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A MULTIDISCIPLINARY APPROACH TO RENEWABLE ENERGY IN DEVELOPING COUNTRIES

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PREFACE

The Tropical Renewable Resources Program (TRRP) at The Ohio State University has an integrated, multidisciplinary capability to identify, analyze, and resolve important renewable resource issues in developing countries. TRRP is a consortium of biological, physical, and social scientists representing sixteen academic departments or units at OSU. The primary concern is with the deterioration of renewable resources and the resulting threat to human well-being in many developing countries.

Members of this consortium represent a wide range of experience in research, teaching, and extension of results on the management of renewable resources in several developing countries, including the Dominican Republic, Costa Rica, Brazil, Thailand, the Philippines, India, Kenya, Ghana, and Nigeria. Current issues and areas of concern include soil erosion and sedimentation control, reservoir management, aquaculture, fuelwood/biomass energy production and end-use conversion, solar ponds, and household use of energy.

The original impetus and support for the idea of a Tropical Renewable Resources Program at OSU was provided by the United States Agency for International Development (USAID) Title XII strengthening grant program. Funds from this program in 1980 facilitated some initial multidisciplinary work by a few faculty members on renewable resource issues in the Dominican Republic. The program also led to the identification of several other OSU faculty with related experience and interests. This larger group was successful in securing some "seed money" from the OSU Graduate School in June 1982 for developing a multidisciplinary research program and securing additional funding support.

The OSU seed money as well as a small grant from the National Science Foundation, the Interamerican Development Bank, and additional strengthening grant funds from USAID provided support for several studies of renewable energy options in selected Third World countries. These analyses have utilized major concepts from several disciplines represented in the TRRP group. In addition, interaction of the research scientists in informal seminars, teaching an interdisciplinary graduate seminar, and as members of multidisciplinary research teams has provided for some modification and integration of key disciplinary concepts. This book

attempts to present both the results of the research conducted by TRRP members and the integrative insights as they relate to renewable energy inventory/use characteristics, feasibility analysis, and implementation strategies in a sample of seven developing countries.

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developing countries has b
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supplies in these countrie
involved in fuelwood defic
people in the developing w

Populations (in mill

Region	Total
Africa	55
Near East and North Africa	
Asia Pacific	31
Latin America	26
Total	112

[1]The table indicates the total pop
consumption (total population le
populations living in the areas un

Source: This table is a revision of
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CHAPTER 1.
OVERVIEW OF RENEWABLE ENERGY IN DEVELOPING COUNTRIES

INTRODUCTION

The growth of interest in the development of renewable energy resources in developing countries has been prompted by increased international prices of gas and oil (fivefold increase between 1972 and 1984) and the rapid depletion of fuelwood supplies in these countries. Table 1.1 summarizes the regions and populations involved in fuelwood deficits and shows that by the year 2000 almost 2.4 billion people in the developing world will be in acute deficit.

TABLE 1.1

Populations (in millions) Involved in Fuelwood Deficit Situations[1]

	1980						2000	
	Acute Scarcity		Deficit		Prospective Deficit		Acute Deficit	
Region	Total	Rural	Total	Rural	Total	Rural	Total	Rural
Africa	55	49	1[illegible]	131	112	102	535	464
Near East and North Africa			104	69	[illegible]		268	158
Asia Pacific	31	29	832	710	161	148	1,671	1,434
Latin America	26	18	201	143	50	30	512	342
Total	112	96	1,283	1,052	323	280	2,986	2,398

[1]The table indicates the total population and the population with a predominant rural type of energy consumption (total population less urban centers over 100,000 inhabitants); these are the estimated populations living in the areas under the identified fuelwood situations.

Source: This table is a revision of Table 2 of the Final Report of the Technical Panel on Fuelwood and Charcoal. Food and Agriculture Organization, Rome, Italy 1981.

While the petroleum crisis may still make some headlines, for more than one-third of the world's population the real energy crisis is a daily search to find firewood for cooking. The search for wood was once an easy task, but receding forests now make it a day's labor in many areas. The total forest area in developing countries exceeds one billion hectares. However, if the current rate of depletion continues and if reforestation efforts are not expanded, this stock of forest resources will disappear within 60 years

(World Bank 1978). World Bank (1980) estimates also show that the gap between current forest replanting and projected demand by the year 2000 for domestic cooking and heating is fivefold in the less developed countries (LDCs) as a group and fifteenfold in African LDCs.

Forests play a significant role in economic development. They have an important influence on the environment and provide innumerable products of vital use to man. The ecological usefulness of forests includes their beneficial effect on water catchment areas, where they have a regulatory influence on stream flows. They also protect soils from erosion and prevent silting of dams and canals. They have pronounced microclimatic effects of benefit to humans and livestock, provide a habitat for wildife, and are attractive places for recreation. Forest products are used extensively in most societies. They provide food, fuel, fiber, and building materials and industrial products such as gums, resins, oils, transmission poles, newsprint and other papers, packaging materials, textiles, and clothing. Thus, they provide many resources for the development of other sectors.

Almost four-fifths of all the wood annually extracted from the forests in tropical countries is used for fuelwood and charcoal; the rest is used for construction materials and lumber for export. According to Eckholm (1976), depletion from these uses plus the accelerating degradation of woodland from slash and burn agriculture and wood gathering frequently leads to poverty and underdevelopment. This depletion produces nearly irreversible consequences in terms of soil erosion. Consequences of soil depletion are increasingly severe flooding, creeping deserts, and overall deterioration in the productive capabilities of agricultural lands. Though the pattern varies slightly by biogeographic region and population density, the trends are unmistakable for the developing world. In many areas, deforestation has resulted in the burning of agricultural residues and dried livestock dung for heating and cooking, thereby depriving the soil of nutrients and impairing soil structure.

Now that fossil energy is no longer cheap, its cost and supply merit the consideration by managers and development planners traditionally given the classical factors of production—land, labor, and capital. The World Bank (1980) argues that this consideration applies not only to forms of energy that are traded internationally, but also to energy produced and consumed domestically and to traditional as well as commercial fuels. The prices, availability, and consumption levels of all forms of energy are inextricably interrelated. Thus, a comprehensive plan will include strategies to expand the sources of supply, reduce dependence on imported, nonrenewable fossil fuels, and make energy use more efficient.

Energy consumption in the developing countries is a relatively small part of the world total but has been growing rapidly as is shown in Table 1.2. During the 25 years preceding the oil price increases in 1973, the relationship between annual gross national product (GNP) growth and energy demand in developing countries was about 1:1.3. This ratio dropped with the oil price increases after 1973, but energy continues to be a critical factor in the economic development process.

TABLE 1.2

World Commercial Energy Consumption, 1975-1990
(Million Barrels a Day of Oil Equivalent)

					Average Annual Growth (percent)		
	1975	1980	1985	1990	1950-74	1975-80	1980-90
World	122.1	137.8	166.0	201.5	5.0%	2.5%	3.9%
Developing Countries	13.9	16.7	22.3	30.6	6.9	3.7	6.2
Oil Importing Developing Countries	10.4	12.4	16.8	22.8	6.9	3.6	6.3

Sources: Data underlying *World Development Report, 1980,* Table 2, pp. II-67; *World Development Report, 1978,* Table 19, p. 20; UN, *World Energy Supplies, 1950-74,* UN Statistical Papers Series J, No. 19 (New York: UN Department of International Economic and Social Affairs, 1974).

The foregoing issues are summarized in a World Bank (1980) energy classification of developing countries shown in Table 1.3. Countries are classified according to their degree of dependence on oil imports and the severity of their fuelwood problem. The countries underlined in Table 1.3 (Egypt, India, Ghana, Barbados, Costa Rica, the Dominican Republic, and the Philippines) provide a reasonably representative sample for the case applications of the inventory/use characteristics, feasibility, and implementation sections of this book.

RENEWABLE AND NONRENEWABLE USE FORECASTS

Worldwatch Institute in Washington, D.C., has developed estimates of future worldwide energy consumption of both nonrenewables and renewables. Table 1.4 presents the Worldwatch forecasts for world energy consumption from 1980 through 2000. Renewables were 16.5 percent of worldwide energy consumption in 1980 and are projected to be 23.9 percent by 2000. Of the nonrenewables, only coal and nuclear power are projected to increase as a percentage of worldwide energy consumption by 2000; coal from 28.9 to 37.3 percent and nuclear power from 2.2 to 4.8 percent. Petroleum is forecast to decline in absolute terms, while natural gas is projected to show a slight increase in absolute terms and a decrease in percentage of worldwide energy consumption from 16.6 to 12.2 percent (Brown and Shaw 1982).

Table 1.5 presents a breakdown of the Worldwatch projections of the renewable energy subset worldwide. With the exception of crop residues and cow dung, all of the renewable energy subsets show absolute growth by the year 2000. Wood remains the number one renewable energy source throughout the forecast period, but declines as a percentage of total renewables from 56.2 percent in 1980 to 45.1 percent by 2000. Hydroelectric power maintains second place at a constant 33 percent of worldwide

TABLE 1.3
An Energy Classification of Developing Countries

	Net Oil Exporting Developing Countries		Oil Importing Developing Countries[1]				
Net Oil Imports As % Commercial Energy Demand[2]	OPEC Members	Non-OPEC	0-25%	26-50%	51-75%	76-100%	
	ALGERIA	*BAHRAIN*	*ARGENTINA*	*CHILE*	*ALBANIA*	Bahamas	Mauritius
	GABON	*BOLIVIA*	*COLOMBIA*	Mongolia	*BRAZIL*	*BARBADOS*	Nicaragua
	IRAN	*MALAYSIA*	Korea, Dem. Rep.	*YUGOSLAVIA*	Korea, Rep. of	Costa Rica	Panama
	IRAQ	*MEXICO*	*ROMANIA*		Lebanon	*CUBA*	Papua New Guinea
	KUWAIT	*OMAN*	South Africa		*TURKEY*	Cyprus	Paraguay
	LIBYA	*PERU*				Dominican Rep.	Portugal
	QATAR	*SYRIAN ARAB REP.*				Fiji	Suriname
	SAUDI ARABIA	*TRINIDAD AND TOBAGO*				*GUATEMALA*	Uruguay
	UNITED ARAB EMIRATES	*TUNISIA*				Guyana	
	VENEZUELA					Ivory Coast	
						Jamaica	
						Jordan	
						Malta	
Countries with Actual or Potential Fuelwood Problems[3]							
	ECUADOR	*ANGOLA*	*INDIA*	*BANGLADESH*	*AFGHANISTAN*	Benin	Mauritania
	INDONESIA	*BURMA*	Viet Nam,	Botswana	Burundi	Bhutan	*MOROCCO*
	NIGERIA	*CHINA*	Zimbabwe	Mozambique	*GHANA*	*CAMEROON*	Nepal
		CONGO, PEOPLE'S REP.		*PAKISTAN*	Malawi	Cape Verde Is.	Niger
		EGYPT		Zambia	Rwanda	Central African Rep.	*PHILLIPINES*
		ZAIRE				Chad	Sao Tome and Principe
						Comoros	Senegal
						El Salvador	Sierra Leone
						Eq. Guinea	Solomon Is.

TABLE 1.3

An Energy Classification of Developing Countries

Net Oil Exporting Developing Countries		Oil Importing Developing Countries[1]				
Net Oil Imports As % Commercial Energy Demand[2]	OPEC Members	Non-OPEC	0-25%	26-50%	51-75%	76-100%
						Ethiopia Gambia, The Grenada Guinea Guinea-Bissau Haiti Honduras Kampuchea, Dem. Kenya Lao PDR Lesotho Liberia Madagascar Maldives Mali Somalia Sri Lanka Sudan Swaziland Tanzania *THAILAND* Togo Uganda Upper Volta Western Samoa Yemen Arab Rep. Yemen PDR
Population (In Millions)	320[4]	1180	820	210	245	395

Countries shown in *ITALICS* are oil and/or gas producers. Table based on *UN World Energy Statistics 1978* (except for Bhutan, Botswana, Lesotho and Swaziland whose position in the Table is estimated) and staff estimates of fuelwood situation. Population data from *World Development Report, 1980* rounded to nearest 5 million.

[1]Excluding countries with 1978 per capita GNP above $3000 and countries with populations of less than 0.5 million that are not members of the World Bank

[2]Imports 1978

[3]Countries were placed in this category if estimated annual consumption of fuelwood could not be sustained through the year 2000, without damage to the ecology, at a level of 0.75 m^3 per capita where income per head (in 1978) was below $300, falling linearly to 0.50 m^3 at $600 and zero at $900. Many countries not included in this group have or will have fuelwood problems in local areas

Source: Energy in the Developing Countries, World Bank, August 1980.

TABLE 1.4

World Consumption of Energy, Nonrenewable and Renewable, 1980, with Projections to 2000

Year		Coal	Petroleum	Natural Gas	Nuclear	Renew-ables	Total
		Percent or Million Metric Tons Coal Equivalent (MMTCE)[1]					
1980	MMTCE	3,149	3,908	1,807	244	1,806	10,914
	%	28.9	35.8	16.6	2.2	16.5	
1985	MMTCE	3,831	3,810	1,850	445	2,055	11,992
1990	MMTCE	4,660	3,712	1,900	645	2,404	13,321
1995	MMTCE	5,145	3,526	1,875	720	2,949	14,215
2000	MMTCE	5,680	3,322	1,850	730	3,635	15,217
	%	37.3	21.8	12.2	4.8	23.9	

[1]Electricity from all courses calculated in terms of coal required to produce equivalent amount.

Source: Brown and Shaw, Washington, DC, March 1982.

TABLE 1.5

World Consumption of Energy from Renewable Sources, 1980, with Projections to 2000

Source		Million Metric Tons Coal Equivalent[1]					
	1980	1980	1985	1990	1995	2000	2000
Wood	56.2%	1,015	1,100	1,220	1,410	1,640	45.1%
Hydroelectric	33.2	600	710	850	1,020	1,200	33.0
Wind	0.2	3	5	17	90	200	5.5
Crop Residues	5.5	100	110	110	100	100	2.8
Waste—Methane	0.2	4	10	30	53	90	2.5
Waste—Electric Steam	0.6	10	12	15	20	25	0.7
Geothermal	0.7	13	27	52	87	140	3.9
Energy Crops	0.2	3	16	30	45	55	1.5
Solar Collectors	0.06	1	5	18	49	100	2.8
Cow Dung	3.2	57	60	60	55	45	1.2
Photovoltaic	0	0	0	2	20	40	1.1
TOTAL		1,806	2,055	2,404	2,949	3,635	

[1]Electricity from all sources calculated in terms of coal required to produce equivalent amount.

Source: Brown and Shaw, Washington DC, March 1982.

renewable energy consumption throughout the forecast period. The remaining forms of renewable energy are each less than six percent of worldwide renewable energy consumption and by 2000 are projected to rank in the following order: wind, geothermal, crop residues and solar collectors. methane from wastes, energy crops, cow dung, photovoltaics and electricity and steam from wastes (Brown and Shaw 1982). Some major limitations of these forecasts and attempts to alter their outcomes include the following: the difficulty of estimating yields and heating value of standing biomass (particularly in subtropical dry forest regions); seedling survival and growth rates of fuelwood plantations; the end use of energy in rural households (particularly fuelwood); and the growth potential of unconventional alternative renewable energy sources, such as solar ponds. These issues are dealt with in Part I of this book.

From the foregoing forecasts, the rank (measured by million metric tons of coal equivalents by the year 2000) of the top ten alternative energy sources showing absolute gains from 1980 to 2000 is as follows: coal, natural gas, wood, hydroelectric, nuclear, wind, geothermal, crop residues and solar collectors, methane from wastes, and energy crops. These alternative energy sources would in turn appear to be the logical focus of future feasibility analysis. The following section attempts to sketch out some key conceptual and measurement issues if proper feasibility analysis of these options is to occur, particularly the comparison of renewable and nonrenewable energy options.

FEASIBILITY ANALYSIS

MEASURING COSTS AND BENEFITS

What passes for "economic" analysis of various energy alternatives varies widely and can be placed on a continuum. One end, or "accounting stance," includes engineering-type cost and financial analysis utilizing current market or administered prices of inputs and outputs. At the other end, one finds income distribution analysis, including consideration of both weighted and unweighted income distribution impacts. In between lie a series of adjustments or shadow pricing methods to account for full opportunity cost, willingness to pay, elasticity of supply and demand, unemployed factors, externalities, economic surplus, and overvalued currency considerations.

Margolis (1969) suggests why private market prices may not reflect full social benefits or costs:

> There are many cases where exchange occurs without money passing hands; where exchanges occur but they are not freely entered into; where exchanges are so constrained by institutional rules that it would be dubious to infer that the terms were satisfactory; and where imperfections in the conditions of exchange would lead us to conclude that the price ratios do not reflect appropriate social judgments about values. Each of these cases gives rise to deficiencies in the use of existing price data as the basis for evaluation of inputs or outputs.(p. 534)

Generating cost estimates from engineering data and basing estimates of future revenues on current market prices can be misleading, particularly if one is concerned with societal costs and benefits. These "costs" generally do not represent full opportunity costs or highest-use value of all factors of production, such as the value of a farmer's time during the busy fall harvest season which must be set aside for collection of crop residue for energy. Alternatively, financial or market wages may overstate labor costs of a proposed fuelwood plantation or coal mine in an area of high under- or unemployment. These costs may also omit major technological externalities such as soil and nutrient loss from complete removal of crop residue or reductions in water pollution from sanitary landfill leachates resulting from recycling of solid waste. "Revenues" may also be overstated, particularly in those cases where local currency is overvalued (which is the case in most developing countries) or where a relatively inelastic demand exists for the end product(s). Economists frequently use shadow exchange rates to adjust for overvaluation of local currencies and the Bruno Criterion can be used to evaluate the foreign exchange saved or earned by alternative energy projects (Ward 1976). This is particularly relevant in evaluating renewable energy options in many developing countries. Frequently, these countries are heavily dependent on export earnings or foreign exchange from food, fiber, and forestry crops which may compete with bioenergy crops for land.

Leftwich (1966) lists the major factors increasing elasticity (price responsiveness) of demand for energy and other end products: the availability of good substitutes, large numbers of uses, high price of the commodity relative to consumers' incomes, and whether the price established is toward the upper (elastic) or lower (inelastic) end of the demand curve. If a particular energy product or by-product has no close substitutes and/or few end uses, current market prices based on a relatively small output of the product will probably grossly overstate the revenues from a future expanded level of production.

Gittinger (1982) argues for distinguishing between financial and economic analysis where financial analysis refers to net returns to private equity capital based on market or administered prices. Financial analysis also treats taxes as a cost and subsidies as a return. Interest paid to outside suppliers of money or capital is a cost, while any imputed interest on equity capital is a part of the return to equity capital. By contrast, Gittinger sees economic analysis as concerned with net economic returns to the whole society, frequently based on shadow prices to adjust for market or administered price imperfections. In economic analysis, taxes and subsidies are treated as transfer payments; that is, taxes are part of the total benefit of a project to society and subsidies are a societal cost.

This financial versus economic distinction is important, but the complementarity of these analytical approaches is equally relevant. Financial analysis provides information on the profitability of a given enterprise (e.g., combustion of crop residues for energy) to individual entrepreneurs or investors and thus gives an indication of the incentive structure and potential adoption rate. Economic or social cost-benefit

analysis attempts to determine profitability from a societal standpoint, taking into consideration externalities or environmental costs, pricing of under- or unemployed factors, currency evaluation, and so on. The appropriateness of these analytical alternatives depends on the question one is asking. Figure 1.1 provides a simplified schematic comparison of these alternative approaches.

FIGURE 1.1 ***Financial and economic efficiency analysis.***

	Financial Analysis	**Economic Analysis**
Focus.	Net returns to equity capital	Net returns to society
Prices:	Market or administered (May assume that markets are perfect or that administered prices have compensated for imperfections.)	May require shadow prices" e.g., monopoly in markets, external effects, un- or under-employed factors, overvalued currency.
Taxes:	Cost of production	Part of total societal benefits
Subsidies:	Source of revenue	Part of total societal cost
Purpose(s):	Measure of profitability to individual investors	Measure "profitability" or net economic returns to society
	Indication of incentive to adopt or implement	Determine if government investment is justified on economic efficiency basis
Income Distribution:	Can be measured in net returns to individual factors of production such as land, labor and capital	Is not considered in economic efficiency analysis (Can be done as separate analysis or as weighted efficiency analysis.)

Generally speaking, it is relatively straightforward to assign values to the cost and benefit streams in financial analysis; market prices suffice. However, this is substantially more difficult in full social analysis. Social costs and benefits must include valuation of all aspects of projects, including those which do not normally have a readily discernible market value. It is easy to imagine how difficult, and controversial, is the quantification of such factors as the social value of endangered species; the social value of scenic, archaeological, or historical resources; or the social costs of visual, noise, or air pollution, or traffic congestion. Resource economists have developed a myriad of methods and models to deal with this problem. However, the science—or art—of assessing these values is not as well-developed, nor as widely accepted as are the shadow pricing techniques for more obvious market imperfections which were discussed previously.

Once all cost and benefit streams have been given their appropriate prices or shadow values, one must decide on an appropriate rate of discount or time value and a criterion for evaluating and ranking the economic efficiency of alternative projects or programs. A long-standing controversy on the appropriate discount rate centers

primarily on those who support various private opportunity cost versus social time preference measures. For example, future costs or uncertainty associated with nuclear waste disposal may be either overlooked or heavily discounted, particularly under a private opportunity cost of capital comparison with an energy tree farm characterized by a several year delay in its benefit stream. Baumol (1969) has written a classic article dealing with the discount rate controversy.

The alternative efficiency criteria include (1) the ratio of benefits to costs, (2) the net present value, (3) the internal rate of return, (4) the payout period, and several other lesser known criteria related to optimal time phasing of projects, and the optimal utilization of scarce foreign exchange. Several authors, including Dasgupta and Pearce (1978), Gittinger (1982), and Ward (1976) have explored this difficult issue in depth. The primary differences in rank of a choice set of energy or other projects related to the foregoing alternative criteria are due to the following:

1. The nature of future benefit and cost streams (e.g., "bunching" of benefits or costs early or late in the time horizon).
2. The ratio of future operating costs to initial capital outlay.
3. The nature of the capital or budget constraint (e.g., user charges to cover the future operation costs and capital outlay).

Several of the foregoing cost-benefit analysis techniques will be applied in Part II to renewable energy cases on fuelwood, ethanol from sugar cane, and hydroelectric power in Ghana, the Caribbean Basin, and the Dominican Republic, respectively.

INCOME DISTRIBUTION

Analysis should also be concerned with the equity impacts of alternative energy strategies. An ongoing debate in Brazil involves the use of sugar cane or cassava for the production of ethanol for mixing with gasoline. Sugar cane is grown primarily on large plantations, while cassava is grown in nominally depressed areas throughout Brazil. Promotion of one crop over the other will have important income distribution impacts that need to be estimated and reported to decision makers. The comparison of pulp versus fuelwood options in the Ghana Subri Forest case in Part II also have important income distribution implications because of differences in the labor intensity of these options.

Economists use several alternative methods for handling income distribution impacts including:

1. Explicit weighting of net benefits by income class, group, or region.
2. Provision of alternative weighting functions and their distributional consequences to decision makers.
3. Estimation of nonweighted net benefits by income class, group, or region.
4. A constrained maximum or minimum targets approach which maximizes economic efficiency subject to an income constraint or vice versa.

Eckstein (1958) first suggested the explicit weighting of net benefits by income class based on past resource allocation and tax decisions. Haveman (1965) developed one of the first applications of Eckstein's approach by utilizing the marginal effective tax rates on personal income as an estimate of the value or marginal utility of a dollar of net benefits to various income groups affected by a U.S. Corps of Engineers water project. Weisbrod (1968) applied the other half of Eckstein's approach by utilizing past expenditure data on Corps of Engineers water resource projects to solve for the implicit weights given to net benefits received by different income classes.

An early example of providing alternative net benefit weighting functions and their distribution consequences was developed by McGuire (1969). The alternative functions are essentially estimates of the marginal utility of a dollar of net benefits to various income groups affected by a given project or program. Value judgments are required to formulate the alternative functions, but the decision on which function to choose is left to the decision maker(s). The estimation of nonweighted net benefits by income class (approach 3) eliminates the need for the analyst to make any value judgment on distribution weights.

The alternative of constrained maximum or minimum targets usually involves establishing a minimum acceptable distribution of net benefits to a designated low income class or group which must be met by each project or program in the choice set. For example, one might include fuelwood projects in a choice set for further evaluation only if at least one-half of each project's benefits accrue to the poorest one-third of the residents in the target area. The task is to pick the most efficient project or to rank the projects (meeting the minimum distribution constraint) on the basis of their economic efficiency; that is, benefit-cost ratio or internal rate of return.

Figure 1.2 summarizes some of the advantages and disadvantages of these alternative approaches for handling income distribution in the analysis of various projects or programs, including biological and other energy options. Key considerations in selecting an approach include:

1. Data availability on income by income class with and without the projects.
2. Existence of a representative government, including expenditure decisions and personal income tax rates from which to derive equity weights.
3. The ability to specify and maintain distribution constraints for high target efficiency of projects.

ENERGY ACCOUNTING AND THEORY OF VALUE

Some methodological disagreement exists between most economists and the majority of physical and biological scientists involved in the analysis of energy systems. The controversy is based pimarily on quite different methods of accounting for or assigning values to energy inputs and outputs. The physical and biological science approach assigns an energy value in British thermal units (Btu's) or kilocalories to both direct and indirect energy inputs and outputs in comparing the

FIGURE 1.2 ***Income distribution analysis.***

Approaches	Advantages	Disadvantages
Explicit weighting by income class, group, or region	Income distribution and efficiency analysis can be combined in what Weisbrod calls "Grand Efficiency"	Difficulty of determining what weights to use
		Past legislative decisions may not reflect current preferences on distribution
		Complicated computations
Provision of alternative weighting functions	A single set of distribution weights do not have to be selected	Higher computation costs (i.e., project must be evaluated for each function)
	Decision makers can identify their distribution preferences	Must still define a choice set of alternative weighting functions
Nonweighted net benefits by income class, group, or region	The analyst is freed of making value judgments on distribution weights	Distribution weights may not be made explicit by decisionmakers
	Separate distribution account is presented	
Constrained maximum or minimum targets	X percent or amount of net benefits to low-income participants are a required outcome of project	Projects may not meet their distribution target (i.e., low target efficiency due to difficulty of specifying and enforcing constraints)
	Less demanding data requirements	Requires monitoring of projects to stay on target

energy efficiency of alternative systems. This methodology is predicated primarily on the concern for the finite nature of fossil fuels (upon which industrialized societies have become heavily dependent) and their rates of depletion. Renborg (1979), a Swedish agricultural economist, summarizes the development of this methodological approach in the case of agricultural biomass.

Advocates for the foregoing method of energy accounting essentially distrust the measure of relative value provided by prices formed in markets or even by legislative intervention in markets (political shadow pricing or administered prices) for that matter. Renborg (1979) cites quotes from Slesser and Hannon to illustrate. According to Slesser, "energy analysts believe that it makes sense to measure the cost of things done, not in money, which is after all no more than a highly sophisticated value judgment, but in terms of thermodynamic potential" (Slesser 1975, p.170). Hannon

expresses a similar view by stating "in the long run we must adopt energy as a standard of value and perhaps even afford legal rights" (Hannon 1975, p.101).

Economists may see some similarities between this "energy theory of value" and the historical labor theory of value. The latter appeared in Adam Smith's *Wealth of Nations* in 1776, but has generally been attributed to Karl Marx.

Samuelson (1964) argues that the important lesson to be learned from a simple labor theory of value is that "it will lead to incorrect and inefficient use of both labor and non-labor resources in even the most perfect socialist society. So long as any economic resource is limited in quantity, i.e., scarce rather than free [market economies will and] socialist planners must give it a price and charge a rent for its use."

Criticism of a simple "energy theory of value" does not mean that it is without utility or that market or politically determined economic measures of energy value are without fault. Energy analysis is useful in describing the flow of energy resources (particularly finite) through a system; the energy flow and ecosystem analysis of a South Indian village in Chapter 9 is a case in point. Market and even politically determined prices for energy may understate such factors as technological externalities, national security, and considerations for future generations which may require shadow pricing by the analyst. However, a simple energy theory of value does not explicitly consider these factors either. In fact, it does not contain any other consumer preference than saving finite energy. Webb and Pearce (1975) point out that this introduces the idea that energy is the most important constraint on economic activity. Thus, policies or options with low energy input may have high total resource costs.

ENVIRONMENTAL IMPACT STATEMENTS

The environmental impact statement (EIS) has been primarily associated with increased environmental awareness in developed countries. For example, such statements have been required on most natural resource related projects in the United States under the auspices of organizations such as the U.S. Environmental Protection Agency. The EIS is intended as a supplement to the typical cost-benefit analysis for projects that have potential environmental impacts.

The increasing evidence of environmental deterioration in many developing countries has prompted the evolution of environmental laws and assessment procedures in several of these countries. The seriousness of the situation is described in the following quote from a recent USAID publication (1979):

> The critical environmental resources of developing countries are today subject to stresses of unprecedented magnitude... the health, nutrition and general well-being of the poor majority are directly dependent on the integrity and productivity of these resources. (p.1)

Eckholm (1976) in analyses done for the U.N. Environment Program reached similar conclusions on the state of the natural environment in the developing world. For example, it is estimated that desertification from deforestation is claiming an area the size of the state of Massachusetts each year.

Gross estimates of the damage caused by deforestation can be misleading, particularly when deforestation on hillsides is a major contributing factor to massive destruction of watersheds throughout a country. For example, a recently completed Country Environmental Profile (CEP) of the Dominican Republic by JRB Associates (1981) estimates soil erosion rates to average 300 metric tons/hectare/ year in most of the nation's watersheds. The resulting sedimentation is filling up the nation's water reservoirs. The useful lives of very costly hydroelectric facilities have already been cut to less than half by siltation. In addition, siltation damage to hydroelectric facilities often results in lower-than-planned power output levels and frequent power outages.

