost=0.47). Further studies are required to evaluate organic coffee production under shade.

Finally, one can conclude that industrialized systems (corn, coffee and sugar cane planted with chemicals) require less area with greater dependence on external resources. On the other hand, systems with extended areas such as wood extraction from forest and organic coffee planted under shade will maintain a forest cover. However, these systems are threatened by population pressure. Agro-forestry systems should be promoted as much as possible as productive alternatives where local conditions are adequate for their implementation. More comprehensive studies that include other variables, such as water and soil pollution by chemicals, should be done to gain a better perspective of the systems.

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APPENDIX

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