Thus, increasing numbers of developing countries have evolved national agencies for the protection of their environments. Environmental impact assessment is one of the roles many of these agencies will play in the future so that the impacts of energy-related projects such as the Aswan High Dam in Egypt, discussed in Part II, can be accurately foreseen and appropriately incorporated into engineering and administrative plans for the projects.

IMPLEMENTATION OF RENEWABLE ENERGY SYSTEMS

Even when the technical and economic analysis of alternative energy systems is reasonably comprehensive, major constraints to implementation may still exist. For example, the immediate response to the deforestation problem has been to propose establishment of agroforestry schemes on eroded lands and/or energy forests on large expanses of marginal lands unsuited for agriculture. However, implementation of the reforestation concept has not been that simple. Thomson (1981) highlights some legal, political, and social impediments to reforestation as follows:

1. Land tenure, tree tenure and associated residential patterns which may discourage wood production and affect the ease with which trees are protected.
2. The enforceability of property rights in land, which influences the decision to invest in slow-maturing crops like trees.
3. The enforceability of property rights in trees, which influences damage claims when protection fails.
4. The collective action capabilities at the local level, given distribution of political authority there and in overriding regimes.

Bromley (1985) suggests that the problem of implementing development in the newly independent tropical countries is one of structure, not low incomes, incorrect prices, badly functioning markets, or lassitude. Structure refers to the institutional

arrangements that define the choice sets (opportunity sets) within which individuals and groups go about the daily business of making a living, gathering firewood, etc. In many cases, colonialism superimposed alien institutional arrangements on top of traditional structures. Bromley argues that, upon receiving independence, many new nation-states were arbitrary consolidations of tribes, clans, and other ethnic entities under some European concept of statehood; this left people who had no experience in modern governance to fend for themselves. Implementation of renewable energy projects is complicated by this colonial legacy.

Part III of this book has four chapters devoted to anthropological, political, social, and environmental education perspectives on the problems of implementing renewable energy projects. The projects involve agroforestry in the Philippines, deforestation in Costa Rica, and soil conservation and sustainable fuelwood production in the Dominican Republic and Barbados. The delineation of property rights, political competition and patronage, degree of centralization, and role of local farmer organizations are some of the issues discussed.

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PART I.

RENEWABLE ENERGY PRODUCTION AND USE CHARACTERISTICS

CHAPTER 2.
BIOMASS INVENTORY METHODS FOR THE DRY FORESTS OF THE DOMINICAN REPUBLIC

Gregg Maxfield
Joseph Kasile

INTRODUCTION

The subtropical dry forests of the Dominican Republic have long served as the most important fuelwood source for the rural poor of the nation. These forests are now being considered by the Dominican government as a supplemental energy source for the country. Comprising approximately 5,905 square kilometers or 12 percent of the nation's land area (Jennings and Ferreiras 1979), the subtropical dry forests could possibly represent a total of 300×10^{12} British thermal units (Btu's) of available energy to the Dominican Republic, equivalent to 52 million barrels of oil. As a first step toward establishing sound management practices and policies for the nation's dry forests, it is necessary to adopt a forest inventory methodology that will assess the total above ground forest biomass, the biomass usable for fuelwood, and the potential energy of the usable biomass. Such an inventory is the first step and serves as the data base upon which a sound, sustainable biomass energy management plan can be developed and implemented.

The vast majority of the biomass regression equations reported to date are for predicting green and dry weights of tree components (leaves, branches, stems, and/or roots) for single-stem broadleaf or conifer species in the temperate regions. Very few biomass studies have been conducted in the subtropical dry forests, and no regression equations have been developed that predict the biomass weight of the species found within these dry forest ecosystems. This is where the scarcity of fuelwood is most acute, and the utilization of the tree components above ground is most common.

The term *subtropical dry forest* refers to the ecological classification system of Holdridge which according to Hartshorn et al. (1981) climatically defines these areas as having 500-1000 millimeters of rainfall annually and a mean biotemperature of 18-24°C. The potential evapotranspiration (PET) ratio of the dry forests is between

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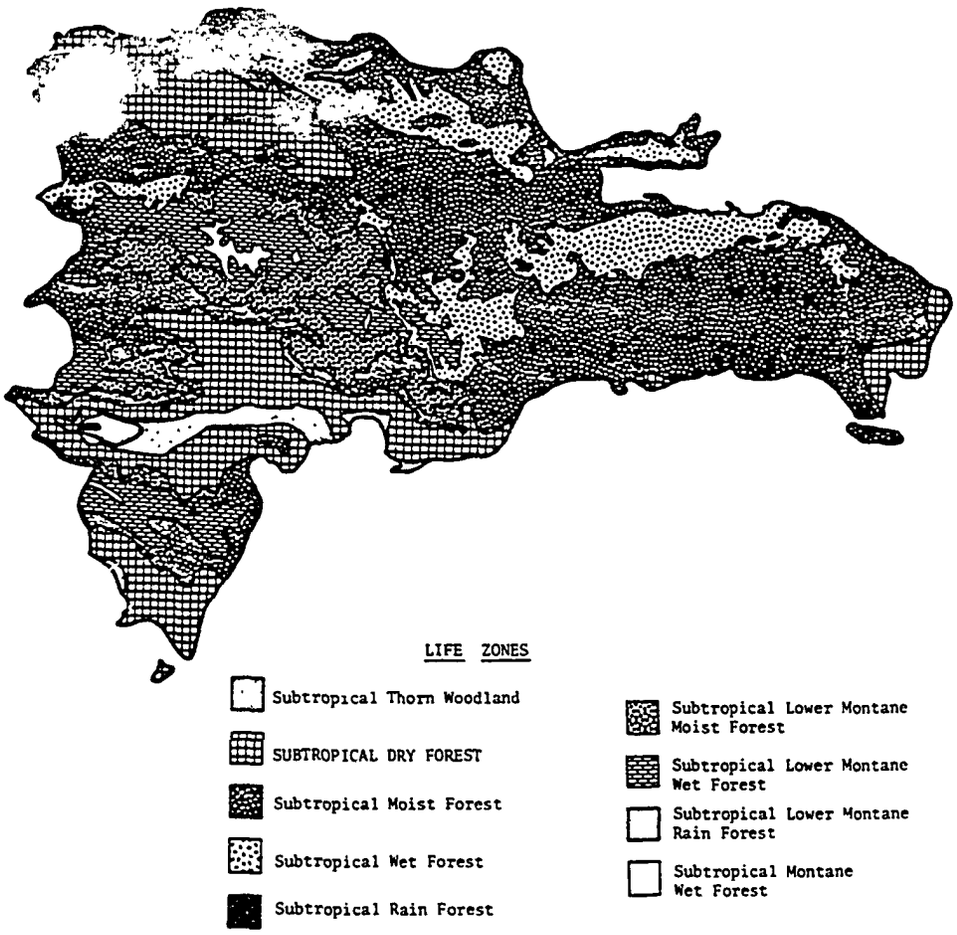
2.0 and 1.0. The subtropical dry forests of the Dominican Republic are typical of subtropical dry forests throughout the world. Although forest species may not be identical, growth form and ecologic dynamics will be similar for all subtropical dry forests. In the Dominican Republic, these dry regions are found primarily on the xeric sites in the northwestern and southwestern regions of the country (Figure 2.1). These dry conditions are caused by the rain shadows occurring on the leeward side of the major mountain ranges, which have a northwest to southeast orientation.

FIGURE 2.1 ***Holdridge life zones of the Dominican Republic.***



Source: Hartshorn, et al. 1981.

The subtropical dry forests of the Dominican Republic are inhospitable. There are high temperatures during most of the year, a lack of available surface water, scarcity of shade due to the feathery leaf structure of the trees, and an abundance of wasp nests and long-thorned cacti (Jennings and Ferreiras 1979).

The natural vegetation of the dry forests consists of a mixture of "sclerophyll" broad-leaved trees and cacti that form a relatively low, single-stratum forest with a mean height of 6-8 meters. Many trees are leguminous and respond to the available water in the soil (Hartshorn et al. 1981). Some of the slow-growing species such as Guayacan (*Guaiacum officinale*) and Tabacuelo (*Pictetia spinifolia*), (Bentances 1983) have extremely dense and heavy wood with specific gravities over 1.0, making them excellent sources of fuelwood and charcoal.

Forestry personnel working in the dry forests of the Dominican Republic suggest that the species distribution within these regions is strongly influenced by the degree of human intervention (in the form of fuelwood gathering) and overgrazing by goats and cows that has taken place (Arand et al. 1983). In regions considered to be "highly intervened," invasive species that have thorns and regenerate primarily in coppice form after being cut predominate, such as *Prosopis juliflora, Acadia macracantha,* and *Acacia tortuosa.* Two cactus species commonly found in these areas are *Cephalocerus polygonus* and *Opuntia moniliformis.* This type of vegetation often occurs along the sides of roads or major footpaths which are the most accessible areas for gathering firewood and for livestock grazing. In the less accessible and less intervened areas, species such as *Acacia scleroxyla* and *Cassia emarginata* are more abundant. *Bursera simaruba* and *Phyllostylon brasiliensis* are tree species not commonly used as firewood or for making charcoal; therefore, they are locally abundant throughout the dry forests.

PROJECT AREA

This project was conducted within the boundaries of an 850 hectare subtropical dry forest in northwestern Dominican Republic that serves as the experimental forest for the Woodfuel Research and Development Program. It is located west of the city of Mao, province of Valverde, and has the geographical coordinates of 19° 31′-19° 34′ N latitude and 71° 05′-71° 08′ W longitude.

The mean annual rainfall in Mao is approximately 740 millimeters, with the maximum rainfall occurring in April. Typically each year has two dry periods, (December-March and July-August) and two rainy periods (March-June and August-December). The average annual temperature for the region is 27.2°C, with August being the hottest month and January the coldest. The annual evapotranspiration occurring in the area is estimated to be 1700 millimeters resulting in a moisture deficit of approximately 960 millimeters.

The soils in the experimental region are sedimentary, alluvial, calcareous, and highly alkaline (pH of 7.5-8.2) consisting of silt loams with combinations of clay (CENDA 1983).

MATERIALS AND METHODS

The field and laboratory data for the energy biomass equation and inventory system development were collected from June-September 1984. Sample trees were selected, either in randomly allocated sample plots or individually, throughout the 850 hectare experimental dry forest in Mao. The twenty species found in the northwestern subtropical dry forest of the Dominican Republic that are considered important for firewood or charcoal making, and/or are abundant in the forest were sampled. The common, scientific, and family names of the twenty species are listed in Table 2.1.

To collaborate with research projects of the Woodfuel Research and Development Program, two-thirds (370 stems) of the field data was collected in ten randomly allocated circular plots within a 300-hectare section of the experimental forest. This area had previously been designated as native dry forest (Mercedes et al. 1984) and had been subject to relatively recent human and animal intervention. Each sample plot was concentric, having a smaller 200-square meter (m^2) subplot (radius = 7.98 meters) within a larger plot of 600-square meters (radius = 13.82 meters).

All trees of the twenty species of interest within the limits of the sample subplots having at least one diameter at breast height (DBH) of its multiple stems greater than or equal to 4.0 centimeters were measured for area biomass calculations.

To develop the regression equations, measurements on a minimum of twenty trees over a wide range of diameters per species were required. In those cases where less than twenty trees of a particular species were measured in the smaller subplots, trees of these species that fell within the limits of the 600 m^2 plot and had a diameter greater than or equal to 4.0 centimeters at 1.3 meters above ground level were measured. These data were kept separate from the 200 m^2 subplot data and used for individual tree regression development but not for the area biomass calculations.

Upon completion of sampling trees within the ten sample plots, additional sampling was conducted on those species that had less than the minimum twenty trees or were lacking certain diameter classes. One hundred eighty-six stems (one-third of the total data collected) were selected in this manner. These data were kept separate from the 200 m^2 data and used only for individual tree calculations. All sample trees had the following measurements taken:

1. Diameter at 0.5 meters above ground level recorded to the nearest 0.1 centimeter. This diameter is referred to as "diameter at knee height" (DKH).
2. Diameter at 1.3 meters above the root collar recorded to the nearest 0.1 centimeter (DBH).
3. Crown diameter (CD) recorded to the nearest 0.1 meter. This variable was measured with a metric tape before felling the tree. The average of two measurements, one in the north-south and the other in the east-west direction, was recorded on the tally sheet. In all directions the outer edge of the crown was considered to be the last green leaf.

TABLE 2.1

Common, Scientific, and Family Names of Species Included in the Biomass Study of the Dry Forest of Mao, Dominican Republic

Common Name	Scientific Name	Family Name
Almácigo	Bursera simaruba	Burseraceae
Aroma	Acacia macracantha	Mimosaceae
Baitoa	Phyllostylon brasiliensis	Ulmaceae
Bayahonda	Acacia tortuosa	Mimosaceae
Brucón	Cassia emarginata	Caesalpiniaceae
Cafetán	Palicourea alpina	Rubiaceae
Cambrón	Prosopis juliflora	Mimosaceae
Candelón	Acacia scleroxyla	Mimosaceae
Ciguamo	Krugiodendron ferreum	Rhamnaceae
Cinazo	Pithecellobium circinale	Mimosaceae
Frijol	Capparis spp.	Capparidaceae
Guaconejo	Amirys spp.	Rutaceae
Guatapanal	Caesalpinia coriaria	Caesalpiniaceae
Guayacán	Guaiacum officinale	Zygophyllaceae
Mostazo	Capparis flexuosa	Capparidaceae
Quina	Exostema caribaeum	Rubiaceae
Sangretoro	Maytenus buxifolia	Celastraceae
Tabacuelo	Pictetia spinifolia	Fabaceae
Trejo	Rheynosia uncinata	Fabaceae
Uvero	Coccoloba leoganensis	Polygonaceae

Source: Maxfield, 1985.

4. Total height (TH) recorded to the nearest 0.1 meter, after felling the tree with an axe. To account for variable stump heights, the total height measurement was made from the point on the stem previously marked at 0.5 meters to the last green leaf on the crown and then 0.5 meters was added.
5. Green weight of the total live biomass (GWT) above ground, recorded to the nearest point.
6. Green weight of the total live usable biomass (GWU) recorded to the nearest pound. This is all the aerial parts of the tree having a diameter greater than or equal to 2.5 centimeters. This minimum diameter is generally considered by the Dominican forestry personnel to be the smallest diameter used by the local people for firewood or for making charcoal.

A circular spring scale was used to measure the green weight of the trees cut in the field. The scale was hung from a portable metal tripod. A collapsible 1.5 meter by 1.5 meter square platform to hold the biomass was then hung with nylon ropes from a hook on the bottom of the scale.

Distinctions were made between:

- all living aerial portions of the tree (GWT) and
- all living woody parts of the tree with a diameter greater than 2.5 centimeters (GWU).

Subsamples were taken from three trees of seventeen of the species and two trees of two of the species for determination of moisture content and heat of combustion of each species. Three subsamples (approximately 2.5-centimeter thick disks) were randomly cut with a hand saw from the stem and large branches from each tree. No subsamples were taken for the species *Rheynosia uncinata* due to its scarceness in the field; it was not included in the biomass study.

Standard methods for moisture content determination were used for all species. The green weight of each subsample in grams was determined within two to five hours after being cut from the sample trees. The subsamples were placed in an oven at 105° ± 5°C for forty-eight hours after which the oven-dry weights were recorded to the nearest 0.1 gram.

The moisture content (MC) of each subsample, based on oven-dry weight, was calculated using the formula:

$$(1) \quad MC(\%) = \frac{\text{green weight (gm)} - \text{oven-dry weight (gm)}}{\text{oven-dry weight (gm)}}$$

In addition to the moisture content, a ratio estimator of the oven-dry weight of a subsample to its green weight, Q, was also calculated for each species so that field weights could be easily converted to dry weights:

$$(2) \quad Q = \frac{\text{oven-dry weight (gm)}}{\text{green weight (gm)}}$$

Two of the subsamples that were used to determine a species' moisture content were randomly selected (from different trees) for determining the gross and net heats of combustion of the species in Btu's per pound. Each subsample, including bark, was ground on a Wiley mill using a #20 mesh screen (2 mm diameter holes) and placed in a sealed glass container. Two pellets of approximately 0.5 grams in weight were made from each pulverized sample. The gross heats of combustion at 14 percent (assumed equivalent to air dried) and at field moisture contents, and the net heat of combustion of the sample in British thermal units per pound (Btu/lb.) were determined using a Parr adiabatic bomb calorimeter.

The formula for determining the gross heat of combustion for each pellet is as follows:

$$(3) \quad Hg = \frac{(t \times W) - e1 - e^2}{m}$$

where:

Hg = gross heat of combustion in Btu/lb.
t = temperature change from when combustion begins to its highest point in degrees Centigrade (°C).
W = energy equivalent of the calorimeter in calories per degree centigrade previously found using benzoic acid standard.
e1 = correction in calories for heat of formation of nitric acid (HNO_3). This equals the milliliters of standard alkali solution (0.0725N sodium carbonate) used in acid titration.
e2 = correction in calories for heat of combustion of fuse wire. This equals 2.3 times the length in centimeters of the fuse wire consumed in firing.
m = mass of sample in grams.
(Parr Instrument Company 1960)

The net heat of combustion of each subsample was obtained by using the following formula:

$$(4) \quad Hn = \frac{Hg\,(100 + MC)}{100 - (MC/7)}$$

where:

Hn = net heat of combustion in Btu/lb.
Hg = gross heat of combustion in Btu/lb.

MC = moisture content of subsample expressed in decimal form. (Panshin and DeZeeuw 1970)

Area biomass and potential energy estimates were made using only the data that were recorded within the ten 200 m^2 sample plots. The heating content for a species was determined by multiplying that species' average heat of combustion value at a specified moisture content by its biomass weight.

RESULTS AND DISCUSSION

Tables 2.2-2.8 summarize the biomass, moisture contents, and energy equivalents of the twenty species considered in the subtropical dry forest region that served as the project area.

For each species, the average dimensions measured for the trees in the field as well as the number of stems and average basal area per hectare are shown in Table 2.2.

The first two columns of Table 2.2 shows the number of stems that were measured at 0.5 and 1.3 meters above ground level, respectively. The comparison of these two columns gives an indication of those species whose stems may be more likely to fork between 0.5 and 1.3 meters.

For the twenty species combined, approximately 1300 stems per hectare have a DBH greater than or equal to 4.0 centimeters. Figure 2.2 shows that nearly half of these stems have a DKH that falls in the 4-6 centimeter range. The high frequency of small-stemmed trees per hectare illustrates the typical configuration of the dry land forests of this region. The mean DKH of all stems measured in the sample plot was 7.8 centimeters. The largest DKH measured was 34.0 centimeters for a single-stemmed *Bursera simaruba.*

The mean height of all the stems measured in the sample plots was 6.0 meters. Figure 2.3 illustrates that more than 60 percent of the stems measured had total heights between 5 and 7 meters, indicating the relatively low canopy of the dry land forests. The tallest tree measured was the same *Bursera simaruba* mentioned previously with a total height of 10.5 meters.

The total basal area at 0.5 and 1.3 meters above ground level for the twenty species is 7.6 and 6.4 square meters (m^2), respectively, of which approximately 60 percent is accounted for in two species not commonly used as firewood or for making charcoal, *Bursera simaruba* and *Phyllostylon brasiliensis.* As seen in Table 2.2, the basal area of the former species is contained in a relatively few number of large stems while that of the latter is made of many smaller stems. If the species *Acacia scleroxyla* is added to *Bursera simaruba* and *Phyllostylon brasiliensis,* over 75 percent of the biomass in the experimental region is included.

The 6.4 m^2 of basal area at 1.3 meters above ground level for stems of the twenty species having at least one DBH greater than or equal to 4.0 centimeters cannot be directly compared, but is relatively similar to the 9.42 m^2 of basal area for stems of 30

TABLE 2.2

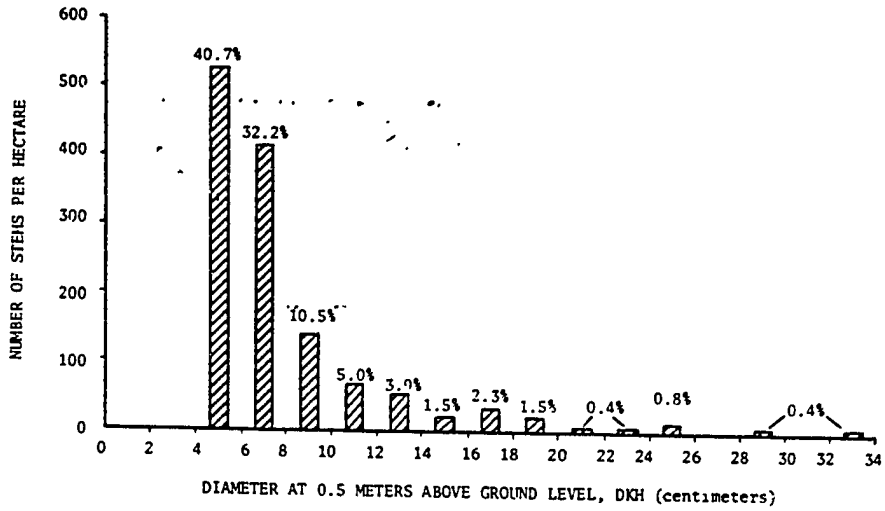
Summary Statistics for 20 Species Measured in Ten 200 m² Sample Plots of Dry Forest Experimental Zone Mao, Dominican Republic[1]

Specie	Number of stems measured at 0.5 m.	1.3 m.	DKH range cm.	DKH cm.	DBH range cm.	DBH cm.	Hgt range m.	Hgt m.	Per Hectare: No. of stems at 0.5m	DKHBA m²	%	DBHBA m²	%
Bursera simaruba	20	20	5.5-34.0	15.5	4.5-32.0	14.6	3.8-10.5	7.0	100	2.30	30.1	2.04	32.0
Acacia macracantha	3	4	5.4-14.7	9.0	4.9-10.9	7.2	5.5-7.2	6.6	15	0.12	1.6	0.10	1.6
Phyllostylon brasiliensis	104	115	4.3-18.5	7.1	3.4-17.4	5.9	4.1-9.6	6.1	520	2.34	30.6	1.83	28.7
Acacia tortuosa	1	1	6.8	6.8	5.5	5.5	6.5	6.5	5	0.02	0.3	0.01	0.2
Cassia emarginata	11	11	4.1-11.6	6.3	4.1-10.5	5.9	5.5-6.6	6.0	55	0.19	2.5	0.16	2.5
Paliccurea alpina	15	18	4.8-12.6	6.2	4.0-10.3	5.1	4.4-6.6	5.3	75	0.14	1.8	0.11	1.7
Prosopis juliflora	12	12	4.5-15.0	6.8	4.2-10.9	5.9	4.2-8.0	6.1	60	0.25	3.3	0.18	2.8
Acacia scleroxyla	25	33	4.7-28.8	9.5	4.0-20.8	7.7	4.7-9.8	6.4	125	1.15	15.0	1.03	16.1
Krugiodendron ferreum	2	2	5.0-5.7	5.4	4.6-4.7	4.7	4.7-4.8	4.8	10	0.02	0.3	0.02	0.3
Pithecellobium circinale	10	10	4.1-8.1	5.6	4.1-6.8	5.2	5.7-6.5	6.1	50	0.05	0.7	0.04	0.6
Capparis spp.	2	4	12.0-13.0	12.5	7.6-10.5	9.0	4.9-5.6	5.3	10	0.12	1.6	0.13	2.0
Amirys spp.	7	9	4.6-9.9	6.8	4.1-8.4	5.8	4.3-6.4	5.0	35	0.14	1.8	0.12	1.9
Caesalpinia coriaria	3	4	9.2-12.5	10.8	8.3-10.3	9.0	4.7-6.4	5.5	15	0.14	1.8	0.13	2.0
Guaiacum officinale	13	15	4.8-8.3	6.3	3.5-7.2	4.9	3.2-5.5	3.9	65	0.19	2.5	0.14	2.2
Capparis flexuosa	5	6	4.3-6.9	5.3	3.4-5.4	4.5	3.8-6.1	5.0	25	0.05	0.6	0.04	0.6
Exostema caribaeum	18	20	4.7-11.2	6.7	3.0-8.1	5.2	5.6-8.0	6.7	90	0.33	4.3	0.22	3.4
Maytenus buxifolia	2	3	7.0	7.0	4.2-5.5	4.7	3.4-4.6	4.0	10	0.04	0.5	0.03	0.5
Pictetia spinifolia	3	3	5.5-7.0	6.0	4.3-5.7	5.0	3.6-5.5	4.6	15	0.04	0.5	0.03	0.5
Rheynosia uncinata	1	1	4.6	4.6	4.2	4.2	3.7	3.7	5	0.01	0.1	0.01	0.2
Coccoloba leoganensis	1	1	5.7	5.7	5.5	5.5	5.3	5.3	5	0.01	0.1	0.01	0.2
TOTAL[2]	258	292	4.1-34.0	7.8	3.0-32.0	6.6	3.2-10.5	6.0	1290	7.65 (1.15)	100.0	6.38 (1.01)	100.0

[1]For stems having at least one DBH greater than or equal to 4.0 centimeters.
[2]Number in parenthesis is standard error of the estimate, (Freese, 1962).

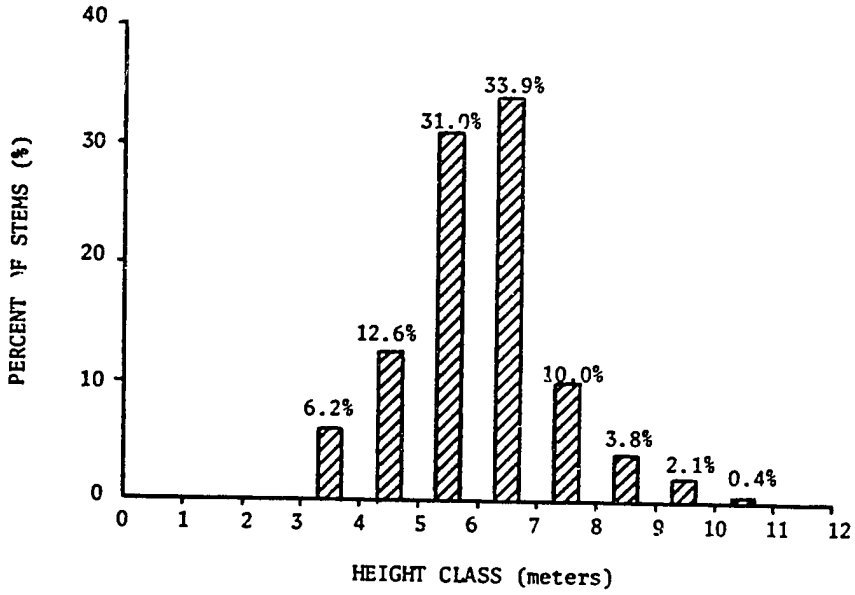
Source: Maxfield, 1985.

FIGURE 2.2 ***Diameter distribution for stems with a DBH greater than or equal to 4.0 centimeters in ten 200 m² sample plots of the Mao subtropical dry forest.***



Source: Maxfield, 1985.

FIGURE 2.3 ***Height distribution for stems with a DBH greater than or equal to 4.0 centimeters in ten 200 m² sample plots of the Mao subtropical dry forest.***



Source: Maxfield, 1985.

species having a DBH greater than or equal to 5.0 centimeters that was reported for a subtropical dry forest in neighboring Puerto Rico (Murphy and Lugo 1985).

The average moisture contents on a dry weight basis for 19 species are presented in Table 2.3. They range from 186 percent for *Bursera simaruba* to 25 percent for *Amirys* spp. and *Pictetia spinifolia.* Eleven of the nineteen species have moisture contents between 40 and 50 percent.

Table 2.4 presents the higher heating values, (i.e. net heat of combustion) and estimates of the gross heats of combustion at 14 percent and field moisture contents for each species. These latter two values were obtained by rearranging equation 4 to the following form:

$$(5) \quad Hg = \frac{100 - (MC/7)}{Hn \times (100 + MC)}$$

where:

Hg = gross heat of combustion in Btu/lb.
Hn = net heat of combustion in Btu/lb.
MC = average moisture content of species

The net heats of combustion (oven-dry) range from 7860-9240 Btu/lb. with fifteen species falling between 8200-8700 Btu/lb. Four species have heating values greater than 8800 Btu/lb. and one is less than 8000 Btu/lb. The gross heats of combustion at field moisture content are more variable between species with a low of 2000 Btu/lb. for *Bursera simaruba* and a high of 7100 Btu/lb. for *Amirys* spp.

Because some heat is initially used to drive off and evaporate moisture in combustion of the wood, the species having the highest field moisture contents (Table 2.3) are those with the lowest gross heats of combustion. Similarly, the species having the highest field moisture contents are the ones with the greatest initial relative increase in heat of combustion as the wood dries to a constant moisture level. The final column of Table 2.4 shows the relative increases in the heat of combustion for each species as its moisture content decreases from field measurements to 14 percent. *Bursera simaruba, Capparis flexuosa,* and *Coccoloba leoganensis* are the species having the greatest relative increase in energy as their wood dries to a 14 percent moisture content. The relative increase in heat of combustion is not considered for the species as the wood is dried further from 14 percent to oven-dry since this is a functional relationship of equation 5 and because it is doubtful that ovens would be used to continue drying the wood past their air-dry moisture contents when used for fuelwood or making charcoal.

Table 2.5 presents the average green and dry weights of the above ground total and usable biomass in metric tons per hectare (mt/ha) for each species. The percentage of the total green weight biomass that is usable for firewood or making charcoal is also shown in Table 2.5. There are approximately 45.60 and 32.47 mt/ha of total and

TABLE 2.3

Moisture Contents and Dry Weight to Green Weight Ratio Estimators for 19 *Species in* the Mao Subtropical Dry Forest

Specie[1]	M.C.(%)[2]	$S_{M.C.}$[4]	Q[3]	S_Q[4]	n
Bursera simaruba Almácigo	186.73	10.15	0.3512	0.0104	9
Acacia macracantha Aroma	43.24	1.33	0.6958	0.0065	9
Phyllostylon brasiliensis Baitoa	48.85	1.45	0.6744	0.0048	9
Acacia tortuosa Bayahonda	39.47	1.54	0.7226	0.0057	6
Cassia emarginata Bructón	44.62	2.27	0.6802	0.0078	9
Policurea alpina Cafetán	49.50	1.00	0.6726	0.0058	9
Prosopis juliflora Cambrón	46.42	2.73	0.6731	0.0146	9
Acacia scleroxyla Candelón	46.02	1.59	0.6909	0.0073	9
Krugiodendron ferreum Ciguamo	43.14	1.33	0.7043	0.0053	6
Pithecellobium circinale Cinazo	40.32	0.96	0.7131	0.0054	9
Capparis spp. Frijol	41.25	0.42	0.7093	0.0025	9
Amirys spp. Guaconejo	24.99	0.84	0.8018	0.0041	9
Caesalpinia coriaria Guatapanal	43.73	1.36	0.7054	0.0092	9
Guaiacum officinale Guayacán	45.10	1.97	0.7026	0.0069	9
Capparis flexuosa Mostazo	62.58	2.36	0.6173	0.0104	9
Exostema caribaeum Quina	30.61	2.41	0.7714	0.0153	9
Maytenus buxifolia Sangretoro	53.16	1.52	0.6577	0.0054	9
Pictetia spinifolia Tabacuelo	25.10	0.67	0.7948	0.0052	9
Coccoloba leoganensis Uvero	61.74	1.35	0.6191	0.0066	9

1/Common names of species as referred to in northwestern Dominican Republic
2/Average moisture content on dry weight basis

3/ $Q = \frac{\text{mean of oven-dry weight of n subsamples}}{\text{mean of green weight of n subsamples}}$

4/Standard error of the estimate

Source: Maxfield, 1985.

TABLE 2.4

Heat of Combustion Values at Oven-dry, 14% and Field Moisture Contents for 19 Species in the Mao Subtropical Dry Forest

Mean Heat of Combustion (Btu/lb.)

Specie[1]	Oven-dry	S_{od}[3]	14% M.C.	S_{14}[3]	Field M.C.	S_{Fld}[3]	n	E(%)[2]
Bursera simaruba Almacigo	7863.87	65.35	6760.17	56.18	2011.00	16.71	4	236.2
Acacia macracantha Aroma	8419.18	6.29	7237.54	5.41	5514.60	4.12	4	31.2
Phyllostylon brasiliensis Baitoa	8188.64	51.30	7039.36	44.10	5117.36	32.06	4	37.6
Acacia tortuosa Bayahonda	8202.18	9.40	7136.96	8.08	5617.02	6.36	4	27.1
Cassia emarginata Brucon	8468.28	40.34	7279.75	34.68	5482.29	26.12	4	32.8
Policurea alpina Cafetan	8430.66	11.60	7247.41	9.97	5240.46	7.21	4	27.7
Prosopis juliflora Cambron	8570.60	6.06	7367.71	5.21	5465.27	3.86	4	34.8
Acacia scleroxyla Candelon	8559.10	42.62	7357.82	36.64	5476.24	27.27	4	34.4
Krugiodendron ferreum Ciguamo	8200.73	43.05	7049.75	37.01	5376.09	28.22	4	31.1
Pithecellobium circinale Cinazo	8364.59	19.29	7190.61	16.58	5617.72	12.96	4	28.0
Capparis spp. Frijol	8651.19	77.62	7436.99	66.73	5763.81	51.71	4	29.0
Amirys spp. Guaconejo	9237.39	40.55	7940.91	34.86	7126.66	31.28	4	11.4
Caesalpinia coriaria Guatapanal	8543.47	52.22	7344.39	44.89	5572.77	34.06	4	31.8
Guaiacum officinale Guayacan	9105.49	36.56	7827.53	31.43	5871.01	23.57	4	33.3
Capparis flexuosa Mostazo	8281.63	35.48	7119.30	30.50	4638.49	19.87	4	53.5
Exostema caribaeum Quina	8896.92	44.56	7648.23	38.31	6513.95	32.62	4	17.4
Maytenus buxifolia Sangretoro	8419.72	28.67	7238.00	24.65	5079.85	17.30	4	42.5
Pictetia spinifolia Tabacuelo	8864.63	45.39	7620.47	39.02	6831.95	34.98	4	11.5
Coccoloba leoganensis Uvero	8382.48	24.10	7205.99	20.72	4725.58	13.59	4	52.5

[1] Common names of species as referred to in northwestern Dominican Republic
[2] Indicates the relative increase in heat of combustion by allowing the wood to dry from field moisture to 14% moisture content.

$$E(\%) = \frac{E_{14} - E_{Field}}{E_{Field}} \times 100$$

[3] Standard error of the estimate

Source: Maxfield, 1985.

usable green weight biomass, respectively, in the subtropical dry forest project area. The 19.04 mt/na of usable biomass on an oven-dry weight basis in the Mao dry forest is similar to 16 mt/ha reported for live trees having a diameter at ground height (DGH) greater than or equal to 5.0 centimeters in the Guanica dry forest of Puerto Rico (Murphy and Lugo 1985).

As with basal area, approximately 75 percent of the usable green weight biomass is in the three species, *Bursera simaruba, Phyllostylon brasiliensis, and Acacia scleroxyla.* The largest portion is in the most massive species *Bursera simaruba.* The same three species contain approximately 70 percent of the usable dry weight biomass. However, due to its high moisture content and low dry weight/green weight ratio, *Bursera simaruba* contributed to less than one-third of this usable dry weight biomass. Of these three species, only *Acacia scleroxyla* is currently being used for firewood and making charcoal.

The ratio of the usable to total green weight biomass shown in Table 2.5, estimates what percentage of the total above ground portion of the stem for a particular species is considered usable for firewood or making charcoal. High percent values such as those of *Bursera simaruba, Acacia macracantha,* and *Prosopis juliflora* indicate that if used for fuelwood, the major part of the above ground portion of the stem would normally be utilized. Low percent values, on the other hand like those of *Coccoloba leoganensis, Capparis flexuosa,* and *Caesalpinia coriaria* demonstrate that a large part of each of these species total above ground biomass are of the crown portions having a diameter less than 2.5 centimeters. The above ground portions having a diameter less than 2.5 centimeters are considered unusable biomass for firewood or charcoal making.

Table 2.6 reports the energy equivalents in British thermal units per hectare (Btu/ha) of the usable biomass for each species and all species combined at oven-dry, 14 percent, and field moisture contents in the study site. At each of these respective moisture contents, 591.5, 508.5, and 314.0 million Btu/ha are estimated to exist in the experimental region for the 19 species combined. Using the conversion factor that 1 barrel of oil is equivalent to 5.8 million Btu's, reported by the National Energy Commission of the Dominican Republic (COENER 1980), the energy content of this biomass represents approximately 102, 88, and 54 barrels of oil per hectare at the oven-dry, 14 percent, and field moisture levels, respectively.

The three species, *Phyllostylon brasiliensis, Acacia scleroxyla,* and *Bursera simaruba* alone, represent 68 percent or 214 million Btu/ha, the equivalent of 37 barrels of oil per hectare. Allowing the wood to air dry to around 14 percent moisture content increases the potential energy of these three species to approximately 380 million Btu/ha (65.5 barrels of oil per hectare) which represents almost 75 percent of the energy of all species combined and an increase of 28.5 barrels of oil per hectare over their field moisture energy levels. For *Bursera simaruba* alone, the 14 percent moisture content represents more than a three-fold increase in energy availability over that of using the wood at field moisture. The total increase in energy contributed by

TABLE 2.5

Average Green and Dry Weights per Hectare of the Biomass for 20 Species in the Mao Subtropical Dry Forest

Specie[1]	Green Weight of Biomass (metric tons/hectare) Total	%	Usable	%	Percentage of Usable Biomass (%)	Dry Weight (mt/ha) Usable	%
Bursera simaruba Almácigo	11.32	24.8	9.91	30.5	87	3.48	18.3
Acacia macracantha Aroma	0.78	1.7	0.59	1.8	75	0.41	2.1
Phyllostylon brasiliensis Baitoa	12.17	26.7	7.76	23.9	63	5.23	27.5
Acacia tortuosa Bayahonda	0.12	0.3	0.09	0.3	78	0.07	0.4
Cassia emarginata Brucón	1.14	2.5	0.68	2.1	60	0.46	2.4
Policurea alpina Cafetán	1.93	4.2	1.11	3.4	57	0.75	3.9
Prosopis juliflora Cambrón	1.34	2.9	1.00	3.1	75	0.68	3.6
Acacia scleroxyla Candelón	9.75	21.4	6.89	21.2	71	4.76	25.0
Krugiodendron ferreum Ciguamo	0.11	0.2	0.06	0.2	59	0.04	0.2
Pithecellobium circinale Cinazo	1.18	2.6	0.74	2.3	63	0.53	2.8
Capparis spp. Frijol	0.52	1.1	0.38	1.2	73	0.27	1.4
Amirys spp. Guaconejo	0.80	1.8	0.44	1.4	55	0.35	1.8
Caesalpinia coriaria Guataparal	1.10	2.4	0.60	1.8	55	0.42	2.2
Guaiacum officinale Guayacán	0.86	1.9	0.59	1.8	69	0.42	2.2
Capparis flexuosa Mostazo	0.51	1.1	0.24	0.7	48	0.15	0.8
Exostema caribaeum Quina	1.48	3.3	1.09	3.3	74	0.84	4.4
Maytenus buxifolia Sangretoro	0.20	0.4	0.12	0.4	57	0.08	0.4
Pictetia spinifolia Tabacuelo	0.12	0.3	0.09	0.3	79	0.07	0.4
Rheynosia uncinata Trejo	0.08	0.2	0.05	0.2	62	-	-
Coccoloba leoganensis Uvero	0.09	0.2	0.04	0.1	45	0.03	0.2
TOTAL[2]	45.60 (8.60)	100.0	32.47 (6.94)	100.0	71	19.04 (10.74)	100.0

[1] Common name of species as referred to in northwestern Dominican Republic
[2] Number in parenthesis is standard error of the estimate, (Freese, 1962)

Source: Maxfield, 1985.

TABLE 2.6

Average Energy Equivalents of the Usable Biomass for 20 Species in the Mao Subtropical Dry Forest

Energy Equivalents of Usable Biomass (Btu/ha x 10^6)

Species[1]	Oven-dry	%	14% Moisture	%	Field Moisture	%
Bursera simaruba Almácigo	171.83	29.1	147.71	29.1	43.94	14.0
Acacia macracantha Aroma	10.86	1.8	9.34	1.8	7.11	2.3
Phyllostylon brasiliensis Baitoa	140.07	23.7	120.41	23.7	87.53	27.9
Acacia tortuosa Bayahonda	1.66	0.3	1.43	0.3	1.12	0.4
Cassia emarginata Brucón	12.70	2.1	10.92	2.1	8.22	2.6
Policurea alpina Cafetán	20.62	3.5	17.72	3.5	12.81	4.1
Prosopis juliflora Cambrón	18.98	3.2	16.32	3.2	12.11	3.9
Acacia scleroxyla Candelón	130.06	22.0	111.80	22.0	83.21	26.5
Krugiodendron ferreum Ciguamo	1.15	0.2	0.99	0.2	0.75	0.2
Pithecellobium circinale Cinazo	13.63	2.3	11.72	2.3	9.16	2.9
Capparis spp. Fríjol	7.22	1.2	6.21	1.2	4.81	1.5
Amyris spp. Guaconejo	8.96	1.5	7.70	1.5	6.91	2.2
Caesalpinia coriaria Guatapanal	11.32	1.9	9.73	1.9	7.38	2.4
Gualacum officinale Guayacán	11.93	2.0	10.25	2.0	7.69	2.4
Capparis flexuosa Mostazo	4.43	0.8	3.81	0.8	2.48	0.8
Exostema caribaeum Quina	21.35	3.6	18.36	3.6	15.63	5.0
Maytenus buxifolia Sangretoro	2.15	0.4	1.85	0.4	1.30	0.4
Pictetia spinifolia Tabacuelo	1.82	0.3	1.56	0.3	1.40	0.4
Rheynosia uncinata Trejo	-	-	-	-	-	-
Coccoloba leoganensis Uvero	0.75	0.1	0.65	0.1	0.43	0.1
TOTAL[2]	591.49 (352.38)	100.0	508.48 (294.34)	100.0	313.99 (179.44)	100.0

1/Common name of species as referred to in northwestern Dominican Republic
2/Number in parenthesis is standard error estimate (Freese, 1962)

Source: Maxfield, 1985.

Bursera simaruba at 14 percent moisture content over field moisture is due to (1) the large number of stems of *Bursera simaruba* present in the area and (2) the fact that as the wood dries from field weight to 14 percent, its gross heat of combustion increases from 2011 to 6760 Btu/ha (Table 2.4).

By not utilizing *Bursera simaruba* and *Phyllostylon brasiliensis* for firewood or making charcoal, the potential energy of the area at oven-dry, 14 percent, and field moisture contents decreases to 280, 240 and 183 million Btu/ha, respectively, (or 48, 41 and 32 barrels of oil equivalent per hectare).

The potential energy for fuelwood and charcoal at 14 percent moisture content of the dry land forests of the Dominican Republic as derived from these are energy estimates represents the equivalent of 52 million barrels of oil. Using the basic parameters of heats of combustion developed here can lead to a management plan that will optimize the growth and production of the natural species of the dry land forests to provide for a considerable portion of the energy needs on a sustained basis. The dry land forests are the energy reservoir of the Dominican Republic.

BIOMASS REGRESSION EQUATIONS

Tables 2.7 and 2.8 present the regression coefficients and sample statistics of the prediction equations to estimate the green weight of the usable biomass or the portions having a diameter greater than or equal to 2.5 centimeters for sixteen individual species and three combined species. During the development of these equations, a double logarithmic transformation was used to ensure that the variances were homogeneous.

Table 2.7 presents the regression equations, with the independent variables that yield the highest coefficient of determination, r^2. Seven of the ten independent variables considered, given the highest r^2 value in all seventeen biomass equations. Each equation in Table 2.7 is of the form:

$$\ln(\text{weight}) = bo + B1 \times \ln(Xi)$$

where:

weight = green weight in pounds of the usable biomass.

X^1:X^1 = basal area of stem at 0.5 meters above ground level (DKHBA).

X^2 = basal area of stem at 0.5 meters above ground level times total stem height (DKHBA x TH).

X^3 = basal area of stem at 0.5 meters above ground level times crown diameter (DKHBA x CD).

X^4 = basal area of stem at 1.3 meters above ground level times total stem height (DBHBA x TH).

X^5 = basal area of stem at 1.3 meters above ground level times crown diameter (DBHBA x CD).

TABLE 2.7

Simple Linear Regression Coefficients and Statistics for Predicting Green Weight of the Usable Biomass of Subtropical Dry Forest Species in Mao, Dominican Republic, with the Regression Model

$$\ln(\text{usable weight}) = b_0 + b_1 + \ln(X_i)^{1}$$

Specie[2]	Coefficients		X_i	Statistics			
	b_0	b_1		n	$S_{y.x}$[3]	r^2	DKH Range (cm)
Bursera simaruba Almacigo	7.191616	1.110368	X_2	36	0.146939	.9898	4.0-34.0
Acacia macracantha Aroma	7.633640	1.043212	X_3	23	0.183606	.9831	4.0-30.0
Phyllostylon brasiliensis Baitoa	7.096829	1.038230	X_2	56	0.144541	.9849	4.0-29.0
Cassia emarginata Brucon	10.008809	1.208762	X_1	26	0.178667	.9574	4.0-16.0
Policurea alpina Cafetan	9.592580	1.125651	X_1	18	0.277910	.8287	4.0-12.0
Prosopis juliflora Cambron	7.518781	0.999669	X_4	22	0.168407	.9827	4.0-30.0
Acacia scleroxyla Candelon	7.762502	1.112649	X_4	46	0.173730	.9854	4.0-29.0
Pithecellobium circinale Cinazo	8.804170	1.315341	X_4	23	0.211858	.8732	4.0-8.0
Capparis spp. Frijol	7.334954	1.053208	X_2	21	0.116820	.9880	4.0-19.0
Amirys spp. Guaconejo	7.661575	1.111198	X_2	21	0.111727	.9759	4.0-11.0
Caesalpinia coriaria Guatapanal	7.882536	1.079668	X_5	24	0.184299	.9822	4.0-24.0
Guaiacum officinale Guayacan	11.386864	1.464382	X_1	24	0.201363	.9156	4.0-10.0
Exostema caribaeum Quina	4.797154	0.820955	X_6	29	0.166601	.9528	4.0-14.0
Maytenus buxifolia Sangretoro	7.850758	1.120838	X_2	22	0.180072	.9516	4.0-14.0
Pictetia spinifolia Tabacuelo	7.390734	1.088975	X_2	13	0.177935	.8886	4.0-7.0
Coccoloba leoganensis Uvero	5.701871	0.974551	X_6	26	0.189499	.9657	4.0-18.0
Others	6.480793	1.157791	X_7	11	0.285666	.8381	4.0-8.8

[1] X_i = independent variable where:

X_1 = DKHBA
X_2 = DKHBA • TH
X_3 = DKHBA • CD
X_4 = DBHBA • TH
X_5 = DBHBA • CD
X_6 = DKHBA • TH^2
X_7 = DBHBA • TH^2

[2] Common name of species as referred to in northwestern Dominican Republic
[3] Standard error of the estimate in natural log (ln) form.

Source: Maxfield, 1985.

X^6 = basal area of stem at 0.5 meters above ground level times total stem height squared (DKHBA x TH^2).

X^7 = basal area of stem at 1.3 meters above ground level times total stem height squared (DBHBA x TH^2).

The umbrella-like crown canopy and multistemmed nature of many species in the natural dry forests make it difficult, time consuming, and expensive to measure accurately the total height or crown diameter of a standing tree. Therefore, the regression equations, shown in Table 2.8 for each species, predict the green weight of the usable biomass with the independent variable being the basal area of the stem at 0.5 meters above the ground level, DKHBA.The basal area at knee height was chosen as the independent variable because it showed a higher correlation to stem biomass for most species. Also, DKHBA is the fastest and easiest variable to measure of all the variables considered in the development of the biomass and energy regression equation development. The equations in Table 2.7 have smaller standard error of the estimates and higher r^2 as compared to those of Table 2.8 which indicate that regression equations in Table 2.7 will give a more precise estimate of the usable and total biomass for stems within the specified diameter ranges of each species. However, in using equations of Table 2.7, another variable (height, crown diameter, or diameter at breast height) must be measured in the field for each stem. This increases the amount of necessary field work and the overall cost of the sampling procedures. Also, in comparing Table 2.7 with Table 2.8, in most cases, the increase in the r^2 from using a variety of independent variables as required by Table 2.7 results in little improvement of the r^2 over using DKHBA as a uniform independent variable. To inventory stands with mixed species, probably the set of equations having the same independent variable (i.e., DKHBA) would be best. In cases where just one or two species are of interest, however, it might be more feasible to use the equations yielding the most precise estimates.

Using the biomass regression equations shown in Tables 2.7 and 2.8 on inventory data, as well as the energy equivalent estimates reported for each species in Table 2.4, will provide accurate biomass and potential energy estimates of the material commonly used for firewood and making charcoal in the native dry forests of the Dominican Republic.

Inventories of the dry land forests can now be conducted in an efficient, accurate manner to determine biomass and energy potential for each area. These areas can then be regulated to provide the continuing, renewable fuelwood energy needs of the Dominican Republic.

CONCLUSIONS

This chapter illustrates the development of energy values and inventory techniques necessary for the inventory of the dry land forests and prerequisite to the

TABLE 2.8

Simple Linear Regression Coefficients and Statistics for Predicting Green Weight of the Usable Biomass of Subtropical Dry Forest Species in Mao, Dominican Republic with the Regression Models

$$\ln(\text{usable weight}) = b_0 + b_1 * \ln(\text{DKHBA})^{1}$$

Specie[2]	Coefficients b_0	Coefficients b_1	n	Statistics $S_{y,x}$[3]	Statistics r^2	DKH Range (cm)
Bursera simaruba Almácigo	10.304117	1.354212	36	0.201718	.9807	4.0-34.0
Acacia macracantha Aroma	10.926375	1.312754	23	0.286349	.9590	4.0-30.0
Phyllostylon brasiliensis Baitoa	10.119439	1.243693	56	0.175208	.9778	4.0-29.0
Cassia emarginata Brucón	10.008809	1.208762	26	0.178667	.9574	4.0-16.0
Palicurea alpina Caretan	9.592580	1.125651	18	0.277910	.8287	4.0-12.0
Prosopis juliflora Cambrón	9.803672	1.137246	22	0.288090	.9493	4.0-30.0
Acacia scleroxyla Candelón	11.106018	1.409781	46	0.270065	.9646	4.0-29.0
Pithecellobium circinale Cinazo	11.074430	1.320648	23	0.270181	.7938	4.0-8.0
Capparis spp. Frijol	10.047913	1.272722	21	0.149780	.9803	4.0-19.0
Amirys spp. Guaconejo	10.624340	1.323345	21	0.127177	.9688	4.0-11.0
Caesalpinia coriaria Guatapanal	11.733678	1.575985	24	0.276606	.9600	4.0-24.0
Guaiacum officinale Guayacán	11.386864	1.464382	24	0.201363	.9156	4.0-10.0
Exostema caribaeum Quina	9.717862	1.171786	29	0.285535	.8613	4.0-14.0
Maytenus buxifolia Sangretoro	10.699403	1.357645	22	0.237306	.9160	4.0-14.0
Pictetia spinifolia Tabacuelo	11.250882	1.495389	13	0.212988	.8403	4.0-7.0
Coccoloba leoganensis Uvero	10.226620	1.189277	26	0.292904	.9181	4.0-18.0
Others	11.351772	1.393268	11	0.433486	.6271	4.0-8.8

1/DKHBA is the basal area at 0.5 meters above ground level expressed in square meters (m^2).
2/Common name of species as referred to in northwestern Dominican Republic
3/Standard error of estimate in natural log (ln) form.

Source: Maxfield, 1985.

implementation of a biomass energy utilization program for the Dominican Republic.

The dry land forests of the Dominican Republic are characterized by multistemmed, small-diameter, thorny, low-canopy trees of high specific gravity. Typical of the subtropical dry land forests throughout the world, these forests have served as a fuelwood source for the rural poor for a long time. However, full utilization of their biomass for energy production has not been achieved.

Energy values for usable biomass (material having a diameter of 2.5 centimeters and larger) were developed at field, 14 percent, and oven-dry moisture content for nineteen primary species of the dry land forests of the Dominican Republic. Regression equations with simple-to-measure independent variables were developed for the 19 dry land forest species that will serve as the basic parameters for the energy inventory process.

These regression equations utilize a single parameter of measurement; diameter at 0.5 meters (DKHBA) was used as the prediction variable of biomass and energy potential for each species. DKHBA is a new concept of measurement that allows fewer measurements per tree than the standard diameter at 1.3 meters used for single-stemmed trees of the temperate zone. DKHBA is well above root collar swell for these small-diameter trees and below most of the thorny branches that make measurement difficult. Almost all the squared correlation coefficients (r^2) were .90 or more.

In addition to individual species regression equations, tables of field moisture contents for each species were determined. A substantial increase in energy availability for these dry land trees can be realized by allowing the material to air dry to 14 percent moisture content before using it for fuelwood or for making charcoal. For *Bursera simaruba* alone, the 14 percent moisture content represents more than a three-fold increase in energy availability over using the wood at field moisture.

To illustrate the procedures, an 850-hectare experimental area of northwest Dominican Republic was inventoried using fixed-radius plots. Based on this inventory. the experimental area of the dry land forests of the Dominican Republic would contain 591.5, 508.5, and 314 million Btu/lb. at oven-dry, 14 percent, and field moisture contents, respectively. Using a conversion of 1 barrel of oil energy equivalent to 5.8 million Btu, this energy biomass converts to 102, 88, and 54 barrels of oil per hectare, respectively. Three species, *Phyllostylon brasiliensis, Acacia scleroxyla,* and *Bursera simaruba* represent 75 percent of the energy of all species at the 14 percent moisture content.

The area inventory summaries indicate the great potential of the dry forests. A complete inventory of the 5905 square kilometers of dry forests of the Dominican Republic utilizing the inventory system and equations developed in this program could represent 300 x 10^{12} Btu's of available gross energy or an oil equivalent of 52 million barrels.

The development of a management plan requires an inventory of the resource. This chapter provides the basic data for the conduct of that inventory for the full utilization

of the dry forests of the Dominican Republic. Such an inventory and the subsequent development of a management plan based on the data and system techniques developed here will insure that the potential 52 million barrels of oil energy equivalent of the Dominican Republic's dry forests are used in a rational, sustainable manner.

The inventory system developed in the Dominican Republic serves as a model for the development of similar inventory systems throughout the subtropical dry land forests of the world. The field instrumentation and technology are readily adaptable to implementation in the less developed countries of the world. The first step in developing a viable management plan for the utilization of an existing biomass energy source is an inventory similar to the one discussed in this chapter for the dry land forests of the Dominican Republic.

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CHAPTER 3.
PRODUCTION OF TROPICAL TREE SEEDLINGS FOR REFORESTATION PROJECTS: USE OF HORMONES TO IMPROVE QUALITY OF NURSERY STOCK

Mel M. Larson

INTRODUCTION

Deforestation is a major concern in many tropical LDCs, and the need for reforestation is well recognized. Planting new stands with selected species can provide site protection and markedly increase forest productivity. The integration of forestry with agriculture and local industry is considered the key to sustainable economic and social development (U.S. Agency for International Development 1984).

Planting trees is expensive, however, with costs often in the range of $300 to $600 per hectare. Examples of planting successes are well publicized, but planting failures are also common. Planting mistakes, represented by poor survival and suboptimal growth, are costly because they are multiplied and compounded throughout the life of the forest stand. Poor quality planting stock is a frequent cause of planting failures, whereas vigorous stock planted on suitable sites can often overcome early adversities such as drought and attacks by insects and disease.

The research reported here illustrates the direct link that exists between physiological processes and seedling vigor. Additional studies of seedling physiology of tropical tree species is sorely needed. An understanding of physiological processes and how they vary among species is required if one is to develop improved nursery and planting practices.

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Bare-root nursery seedlings often lose most of their smaller roots and growing tips during lifting, grading, and transporting operations. When outplanted in the field, seedlings must quickly regenerate new roots in order to penetrate into deeper, moist subsoil layers. Delayed or reduced root regeneration often results in severe internal water stresses followed by dieback or death of trees (Hartwig and Larson 1980, Larson 1984).

Many tropical species such as teak are planted as "stump" seedlings (Evans 1982). Stump seedlings are similar to regular bare-root stock except that when seedlings are lifted from the nursery bed, tops are pruned off just above the soil line. The trees are outplanted in the normal way with only stumps appearing above the soil. This detopping treatment prevents the otherwise excessive loss of water through leaves during transport and storage, although timely root regeneration is still required to maintain turgidity in new shoots that quickly arise from stumps after outplanting. Plant hormones probably control most developmental processes, including root regeneration. Carlson and Larson (1977) found that red oak (*Quercus rubra*) seedlings, pruned to induce root regeneration, exhibited a rapid buildup of auxin and cytokinin above base levels prior to emergence of new roots. Application of indoleacetic acid (IAA), an auxin, together with kinetin, a cytokinin, to roots of red oak seedlings before planting greatly increased root regeneration (Hartwig and Larson 1980).

Toothpicks impregnated with indolebutyric acid (IBA) and inserted into roots of nursery seedlings improved root regeneration of several temperate woody species (Struve and Moser 1984, Struve, Selly, and Moser 1984, Van Sambeek and Rietveld 1982).

Certain tree species, such as pochote (*Bombacopsis quinatum*), produce small amounts of seed of short viability at irregular intervals (Morales and Whitmore 1978). Use of cuttings allows multiplication of these species as well as selection of superior genotypes for planting. Application of auxins to cuttings has been used to increase adventitious rooting in several tropical species (Howland and Bowen 1977, Lundquist and Torrey 1984, Zanoni 1975). Insertion of auxin impregnated toothpicks could be a convenient way to improve rooting success and seedling survival.

The objectives of this research were as follows: (1) to investigate the effects of applying IAA and kinetin to stump seedlings of pochote (*Bombacopsis quinatum*) and melina (*Gmelina arborea*) on root regeneration and early growth after planting; (2) to determine optimum concentration of IAA/kinetin mixture that, when applied to roots, maximizes early root and shoot growth of the two species; and (3) to test the effectiveness of IBA-impregnated toothpicks in promoting early root and shoot development when inserted into roots of stump seedlings, juvenile shoot cuttings, and secondary shoot cuttings.

METHODS

PLANT MATERIAL

Stump seedlings of pochote and melina were obtained in early April from Hojancha nursery located 150 kilometers west of San Jose, Costa Rica. When lifted, pochote stock was 6 months from seed; melina stock, 3 months.

Pochote cuttings were of two types: (1) juvenile cuttings taken from the pruned-off tops of stump seedlings, and (2) secondary cuttings from sprouts of "living fence" trees. The melina cuttings were also secondary cuttings from a living fence located near the nursery.

The stump seedlings and cuttings were taken to the forestry nursery at the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE), located 45 kilometers east of San Jose, and immediately used in the experiments.

IAA/KINETIN APPLIED TO STUMP SEEDLINGS VIA ROOT SOAK SOLUTIONS

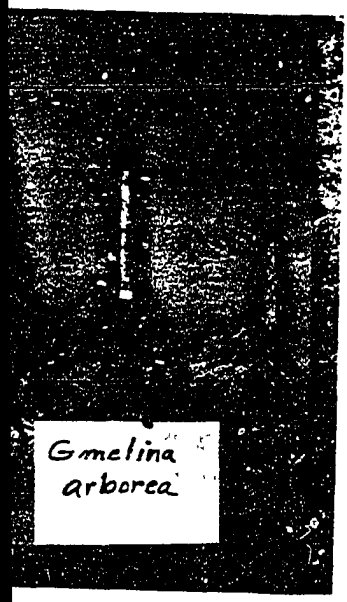
IAA stock solutions were prepared by dissolving IAA in a small amount of ethanol, and then adding this solution to water. Kinetin stock solutions were prepared by heating the water to near boiling before adding the kinetin.

Sixteen combinations of IAA/kinetin mixtures were prepared. This included all combinations of IAA at 0, 40, 160, and 320 ppm with kinetin at 0, 0.02, 0.20, and 2.00 ppm (*Note:* 1 ppm = 1 mg/liter). Ten stump seedlings of each species were root-soaked in each of the hormone mixtures for about 20 hours. This was accomplished by placing each group of stump seedlings in a small plastic bag and adding sufficient hormone solution to cover the roots.

Before soaking, stump seedlings were pruned to a maximum top length of 10 centimeters and a root length of 15 centimeters. A subsample of 35 stump seedlings of each species was weighed and the diameter of the thickest part of the taproot was measured just below the root collar (Figure 3.1). Trees were individually planted in 1:1:1 mixture of clay loam : peat moss : sand in 10 x 20-centimeter black plastic containers. Plants were placed on a cement bench in a screen-sided shed (with translucent panels in the roof to increase light), watered daily, and harvested at 38 days.

Harvest measurements included number and dry weight of leaves; and number, length, and dry weight of shoots. Plant material was oven-dried at 72° C. Prior to planting, samples of root and stump top material were oven-dried and used to determine total nonstructural carbohydrate (TNC) using the method described by Smith (1969).

f various sizes of pochote (A) and melina (B) "stump"
m the nursery.



IBA APPLIED TO STUMP SEEDLINGS VIA TOOTHPICK METHOD

Round, 7-centimeter long toothpicks were first soaked in ethanol for 24 hours and oven-dried at 72° C. Groups of 100 toothpicks were placed in each of four IBA-ethanol solutions at 0, 200, 1000, and 3000 ppm IBA for 24 hours, dried at 50° C, and stored in a sealed glass container until used.

A small hole was drilled in the upper middle section of each taproot of each pochote and melina stump seedling, and a toothpick from one of the four IBA levels was inserted (Figure 3.2). Each species was replicated 10 times at each IBA level. Prior to planting, the diameter of the thickest part of taproot of each tree was recorded. Trees were grown for 32 days in containers as described above.

IBA APPLIED TO CUTTINGS VIA TOOTHPICK METHOD

Juvenile and secondary pochote cuttings and secondary melina cuttings were each cut to 30 centimeters in length. The juvenile pochote shoots (pruned-off tops of stump seedlings) were originally 80 to 110 centimeters long but only the bottom 30-centimeter section of each was used. Two toothpicks from one of the four IBA levels described above were inserted in each cutting, one at 2.5 centimeters from the lower end and another at 7.5 centimeters (Figure 3.3). The diameter at midpoint of each cutting was recorded.

The number of cuttings utilized in this experiment varied by type and species. Juvenile pochote cuttings were replicated 5 times, secondary pochote cuttings replicated 10 times, and secondary melina cuttings replicated 6 times at each of the four IBA levels. The cuttings were planted in sterilized river sand in black plastic containers, watered twice daily, and harvested at 46 days. Growing conditions and harvest measurements were similar to those described for the first experiment.

STATISTICAL DESIGN AND ANALYSIS OF DATA

The statistical design was a 4 x 4 factorial for the IAA/kinetin root soak experiment and a one-way completely randomized design for the two IBA toothpick experiments. Data were subjected to analysis of variance and regression analysis. Coefficients of determination (r^2) were calculated for certain sets as indicated in the following section.

RESULTS

Root regeneration of pochote and melina stump seedlings was greatly improved by soaking roots in IAA solutions prior to planting (Figure 3.4). IAA was particulary effective for pochote. Trees soaked at 320 ppm IAA averaged 30 new roots per tree compared with only 11.5 new roots for untreated control trees. Regression analyses of these data imply that maximum number and dry weight of roots would occur for trees treated with IAA at slightly less than 300 ppm.

FIGURE 3.2 ***Examples of good root regeneration (light-colored roots) of pochote (A) and meline (B) stump seedlings after 32 days.*** One IBA-treated toothpick inserted in each seedling taproot (arrow) prior to planting did not improve root regeneration.

FIGURE 3.3 ***A rooted, juvenile cutting of pochote after 46 days.*** Two IBA-treated toothpicks (arrows) inserted in each cutting prior to planting did not improve rooting.

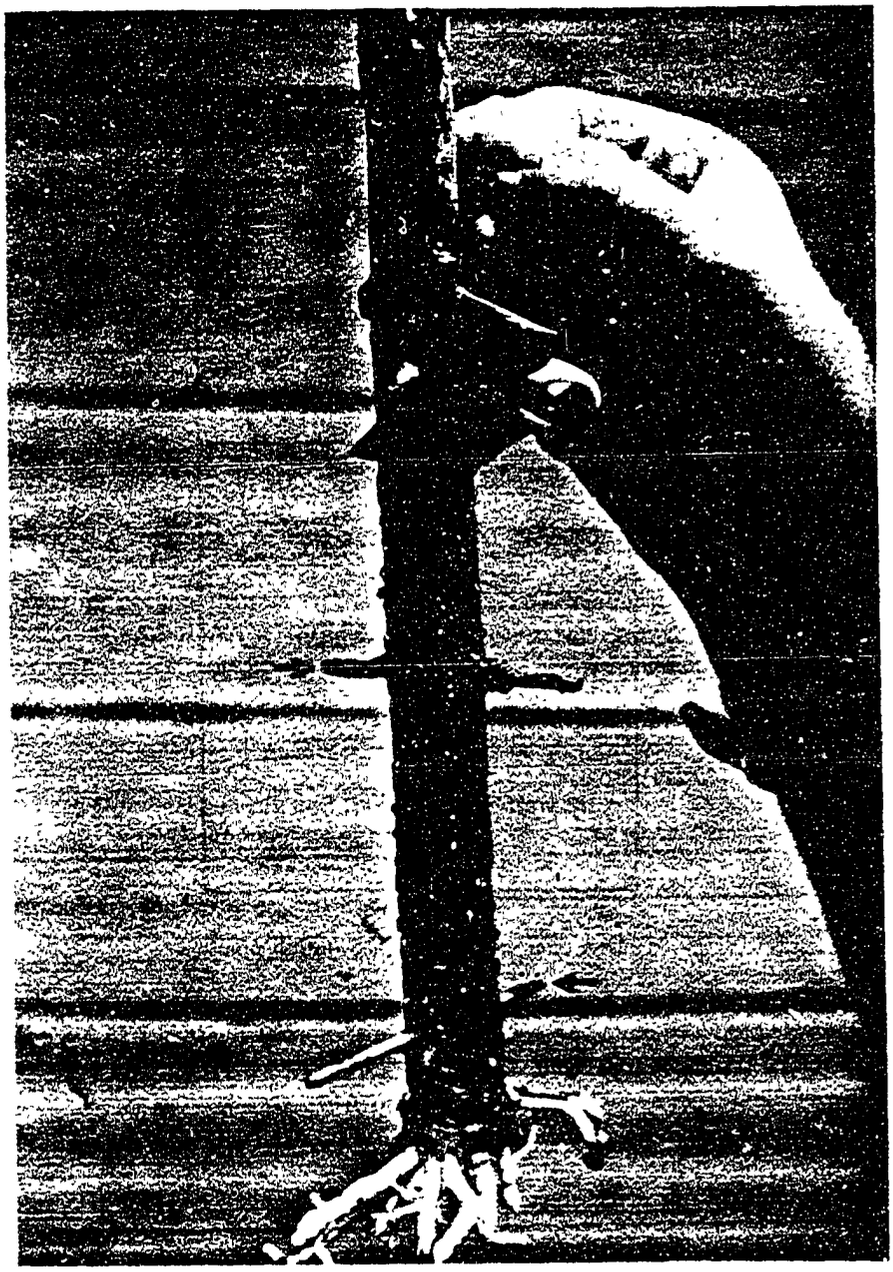
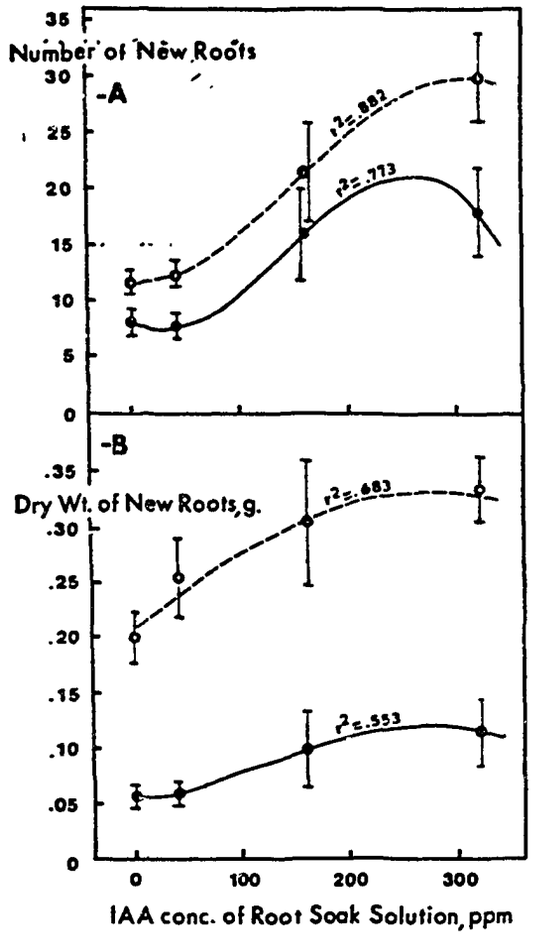


FIGURE 3.4 ***(A) Number of roots per tree and (B) dry weight of new roots for pochote (---) and melina (———) as related to the IAA concentration of root soak solution prior to planting.*** Each point is the mean of four 10-tree groups. Also shown are SDs of each mean and the r^2 values for each regression.



Pochote produced more new roots than melina, especially at higher IAA levels (species x IAA interaction significant at $P \leq 0.05$). Root dry weight of pochote averaged about three times that of melina (Figure 3.4).

Kinetin, alone or in combination with IAA, had no significant effect on the root growth of either species.

The amount of kinetin present in IAA solutions did influence production of leaves, however. The two species responded similarly to hormone treatments. Species data

are combined in Table 3.1. These data suggest that leaf dry weights are not increased at high levels of IAA unless kinetin is also increased to optimum levels. Thus, lowest leaf dry weights were found in plants at 160 ppm and 320 ppm IAA without kinetin, while the three best treatments were 160 ppm IAA/0.02 ppm kinetin, 160 ppm IAA/0.20 ppm kinetin, and 320 ppm IAA/2.00 ppm kinetin.

TABLE 3.1

Total Dry Weight of Leaves per Seedling (Species Combined) at Each of 16 IAA Kinetin Root Soak Levels

	IAA, ppm			
Kinetin, ppm	0	40	160	320
0	0.514g	0.640g	0.452g	0.483g
0.02	0.573	0.606	0.790*	0.582
0.20	0.505	0.613	0.722*	0.502
2.00	0.655	0.550	0.542	0.691

*Indicates a value greater than 0,0 control (0.514 g) at p = 0.05, LSD = 0.193 g.

Leaf dry weight per seedling averaged 0.893 gram for pochote compared with 0.285 gram for melina. Stem growth (length and dry weight per plant) was also much greater for pochote than for melina (Table 3.2). IAA treatments had little effect on pochote stems, but IAA at 320 ppm decreased melina stem growth about 30 percent. For both species, stem growth differences among kinetin treatments were small.

TABLE 3.2

Number, Length, and Dry Weight of New Stems per Seedling of Pochot and Melina at Four IAA Root Soak Levels Combined

	IAA, ppm			
	0	40	160	320
Pochote:				
Number of New Stems	2.3	2.4	2.2	2.5
Length of New Stems, cm	47.2	48.1	45.8	
Dry Weight of New Stems, g	0.595	0.614	0.589	0.587
Melina:				
Number of New Stems	2.3	2.4	2.1	1.8*
Length of New Stems, cm	31.6	32.8	32.6	22.5*
Dry Weight of New Stems, g	0.173	0.180	0.211	0.119*

*Indicates significant difference from control (0-level) at p = 0.05; Duncan's New Multiple Range Test (Duncan 1955).

IAA treatments altered the relative partitioning or distribution of dry weight growth to roots, stems, and leaves (Table 3.3). Distribution was most altered in melina at 320 ppm IAA, where the percentage of root dry weight to total dry weight growth was 26.3 percent compared with 11.3 percent for control plants. New roots of pochote at 320 ppm IAA accounted for 18.1 percent of the total dry weight growth compared with 12.5 percent for control plants.

TABLE 3.3

Dry Weight Distribution in Percent of Total Dry Weight of New Growth for Each Species at Each IAA/Treatment Level

	IAA, ppm			
	0	40	160	320
	—percent—			
Melina				
Roots	11.3	12.4	15.0*	26.3*
Stems	33.1	33.8	31.5	27.0*
Leaves	55.6	53.8	53.5	46.7*
Pochote:				
Roots	12.5	14.4	17.0*	18.1*
Stems	36.0	34.7	32.9*	31.9*
Leaves	51.5	50.9	50.1	50.0

*Indicates a value significantly different from control (0-level) at p = 0.05.

Pochote stump seedlings were larger and had a higher percentage of total nonstructural carbohydrate (TNC) than melina plants, as determined by random samples of seedlings at time of planting (Table 3.4). In both species, stump sections had much lower carbohydrate content than roots. Fresh weight and taproot diameter of pochote plants averaged about twice those of melina (Table 3.4).

Toothpicks soaked in the various IBA solutions (20 to 3000 ppm) and inserted into taproots of pochote and melina stump seedlings had no significant effect on growth after planting.

Prior to planting, the taproot diameter and total fresh weight of each seedling that received toothpicks were determined. These two variables were related (r^2 values were 0.844** for pochote and 0.477** for melina; ** indicates significance at the p = 0.01 level). Taproot diameter is a convenient measure of seedling size in the field.

Among pochote stump seedlings, certain sizes of plants grew better than others. Regression analysis revealed that seedlings with a taproot diameter of 28 to 32 millimeters formed greater numbers of new roots (Figure 3.5) and produced higher dry weights of new leaves, stems, and roots (Figure 3.6) than seedlings with larger or

TABLE 3.4

Mean Fresh Weight, Taproot Diameter, and Total Nonstructural Carbohydrate Content (TNC) of Pochote and Melina, IAA/Kinetin Root Soak Experiment

	Seedling Fresh Weight[1]	Taproot Diameter[1]	TNC[2]	
			Stumps	Roots
Pochote	58.2 g ± 3.5	2.41 cm ± 0.06	11.7%	43.3%
Melina	26.1 g ± 1.4	1.58 cm ± 0.05	5.3	14.0

[1]Means values with standard errors, n = 35 per species; taproot diameter measured at thickest section of root.

[2]Determined from a composite sample of six trees; stumps were the 10-cm long stem sections above the root collar that remained after detopping.

FIGURE 3.5 ***Relationship between diameter of taproots of pochote seedlings at time of planting and number of new roots per tree.*** The r^2 value for the regression was 0.511**, n = 38.

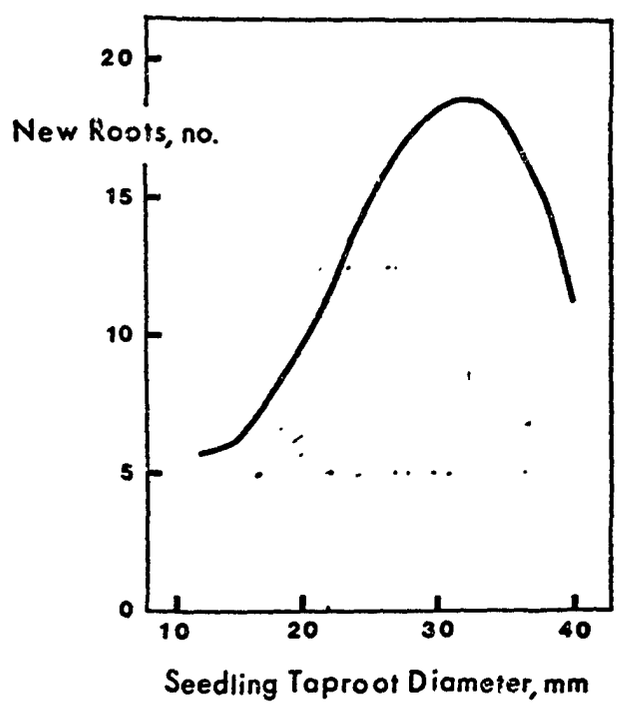
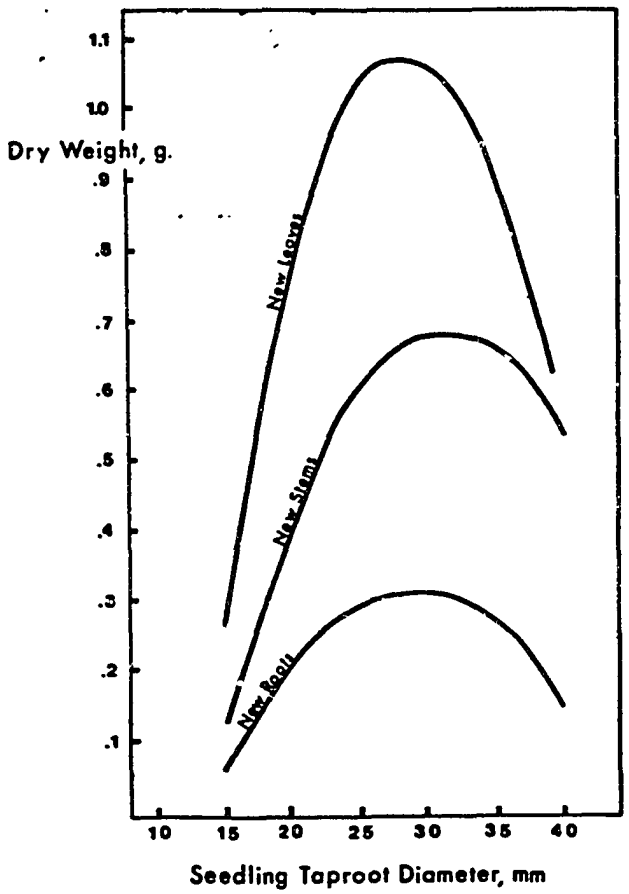


FIGURE 3.6 ***Relationship between diameter of taproots of pochote seedlings at time of planting and dry weight of new growth.*** The r^2 values for the regressions are 0.306** for new leaves, 0.387** for new stems, and 0.393** for new roots, n = 38.



smaller taproots. For melina stump seedlings, the relationship between taproot diameter at time of planting to various growth measurements was weak.

Insertion of IBA-impregnated toothpicks into cuttings of either pochote or melina did not improve either rooting or shoot growth.

Secondary cuttings (i.e., stem cuttings from living fences) of both species exhibited weak shoot development (Table 3.5), and none formed adventitious roots during the

46-day growing period. In contrast, juvenile cuttings (i.e., stem cuttings from seedlings) of pochote grew well, averaging nearly eight new roots per plant (Table 3.5, Figure 3.3). Also, shoot growth and number of new adventitious roots were linearly correlated with cutting diameter. Juvenile cuttings of melina were not available for this study.

TABLE 3.5

Mean Growth of Juvenile and Secondary Cuttings after 45 Days, and Coefficient of Determination of New Growth versus Diameter of Cutting

Type of Cutting and Measurement		Coefficient of Determination (r^2)[4]
Pochote, juvenile[1]		
Shoot dry weight	1.108 g	0.341**
Length of new stems	19.0 cm	0.581**
Number of new roots	7.9	0.490**
Diameter range[2]	1.1 to 2.0 cm	———
Pochote, secondary[3]		
Shoot dry weight	0.135 g	0.003 ns
Length new stems	4.8 cm	0.013 ns
Diameter range[2]	1.2 to 2.0 cm	———
Melina, secondary[3]		
Shoot dry weight	0.313 g	0.062 ns
Length new stems	7.9 cm	0.002 ns
Diameter range[2]	1.6 to 3.2 cm	———

[1]Cuttings from pruned-off tops of stump seedlings.
[2]Diameters measured at midpoint of cutting at time of planting.
[3]Cuttings from trees of living fences.
[4]Double asterisks (**) indicate significance at p = 0.01; ns indicates not significant.

CONCLUSIONS

Results reported here demonstrate that root regeneration of pochote and melina stump seedlings can be greatly increased by simply soaking roots in an IAA solution before planting. Other research has shown that nursery stock with high potential for root regeneration survive and grow better in the field than stock with low potential (Burdett et al. 1984, Larson 1984, Struve and Moser 1984). Kelly and Moser (1983) found auxin treatments were more effective for trees planted in soil at 21° C than in soil at 10°. Thus, use of auxins to improve root regeneratin may be especially effective for trees planted in warm, tropical soils.

Regression analyses indicated that root regeneration of pochote and melina seedlings would have peak values at IAA levels slightly less than 300 ppm. However, due to high variability in these data, additional tests are needed to verify optimum levels for root and shoot growth. Also, trees planted in the field may have a somewhat different optimum IAA level than trees grown at a nursery or greenhouse (Hartwig and Larson 1980).

At high IAA levels, proportionately more of the total dry weight increase went to root growth than to shoot growth in both species. For pochote, the major part of this diversion to roots was at the expense of stem growth rather than leaf growth.

Addition of kinetin to root soak solutions did not improve root growth although dry weight of leaves was increased 33 to 54 percent above that of control plants in certain treatments containing kinetin. Other cytokinin compounds such as zeatin, zeatin riboside, benzyladenine, and other purine derivatives may be effective (Carlson and Larson 1977, Dixon et al. 1984, Hare 1984).

IBA-treated toothpicks inserted into taproots before planting did not improve growth of either pochote or melina stump seedlings. In contrast to these results, Struve et al. (1984a) cite several reports where IBA-treated toothpicks increased root regeneration of various temperate species. Additional research with tropical species should include testing auxin derivatives, analogs, and synergists that may be more effective than the compounds used here (see Haissig 1983, Kling and Meyer 1983, Magley and Struve 1983, Wrightman et al. 1980). An alternative method of application is to spray roots with auxin plus sticker-extender (Van Sambeek and Rietveld 1982).

Root regeneration and early growth was much greater for pochote than for melina. One possible reason is that TNC of pochote taproots, on a total weight basis, was six times higher than that of melina. Mori (1981) reported that survival and growth of stump seedlings of two Malaysian diptocarp species was directly related to starch reserves before planting. In other species, such as red oak, a direct relationship between carbohydrate reserves and growth after planting cannot be demonstrated (Larson 1978). A greater understanding of the interactions between factors (food reserves, hormones, water relations, etc.) that affect seedling growth is needed.

The relationship of new growth to diameter of taproots was stronger among pochote than among melina seedlings. Pochote taproots with diameters near 30 millimeters produced the most root and shoot growth. All taproots were pruned to 15 centimeters in length, however, and longer taproots may have a different relationship between growth and taproot diameter. Nevertheless, there appears to be an optimum size of pochote stock for maximum growth after planting and nursery schedules should be adjusted to achieve this. Canadas (1963) reported a significant correlation between field performance and initial stump diameter for mahogany (*Swietenia humilis*) but not for four other species planted at the same time.

IBA-treated toothpicks inserted into pochote and melina cuttings had little effect on rooting or shoot growth. The effectiveness of IBA apparently varies with species. IBA that was applied to cuttings of six tropical species, including melina, produced

little success (Garcia 1974), whereas IBA improved rooting in *Casuarina* sp. (Lundquist and Torrey 1984) and peach (Erez 1984). Other compounds and methods of application have proven effective for certain species. Dipping of cuttings in talc containing a mixture of IAA and naphthaleneacetic acid (NAA) at 3000 ppm markedly improved rooting in melina, teak, and obeche (*Triplochiton scleroxylon*) but was of no benefit in *Pinus caribaea* or *Cedrela odorada* (Howland and Bowen 1977). Maple cuttings rooted excellently when treated with a mixture of catechol (4.5 x 10^{-3}M) and IAA (1.1 x 10^{-3}M) for 24 hours (Kling and Meyer 1983).

In this study, secondary cuttings of pochote and melina taken from living fence trees near the end of the dry period did not form roots during the 46-day growing period. The cuttings were 30 centimeters long and none exceeded 3.2 centimeters in diameter. Larger secondary cuttings may be easier to root. Melchior and Quijada (1972) reported best results when pochote cuttings were 9.9 to 25.0 centimeters in diameter and 80 centimeters long. Lozano (1962) found cuttings 6 to 12 centimeters in diameter rooted better than those 3 to 6 centimeters in *Gliricidia sepium* and *Erythrina poeppigiana*.

The juvenile cuttings of pochote rooted easily (Figure 3.3). Nearly all cuttings had broken bud 9 days after planting, and evidence of rooting was apparent after 3 weeks from planting. IBA toothpicks were without benefit and not required for good rooting. Rooting and shoot growth were positively correlated with cutting diameter, although the diameter range was only 1.1 to 2.0 centimeters.

Results reported here suggest that cuttings made from the pruned-off tops of stump seedlings (normally discarded at the nursery) could be quickly rooted in containers and outplanted after 5 to 6 weeks. Also, more than one cutting could be taken from each seedling top since only the basal 30-centimeter section was used. Leakey (1983) reported that in 3-month-old stockplants of *Triplochiton scleroxylon*, cuttings taken from the upper mainstem rooted better than those from the lower mainstem. Zanoni (1975) also reported that subapical cuttings rooted better than either apical or basal cuttings in three tropical species.

Establishment of stands by cuttings allows foresters to circumvent seed supply problems and to select and plant superior clones. Outplanting cuttings with high vigor can have long-term benefits. Struve, Talbert, and McKeand (1984b) found that rooted cuttings of white pine performed as well or better than seedling origin trees, and that number of roots on cuttings at planting was positively correlated with tree diameter at 40 years.

These results contribute additional knowledge to be applied to improving reforestation techniques and developing sustainable forest resource management programs, particularly in LDC's.

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CHAPTER 4.
SOLAR PONDS— HAVE THEY COME OF AGE?

R. Peter Fynn
Robert Bailey

INTRODUCTION

Has the time come to exploit solar ponds? We know we can heat brine to boiling, but we have yet to exploit that knowledge in a meaningful and beneficial way. Much research has been done on solar ponds, but they have yet to be exploited commercially to any significant extent.

What is a solar pond? A solar pond is a body of liquid which collects solar energy and stores it as heat. The type of solar pond that will be discussed in this chapter is the salt stabilized solar pond. This type of pond relies upon a salt solution (usually sodium chloride) of increasing concentration with depth to suppress natural convection. Hot, concentrated brine at the bottom of such a pond is prevented from rising to the surface and losing its stored heat because the upper portion of the pond contains less salt and is, therefore, less dense than the lower portion. Such ponds have been used in research applications in the United States, with a very small number being used in commercial applications (Fynn and Short 1983, Nielsen 1980, Zangrando 1980). Solar ponds have not yet been used in the United States to produce electricity as has been done with some success in Israel, where there are ponds producing up to 150 kilowatts of electricity.

This chapter will consider some of the design problems associated with building a solar pond in the tropics specifically for the production of electricity. It will concentrate on the items that need to be considered in siting, constructing, and operating a solar pond, so that those who find themselves in a position to exploit the potential of a solar pond will be in a position to proceed.

The design of a facility that can produce very hot brine needs to take into account some environmental factors that are unique to solar ponds. It is these factors and how the concept of the solar pond fits into the infrastructure of the surrounding countryside and population demographics that need to be considered.

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The following subjects will be considered in this discussion:

1. The installation situation
2. Siting the solar pond
3. Land use and ownership
4. Solar pond design
5. Lining the solar pond
6. Brine supply and quality
7. Setting up the gradient zone
8. Using the heat
9. Modeling

THE INSTALLATION SITUATION

The problem is to design a solar pond facility that will eventually provide electricity for the rural population of a country in the tropics. We will use the Dominican Republic as a case example. The electricity supply at present is generated from hydropower dams and imported fossil fuels. Importation of fossil fuels is a major consumer of scarce foreign exchange capability. However, sunlight is abundant; thus, the possibility of electricity generation with solar energy merits detailed investigation. Two sites in the Dominican Republic will be considered. Their characteristics are listed in Table 4.1.

TABLE 4.1

Characteristics of Two Alternative Sites for Tropical Solar Pond Assessment

Item	Site 1	Site 2
Solar radiation, w/m²	200	200
Water access	Brackish 1 km	Fresh 1 km
Salt access	Seawater	Rocksalt (mined)
Ambient temperature °C	26	26
Groundwater temperature °C	24	24
Groundwater depth, m	4	2
Land slope, %	0.01	0.05
Ground cover	light scrub	none
Accessibility by road	paved (1 km)	unpaved
Proximity of overhead lines	1 km	1 km

The sites are somewhat similar, and at first glance seem to be equally appropriate for solar pond development. However, their differences will become apparent later.

On traveling to the sites and studying the demographics of the population and the energy use and distribution within the areas, it is noted that the use of electricity is confined to refrigeration, lighting, radio, television, and ironing, with some other

miscellaneous items that differ from house to house. The electric load curve is remarkably flat except for the late evening, when it increases due to increased use of lights, televisions, and radios. Any electrical supply system must supply a load throughout the day and night; thus, a storage system of some sort is needed. A solar pond lends itself naturally to such a situation; the large volume of brine in the bottom of the pond serves as a buffer, accumulating heat during the periods of sunlight and holding it through the nights and overcast days. If the solar pond can be built economically and in a responsible manner, taking into consideration such factors as the environment, markets, and people, it can be both productive and environmentally benign.

Solar energy is a diffuse form of energy and requires a large land area to collect it. For example, a one megawatt power plant, located at either of these sites and operating continuously, would require approximately 50 hectares, or 125 acres, of flat land for the pond alone. This figure is, of course, subject to detailed design, but it suffices to demonstrate that the solar pond is indeed a small sea that is boiling hot. Smaller ponds can be built to give the same output, but the output will not be continuous for a 24-hour period.

Once the solar energy is collected, it is stored in the solar pond as heat. This passive collection feature is characteristic of the solar pond. The radiation penetrates the solution and heats it up, so the bottom part of the pond becomes hot. It can actually go above the boiling point of water. But if it goes above the boiling point of the brine itself, the pond will have some stability problems, and the gradient will probably be destroyed. This need not be catastrophic; the gradient can be re-established. The hot brine in the bottom of the pond can be used to boil a low boiling temperature fluid such as Freon®, which can be used to drive an engine that drives a generator to make electricity. It sounds simple, and in principle it is. But in practice, there are some major problems associated with the siting, building, and operation of a solar pond.

THE SOLAR POND SITE

The siting of the solar pond is critical to the success of the project. A solar pond depends on the inherent insulation properties of dry soil to provide protection against excessive heat losses downwards and sideways into the ground. The close proximity of a salt supply and a water supply, brackish or otherwise, leads to a dramatic reduction in the initial costs of the solar pond. Such a cost reduction is essential if the solar pond is to be an economic provider of electricity.

The following criteria should be taken into account in the site selection process so that the selected site satisfies as many requirements as possible.

SUBTERRANEAN WATER

Water below the ground can be a major problem in the performance of a solar pond. A shallow water table can lead to large heat losses to the ground below a solar

pond due to the large thermal conductivity (up to 2.6 watts/meter/°C) of the wet soil. Contrary to expectations, experience has shown that the heat in a solar pond will not necessarily dry out the soil beneath the pond, particularly if the ground water is moving. It is important that the ground be free-draining immediately under the pond, and that the water table does not come too close to the bottom of the pond, or the storage efficiency of the pond will be severely impaired.

The two sites mentioned above have a rather shallow ground water depth, but these are real-life compromises that have to be met. Advantages of the sites may outweigh this disadvantage. The water depth is from 2 to 4 meters below the surface. A simple computer model shows that, with a reasonable soil thermal conductivity (2.0 watts/meter/°C) and a ground water depth of more than 2 meters, the solar ponds can achieve and maintain temperatures above 80°C, while supplying a significant amount of energy for conversion into electricity. However, with the ground water at a 4-meter depth, the temperature maintained can be above 90°C. This can make a significant difference in the thermodynamic performance of the thermal energy conversion machinery.

AVAILABILITY AND QUALITY OF WATER

Water or brine is required for the establishment of the solar pond, and for its continued operation. The initial quantities of water or brine required are large. However, once established, brine (or salt) can be recycled and water is only required for washing the surface of the pond, and for make-up of evaporation losses.

AREA CARTOGRAPHICS AND DEMOGRAPHICS

Maps, photographs, and other site-related data for the areas should be studied to make sure that the ponds are sited in suitable areas that can make use of the power supplied by the solar ponds. The maps and photographs must be verified by site visits and discussions with the local populace. Slope of the land is an important feature in site selection. Slopes of more than one-half of a percent will mean that the land leveling costs could make the site uneconomic, depending on the pond design. Slopes of less than one-tenth of a percent may be regarded as being flat.

SOLAR RADIATION AVAILABILITY

Solar radiation availability actually plays a small part in the siting of a solar pond in many parts of the tropics. The reason for this is that insolation in the tropics is high, and the difference in cloudiness that may exist from one site to another is often outweighed in the site selection process by other advantages and disadvantages. The solar pond efficiency is calculated from a combination of insolation input, load, and losses to the ground and the air. These have to be balanced to determine optimal performance for a solar pond at a given site. This physical optimum must then be balanced with other local conditions and requirements (discussed below) to select the preferred site.

LAND USE AND OWNERSHIP

Investigators must check site records by going to the local Agricultural and Land offices and ascertaining who owns the relevant tracts of land. In the two cases considered here, the land is owned by a government agency and is not used for agricultural production at either site. At one site, the land is saline and supports a growth of cactus and thorny scrub. There is no apparent use for the land in the area of the site, except as evaporation ponds for salt production.

The solar pond requires low-priced, flat land. For this reason, it is important that the land have little or no commercial value so that opportunity costs of construction of the solar pond are minimized. It is hoped that previously unproductive land can be made productive by the installation of a solar pond. Ownership is also important; that is, if the land is owned by an individual or company, it will have a market value which is related to its current use. When the land is owned by the government, and it is unproductive at present, it will not have an established market price and its value, or opportunity cost, may be difficult to estimate accurately.

SOLAR POND DESIGN

The design of the solar pond draws heavily on the experience of those who work in the field and upon the civil engineering industry. The pond will be built, operated, and maintained by local people, giving them a pride and feeling of accomplishment.

The starting point is one of area. How is the area derived? The annual average radiation for the sites has been given as 200 watts per square meter. From research and experience, it is known that the collection efficiency of a solar pond with a typical configuration, which will be discussed below, will be on the order of 30 percent. The storage efficiency will depend on the type of soil and the ground water depth under the pond, and upon the thickness of the gradient zone in the top portion of the pond. On an annual basis, this can typically be from 40 percent to 60 percent efficient. There will be loss when converting from heat to electricity, and, at the low temperatures encountered in a solar pond, this efficiency is typically 6 percent to 7.5 percent.

Thus, using the average insolation and typical efficiencies given above, the gross output of the pond can be calculated as follows:

$$\text{Gross output (watts/m}^2\text{/yr)} = 200 \times 0.3 \times 0.5 \times 0.067 = 2.01$$

Multiplying by the number of hours in the year, 8760, yields the number of watt-hours per square meter per year that may be delivered by the solar pond (Merriam 1983):

$$2.01 \times 8760 = 17{,}600 \text{ whr/m}^2\text{/yr} = 17.6 \text{ kwh/m}^2\text{/yr}$$

This figure can now be used on a preliminary basis to establish the dimensions of the solar pond required to provide a given amount of electrical energy on a continuous basis. Of course, electricity may be supplied at a faster rate but for a shorter time each day. This calculation is based on a supply for 24 hours a day.

For example, the solar pond area required to give a gross electrical output of 1 megawatt (1 MWe), or 1000 kilowatts, would be:

$$1000 \times 24 \times 365 \div 17.6 = 497{,}727 \text{ m}^2, \text{ or} \sim 50 \text{ hectares (125 acres)}$$

Of course, this number cannot be used as a final area figure. A qualified, experienced solar pond design engineer will take into account the site conditions and will conduct computer simulation runs taking into account the variations of solar radiation, the ground water depth, the soil thermal characteristics, the depth of the solar pond, the pattern of energy use, the pumping requirements of the solar pond, and any other unique site factors that may be deemed relevant.

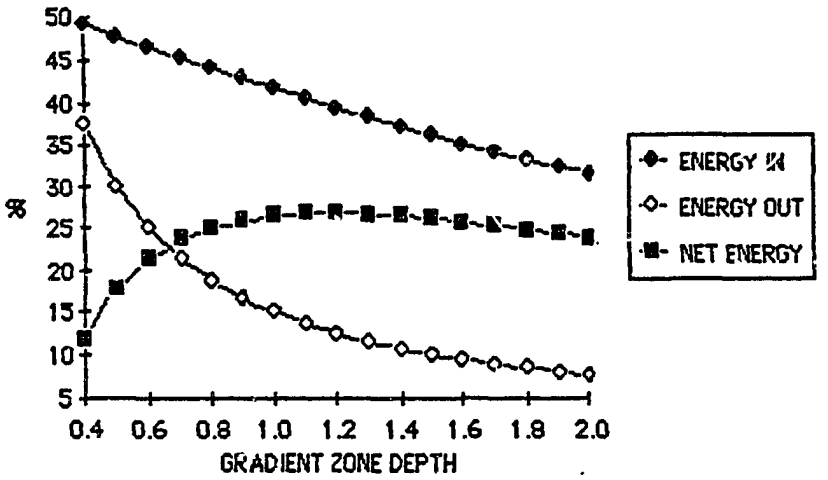
SOLAR POND DEPTH

The depth of the lower convective zone of the solar pond is dictated by the requirement for thermal storage or capacitance of the system. However, the deeper this zone is, the more salt that is required, and salt is a major cost of the system. Thus, the depth of the lower convective zone is a trade-off between the increased storage capacity and the increased cost of salt. Thermal storage capacity is not a major requirement of the system in terms of solar pond operation in most parts of the tropics, whereas the cost of salt is usually a major factor. However, a low temperature zone at the bottom of the solar pond may be introduced to reduce bottom heat losses.

There is an optimum gradient zone depth calculated from, on the one hand, the need for a deep gradient zone for insulation properties, and, on the other hand, the need for a shallow gradient zone for high radiation transmission into the storage zone of the solar pond. Figure 4.1 is a graph showing the energy penetration into a solar pond, the energy losses from a solar pond, and the net energy gain plotted against gradient zone depths. A gradient zone depth of 1.0 to 1.5 meters gives an optimum energy collection percentage.

All solar ponds that are in operation have an upper convective zone depth of some significance. From experience, an upper convective zone depth of about 30 centimeters will probably exist at the top of the solar pond. Thus, the configuration of the solar pond will probably be as follows. The upper convective zone will be 0.3 meters deep, the non-convective, or gradient zone will be about 1.2 meters deep, and the lower convective, or storage, zone will be from 1.0 meters deep to 2.0 meters deep depending on requirements.

FIGURE 4.1 ***Graph showing energy flows at different Gradient zone depths.***



LINING THE SOLAR POND

A solar pond must be lined in some way to prevent the salt solution from leaking into the ground. There are three reasons for this. The first is to conserve capital. The salt in a solar pond is often one of the most expensive components, and that investment should not be lost unnecessarily. The second is to conserve heat. The soil underneath a solar pond is the insulation against downwards heat loss, and the soil thermal conductivity increases rapidly with an increase in soil moisture content (Fynn and Short 1983). Third, in some areas, the seepage of concentrated brine may constitute a threat to groundwater quality. The function of a liner is to prevent all three things from occurring.

A number of liners have been used with solar ponds. It is necessary to select a liner that resists, on a continuous basis, temperatures of up to 110°C (230°F), degradation from salt, and breakdown from ultraviolet rays in the solar radiation. A liner that is manufactured locally is preferable as this is also a high-cost item. The area of the solar pond is large, so a large liner is needed. It is advisable to spend some time selecting the right liner option to provide the optimal combination of quality and economy. A partial list of liners that have been used for solar ponds includes:

1. High Density Polyethylene (HDPE)—40 mil. This liner is manufactured in rolls. These rolls are laid on the ground with one edge overlapping the edge of the

adjacent roll. The edges are then welded together using a specially developed welder. This material is available from Gundle Lining Systems Inc., 1340 Richey Road, Houston, Texas, USA.

2. M-303 5-ply Hypalon membrane—45 mil. This liner is also manufactured in rolls as above. The seams between adjacent rolls are made using an adhesive between the surfaces of the two edges to be joined. This material is available from Burke Rubber Company, 2250 South Tenth Street, San Jose, California, USA.
3. XR-5SP solar pond liner—40 mil. This liner is also manufactured in rolls which are laid out and overlapped. The overlap is heat sealed using a special machine developed for the purpose. This liner is available from the Seaman Corporation, 102 N. Washington Street, Millersburg, Ohio, USA.

All liners considered here have been used extensively for liquid containment, and some have been used in solar pond work. The designer would do well to investigate the liner proposed, and to obtain details of the performance of any proposed liner, particularly if it is made locally.

It is difficult to give an accurate estimate for the cost of liners. Generally, liner prices are quoted free on board (FOB) the factory, which is often far from the site of the proposed solar pond. However, examples of the range of prices per square meter are helpful in estimating the local cost of a liner (Table 4.2).

These figures are based on quoted prices for liners for a solar pond of 50 hectares (125 acres), and it can be seen that they differ markedly. For smaller ponds, the unit prices will increase substantially. The total liner price, installed, for a 1 megawatt solar pond (continuous output) thus varies between $1,320,000 and $4,285,000 (U.S. dollars). By comparison, the capital cost for new fossil fueled power plants varies between $2,500 to $3,000 per kilowatt; clearly, a solar pond liner installed price of between $1,320 and $4,285 per kilowatt is a very significant factor in the cost equation. However, the operating cost of a solar pond power plant is low compared with that of a fossil fueled power plant; the fuel is solar radiation.

TABLE 4.2

Liner Prices per Square Meter for a 50-Hectare Solar Pond in U.S. Dollars

Item	Minimum	Maximum
FOB factory price	$1.75	$7.43
Seaming	0.10	incl.
Freight overland	0.10	0.10
Sea freight	0.08	0.08
Insurance	0.01	0.01
TOTAL Cost, Insurance, and Freight (CIF)	2.04	7.62
Installation (local)	0.60	0.85
TOTAL PRICE (U.S.$/m²)	2.64	8.57

BRINE SUPPLY AND QUALITY

The quantities of sodium chloride required in a salt stabilized solar pond are large—approximately 0.4 of a tonne per square meter of pond surface area. A one-hectare solar pond would therefore require approximately 4000 tonnes of salt for pond stabilization. This is a considerable amount of salt and its provision can severely affect the price and supply of salt in the country if it were to be purchased on the open market. Brine or salt must be provided at a low cost so that the solar pond can be economically built and run to provide electricity at a price compatible with the price of electricity available from other generating devices. The value of the salt in a pond is one of the largest single cost items, so the control of this cost is essential to achieving economic viability.

Prices of sodium chloride in crystalline form are typically $25 to $40 per tonne (U.S. dollars). At the lower price, this is equivalent to an investment of $5,000,000 for a 50-hectare,1 megawatt solar pond. Such a cost, together with the liner costs mentioned above, can make the solar pond uneconomic unless the salt can be regarded as having a residual,or salvage, value. Even so, a major amount of capital would be locked up in the cost of the salt. Regardless of the accounting techniques used, it is desirable for several reasons that a solar pond project supply its own salt, ideally in the form of brine. First, the purchase of such a large quantity of salt on the open market could lead to rapid price increases. Second, production facilities could be used to build more solar ponds in the vicinity. Third, the brine production facilities would be under the control of the solar pond facility; thus, the cost of the brine would be less subject to market variations. Of course, local labor would be used to produce the brine.

A solar pond can make use of a variety of qualities of water, provided that there is not a chemical reaction between the different salts present to form cloudiness within the nonconvective zone of the pond. Thus, local brackish water, sea water, or potable water can be used. Generally, however, potable water is too expensive to use for a solar pond.

Water is required for the establishment of the solar pond, and for its continued operation. The initial quantities of water required are large in a pond that is approximately 2.5 meters deep. However, once the solar pond is established, water is only required for washing the surface of the pond and for replacing evaporation losses.

The maintenance of the clarity of the water in a solar pond is essential to the efficiency of the pond. A small degradation in water clarity can jeopardize the operation of an electricity-producing solar pond by decreasing radiation input and thus reducing the pond's lower convective zone temperature to a temperature at which the generator may not be able to function at the required load. Combining the two facts that the cost of a solar pond operation is strongly influenced by the surface area of the pond, and that the output for a given area is strongly influenced by brine

clarity, it is essential that the pond be maintained as clear as possible. The question then arises, how clear is "as clear as possible"?

In the following discussion we will try to answer that question using two curves of radiation transmission and a mathematical analysis (Nielsen 1980). The two curves used are as follows:

A. Figure 4.2 shows a curve for solar radiation transmitted to depth z in a solar pond, expressed as a fraction of radiation at the surface of the solar pond, I_O. The equation from which this curve was drawn is:

$$(1) \quad I_Z = I_O \times 0.5277e\text{-}0.3284z$$

where I_Z is the radiation transmitted to a plane z meters below the surface of the pond, and I_O is the radiation at the surface of the pond.

B. Figure 4.3 is a curve showing solar radiation transmitted to depth z in a different solar pond, expressed as a fraction of radiation at the surface of the solar pond, Io. The equation from which this curve was drawn is:

$$(2) \quad I_Z = I_O \times 0.5537e\text{-}0.285z$$

where I_Z, z, and I_O are as before.

The difference in the fraction transmitted to a depth of 1.5 meters can be seen to be 12 percent, with equation #2 giving the better fraction transmitted. This figure is derived as follows. The radiation received at 1.5 meters below the surface is 32.24 percent for equation #1, and 36.1 percent for equation #2. The difference between the two is 3.86 percent, which is a 12 percent increase above 32.24 percent.

FIGURE 4.2 ***Graphical representation of equation #1 showing percent of surface radiation transmitted to varying depths in a solar pond.***

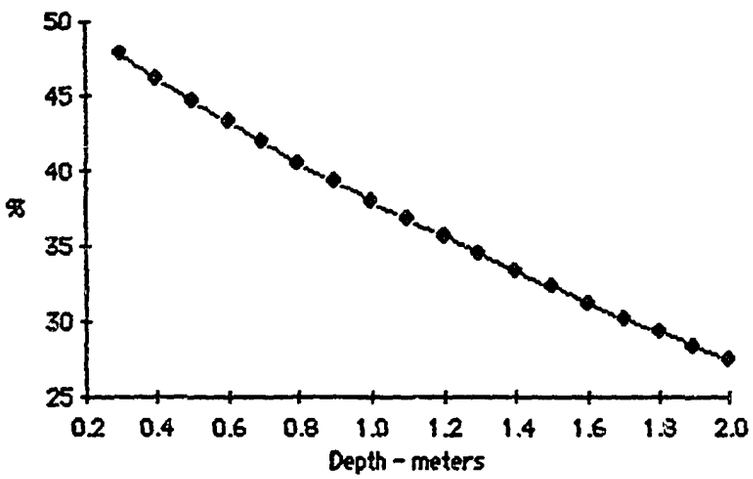
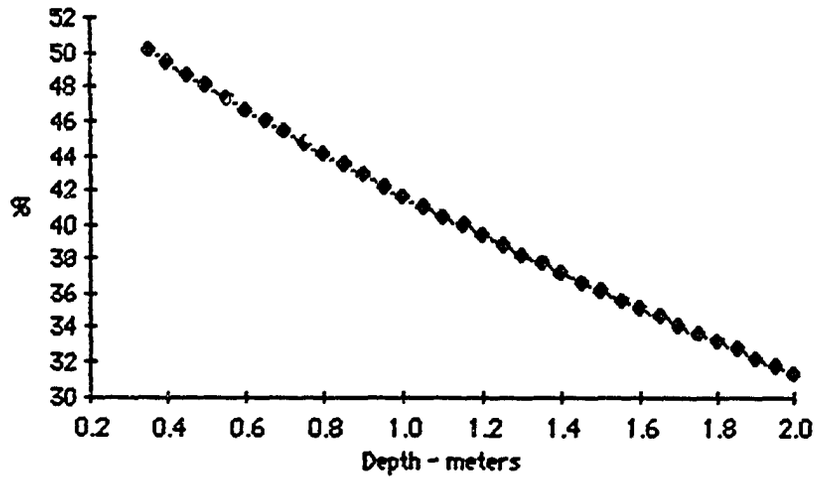


FIGURE 4.3 ***Graphical representation of equation #2 showing percent of surface radiation transmitted to varying depths in a solar pond.***



How does this difference affect the output performance of the solar pond? For the benefit of the analysis we will assume that the following geometrical configuration for the solar pond has been specified:

Depth of heat extraction	1.5 m
Depth of upper convective zone	0.3 m
Average incident radiation	200 w/sqm
Thermal conductivity of gradient zone	0.602 w/m deg C

The following families of curves for the two radiation transmission equations given above are derived mathematically. Figure 4.4 is a family of curves for transmission equation #1, and it shows the delta T that can be maintained by the solar pond built to the conditions described above, plotted against the depth of heat extraction for various efficiencies, which are the proportion of incident energy on the surface of the pond that reaches the depth shown. This energy is lost from the lower convective zone in two ways: (1) to the load on the solar pond, and (2) to the bottom heat losses of the pond.

Figure 4.5 shows the family of curves derived mathematically for equation #2, plotting delta T against the depth for different efficiencies, as before.

Now the importance of the clarity of the water above the heat extraction level can be studied.

Assume that one wishes to maintain a temperature of 90°C in the heat extraction zone of the solar pond in order to operate the heat engine at a reasonable temperature

FIGURE 4.4 ***Delta T vs. depth curves for varying "efficiencies" for equation #1.***

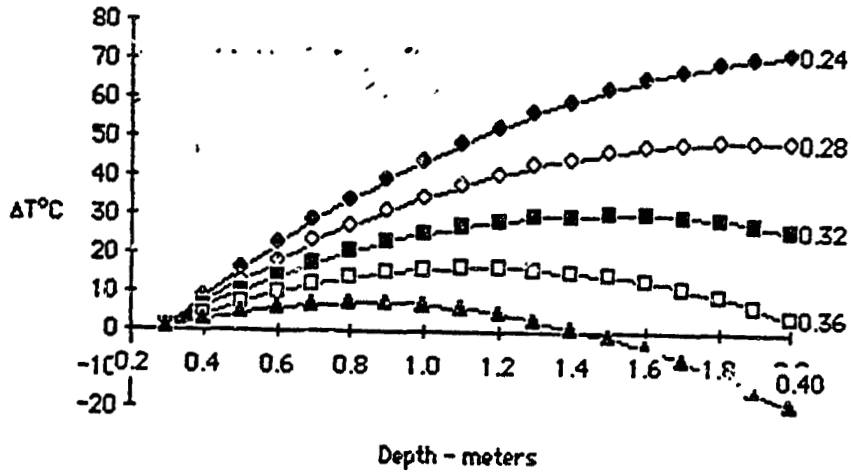
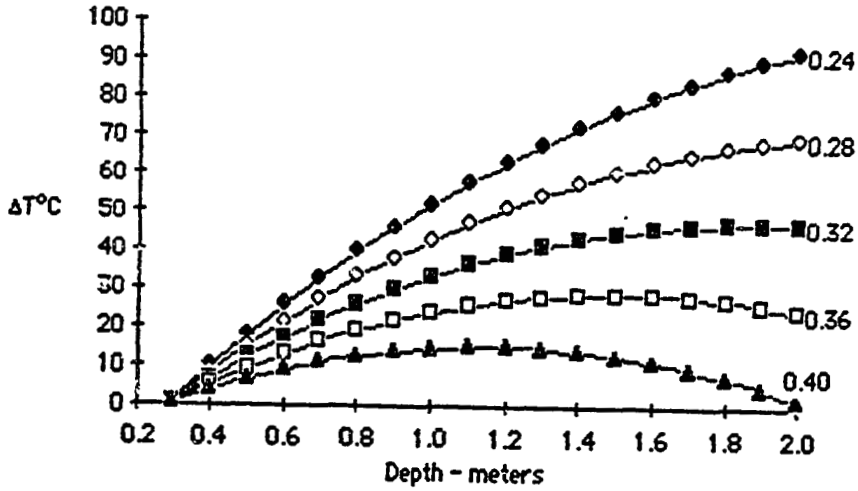


FIGURE 4.5 ***Delta T vs. depth curves for varying "efficiencies" for equation #2.***



difference to obtain a good thermal efficiency within the thermal constraints of the solar pond and the environment. At the heat extraction level, heat flow will be going to two heat sinks. One is the ground, and the other is the load. If the solar pond temperature is 90°C at the heat extraction level, conditions for our average site dictate a ground heat loss of about 44.0 watts per square meter. This is calculated on the supposition that the ground water depth is 3 meters, the ground water temperature is 24°C, and the soil thermal conductivity is 2.0 watts per meter degree Celsius.

In the two cases above, how much energy is left to be extracted to drive the electric generator?

In the first case, using equation #1, one finds that at an extraction depth of 1.5 meters in a pond of the above configuration, and a temperature increment of 90-26 = 64°C, there is an efficiency of 24 percent. At an input of 200 watts per square meter, this gives an energy availability of 200 x 0.24 = 48 watts/square meter. The bottom heat loss is 44.0 watts/square meter giving a net available energy of 4 watts/square meter.

In the second case, using equation #2, with the same conditions as above, the efficiency is 27 percent. At the same input of 200 watts/square meter, this gives an energy availability of 54 watts/square meter. Bottom heat loss is the same at 44 watts/square meter, giving a net available energy of 10 watts/square meter. The increase is 10-4 = 6 watts/square meter, which is an increase in output of 150 percent.

This may be surprising, but it is a consequence of a high water table and a small difference in the turbidity of the gradient zone. It simply goes to show that the clarity of the gradient zone is extremely important, and that the ground heat losses should not be underestimated. It should also be pointed out that these figures are gross heat output figures; they have not been converted into electrical output figures, which need to take into account the power cycle efficiency.

SETTING UP THE GRADIENT ZONE

Sometimes, would-be solar pond operators find setting up the gradient zone a difficult problem. The gradient zone is naturally stable; the salt diffuses so slowly that the zone will not mix itself. In some solar ponds, the zone can be set up by the Zangrando method (Zangrando 1980). Basically, this method requires that the solar pond be filled with a large quantity of high-concentration brine (24 percent). Then fresh water is introduced into the brine in such a way as to dilute it with increasing dilution toward the surface of the solar pond.

In the situation of making brine from the sea, it will pay in time—and therefore money—to introduce the concentrated seawater to the solar pond when and as the concentration becomes correct for the application. Thus, a large quantity of 24 percent by weight brine will be made first to establish the lower convective zone of the solar pond. Then, as the seawater becomes concentrated to the appropriate level—22 percent, 20 percent, 18 percent, etc.—the appropriate quantities of concentrated

brine will be pumped onto the surface of the pond using a flat spreader floating on the surface of the solar pond to distribute the brine horizontally. This will provide discrete layers of decreasing concentrations of brine that will end up building the gradient zone. In the case of the salt coming from the mines, the gradient zone would be established using the Zangrando method.

USING THE HEAT

The energy in a solar pond is stored as heat in the lower convective zone. In order to use this energy, it is necessary to be able to extract this heat. This can be done in various ways. The most usual is to pump the hot brine to a heat exchanger or evaporator outside the solar pond. Some work has been done on the installation of heat exchangers within the solar pond, but there are problems with maintenance and corrosion that need to be taken into account (Fynn and Short 1983). The difficulty of providing support and maintenance for a large heat exchanger in a solar pond of 50 hectares (125 acres) or more has not really been addressed. However, the problems associated with pumping the hot brine are not to be taken lightly either. The main difficulty is that the temperature encountered in the solar pond results in low thermodynamic efficiencies. As a result, large quantities of brine have to be pumped in order to extract the energy stored in the pond. This is one of the engineering design challenges facing solar pond designers. However, the analysis of heat exchangers is well-known, and careful design and attention to detail should suffice to create a system that will be suitable for the purpose.

Pumping the hot brine will not disturb the gradient zone provided that the diffusers are correctly designed to extract and return the brine in a horizontal plane and at low velocities. More work needs to be done in the area of brine extraction, but that work is required to see how best to reduce pumping requirements. Reasonably good information exists on minimizing gradient zone erosion, but further work should also be done in this area.

The hot brine can be passed through an evaporator to boil a low boiling temperature liquid which can be used to power a machine to provide mechanical work or electricity. The design of such machinery is best left to the experts in the field of low temperature machinery who know how to select the working fluids and who have a good knowledge of the organic Rankine cycle and other practical engine cycles for the extraction of work by expanding a vapor.

MODELING

An essential part of the application of solar ponds is the mathematical modeling of the process of heat collection, loss, storage, and use (Hull 1980, Kooi 1979). This procedure is essential to the correct design of the solar pond facility. Of course,the predictions made are only as good as the instruments that collect the data. To take

readings from a pyranometer which may be one square centimeter in area and calculate the output, from a solar pond of 50 hectares may seem inadequate to some, but it is state-of-the-art technology. It is better than guessing with no data input at all. Much modeling of solar ponds has been done at the Ohio State University; this work has revealed many of the limitations and difficulties with modeling. Knowing which areas are particularly sensitive is helpful in predicting performance. However, in new areas, some sort of pilot project should be undertaken to verify the model, the energy collected, the output and the performance of all the parts of the solar pond. Then a larger solar pond can be built.

How big should the pilot project be? Should it be 1 hectare, 5 hectares, or 50 hectares? It depends what one is prepared to risk in terms of money and time. A large money risk on a large project may well pay off if it works as well as or better than anticipated, because much time will have been saved and a large step forward will have been made. Even if the system does not work quite as well as hoped, the risk may be worth it. The security of a country is difficult to measure in monetary terms, and the local production of energy in many countries may lead to improved security for that country.

CONCLUSIONS

Of the two sites in the Dominican Republic that were examined as illustrative of the analytical issues and approach for solar pond siting, site 1 ranks higher for a number of reasons. These reasons include the results of computer modeling and the observations made during visits to the sites. Two factors stood out—one was the cost of rocksalt and the other was the effect of ground water depth. The cost of rocksalt at site 2 was prohibitive, being about $45 per tonne. Interest cost on this alone would be a large portion of the cost of the solar pond installation. Much of this salt is used locally, and the disruption of the market would be severe. The mathematical simulation showed that, with the shallow ground water level at site 2, the heat loss from the bottom of the solar pond was excessive. In contrast, the seawater at site 1 could be used to make evaporation ponds, and there was plenty of land available to build such evaporation ponds. The ground water level was deeper, and the simulation showed that, although it needed to be watched, the heat loss to the ground was not excessive. Other factors such as the proximity of agricultural land and a large freshwater fishery, and a problem with cooling water militated against site 2. Site 1 is on saline land with no agricultural land nearby. Any fisheries located near site 1 are using seawater, and cooling water is available in a nearby drainage canal. Although site 2 may be able to support a solar pond facility, site 1 is the logical choice for a pilot project. From the results of that pilot project, further ponds may be built in other parts of the country.

We believe the time has come for the "production" solar pond. However, the siting criteria and appropriate use of the solar pond are crucial to its success and continued

use. One cannot afford to be overly optimistic about such systems, nor to prom unreasonable results. However, it appears possible to build solar ponds that w produce electricity from solar energy using local resources, local personnel, and imported fuels.

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CHAPTER 5.
FUEL USE IN RURAL HOUSEHOLDS IN THE CENTRAL PHILIPPINES

Fern E. Hunt
Lucylen B. Ponce

INTRODUCTION

Noncommercial (traditional) fuels were generally ignored in past analyses of national energy consumption However, such fuels have received increasing attention in recent years with recognition that excluding them leads to erroneous conclusions about total energy needs in national policy and program development. One reason for the omission of traditional fuels from energy analyses in the past was failure to recognize the magnitude of use and the impending problems associated with continued consumption at current rates. An associated reason was lack of data (Dunkerley and Ramsay 1982, Revelle 1978, Landsberg 1979, and Tinker 1981).

In developing countries, a relatively small percentage of the population generally has access to commercial energy sources (Brown 1978). Where commercial forms of fuel or energy sources are not available, wood and agricultural residues are depended on for necessary energy. Households are the major consumers of noncommercial (traditional) fuels, and firewood and charcoal are used extensively in urban as well as rural households in many developing countries. Fuel scarcity imposes hardships, particularly on rural poor households (about 50 percent of the world population) who must use various forms of the biomass available as their sources of energy for cooking and water heating (Dunkerley and Ramsay 1982).

Choice of energy technology has long-term impacts on regions and is a worldwide concern. The constant search for firewood for households, combined with clearing of wooded areas for agricultural purposes and with indiscriminant logging operations, has resulted in widespread deforestation in many parts of the world. The deforestation has produced serious environmental consequences as well as implications for daily lives of local populations. Overuse of biomass for fuel can result in increased time required for fuel gathering and lowered agricultural productivity (Tinker 1981, Dunkerley and Ramsay 1982) not only through soil erosion in denuded areas, but

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also through diversion of crop residues from crop production applications to use for fuel. In addition, loss of forests may lead to extinction of plant and animal species and deterioration of watersheds, culminating in disastrous flooding and mud slides during rainy seasons (Dunkerley and Ramsay 1982, McCue 1982).

The Philippines is among the developing countries reported to be experiencing rapid deforestation. The Philippine nation has over 7000 islands with a total land area of about 30 million hectares, about 60 percent of which is in upland. Most of the uplands were originally covered with tropical hardwood rainforest, but in the twentieth century, especially in the past 25 years, about two-thirds of the forest cover has been removed in logging and farming operations. In Leyte Province, the site of the study reported herein, about one-half of the land consists of uplands and the other half, coastal plains. Primary forests cover about one-fourth of the total area, less than 40 percent of the original forest cover (MADECOR 1981).

Ninety-three to 95 percent of the annual total commercial energy used in the Philippines is supplied from oil; however, about two-thirds of the total national energy consumption is estimated to come from noncommercial sources (farm wastes and fuelwood). In Region VIII, where this study was conducted, the household sector is reported to account for the greatest share of energy consumption, and wood is reported to be the most important fuel. Energy consumption by various sectors of the economy in Region VIII has been estimated (MADECOR 1981) as follows:

Household	77.90%
Transportation	19.25%
Farming	2.35%
Rural industries	0.49%

Although the largest share of energy consumption in the region is attributed to households, household use of fuel is seldom mentioned in the literature as a contributor in deforestation.

Cecelski et al. (1979) summarized the reasons for need to investigate household energy usage in less-developed countries from the household and the public policy points of view:

> The provision of household energy needs takes up a substantial part of the resources of poor households—either in cash or in time...required to gather the materials. The problems are likely to be more acute in the future. At the lowest income levels, energy is used almost exclusively to satisfy the most basic human needs, in particular, food preparation. Curtailment in consumption leads to a decline in nutritional status. Household energy consumption accounts for a major part of total energy consumption (50% or more) in developing countries, and a substantial part of this share is consumed by the poor. Overuse of firewood, the main fuel particularly of the rural poor, can lead to widespread deforestation and soil erosion, thereby reducing agricultural productivity, and can even lead to flood disasters in regions having rainy seasons.(p. 1)

This descriptive study was conducted to contribute information on types, amounts, sources, and ways in which fuel is obtained and used in households in a selected rural area of the Central Philippines. Also, factors associated with usage and homemaker attitudes toward fuels, firewood production, and conservation were explored. Information presented provides some insights into the role of households in deforestation in the region.

METHOD

Data on household use of energy resources were obtained by personal interviews with 150 females in charge of households randomly selected from villages in Baybay, Leyte Province, The Philippines, during the month of August 1983. The sample was selected from the area within a 20-kilometer radius of Visayas State College of Agriculture. Permission to collect data in the area was obtained from the mayor of Baybay. The sampling area was selected in consultation with faculty members at Visayas State College of Agriculture who were familiar with the social and economic conditions in the Central Philippine region. The sampling area was considered to be typical of the rural, central region of the Philippines. The region was referred to locally as the "coconut capital of the world".

The interview instrument was developed at Visayas State College of Agriculture by a committee composed of the authors and members of the faculty of the Department of Home Science. The interviewing was completed by local interviewers who were selected and trained in the Center for Social Research at Visayas State College of Agriculture. The data were collected in August 1983, a period between the wet and dry seasons in the area.

In selecting the sample for the study, villages within the sampling area were listed and categorized into two groups: coastal and upland. Because of limited time and funds, interior villages not accessible by land transportation were excluded. Sixteen villages in each of the two categories were identified, and five villages from each of the two groups were randomly selected. Households in each of the five villages were identified through the Barangay (community) Captains, and 15 households in each were randomly selected for interviews making a total of 150 interviews.

DESCRIPTION OF THE SAMPLE

Distribution of the respondents by selected household characteristics is presented in Table 5.1. The primary occupation of almost 80 percent of the households was agriculture—rice farming, growing root crops, and coconut farming. A secondary source of income was reported by 53 percent of the households. Most of the supplementary income came from growing rice, operating sari-sari stores, copra trading, root crop farming, and operating piggeries.

TABLE 5.1

Distribution of Participants by Household Characteristics (N = 150)

Variables	Frequency	Percent
Household size (No.)		
2	13	8.7
3	13	8.7
4	27	18.0
5	31	20.7
6	26	17.3
7	14	9.3
8	14	9.3
9	12	8.0
Main source of income for the household		
Rice farming	65	43.3
Spouse salary	23	15.3
Root crops	19	12.7
Coconut farm	12	8.0
Sari-sari store	7	4.7
Fishing	6	4.0
Carpentry	5	3.3
Driving	5	3.3
Copra trading	3	2.0
Tailoring	2	1.3
Dressmaking	1	0.7
Nipa sales	1	0.7
Painting	1	0.7
Additional sources of income		
None	71	47.3
Copra trading	17	21.5
Rice growing	17	21.5
Sari-sari store	17	21.5
Root crops	14	17.7
Piggery	6	7.6
Rice trading	3	3.8
Money from children	2	2.5
Tuba gathering	2	2.5
Gambling	1	1.3
Years of schooling—Female head of household		
No data	1	0.7
0	4	2.7
1	4	2.7
2	7	4.7
3	6	4.0
4	19	12.8
5	12	8.1
6	41	27.5
7	7	4.7
8	8	5.4
9	6	4.0
10	22	14.8

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TABLE 5.1

Distribution of Participants by Household Characteristics (N = 150)

Variables	Frequency	Percent
Years of schooling—Female head of household		
11	2	1.3
12	8	5.4
14	3	2.0
Years of schooling—Male head of household		
No data	4	2.7
0	4	2.7
1	1	0.7
2	5	3.4
3	8	5.5
4	21	14.4
5	13	8.9
6	44	30.1
7	7	4.8
8	7	4.8
9	5	3.4
10	14	9.6
11	2	1.4
12	7	4.8
14	7	4.8
18	1	0.7
Home ownership		
Own	147	98.0
Mortgage	2	1.3
Rent	1	0.7
Amount of land owned (hectares)		
None	62	41.3
0.02	2	2.3
0.03	1	1.1
0.10	2	2.3
0.13	1	1.1
0.14	1	1.1
0.25	7	8.0
0.30	1	1.1
0.33	5	5.7
0.50	22	25.0
0.67	1	1.1
0.75	3	3.4
1.00	7	8.0
1.25	1	1.1
1.50	4	4.5
1.75	1	1.1
2.00	10	11.4
2.50	4	4.5
3.00	8	9.1
4.00	1	1.1
5.00	2	2.3
6.00	2	2.3
7.00	2	2.3

Household sizes ranged from two members (8.7 percent) to nine members (8.0 percent). The average size was 5.7 people, and the mode and median were both 5 people. Households commonly included one or more grandparents and/or other relatives.

Most of the participants and their spouses had at least some schooling, but 62 percent of the wives and 66 percent of the male heads of households had no more than six years of education.

Homes were clustered in small settlements surrounded by the small farm plots. Home ownership was more prevalent than land ownership. Ninety-nine percent of the participants reported that they owned or had a mortgage on their homes, whereas only 59 percent reported that they owned some land. Land holdings tended to be small. About 60 percent of land owners owned one hectare or less. Only six households had 5 or more hectares and the largest farm reported was 7 hectares.

FINDINGS

Most households had neither gas nor electric service. In general, very few households had energy-using devices other than cookstoves and kerosene lamps. All had one or more cookstoves. Battery-powered radios and charcoal-heated irons were the most common energy-using equipment besides stoves and lamps (Table 5.2). Findings will be reported first on ownership and use of cookstoves—the major contributor to use of fuel in the households studied. Information on the acquisition and use of fuels in the households will follow.

STOVES AND FUELS USED

The stoves available to the respondents were simple in design and had no provision for control of heat during cooking. Most women know, however, that the different materials used as fuel differ in their heating characteristics. Also, they know that certain stove designs have better results than others with certain fuels. They employed this knowledge of the different stove designs and properties of materials available for fuel in their food preparation. Heating characteristics of the different fuels were not studied in this survey. Generally, only one cooking job could be handled on a stove at one time, and each household owned more than one stove.

Four basic types of kitchen stoves were used in the households studied, although a variety of design variations may have been represented among them. Lozada et al. (1982) reported that he had found over 80 styles or variations in design in use in a survey of stoves he conducted. Clay (cylinder) and steel (tripod or grate) types were most commonly found in the participants' kitchens. Almost 51 percent of the households used clay stoves, and nearly one-half (46.7 percent) of those repondents had and used two such stoves. Steel stoves, either in tripod or rectangular grate form, were the second most important type used (46.7 percent), and 41.4 percent owned and used two. Fourteen percent of the women said they used stone stoves, and slightly

TABLE 5.2

Ownership of Energy-Using Home Equipment in Rural Households near Baybay, Leyte Province, The Philippines (N = 150)

Equipment	Ownership No.	Ownership %
Lights	150	100.0
Radio	69	46.0
Iron (generally charcoal type)	48	32.0
Stereo	16	10.7
Cassette	14	9.3
Television	8	5.3
Electric fan	9	6.0
Refrigerator (generally kerosene)	7	4.7

over one-half used two of them for cooking. Five of the 150 participating households had an LP (bottled) gas stove, but those stoves generally were not used for all cooking done in the home because of the cost and difficulty in obtaining the fuel.

Cookstoves were generally located and used inside the house (94.7 percent). Although kitchens were fairly open and airy, having open windows and wide cracks between bamboo poles from which the walls were constructed, considerable smoke accumulated in the kitchen environment during cooking. Practically all of the women (99.3 percent) said that the smoke bothered them: 94.6 percent said that it hurt their eyes and 5.4 percent said that it affected their respiratory system, causing coughing and throat irritation.

Usage Patterns: Fuels and Cookstoves

All but one respondent reported that food was generally cooked before every meal. In meal preparation, 68 percent of the participants said that they usually used one cooking stove per meal and 31 percent said they used two. One stove was generally used to cook more than one food. If grains (e.g., rice) were cooked, they were usually prepared first. Two cooking pans were commonly used by 73 percent of the participants, and three pans were used by 24 percent. Foods cooked first were kept warm by placing them beside the cookstove while other foods were cooked.

Most of the women said that sometimes partly burned firewood is left after a meal is cooked. When that happens, 62 percent said that they generally put something else on to cook to take advantage of the heat, and 35 percent said they extinguish the fire to save the fuel for later use.

Best Fuels for Selected Cooking Tasks

Opinions on the best fuel for cooking varied with the method of cooking to be used (Table 5.3). Wood and the spine of the coconut frond are similar in burning

TABLE 5.3

Preferred Fuels for Cooking Selected Foods

Foods and Fuels	Frequency[1]	Percent
Boiling/steaming (rice or corn)		
Wood	109	72.7
Coconut fronds	36	24.0
Coconut husks and shells	2	1.3
Charcoal	2	1.3
Bamboo poles	1	0.7
Stewing meat		
Wood	101	67.3
Coconut fronds	22	14.7
Coconut husks and shells	19	12.7
Charcoal	3	2.0
Bamboo poles	3	2.0
Broiling		
Charcoal	52	38.3
Coconut shells	48	32.2
Coconut husks and shells	17	11.4
Wood	16	10.7
No data	1	0.7
Roasting		
Coconut husks and shells	108	72.5
Coconut shells	30	20.1
Charcoal	5	3.4
Wood	3	2.0
No data	1	0.7
Barbecuing meat and chicken		
Charcoal	62	45.6
Coconut shells	48	35.3
Coconut husks and shells	11	8.1
No data	14	9.3

[1]Frequencies do not add up to 150 for most cooking methods because not all people did all types of cooking listed.

characteristics and were considered best for boiling and simmering (moist heat) methods of cooking. For dry, direct heat applications such as broiling and barbecuing, the women said that the heat provided from burning charcoal and coconut shells provided the desired heating characteristics. In roasting, where less intense heat and slower cooking were desired, the respondents said they liked the effects produced by burning coconut husks with the shells. Of the 135 participants who responded to the question, "Does the fuel available affect what you cook?" all but one said "No."

When specific foods were listed by stove and fuel type (Table 5.4), the response on preference was somewhat different from that on general opinion of "best" fuel for

TABLE 5.4

Preferred Type of Stove and Fuel for Cooking Specific Foods (N = 150)

Food	Preferred Stove Material	%	Preferred Fuel Material	%
Hot beverages	Clay	48.0	Coconut frond	59.3
	Steel	35.3	Wood	37.3
	Stone	10.7		
Eggs	Clay	48.0	Coconut frond	62.0
	Steel	35.3	Wood	34.7
	Stone	10.7		
Vegetables	Clay	53.3	Coconut frond	62.7
	Steel	32.7	Wood	34.7
	Stone	10.0		
Fish	Clay	48.0	Coconut frond	60.7
	Steel	35.0	Wood	36.7
	Stone	10.7		
Grains	Clay	48.0	Coconut frond	60.7
	Steel	35.3	Wood	36.7
	Stone	10.7		
Legumes	Clay	46.7	Coconut frond	57.3
	Steel	36.0	Wood	54.7
	Stone	10.7		
Meats	Clay	46.0	Coconut frond	54.7
	Steel	37.3	Wood	37.3
	Stone	10.7		
Bananas and breadfruit	Clay	45.3	Coconut frond	56.7
	Steel	38.0	Wood	37.3
	Stone	10.7		
Root crops	Clay	42.8	Coconut frond	58.0
	Steel	40.0	Wood	31.3
	Stone	11.0		

cooking. Coconut frond and wood were listed most often as the preferred fuel; and for every food, coconut frond was the most often preferred fuel. For all but one food, those two fuels together were preferred by more than 90 percent of the respondents. Reasons for fuel preference were not given, but preference may have been associated with cost and availability of fuel. Clay or steel was the preferred type of stove. Together the two types of preferred stoves accounted for 80 percent of the responses for each food.

According to Lozada et al. (1982), the most commonly used Philippine firewood stoves have low to moderate efficiency ratings (5 percent to 12 percent). However, their low initial cost and relatively long service life are important explanatory factors in their popularity.

Water Heating

Ninety-five percent of the participants said they heated water for a hot beverage in the morning on the day preceding the interview. The amount of water heated by 88 percent of the repondents was 2 liters or less. Few of the participants heated water for hot beverages at noon (3.3 percent) or for serving later in the day (12 percent).

When water was heated for beverages, it was generally done with leftover hot coals after a meal was cooked (68%), but use of a separate stove for heating beverage water was reported by about one-fourth of the participants.

The majority of the respondents did no water heating with fuel other than for hot beverages and cooking food. Those who did report some water heating for other purposes listed purposes such as sterilizing kitchen utensils, washing feet, and bathing a baby. Coconut fronds and wood were the principal fuels used when water was heated for purposes other than drinking (60 percent and 36 percent, respectively). In about 80 percent of those cases, not more than 2 liters was warmed and the heating was accomplished in 15 minutes or less.

HOUSEHOLD FUEL: ACQUISITION AND USE

Proper assessment of energy consumption and comparison of energy use among sectors of the economy and geographic areas requires data on the heat values (Btu's or joules) of fuels used. An important factor affecting heat value of the biomass used as fuel is moisture content, which varies with season, greenness, and storage conditions. In this study, best estimates were obtained on volume of fuel used rather than weight (mass) because of the variability in weight due to water content. A desirable next step would be to determine heat values for the common volumes or market units of the types of biomass reported. Acquisition of fuels—and types and amounts used in the rural households studied—are described in this section.

Type and Amount of Fuel Used

A fairly wide variety of locally available biomass was used for fuel in households. Most fuel use was for cooking. Relatively little fuel was purchased. Eighty-eight percent of the participants said they used some combination of noncommercial fuels (wood, coconut fronds, bamboo poles, coconut shells, coconut husks, coconut husks with shells, charcoal, corncobs, and wood shavings) rather than a single type of fuel. The most commonly used fuels were wood, coconut fronds (9.3 percent did not use), coconut husk with shell (57.3 percent did not use), and bamboo poles (72 percent did not use).

WOOD: Only 10.7 percent of the respondents did not report use of wood for fuel. Among those who did use wood, the range in amount reported was 1 to 10 bundles per week (mode = 5, mean = 6). But 60 percent used 3 bundles or fewer, and 89 percent used 5 or fewer. The approximate dimensions of a bundle of wood are as follows: length, 1.5 feet (46 centimeters); diameter, 0.5 foot (15 centimeters).

COCONUT FRONDS: The hard, woody central spine of the coconut palm leaf with the softer, leafy foilage removed was called the frond. Over 90 percent of the households reported using at least some coconut fronds for fuel. Among the users, 93.4 percent used 6 or fewer bundles per week (mode = 2, mean = 3.5). Dimensions of a bundle of palm fronds were as follows: length, 1 foot (30.5 centimeters); diameter, 0.75 foot (23 centimeters).

COCONUT HUSKS AND SHELLS: More respondents used coconut shells (21 percent) than husks (8 percent). The shells are a dense, hard, thin material in contrast to the porous, thick husk. Therefore, the shells liberate more intense heat during burning than the husk does.

COCONUT HUSK WITH SHELL: The coconut husk with shell is a popular fuel material producing cooking heat with intensity intermediate between that of the husk and shell. Coconut husk with shell was used as a cooking fuel more than either coconut husk or shell separately. Forty-three percent of the repondents reported use of the husk with shell whereas only 21.3 percent said they used coconut shells and 8 percent reported use of coconut husks. The range in amount reported as used per week was 0.01 to 5.0 sacks. The mean amount was 1.3 sacks per week and the mode, 1 sack. A sack was used as a unit of dry measure for several fuel materials and had a volume of about 50 litres.

BAMBOO POLES: Twenty-eight percent of the sample reported that they burned some bamboo poles for cooking heat. Among those who used the poles, the range in amount reported was 1 to 9 bundles per week (mode = 1, mean = 2). Dimensions of a bundle of bamboo poles were as follows: length, 1.5 feet (46 centimeters); diameter, 1 foot (30.5 centimeters).

COCONUT LEAVES: Twenty-two percent of the respondents said they used the coconut palm leaf as cooking fuel. The soft foilage of the coconut palm leaf is used dry, separated from the frond. The dried leafy part ignites readily and is used primarily to start the cooking fire.

CHARCOAL: Charcoal may be produced from wood, coconut husks, or rice chaff (husks). The type of charcoal used was not ascertained in this study. Relatively little charcoal use was reported by the respondents, possibly because it is more expensive than some other fuels. Less than five percent of the households reported using charcoal, with amounts reported ranging form 0.25 to 1 ganta. The ganta is a volume measure for dry materials, especially grains and legumes, and is equivalent to 3 litres.

DRIED WHOLE YOUNG COCONUT: Use of dried whole young coconut as cooking fuel was reported by 1.3 percent of the households. Each of the two respondents reported using one sack per week.

KEROSENE: Four percent of the households reported use of some kerosene. The amount used ranged from 0.25 gallon to 2.5 gallons per week.

PROPANE GAS: Propane gas is expensive and difficult to obtain on a regular basis. Only two percent of the households reported its use and each reported using one tank per month. One tank contains about 11 kilograms.

SOURCES AND METHODS OF OBTAINING FUEL

Gathering Fuel

Most of the major fuels used—wood, coconut fronds coconut husks, coconut shells—were obtained by gathering (Table 5.5). One or more household members usually did the gathering. The fuels were obtained primarily from three sources—the family farm, the mountains, and/or the village around the dwelling. The families lived in small community groupings of houses, and the farms were located outside the small villages. Places outside the village where fuel was gathered and which were not owned by the respondents were referred to as mountains.

The persons most often reported as gatherers of fuel were the husbands (about one-third of the cases); respondents were next (slightly over 25 percent of those reporting collection of fuels), and considerably less often reported were sons. Helpers were most often the respondent or another household member other than a son or daughter.

TABLE 5.5

Methods of Obtaining Fuel

Fuel Type/ Method of Obtaining	Frequency	Percent
Palm fronds		
Don't use	15	10.0
Gather	130	86.7
Buy	5	3.3
Wood		
Don't use	16	10.7
Gather	114	76.0
Buy	12	8.0
Buy and gather	8	5.3
Coconut husks		
Don't use	92	61.3
Gather	56	37.3
Buy	2	1.3
Coconut shells		
Don't use	118	78.7
Gather	30	20.0
Buy	2	1.3

Distance of Fuel Source from Home

Practically all of the respondents lived within 3 kilometers of the sources used; 75 percent or more lived within 1 kilometer. The three households reporting use of propane gas travelled farthest—10 to 33 kilometers—to obtain tanks of that fuel.

Quantity of Fuel Gathered at One Time

For fuels gathered in sacks (coconut shells, husks, husks with shells, small young dried coconuts, coconut leaves, and wood shavings), the most common quantity gathered at a time was one sack. Fuels gathered in bundles (wood, coconut fronds and bamboo poles) were more often obtained in multiple units. Wood and coconut fronds were most often collected two bundles at a time, and about 95 percent of those who used either fuel gathered no more than five bundles per time. For bamboo poles, an infrequently reported fuel, more than one-half of the respondents using them reported that they usually gathered only one bundle at a time.

Frequency of Gathering Fuel and Time Spent

For most of the fuels gathered, frequency of collecting was most often once a week. Coconut fronds, however, more often than other fuels, were gathered twice a week.

Considerable variability occurred in time required for collecting fuel. In general, gathering wood was more time-consuming for more people than was collecting coconut fronds, husks, shells, leaves, or any of the other combustible agricultural residues considered. For example, 71.3 percent of the repondents required 2 hours or more to collect wood; whereas 40.7 percent of the respondents required 2 hours or longer to collect bamboo poles, and 60.0 percent required at least 2 hours to collect coconut fronds. Nearly half (47 percent) of the women said they combined trips to obtain fuel with other errands, primarily going to the farm to harvest vegetables, gathering root crops, or weeding the farm.

Ease of Obtaining Fuelwood

About 35 percent of the participants reported that firewood was more difficult to get at the time of the survey than it was 5 years earlier. Reasons given for the increased difficulty were as follows:

- Firewood is scarcer today because there are more firewood users than five years ago.
- Five years ago, the source of firewood was nearer than today.

One-fifth of the respondents said that they have had trouble in getting the fuel they need. Reasons were given by only 18 percent of the women. The problems, they said, were as follows:

- Absence of the regular fuel gatherer.
- Fewer tree lots where fuelwood may be gathered.

- Difficulty in gathering fuelwood from the mountain in rainy weather; also, the firewood is heavy when wet.
- The gathering takes too much time.

Effect of Season on Use Patterns and Ease of Obtaining Fuel

Eighty percent of the respondents reported that they use the same fuel in both dry and wet seasons. The few who used different fuels said that some fuels are difficult or impossible to ignite when saturated with moisture.

Those who do not change fuels stock up fuel in dry weather for use on rainy days. Over 39 percent of the participants said that it took longer in wet than in dry weather to collect fuelwood because the roads are slippery and the wet wood is heavier to carry. According to 59 percent of the respondents, they make more frequent trips to collect fuelwood in dry than in wet weather because they collect extra in dry weather to store for the wet season.

Firewood Storage

Practically all of the respondents said that they store fuel for rainy days. Fuelwood is stored in several places: under the house (46.7 percent), under the cookstove platform in the kitchen (29.3 percent), in a separate storehouse (18.7 percent), or in a small cabinet in the kitchen (4.6 percent).

Attitudes on Possibilities for Improving Fuelwood Supplies

A majority of the respondents (61 percent) thought a community tree lot would not be a good thing for their barangay. The major reason given was that apportioning the wood equally among the barangay residents would be difficult and, hence, the lot could be a source of trouble. Those in favor of a barangay tree lot thought it would be good for the people in the barangay to have their own source of firewood and that fuelwood would be easier to gather.

In relation to ways to lessen firewood supply problems, slightly over one-half of the participants said that they would not plant trees on the land they own and/or live on. However, slightly more than one-half (51 percent) said they would plant trees for firewood if they were a fast-growing variety which could yield firewood in a year or two. The advantages they listed included:

- Firewood would be available in a relatively short time.
- Firewood would be available when they need it without having to buy it.
- Firewood could be sold as a source of money and their land would become more productive.

Over 90 percent of the respondents identified the ipil-ipil tree (*Leucaena leucocephalis*) as one that is fast growing and good for fuel. Those who did not favor planting their own fast-growing trees (47.3 percent) said firewood is still plentiful in the mountains and there is no need to plant trees for fuel. Families probably

considered use of their small farms for food production more important than for fuel production.

Fuel Purchased

Few of the respondents reported the purchase of any type of fuel. However, among those fuels that were purchased, wood was listed most often (12 percent) and charcoal, second (5.3 percent of the sample). Five households in the sample of 150 said they had purchased kerosene; 5 had purchased coconut fronds; and 3 had purchased propane gas.

In most cases, the amount of fuel purchased would last a week except for propane gas (which lasted as little as 1 month for one and as long as 3 months for another respondent). All of the participants who bought fuel said that the fuels cost more at the time of the survey than 5 years earlier.

CONCLUSIONS

Observations in the literature that households in less developed countries rely primarily on noncommercial fuel resources were supported in this study. Firewood, various products of the coconut palm tree (fronds, leaves, coconut shells and husks, and immature dried coconuts), and, to some extent, bamboo were the major cooking fuels used in the Philippine community included in this study. This region of the Philippines is known as the "coconut capital of the world." Not only does the coconut palm provide a commercial crop in which harvesting does not destroy the plant, but also the residues from processing the nut (husk and shell) and the fronds that are shed naturally by the tree as it grows provide important fuel resources that are readily accessible and acceptable to households.

Residents in the area reported that firewood is becoming scarcer than previously, and costs per bundle are increasing. The costs include not only cash outlays but also increased time and human energy inputs for those who collect the firewood. Reductions in forest biomass in the area studied are implied in the responses.

Although firewood is becoming increasingly more difficult to obtain for some of the participants in the study, which they attribute to increasing numbers of users and the growing scarcity, less than one-half of the sample agreed that community wood lots and tree planting on occupied/owned land should be considered. A chief reason offered was that it might be a source of trouble in the community.

If a community tree lot appeared to be the most appropriate solution to the problem of fuel scarcity, a system for managing the fuelwood production and providing for equitable distribution would need to be developed. Educational programs on management strategies and community participation in decision making may be needed.

Once established, the ipil-ipil tree, a fast-growing variety, can be harvested annually. The annual growth from a few trees can provide a year's supply of firewood

for a household. Yet nearly one-half of the respondents said they would not plant the trees. A view expressed by some respondents, which might be construed to represent lack of foresight on the part of the residents, was that since firewood is still available in the mountains, there is no need to plant trees for fuel. Possibly hardship from scarcity of fuel has not been felt sufficiently by enough people in the area to stimulate change in attitude or behavior.

Reasons for reluctance to plant fast-growing trees for fuel should be explored further. Most of the respondents said they owned their home in their village, but only about 60 percent owned even a small piece of land. How planting a few fast-growing trees for their fuel would affect other valued uses of the scarce land (such as food production) about their house or at their farm may be an overriding consideration.

Clay and steel cookstoves were the two types most commonly found in the rural kitchens and the types most often listed by participants as preferred. Lozada et al. (1982) reported that the steel tripod cookstoves are no more that 5 to 8 percent efficient and that their use should be discouraged; further, the efficiency of the half-cylinder clay style is only 8 to 11 percent. Improving efficiency of cookstoves has been suggested as a logical, practical, and important means of reducing demand for firewood. Lozada et al. (1982) said that the relatively long service life and low cost of the steel and clay cookstoves were probably the reasons for their popularity. It may be, also, that people have felt comfortable in their ability to prepare food to their family's satisfaction with their traditional equipment and are reluctant to change to newer types of stoves. Reasons for popularity of the stoves and fuels used were not explored in this study. However, such information would be useful in implementing any program of intervention.

In most of the respondents' homes, cooking was done indoors. Nearly all of the women said that the smoke which permeated the kitchen during cooking bothered their eyes; only a few mentioned respiratory problems associated with the smoke pollution. Information on incidence of eye and repiratory health problems was not obtained in this study. Such information would provide a basis for determining need for attention to improved methods of venting the stoves and to health care.

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PART II
FEASIBILITY ANALYSIS OF RENEWABLE ENERGY OPTIONS

CHAPTER 6.
FINANCIAL AND ECONOMIC ANALYSIS OF FUELWOOD AND PULP IN GHANA

Fred J Hitzhusen
Kwadwo Boakye-Dankwa

INTRODUCTION

The Subri Forestry Project dates as far back as 1971 when the Ghana Forestry Department embarked on an intensive reforestation program with the aim of converting about 100,000 hectares of degraded forest reserves to plantations of fast growing species. To achieve this, exploited areas were clear felled and the trees and other ground cover burnt. This involved enormous waste of the country's natural resources. To eliminate this waste, the government of Ghana proposed a charcoal production and utilization project. One of the areas selected for this program was the Subri Forest Reserve in the high forest zone situated 45 kilometers to the east of Takoradi in the western region. In order to implement the program, the United Nations Development Program (UNDP) was contacted for financing. The request was approved in April 1975, and the Food and Agriculture Organization (FAO) was designated as the executing agency.

The preliminary phase of the project was started in February 1976 with field operations at Subri Forest Reserve near Daboase, a village 7 kilometers southeast of the southern boundary of the reserve. The Subri Forest Reserve forms part of the catchment area of the Pra River from which most of the water supply for the cities of Sekondi and Takoradi is derived. According to the last published management plan, the productive area of the reserve is about 224 square miles (58,000 hectares). This together with adjacent reserves totals more than 200,000 hectares.

The forest type in the project area falls within the tropical moist semideciduous forest, with the Celtis-Triplochiton Association predominating in the north and east and the Lophiza-Triplochiton Association in the south. The topography is steeply dissected with short slopes of between 30 to 60 degrees and a moderate range of elevation which rarely exceeds 150 meters. Drainage on the west is toward the River

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Bonsa and on the east toward the River Pra. A considerable network of smaller rivers and streams is present, and swampy areas are frequent in valley bottoms and near streams. Major species planted include *Gmelina arborea, Cassia siamea,* and *Pinus caribaea.* The project document provides for the management of the forest reserve to maximize the sustained output of renewable fuels without prejudice to the flow of other forest products or damage to the environment. The change of project from "Charcoal Production and Utilization" to "The Development of Forest Energy Resources in Ghana" reflects the change of emphasis of decision makers in Ghana.

ANALYSIS OF THE SUBRI FORESTRY PROJECT

The financial and economic analyses of the pulpwood and fuelwood scenarios of the Subri project are based on the Subri Conversion Technique, which was initiated in 1977. The technique aims to establish fast-growing species like *Gmelina* for pulp and *Cassia* for fuelwood without totally destroying the natural forest by fire during site preparation. In areas selected for conversion, valuable trees are retained and all other material is utilized.

The technique in summary involves:

- Selection of trees as standards (30 to 40 per hectare).
- Utilizing all wood.
- No burning.
- Practice of agrisilviculture after conversion operation by interplanting plantain (foodcrop) with the tree species.
- Site conversion operation followed by plantation establishment.

The analyses which follow are based on the following main features of the project:

1. The conversion of a total of 2500 hectares of natural forest through clearing, logging, sawmilling, and charcoaling.
2. The reforestation of the areas converted with *Gmelina arborea* for pulpwood or *Cassia siamea* for fuelwood.
3. The construction of forest roads.
4. The provision of equipment and skilled personnel for the workshop.
5. The construction of staff housing.
6. Hiring of skilled personnel for project.
7. The provision of vehicles necessary for project administration.
8. The provision of general consultancy services.

Following is a brief description of the project and detailed features of the project. Data for cost and revenue estimates for various project components on which the financial and economic analyses of the two scenarios are based were collected during a field trip to Ghana in late 1982.

PROJECT OBJECTIVES (SCENARIOS ON WHICH ESTIMATES ARE BASED)

The objectives of the project are to establish an industrial plantation capable of supplying pulpwood for a paper mill and to establish a fuelwood plantation. In the process of plantation establishment, agrisilvicultural techniques will be incorporated to provide food (mainly plantain).

General Description

The project involves establishment of some 2500 hectares of *Gmelina arborea* and *Cassia siamea* and using agro-forestry techniques to produce plantain in the early stages of tree growth. The project will also process the wood gained through clearing by making charcoal and timber as well as selling firewood.

CONVERSION

The project will be based on the Subri Conversion Technique described earlier.

The logging operation starts with site planning: marking roads, boundaries, and processing sites. This will be followed by cutting of climbers, underbrush clearing, and selecting of standards.

Sawmilling is done at each conversion site. One mobile sawmill is on each site. The mill allows conversion of logs up to 5.5 meters in length and up to 2 meters in diameter. Each mill will have an input of 15 cubic meters (m^3) of logs per working day, or 3750 m^3 per year. There will be the need to install a stationary sawmill at Daboase to take care of 15,000 m^3 additional logs available, and another 15,000 m^3 per year classified as export trade species partly suitable for local conversion.

At least 80,000 m^3 will be available for charcoaling and this wood has to be removed from the logging site to facilitate reforestation. One m^3 will give 130 kilograms of charcoal. Total production of charcoal will be 11,000 tons per year. Charcoal production in semimobile kilns has been successful. A unit consists of five men and two kilns producing 120 tons per year. Total production of charcoal in semimobile kilns will be about 1000 tons per year. Large stationary kilns will be installed at the wood utilization center. In addition, some wood will be sold as fuelwood at the roadside, especially because direct sales of fuelwood will reduce the relatively large charcoaling operation.

REFORESTATION

Reforestation activity begins with seed collection from existing seed stands of trees. The existing nursery is well established; hence, there is no need for a new nursery. Planting starts in the rainy season. After the logging operation, the planting site is cleared; clearing of debris requires 8 man days per hectare. Clearing of planting lines, pitting, and plant distribution requires 12 man days per hectare. Planting operation at 5 meters x 2 meters on the prepared site will take 5 man days per hectare. The plantain

suckers are planted at 5 meters x 4 meters. They are planted 2 to 3 months before the trees and harvested some 9 months later. About 1250 hectares will be planted with plantain. Maintenance of the plantation will be combined with that of the plantain. First year weeding will require 10 man days per hectare and second year weeding, 8 man days per hectare. For pulpwood there is no need for thinnings and a longer rotation. The next generation will be raised on stump shoots (coppice regeneration). Thinning of the coppice to 1 to 2 shoots and brush clearing will take 15 man days per hectare.

CONSTRUCTION

Road construction entails construction and upgrading of 14 kilometers per year for 5 years. There is already a system of old roads in the areas used by concessionaries, and these are estimated to be about 60 percent of the road system. The primary roads will be all-weather roads of 10-meter width, while secondary roads will be about 7 meters. Skidding trails will be constructed as part of the logging operation. Some of the logging equipment will also be used for road construction.

WORKSHOP

The central workshop of Daboase which has four vehicle repair bays, classroom, stores, and electrical shop will be utilized by the project. An estimate has been made of the cost to restore the workshop. The workshop will repair and maintain the vehicles and machines of the project, and manufacture parts and items for the project. There will be three mobile workshops to make daily maintenance service of the field equipment.

HOUSING CONSTRUCTION

A total of 20 houses, an office block, and labor camps will be built. They will be designed to use local timber as much as possible.

PROJECT MANAGEMENT

A construction management team including five non-nationals will be recruited.

ADMINISTRATIVE VEHICLES

The project will provide 6 four-wheel drive vehicles for supervision, a 10-ton truck to transport materials (occasionally labor), 10 motorcycles, 15 bicycles, a utility car for the headquarters, and a 20 percent provision for spares.

CONSULTANCY SERVICES

The project will provide for various short-term consultancies to assist with any unforseen start-up problems. They will be needed in the areas of silviculture, sawmilling, charcoaling, workshop, stores, and market survey.

ANALYSIS OF THE PULPWOOD AND FUELWOOD SCENARIOS

The following section is devoted to the financial and economic analyses of the Subri project. The distinciton between financial analysis and economic analysis is as follows: Financial analysis is based on net returns to private equity capital based on market or administered prices; economic analysis is based on net returns to the whole society, frequently based on shadow prices to adjust for market or administered price imperfections (See Chapter 1 discussion). The economic or cost-benefit analysis purpose is to obtain a net social value of alternative investment options (the two scenarios). This procedure entails a comparison of the benefits to costs of an investment over its useful life.

Various measures of project worth can be calculated from the project cash flow tables. This study, however, uses two common, discounted measures: (1) the net present value and (2) the internal rate of return. The former indicates the difference between the present values of the total benefits and costs. The latter measure indicates the average return on project resources during the time they are committed to the project. The pulpwood scenario is analyzed first, then the fuelwood scenario. The results of the two scenarios are then discussed. Conclusions, policy implications, and limitations of the study are then presented.

ANALYSIS OF THE PULP SCENARIO

Financial Analysis

This section deals with the financial aspects of the "pulpwood scenario" for Ghana's Subri Forest Project. One of the objectives of financial analysis is to help decisionmakers formulate a judgment about the project's financial efficiency, incentives, creditworthiness, and liquidity (Gittinger 1982). For this reason the financial rate of return (internal rate of return) and the net present value of the Ghana project investment have been used to assess its financial viability. Throughout the analysis, the 1982 market prices for various project resources were used to estimate the project costs, and 1982 farm-gate prices were used to estimate the returns of the 2500-hectare project. All the input and and output prices are "constant" prices, with the assumption that inflation will affect all costs and benefits equally over the 20 years of the project's economic life.

The assumptions underlying the project's 20-year life span are that the coppice yield may decline after the second generation harvested in years 16 through 20. Greater risks and uncertainty about price estimation over the longer horizon result from the country's economic instability, and the discounted net present values become very small due to small values of discount factors beyond year 20 (Gittinger 1982). The total project costs are divided into operating costs and capital outlay; a detailed presentation of these components is presented in Hitzhusen et al. (1984).

Project Financing

A loan of 15 million cedis (about $5.5 million) will be required to establish the 2500 hectares over 5 years. The loan will be used to finance the purchasing of equipment and spares for maintaining equipment. Funds for operating costs, staff, and labor will be provided from internal sources. The loan has an interest rate of 10 percent and a 1-year grace period. Debt service is to be paid in a series of equal annual installments from years 1 through 5. This is also termed level payments or an equated annuity (Ward 1976). In the computation of the cash flow, an equal payment of ¢3,956,955 is thus applied for the first 5 years of the project. The loan in disbursement is assumed to be in declining order of 5, 4, 3, 2, and 1 million for years 1, 2, 3, 4, and 5. These are taken into account in arriving at the net benefits after financing.

DEPRECIATION: The straight line depreciation method is adopted assuming no taxes are involved. Also, a zero salvage value is assumed at the end of the equipment's technical life. The depreciation values are excluded from calculation of financial rates of return and net present values. All initial capital outlay (¢16,761,060) was assumed to occur in year zero. The equipment replaced includes the planting and demarcation in year 4; administrative vehicles in years 6, 11, and 16; workshop equipment in years 6, 11, and 16; and harvesting equipment in year 15. Annual depreciation is ¢1,875,370 in years 1 through 5; ¢1,709,705 in years 6 through 10; and ¢570,280 in years 11 through 20.

PROJECT FINANCIAL RETURNS OR NET BENEFITS: The benefit stream of the project includes benefits realized from utilizing the waste products during land clearing in the first 5 years. The products are charcoal sold on site at ¢60 per ton; sawn timber at ¢1,500 per cubic meter, and logs at ¢140 per cubic meter. These contribute a total annual benefit of ¢8,130,000 in years 1 through 5, or an undiscounted total of ¢40,650,000. The second part of the benefit stream is the sales of the project's main products (harvest of *Gmelina*) from year 6 through year 20, giving an annual gross benefit of ¢4,713,000, the total of which is ¢70,695,000. The estimated total benefits are ¢111,345,000 over the project life.

The calculated annual net cash flows are ¢3,059,544 in year 1, dropping to a net loss of (¢3,627,298) in year 5, then rising to ¢1,844,860 in years 7 through 15. In year 16 there is a net loss of ¢1,759,588. From years 18 through 20 the project nets an annual cash flow of ¢1,896,812.

Under the internal rate of return efficiency criterion, the project is revealed to be financially nonviable and, hence, nonattractive for private investment since its return to capital investment of 4.3 percent is less than the 10 percent rate, which is considered as the opportunity cost of the capital invested (Earl 1981). Also, the project has a negative discounted net present value of ¢6,625,647 at the 10 percent discount rate.

Economic Analysis (Pulp Scenario)

"Once financial prices for costs and benefits or returns have been determined and entered in the project accounts, the analyst estimates the economic value of a proposed project to the nation as a whole. The financial prices are the starting point for the economic analysis; they are adjusted as needed to reflect the value to the society as a whole of both the inputs and outputs of the project" (Gittinger 1982, p. 243). Whereas financial analysis is concerned mainly with estimation of the profitability of a project from the private individual point of view (return to equity), economic analysis is concerned with the profitability of the proposed project from the standpoint of the whole society. Thus, economic analysis considers third party effects of a project even though these may not be easily priced and adequately compensated. The necessity of shadow prices in less developed countries in general and Ghana in particular is great because of certain features of these economies. The coexistence of traditional and modern sectors is one feature which distinguishes these economies from those of developed countries. In the Subri Reforestation Project, price adjustments were considered necessary on wages, the prices of imported inputs, exported outputs, and domestically produced tradeable inputs and outputs. This section presents the methodology for shadow pricing foreign exchange and labor which was found relevant to this project.

FOREIGN EXCHANGE: The prices used for the financial analysis were the prevailing prices in Ghana in 1982. At that time, the official exchange rate was U.S. $1 = ¢2.75 Ghana cedis (Boakye-Dankwa 1982). However, according to information from the informal market, the exchange rate at that time was between 50-70 Ghana cedis for one U.S. dollar.

There is no doubt, therefore, that the domestic currency was highly overvalued, assuming that a significant amount of trade goes on in the informal market. On the basis of the information above, it was conservatively estimated that the cedis is overvalued (or is likely to be overvalued over the 20-year life of the project) by 50 percent. The method suggested by Gittinger (1982) was used as follows:

SER = OER [1 X Fx premium]
where
SER = shadow exchange rate
OER = official exchange rate
Fx premium = foreign exchange premium

The shadow exchange rate calculated using this formula turned out to be U.S. $1 = ¢4.125 Ghana cedis; i.e., SER = 2.75 [1 + 0.50] = 4.125.

This shadow exchange rate was then used to value all the imported inputs. The typical approach of estimating the shadow exchange rate is usually not as simple as presented here. One of the earliest efforts to calculate the shadow price of foreign

exchange was that of Bruno (1965) utilized later by Ward (1976) and described in Hitzhusen et al.(1984). It was not possible to use this approach in the Subri case because of a lack of adequate data.

SHADOW WAGE RATE: The wage rates used in the financial analysis of this project were those obtained from a visit to the project area in Ghana by Boakye-Dankwa (1982). It was observed that the project wage rates were higher than the government wage rates to enable the project to attract the required number of skilled personnel. For the purpose of the economic analysis, the following categories of workers were identified:

1. Professionals (e.g., executives).
2. Skilled workers (e.g., mechanics).
3. Semi-skilled workers.
4. Unskilled workers (laborers).

Because of the relative scarcity of professionals and skilled workers, it was assumed that they earn salaries that reflect their true value marginal product and as such no adjustments were necessary (Gittinger 1982).

Therefore, it was only necessary to estimate a shadow wage rate for the semiskilled and unskilled workers. The unemployment rate among these categories of workers is about 15-20 percent (Earl 1981). However, the actual rate of unemployment among these categories of workers in Ghana is probably higher than this, given the worsening economic situation there. The method utilized by the World Bank was used in this study because of the ease of computation, data availability, and the special situation in Ghana. The World Bank values labor according to the principle of opportunity costs; that is, giving it the value (in domestic currency) of output foregone by taking it away from its previous employment and utilizing it on the project (Gittinger 1982). In determining the opportunity cost, the extent of unemployment is considered. Where unemployment is "serious," family labor is usually valued at zero and hired labor is valued at some fraction of the market wage. Where unemployment is not "serious," hired labor is usually valued at the market wage and family labor is valued at anything from zero to the market wage, depending on the situation.

In the estimation of shadow wages for the Subri Reforestation Project, the seasonal pattern of agricultural employment was used as a basis for calculating the opportunity cost of labor. During peak season in Ghana, virtually every agricultural laborer can find a job and the marginal value product of agricultural labor is definitely not zero. The peak season in Ghana is about 5 months during which agricultural labor is paid 8 cedis per day (Boakye-Dankwa 1982). On this basis, the shadow wage rate can be calculated from the relationship:

$$SWR = n \times W$$

where
SWR = shadow wage rate
W = daily market wage during the peak season
n = number of days in peak season per year
therefore,
SWR = 120 x 8 = ¢960.

On the assumption that both semiskilled and unskilled laborers could be grouped together, the amount of ¢960 was used as the yearly shadow wage rate in the economic analysis. This method was considered most appropriate because of the economic situation in Ghana. However, because of lack of sufficient data, it was not possible to separate clearly the semiskilled from the unskilled workers. A better estimate of the shadow wage rate can be obtained if accurate data can be made available on the exact number and type of workers employed in the project.

Results of Economic Analysis (Pulp)

Prices of imported inputs were adjusted on the basis of the shadow exchange rate (SER) derived, and a separate time series of benefits and costs was generated to show the effect of the shadow exchange rate on the profitability of the project from the societal point of view. The net present value (NPV) and internal rate of return (IRR) using the SER give unfavorable results. The NPV is -¢10,611,071 while the IRR is 1.9 percent. Thus, by both criteria, this option is not profitable.

Similarly, adjustments were made on wages of semiskilled and unskilled workers based on the shadow wage rate, and a separate time series of benefits and costs was derived. The results are improved with labor shadow pricing. The NPV is ¢9,559,789 and the IRR is 20.2 percent compared with the discount rate of 10 percent used. Thus, the project is attractive after shadow pricing labor. Finally, the combined effect of both the shadow exchange rate and the shadow wage rate on the profitability of the project is estimated in a separate time series of benefits and costs. With these adjustments, the project is marginally feasible. The NPV is ¢267,441 and the IRR is 10.2 percent.

ANALYSIS OF THE FUELWOOD SCENARIO

Financial Analysis

The financial analysis of the fuelwood option is presented here. The framework for the analysis and a detailed cost breakdown are presented in Hitzhusen et al. (1984). The species concerned is *Cassia siamea* on a 5-year cycle with 500 hectares per cycle. Trees will be cut at age 4, and a 20-year project life is assumed.

The financial benefit stream of the project includes sales of products from the site conversion operations. The products are fuelwood sold at ¢50/m^3, wood for charcoal at ¢60/m^3, logs for timber at ¢100/m^3 for lesser known species and at ¢140/m^3 for

export grades, sawn timber at ¢1500/m³ for local market and at ¢600/m³ for export market, and charcoal (bulk) at ¢1500/ton. These contribute a total of ¢9.237 million in year 1, ¢27.711 million in year 2 and ¢30.790 million each in years 3-5. The other component of the benefit stream is the sale from the harvest of the *Cassia* species from years 6-20. A constant average yield of 160 m³ per annum is assumed, and a fuelwood price of ¢53 is used in calculating the fuelwood value.

Financial Analysis Results (Fuelwood)

The project will sustain two consecutive years of net losses amounting to ¢22.756 million in year 1 and ¢1.760 million in the second year after which revenues exceed costs. A net loss of ¢1.223 is also incurred in year 9. These losses result from the high capital expenditure of ¢17.976 million during the initial year, and capital replacement costs of ¢2.885 in year 9. Starting in year 1, revenues gradually build up from ¢9.237 million to a peak of ¢30.792 million for three consecutive periods (years 3-5). The subsequent decline down to ¢8.972 million in years 6-20 is a consequence of diminished revenues from site conversion operations. Stabilization of revenues from years 6-20 results from an assumed constant yield from the fuelwood plantation.

The estimated internal financial rate of return is 30.4 percent. Since it is derived from constant prices, it compares very favorably with the assumed 10 percent cost of borrowing for such investments. The financial rate of return is high because of the early inflows of revenue arising from the successful Subri Conversion Technique. These revenues arise from the sale of timber, lumber, charcoal, and fuelwood. The discounted net present value is ¢25.680 million. Thus, the project is viable under both criteria.

Economic Analysis Results (Fuelwood)

Economic analysis for this scenario follows the pattern outlined for that of the pulpwood scenario. Thus, in estimating the return from this scenario, it was assumed that the cedi is overvalued by 50 percent which is thought to reflect more accurately its real exchange value or its likely value over the project life. Similarly, unskilled and semiskilled workers were grouped together, and the shadow wage rate derived earlier for the first scenario was applied. The results of shadow pricing labor and foreign exchange costs are shown, respectively, in Appendices A-1 and A-2. With respect to labor shadow pricing, the discounted net present value increases to ¢40,290,000 and the IRR similarly rises to 40.1 percent. Note also that only the initial year shows a negative net benefit. Thus, with labor shadow pricing, the attractiveness of this scenario is further increased.

With foreign exchange shadow pricing, this scenario is still acceptable. The IRR is now 21.4 percent compared to a discount rate of 10 percent. The discounted net present value is ¢15,120,000, and four years of negative net benefits emerge.

Finally, the combined effect of shadow pricing both labor and foreign exchange is depicted in Appendix A-3. It is quite obvious that the positive effect of labor shadow

pricing is greater than the negative effect of shadow pricing foreign exchange. The project is still attractive with an IRR of 30.6 percent and a discounted net present value of ¢30,600,000.

COMPARISON OF PULP AND FUELWOOD SCENARIO RESULTS

The summary of the financial and economic analysis of the pulp and fuelwood scenarios is shown in Table 6.1. For the financial analysis, the fuelwood option is more attractive under the two decision criteria chosen (i.e., the NPV and IRR). The NPV for the fuelwood option is ¢25,680,000 while that for the pulp is -¢6,625,647. Similarly, the IRR is 30.4 percent and 4.3 percent for the fuelwood and pulp, respectively. The differences in the financial results stem from the fact that the pulp scenario is more capital intensive, thus giving rise to higher capital costs. Also, there is increased utilization of the sawmilling operations which results in increased charcoal sales.

The economic analysis results also favor the fuelwood option. The NPV and IRR with labor shadow pricing are higher for the fuelwood scenario, although the more labor intensive pulp option makes some relative gain in feasibility. With the shadow exchange rate, the substitution-oriented pulp scenario is the least attractive option with a negative NPV and a 1.9 percent IRR. The figures for the NPV and IRR for the fuelwood option are ¢15,120,000 and 21.4 percent, respectively. Lastly, the combined effect of both labor shadow pricing and the shadow exchange rate still favors the fuelwood option. Using the IRR, for example, the pulp scenario is just marginal, 10.2 percent, while the IRR for the fuelwood option is 30.6 percent.

TABLE 6.1

Summary of Financial and Economic Analysis Results of Pulpwood and Fuelwood Scenarios

	Decision Criteria	Pulpwood Scenario	Fuelwood Scenario
1.	Discounted Financial Net Present Value (DNPV)	-¢6,625,647	¢25,680,000
2.	Financial Internal Rate of Return (IRR)	4.3%	30.4%
3.	DNPV with Labor Shadow Pricing	¢9,559,787	¢40,290,000
4.	IRR with Labor Shadow Pricing	20.2%	40.1%
5.	DNPV with Shadow Exchange Rate	-¢10,611,071	¢15,120,000
6.	IRR with Shadow Exchange Rate	1.9%	21.4%
7.	DNPV with Shadow Pricing of Labor and Foreign Exchange	¢267,441	¢30,600,000
8.	IRR with Shadow Pricing of Labor and Foreign Exchange	10.2%	30.6%

CONCLUSIONS

The results from analyses of the pulp and fuelwood scenarios are preliminary, and as such any conclusions drawn should be treated with caution. There is the need for further extension of this study to include several of the issues that were not addressed due to time and data constraints.

A complete economic analysis of a project like the Subri Forestry Project should include an assessment of any technological externalities as well as physical environmental impacts that would affect producers and consumers of some of the inputs and products of the project. However, while environmental effects like flooding and erosion are critical in some reforestation projects, available information suggests that these are not critical in the Subri project area where the aim is to replant exploited areas in the reserve.

The analysis also did not include the benefits from intercropping plantain with the tree species. It is estimated that some 75,000 bunches of plantain equivalent to about 675 tons will be produced annually. This obviously will enhance the social welfare of the local people. However, there is a valuation problem in pricing the plantain output. For similar reasons, mainly lack of time and data, the value of tree standards left was not included in the analysis (Masson 1981).

On the cost side, a zero opportunity cost for land was assumed. There may be reasons to shadow price land appropriately (Roetzer 1982). A further examination of depreciation of machinery, equipment, and buildings, as well as applying contingency allowances to reflect relative price changes, would also be worthwhile.

An important problem not addressed is valuing fuelwood. Since much fuelwood is not traded in the market and/or is cut (usually illegally) from public lands, the prices used may not adequately reflect the full opportunity cost of fuelwood. Thus, there may be a need to shadow price fuelwood (African Development Bank 1982), but this would only further increase the relative feasibility of the fuelwood option.

Import substitution considerations were also omitted particularly, with respect to the pulp option since it is intended to substitute for imported paper. Application of the Bruno criterion, via the domestic resource cost, would be worthwhile. Also, in applying the shadow exchange rate to the imported items, exported items were excluded. These would also need to be shadow priced. Again, there is the need to reconsider the SER in view of the change in official exchange rate in Ghana from $1 = ¢2.75 to $1 = ¢30. With respect to labor, there is also the need to derive different shadow wage rates for unskilled and semiskilled labor.

Lastly, a project like this especially in the current Ghanaian situation is likely to be faced with uncertainty. As such, sensitivity analysis should be done to see how the results on key variables change given different assumptions. For example, yield variation has to be considered due to yield reduction by poaching or tree mortality. Also, modifying the price assumptions by examining the effect of different coppicing and harvesting times may be an important extension of the analyses. Sensitivity analysis of the SER and SWR may also be worthwhile. The handling of inflation and

the choice of the discount rate, given the economy in Ghana, may need to be examined further. This calls for examining other criteria like the breakeven analysis (FAO 1979).

This preliminary study does emphasize the difficulty in doing empirical research in forestry. This is particularly true in a country like Ghana where current political and economic conditions have stymied many economic activities and stimulated a "brain drain" from the country.

Despite the limitations, this case study is an example of how economic valuation techniques can provide additional information to decision makers on various options available. The separate options evaluated are all possible components of a forest resource management program. Additional analysis to examine several of the issues highlighted has been done by a group of graduate students at the Ohio State University and includes the following: (1) deriving a shadow land value to incorporate into the economic analysis, since there is evidence of a positive opportunity cost of land; (2) estimating the net foreign exchange savings by substituting the pulp produced for imported paper; (3) shadow pricing fuelwood, since the price used may under or overvalue fuelwood, depending on end use and the impact of fuelwood on the market concentration and environmental impacts; (4) doing a sensitivity analysis on the key variables to see their effect on project outcome. The results are in an unpublished draft (Miranda et al. 1985) and are generally supportive of the foregoing findings on the pulp and fuelwood options.

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TABLE A-1

Subri Forestry Project—Fuelwood Scenario Stream of Costs and Benefits with Labor Shadow Pricing (in million cedis)

Years	0	1	2	3	4	5	6	7	8	9
Capital Costs	17.976			2.885						2.885
Operating Cost	4.167	8.953	13.788	14.502	15.114	7.044	6.785	6.404	6.267	5.896
Total Cost	22.143	8.953	13.788	14.502	17.999	7.044	6.785	6.404	6.267	8.781
Total Benefits		9.237	27.711	30.790	30.790	30.790	8.972	8.972	8.972	8.972
Net Benefits	-22.143	0.284	13.923	16.288	12.791	23.746	2.187	2.568	2.705	0.191

Years	10	11	12	13	14	15	16	17	18	19	20
Capital Costs					2.885						
Operating Cost	5.737	5.403	5.069	4.735	4.402	4.068	4.068	4.068	4.068	4.068	4.068
Total Cost	5.737	5.403	5.069	4.735	7.287	4.068	4.068	4.068	4.068	4.068	4.068
Total Benefits	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972
Net Benefits	3.235	3.569	3.903	4.237	1.685	4.904	4.904	4.904	4.904	4.904	4.904

DNPV = ¢40,290,000
IRR = 0.401

Source: Hitzhusen, et al., 1984.

TABLE A-2

Subri Forestry Project—Fuelwood Scenario Stream of Costs and Benefits with Foreign Exchange Shadow Pricing (in million cedis)

Years	0	1	2	3	4	5	6	7	8	9
Capital Costs	22.263				2.885				2.885	
Operating Cost	5.518	11.744	16.579	17.293	17.906	9.206	8.720	8.385	8.248	7.887
Total Cost	27.781	11.744	16.579	17.293	20.791	9.206	8.720	8.385	8.248	10.762
Total Benefits		9.237	27.711	30.790	30.790	30.790	8.972	8.972	8.972	8.972
Net Benefits	-27.781	-2.507	11.132	13.497	9.999	21.584	0.252	0.587	0.724	-1.790

Years	10	11	12	13	14	15	16	17	18	19	20
Capital Costs					2.885						
Operating Cost	7.718	7.384	7.050	6.726	6.383	6.049	6.049	6.049	6.049	6.049	6.049
Total Cost	7.718	7.384	7.050	6.716	9.268	6.049	6.049	6.049	6.049	6.049	6.049
Total Benefits	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.872	8.972	8.972	8.972
Net Benefits	1.254	1.588	1.922	2.256	-0.296	2.923	2.923	2.923	2.923	2.923	2.923

DNPV = 15,120,000
IRR = 0.214

Source: Hitzhusen, et al., 1984.

TABLE A-3

Subri Forestry Project—Fuelwood Scenario Stream of Costs and Benefits with Shadow Pricing of Labor and Foreign Exchange
(in million cedis)

Years	0	1	2	3	4	5	6	7	8	9
Capital Costs	22.263				2.885				2.885	
Operating Cost	4.905	9.700	14.535	15.249	15.862	7.792	7.306	6.971	6.834	6.463
Total Cost	27.168	9.700	14.535	15.249	18.747	5.592	7.306	6.971	6.834	9 348
Total Benefits		9.237	27.722	30.790	30.790	30.790	8.972	8.972	8.972	8.972
Net Benefits	27.168	0.463	13.176	15.541	12.043	22.998	1.666	2.001	2.138	-0.376

Years	10	11	12	13	14	15	16	17	18	19	20
Capital Costs					2.885						
Operating Cost	6.304	5.970	5.636	5.302	4.969	4.635	4.635	4.635	4.635	4.635	4 635
Total Cost	6.304	5.970	5.636	5.302	7.854	4.635	4.635	4.635	4.635	4.635	4.635
Total Benefits	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972	8.972
Net Benefits	2.668	3.002	3.336	3.670	1.118	4.337	4.337	4.337	4.337	4.337	4.337

DNPV = 30,600,000
IRR = 0.306

Source: Hitzhusen, et al., 1984.

CHAPTER 7.
FUEL ALCOHOL: A POTENTIAL AGRICULTURAL TRADE COMMODITY

Norman Rask

INTRODUCTION

Alcohol was an obvious fuel choice when commercialization of the automobile was being initiated at the turn of the century. Gasoline, however, soon became the preferred automotive fuel following discoveries of large reserves of petroleum and the subsequent decline in prices of petroleum products. Since then, there have been only a few sporadic uses of alcohol fuel. Some countries have turned to alcohol in times of gasoline shortage, while others have produced and used alcohol from surplus molasses. Only in the past decade, following a ten-fold increase in the price of petroleum has alcohol again become a serious substitute for petroleum products. This renewed interest is based on both economic and strategic considerations, and has stirred some controversy concerning the specific role alcohol will or should play as an alternative fuel. There have also been questions raised about use of agricultural resources and competition with food production if agriculture becomes a principal alcohol fuel supplier.

The impact of alcohol trade on world agriculture will depend on its capacity to respond to both food and fuel demands. This capacity may be greater than many anticipated a few years ago. Recent changes in international financial and commodity flows suggest that food trade demands may be less during the remainder of this decade and that alcohol production from sugar cane could be an important growth industry for agriculture. Experience with alcohol production and use on a commercial scale in several countries has demonstrated the technical feasibility and economic justification for alcohol as an alternative automotive fuel. Greatest economic returns, however, would come from use as an octane enhancer in mixtures with gasoline. This implies international trade in alcohol to reach the large automotive fuel markets of the industrialized countries.

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The following discussion of fuel alcohol as a trade commodity begins with a description of events in food, energy, and financial markets that have created a favorable economic environment for alcohol fuels. This is followed by discussion of costs of alcohol production and of the relative value of alcohol as a fuel. Policy considerations are explored in the final section.

FOOD, ENERGY, AND FINANCIAL MARKETS

Over the past decade there have been substantial changes in international financial and commodity flows. Petroleum price increases have contributed significantly to these changes. For most countries, petroleum imports have taken a greater percentage of foreign exchange earnings. At the same time, many oil-exporting countries, especially during the late 1970s, were unable to absorb the large increase in dollar earnings. These excess petro-dollar earnings were subsequently recycled through international financial markets. Developing countries have been burdened not only with high import costs for petroleum, but also with high debt loads, in part the result of expansive lending from recycled petro-dollars.

The availability of credit at first helped raise the level of world agricultural trade and the level of consumption of food in developing countries. However, in the early 1980s, the demand for foreign exchange earnings to service this debt at high interest rates resulted in reduced food demand and lowered trade in agricultural commodities. Consequently, most projections now call for adequate to over capacity in world agriculture in the near term.

This convergence of events in international food, energy, and financial markets has created a favorable environment for international trade in fuel alcohol. Further, an expansion in trade of fuel alcohol would have positive impacts on each of the above factors. It would increase agricultural growth in a sector where global productive capacity now exceeds projected demand. Second, by adding to total energy supplies, it would substitute partially for petroleum and thus delay and dampen future energy price increases. Third, it would improve balance of payments for developing countries through substitution of domestic alcohol for imported petroleum products as well as generate export receipts as is already happening in Brazil.

An international alcohol fuel market will have specific characteristics that require special policy considerations. The supply will likely come from a number of relatively small tropical countries (Brazil excepted), while the principal demand will be large industrial countries. This raises several issues. Alcohol production requires incountry policies regarding the production and use of alcohol. Also investment financing would need to be arranged for the producing countries.

Each producing country will have a unique set of resource situations related to available land, alternative land use opportunities, domestic energy needs, and other considerations that would affect costs and quantity of alcohol produced as well as the allocation between domestic use and export. For example, many sugar cane

producing countries are now facing an international sugar market where prices are below costs of production. A guaranteed alcohol market could be an attractive alternative to sugar in these situations. Other countries, with quota access to protected sugar markets in the United States or European Economic Community (EEC), may find sugar exports a better alternative than alcohol for this portion of their market. Finally, capital costs will vary depending on the availability of a local capital goods industry. Brazil, for example, with well-developed capital industry, would have 25-50 percent lower investment costs than a country that had to import all equipment (World Bank 1980).

THE MAJOR ISSUES

The concept of a significant international fuel alcohol market raises a series of questions that have not been studied adequately. Most recent research has addressed the feasibility of using alcohol as a fuel substitute for petroleum within the context of a specific country. These studies have focused on several key issues. Often, there is a reluctance to contemplate a major use of agricultural resources for non-food purposes. For many countries, this will always be a concern. However, from a global viewpoint, it was a more important question during the late 1970s than it is today. For the 1980s it will probably not be as serious an economic issue. Also, with sugar cane produced under plantation sustems, there are related concerns of concentrated land use and ownership and seasonal labor employment in the vicinity of alcohol distilleries.

Cost of production, relative to value of gasoline, has been cited as a negative feature of alcohol fuels. The U.S. corn-ethanol and the Brazilian-sugar-cane-ethanol systems are the most frequently studied. The U.S. case is clearly not economically viable and requires massive subsidies at current petroleum prices. In the Brazil case, most studies have been based on the early years of the Programa Nacional do Alcool (PROALCOOL) and show negative to slightly positive returns, depending on the assumptions chosen. However, recent productivity improvements, new technologies for continuous fermentation, efficient and alternative uses for bagasse, and more efficient land use through rotation and intercropping have lowered current costs of production, with excellent prospects for further economies.

In comparisons of alcohol-gasoline cost levels, alcohol is generally viewed as equal to gasoline in alcohol-gasoline mixtures and some 80-85 percent of gasoline value when used as a pure fuel. The comparisons, however, ignore the vast high octane gasoline markets that could be made available through trade. While estimates vary, alcohol as an octane enhancer could command a 20-30 percent premium over gasoline prices, a situation that would make alcohol from sugar cane an attractive free market commodity under most cost levels reported in the literature.

Future petroleum supply is subject to both discovery and political uncertainties, and demand has not fully adjusted to recent price changes. Thus, while future gasoline

prices are certainly important to the economic viability of alcohol fuels, they remain an uncertain variable. We do know that the historic link between economic growth and energy use had been broken as higher energy prices have triggered conservation and more efficient energy-using technologies. These changes, however, have not fully worked themselves through the industrialized economies. Also, the shock of higher energy prices had slowed economic growth. Thus, world demand for petroleum is currently some 20 percent less than in 1980. On the supply side, there is a 10 billion barrel per day or 20 percent excess capacity, principally in the OPEC countries. In looking ahead, the two principal world oil producers, the USSR and the USA, are expected to show declining production during the 1980s, while new areas will show marginal increases. Most world supply demand projections point toward a firming of demand against a stable to declining supply of oil at the end of the decade, with constant to declining real prices over the next 3-5 years and a gradual increase in real prices by 1990 (USDOE 1982).

It is generally felt that real prices will be substantially above present levels in the 1990s. While there are many uncertainties in projecting supply, demand, and price for petroleum, it appears likely that the price situation for alcohol as an alternative fuel will be increasingly more positive in the future.

Alcohol fuels policy in the importing countries is the final key issue. With lowered demand and excess supply of petroleum, it is difficult to interest major companies in alternative fuels. For example, large integrated petroleum companies, with oil refineries operating at less than 75 percent of capacity, are hesitant to make the necessary capital alterations at the refineries in order to optimize the use of alcohol as an octane enhancer. Thus, in the U.S. fuel market, for example, all alcohol-gasoline blends are sold by small independent gasoline distributors. This restricts the market for alcohol. Further, in the United States, alcohol production and use policies and import tariffs combine to economically restrict alcohol use to a few states only. The policies effectively eliminate a major part of the potential market for alcohol imports and create a high level of uncertainty for both producers and consumers. Reformulation of these policies is a necessary prerequisite to the creation of a viable international market for fuel alcohol. The above issues are explored in greater detail below.

THE FOOD-FUEL DEBATE

The oil crisis of the late 1970s, coincided with a period of rapidly increasing demand for agricultural commodities. In this setting, alcohol production was viewed as a threat to the availability of future food supplies. However, world agriculture demonstrated a greater than anticipated supply response to the increased prices. Also, the return of good harvests in the early 1980s, and a concurrent fall-off in effective demand caused by world recession and high debt loads, have contributed to the excess supply situation. As a result, the agricultural community is once more aggressively looking for alternative market outlets.

Projections of future food supply and demand are uncertain. However, several factors point to a continuation of historic supply growth, with demand growth somewhat slower than that experienced over the past 15 years. USDA estimates that demand in developed countries such as the United States will be quite flat, growing roughly in line with population increases, since income-related growth in demand has been largely saturated (Lee 1983). Internationally, less credit will be available to finance food imports, many debtor nations will need scarce foreign exchange to reduced debt obligations, and recovery from global recession will be slow: "...hence; income and demand will increase slowly." Based on these considerations, Lee projects a "strong tendency toward excess supply" for the 1980s.

Obviously, specific countries will deviate from this general pattern, depending on a series of individual resource situations. An earlier paper (Rask 1980), developed a country classification based on self-sufficiency ratios for agriculture and energy production, arguing that countries with deficit energy (oil importing) and surplus agriculture (food exporting) would be early candidates for alcohol production programs. A large number of the countries identified as likely candidates for alcohol programs are located in the Western Hemisphere.

A study by Filho et al. (1981) estimated the substitution effect of increased sugar cane plantings on the area of other crops. The location of the study was north central Sao Paulo, Brazil, an area of very intensive crop cultivation, with one-third to one-half of the cropped area in sugar cane in 1978. The period of the study was 1974-79. During this 6-year period, the area in sugar cane increased by 48 percent. The majority (65 percent) of the increase resulted from conversion of pasture land to sugar cane land. Fifteen percent came from corn land and 7 percent from land devoted to export crops. During this same period, the area planted to coffee, soybeans, and oranges also increased in this region. According to IEA (1983), labor requirements per hectare for sugar cane in this area are about 18 days per year, whereas for corn and pasture they are 4 days and 1 day, respectively. Thus, the change in land use to sugar cane resulted in a dramatic increase in labor employment on farms in the region.

THE ECONOMICS OF ALCOHOL PRODUCTION AND USE

Economic studies of fuel alcohol production and use have focused principally on Brazil and the United States where substantial commercialization of ethanol as a motor fuel has occurred. In both cases, the price and, to some extent, costs of production of alcohol are determined in controlled markets. Attempts to sort out the various subsidies, incentives, and other economic distortions have given rise to varying cost estimates by researchers, even when considering the same base data. Costs of production estimates in Brazil, based on actual distillery data form the late 1970s and early 1980s range from $.23-$.30 per liter (ASTEL 1983, Barzelay and Pearsen 1982, Borges 1982).

I have attempted to apply somewhat similar methodology to 1981-82 alcohol production cost data (IAA 1983), adjusting currency values to reflect an early 1984 situation. This yields a cost for anhydrous ethanol of approximately $.21 per liter for plants annexed to sugar mills and $.22 for autonomous plants.

Recent technological innovations in Brazilian distilleries should result in increased efficiencies and thus lower costs. One of the more promising improvements is continuous fermentation technology which will decrease effluent disposal costs and is expected to increase alcohol yield by about 7 percent. Total cost savings per liter of alcohol produced under continuous fermentation are estimated at about 10 percent. A second area for efficiency improvement is the use of high-pressure boilers which will reduce the need for bagasse as a source of process heat, allowing increased returns from by-product use of the bagasse.

Finally, short season rotation crops, and limited intertilling of crops—practices which are becoming common in the central Sao Paulo area—increase year-round employment of labor, reduce some tillage and chemical production costs for sugar cane, and provide additional sources of revenue. I have estimated the potential net revenue gains from by-product bagasse sales and rotation crops to approximate 7 percent of alcohol production costs in the Sao Paulo context. Thus, the potential for sizeable cost efficiencies is evident in new technologies now being adopted in Brazil.

In addition to domestic production costs, an export-oriented alcohol industry must consider storage, handling, and transportation costs to final market. For Brazilian alcohol currently shipped to the U.S. fuel market, these costs are about $.03-$.04 per liter. Thus, total economic costs for anhydrous alcohol produced in Brazil and transported to a foreign market probably approximate $.25-$.30 per liter.

The cost situation in the United States is considerably less favorable. Estimates range from $.35-$.48 per liter as the price of corn varies from $2.50-$4.00 per bushel (Gill and Prato 1983).

The opportunity cost of alcohol is determined by its use value relative to gasoline. In gasoline-alcohol mixtures of up to 10 percent alcohol, the value of alcohol is determined more by its octane-enhancing characteristics than by its energy potential. Jawetz (1983) estimates that a 10 percent mixture will raise the octane level by 3 points. In the United States, some fuel wholesalers follow a practice of mixing 45 percent regular gasoline, 45 percent premium gasoline, and 10 percent ethanol. The resulting mixture is sold as a premium fuel with a net price increase of about $.007 per liter. This increased value is attributed to one-tenth of a liter of alcohol. Thus, ethanol as an octane enhancer would be worth $.07 per liter more than gasoline. Additional savings may be possible if the ethanol is integrated into the total petroleum refinery process.

Wholesale unleaded regular gasoline, based on $29 per barrel oil is currently selling in the United States for about $.23 per liter. Adding the octane enhancement value would indicate a potential market price for alcohol of about $.30 per liter. Even if one allows for some margin of error in the cost estimates, it still appears to be an

attractive market potential for Brazilian alcohol under current production technologies. In another study, I have estimated a breakeven price of $.29 per liter for Caribbean-based alcohol landed at U.S. ports (Rask 1983).

Additional study of both alcohol production cost and opportunity cost are necessary. However, the initial work reported above would indicate that there is marginal economic justification for trade in alcohol and that cost-reducing technologies and higher real prices for petroleum in the late 1980s and 1990s will further improve the economic prospects for alcohol trade. A positive cost-return situation, however, is not sufficient to initiate trade. These are substantital policy problems and needs that must be resolved.

POLICIES TO INITIATE AND FACILITATE TRADE

The key policy issues for alcohol-producing countries are market guarantees, price protection, and investment financing. This follows from the nature of the proposed alcohol market. As noted earlier, the supply would come from many smaller countries, while demand would be concentrated primarily in several large countries. Further, the free market price of alcohol would be tied to price of petroleum, which is subject to considerable uncertainty and political influence. Thus, in order to initiate the supply of alcohol, it would be desirable for the large importing countries to provide a measure of security through a long-term market guarantee. This guarantee would include an agreement to accept a specified annual level of alcohol imports, and would provide a minimum purchase price. Alternatively, bilateral trade agreements could be established, in which alcohol-exporting countries would agree to accept some level of imports in exchange for guaranteed alcohol sales.

The principal importing market would probably be the United States, where the automotive fuel market currently consumes almost 400 billion liters of gasoline annually. In 1983, the United States used about 1.5 billion liters of alcohol in 10 percent mixture with gasoline. At this 10 percent level of concentration, the potential alcohol market would be 40 billion liters. However, U.S. production and use policies have seriously limited the market for fuel alcohol. These policies would need to be changed. U.S. policies were initiated to stimulate development of a domestic alcohol industry. As noted earlier, this is a very high-cost industry and must be subsidized. Basically, the subsidy is a federal tax exemption of $.13 per liter of alcohol on final sales of gasoline-alcohol mixtures. The federal subsidy is not sufficient to cover high alcohol production costs. Therefore, selected states also provide tax exemptions for an overall average federal-state tax exemption of $.21 per liter. This results in an alcohol price of $.42-$.45 per liter.

This has two market effects. First, nonfuel uses of alcohol are excluded by the artificially high prices. Second, the price of alcohol is too high to compete with gasoline in states that do not provide state tax exemptions. The result has been a concentration of almost half of the alcohol sales in just two states (Iowa and

California) which have high state subsidies. Most states have little or no alcohol sales. Finally, a $.14 per liter duty is assessed against imported alcohol.

These subsidies have undergone frequent changes, a situation that has left potential suppliers and users wary of making investment decisions either to produce alcohol for the U.S. market, or within that market, to optimize its use through integration at the refinery level. The suggested policy change is to use a producer subsidy rather than a tax exemption to support the U.S. alcohol producers. This would allow the alcohol market price to drop to its opportunity cost level and would make alcohol available economically as a fuel substitute in all states. At this lower price, alcohol would also be competitive in other petro-chemical uses. Potentially, this would provide the necessary market conditions for a large expansion in demand. Import duties could be removed, and price signals to potential import suppliers would be more realistic. Finally, in order to generate the international supply response, the United States would initislly have to provide the market guarantees noted above. Without these policy changes [illegible] alcohol market, it is unlikely that a significant level of int[illegible] alcohol trade would be possible.

CONCLUSIONS

A convergence of events in international food, energy, and financial markets has created a favorable environment for international trade in alcohol. Costs of production from sugar cane in tropical countries appear to be favorable for supplying alcohol to an octane enhancement market. New technologies promise to reduce these costs further, while petroleum prices are expected to increase in real terms by the end of the decade. Alcohol policies that provide some level of market and price guarantees are necessary to stimulate an initial supply response. Substantial changes are needed in U.S. alcohol production and use policy if the large U.S. fuel market is to be opened to international alcohol suppliers.

Significant questions need further study. They include the following: the use of land resources for nonfood purposes; the actual and potential production cost and use value of alcohol; country level differences in the availability of resources and in technical and cost coefficients; and the design of appropriate alcohol production and use policies to facilitate the emergence of alcohol as a viable agricultural trade commodity.

The potential international fuel alcohol market is very large and the opportunities and implications for agriculture are significant. We need to make these issues part of our research agenda.

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CHAPTER 8.
HYDROPOWER IMPACTS OF SOIL EROSION: PRIVATE AND SOCIAL COST-BENEFIT PERSPECTIVES

Fredrick Hitzhusen
Robert Macgregor
Douglas Southgate
Alberto Veloz

INTRODUCTION

Soil erosion and resulting sedimentation problems are major concerns throughout the world. This chapter is primarily concerned with developing a comparative private and social cost-benefit perspective for sedimentation management in developing countries. A case application of this methodology in the Valdesia Watershed and Reservoir in the Dominican Republic evaluates both the on-site and off-site (downstream hydropower) impacts of implementing soil-conserving practices in the watershed. Specific policy implications for improved sedimentation management are developed from the Valdesia case analysis.

Dregne (1982) evaluated the general state of land degradation worldwide. Although Dregne's assessment focuses on the effect of land degradation on future food production, the degraded areas he identifies are areas where hydropower, flood control, and irrigation reservoirs would be at high risk of excessively rapid sedimentation. Figure 8.1 gives a generalized regional perspective on the degree of land degradation worldwide. Much of southwest Asia; large areas of China, India, and Southeast Asia; northern Africa; Central America; and Mexico suffer from severe land degradation.

The off-site impacts of land degradation or soil erosion are illustrated in the reservoir sedimentation literature by such authors as Robinson (1981), Das (1977), and Allen (1972). The severe effect that sedimentation can have on the economic life and power production capacity of a reservoir is dramatically illustrated by the wide

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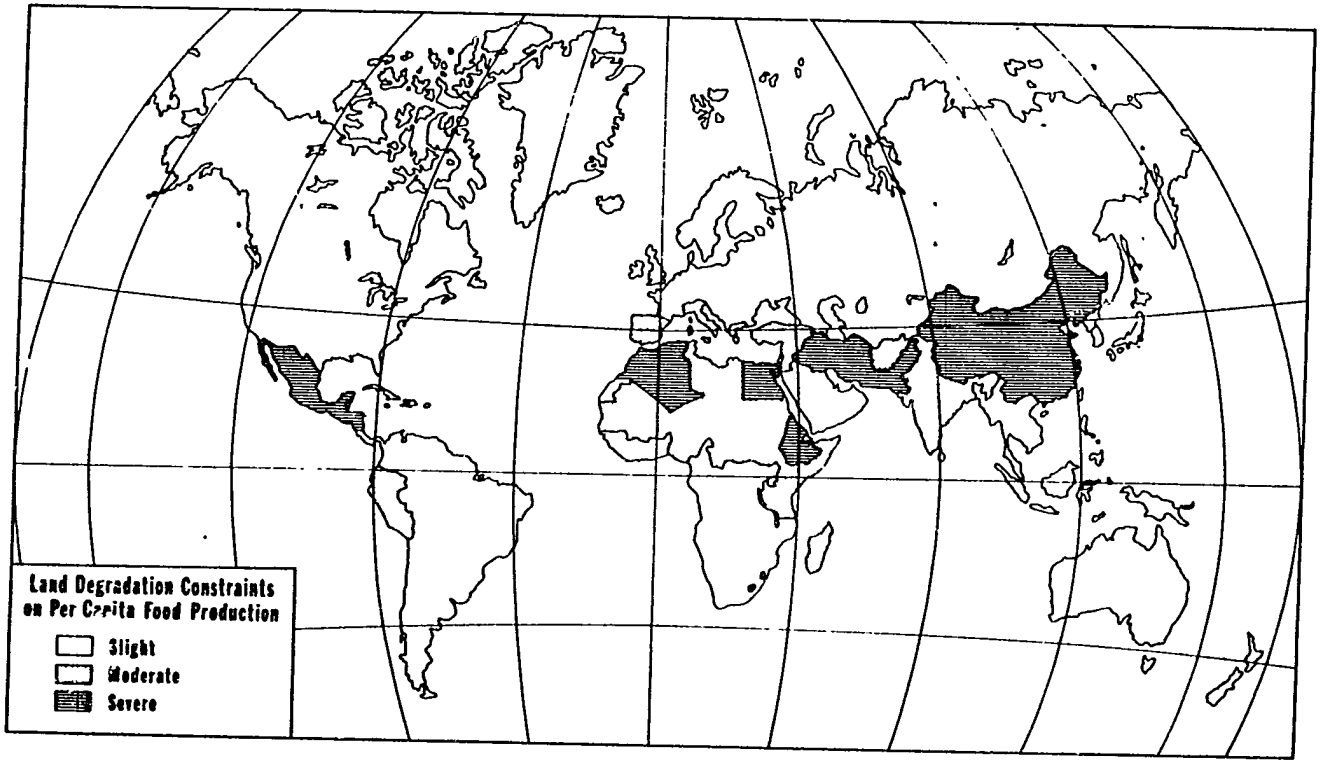
FIGURE 8.1 ***Severity of current land degradation contsraints on per capita food production, by continent.***



Source: Dregne, Harold E. 1982. *Impact of land degradation on future world food production,* E-RS-677, Washington, D.C.: U.S. Department of Agriculture.

disparity between design expectations and performance of the Sanmen Dam on the Yellow River in China reported by Robinson (1981).

The Yellow River has the highest sediment load of any river in the world. Sediment concentration averages 40 kilograms/cubic meter (kg/m^3) and reaches 700 kg/m^3 in the middle sections of the river. In downstream reaches, riverbed sediment deposition raises the bed 5 to 30 centimeters per year and in some places the riverbed is diked to 10 meters above the surrounding land. The Sanmen Gorge Dam was finished in 1960. It had a 98-meter height and design storage of 33 x 10^9 cubic meters. The Soviet design engineers expected that 60 percent of a sediment load of 1.4 x 10^9 metric tons/year would be captured by the dam. Instead, the actual sediment load has been closer to 1.9 x 10^9 metric tons annually, and the dam has experienced about 90 percent capture. The Chinese use continuous sluicing of sediments to hold deposition to 0.4 x 10^9 metric tons/year, but power and water storage capacities are seriously compromised and deteriorating. Expected total useful life of the dam, even with this continuous sluicing effort, has fallen to only 27 years, versus the original 55 years, due to the unexpectedly high rate of sediment accumulation. This experience is by no means restricted to Asia (Rapp 1977, Allen 1972) nor solely to developing countries (Linsley and Franzini 1979). The repercussions for economic analysis of proposed water resource projects, particularly hydroelectric power, are profound.

Table 8.1 summarizes regional hydroelectric potential and recent installed capacity and output for the world. The subregion data illustrate the large remaining undeveloped potential of hydroelectric power in the developing world, particularly Asia, Africa, and South America. Among the major world regions, Asia ranks second in current hydroelectric production and first in potential installable capacity. China represents one-half of Asia's total potential. In many cases, the hydroelectric potential of each country far exceeds the total recent production from all sources (United Nations Statistical Office 1981, World Energy Conference 1974).

In the long term, it is reasonable to expect a continued rise in the price of fossil fuels, including those used for generating electric power. The rising price of producing thermoelectric power can be expected to promote the continued development of renewable energy sources. The potential contribution of hydroelectric power to the energy budgets of Third World countries in the coming decades is tremendous; many countries are already highly dependent on hydropower for their electricity, and this can be expected to be increasingly true in the future. Concurrent with the growing demand for electricity is an increasing need for reliable water supplies for irrigation and for municipal and industrial uses. Projections of water demand suggest that it will increase by between 2.25 and 8 times between 1975 and 2000 (Council on Environmental Quality 1980). Finally, although hydroelectric power is widely viewed as a renewable resource, reservoir sites might be viewed as a unique, nonrenewable resource; when such a site is incapacitated, it is very costly to restore.

Clearly, any threat to the longevity of existing and future water resource developments could have serious repercussions and warrants careful evaluation and planning.

TABLE 8.1

Regional Summary of Hydroelectric Power Potential and Recent Actual Capacity and Output

	Installed and Installable		Recent Production	
	MW[1]	TJ[1]	MW[1]	TJ[1]
ASIA	689,204	9,513,575	47,118	714,357
East	339,146	4,835,549	14,752	198,938
Japan	49,592	468,014	19,897	296,172
Middle South	108,683	1,626,113	8,664	165,240
Southeast	173,663	2,310,440	2,665	39,899
Southwest	18,120	273,460	1,234	14,108
AFRICA	437,104	7,271,754	8,154	108,594
Western	53,222	802,213	1,579	18,893
Eastern	140,080	2,402,162	2,201	43,053
Middle	208,064	3,680,638	1,104	17,642
Northern	25,764	291,348	3,090	26,316
Southern	9,974	95,393	180	2,700
SOUTH AMERICA	288,289	5,893,312	18,773	335,180
Tropical	215,877	4,744,566	14,670	290,759
Temperate	72,412	1,148,746	4,103	44,421
NORTH AMERICA	330,455	5,356,250	90,210	1,632,002
United States & Canada	290,209	4,581,753	85,905	1,565,820
Middle America	37,846	731,297	4,109	64,065
Caribbean	2,400	43,200	196	2,117
OCEANIA	36,515	727,456	7,609	104,030
WORLD TOTAL	2,265,974	35,304,871	307,362	4,713,302

[1]TJ = Terajoules, MW = Megawatts
TJ x 23.2 = MT oil equivalent
TJ x 2.78 x 10^5 = KWH = Kilowatt-hours

Source: Adapted from Dunkerley, J., Ramsay, W., Gordon, L., and Cecelski, E. 1981. *Energy strategies for developing nations.* Resources for the Future, Johns Hopkins University Press, Baltimore, Maryland, pp. 159-62.

The primary and most immediate threat to hydroelectric and other water storage projects is sedimentation. A major cause is excessive erosion from watershed overuse or misuse. The general pattern of heavy land use leading to high erosion rates results from a combination of traditional shifting agriculture and population growth. In reservoir watersheds, this pattern may be preexisting, or the reservoir project may provide the access route for transient farmers into a previously relatively undisturbed area. Another contributor to watershed erosion and sedimentation is deforestation.

This may initially be by large-scale legal (or illegal) logging, but a deforested state is often maintained by subsequent agricultural use including, in many areas, extensive livestock grazing. Other important contributors to reservoir sedimentation include streambank cutting and what Sanches (1979) calls "civil engineering erosion" from improper location, construction, and maintenance of roads, culverts, bridges, and channels. The following outline illustrates the upstream and reservoir site options for the management of sedimentation:

I. Upstream Options for Reservoir and Sedimentation Management
   A. Soil-conserving practices in watershed for sheet and rill erosion; e.g., cover crops, contour farming, strip cropping, terracing, reduced tillage and compaction.
   B. Relocation of people from the most erosion prone areas in the watershed.
   C. Checking dams for gully erosion.
   D. Measures to reduce streambank erosion/cutting; e.g., trees and other vegetation cover and facing of stone, concrete, sand bags, etc.
   E. Improved road, culvert, bridge, and channel location, construction, and maintenance.

II. Reservoir Site Options
   A. Trees and other vegetation cover to stabilize reservoir bank.
   B. Discharge of some sediment through sluice gates.
   C. Physical removal of sediment deposits; e.g., hydraulic or mechanical dredge, and drainage combined with earthmoving equipment.

It is usually much more feasible and less costly to keep sediment out of a reservoir than to cope with it after it gets there (Allen 1972, Glymph 1973, Davis 1969). Thus, the focus of the following conceptual section and the Valdesia case application is on watershed erosion control.

A SOCIAL COST-BENEFIT PERSPECTIVE

CONCEPTUAL MODEL

The design of socially optimum policies with respect to sediment management requires a comprehensive conceptualization and estimation of the level and distribution of social costs and benefits of alternative strategies. A general conceptual model might include the following:

$$NPV_s = \sum_{y=1}^{Y} \sum_{t=1}^{T} \sum_{i=1}^{I} \frac{B_{syti}}{(1+r)^t}$$

$$\ldots \sum_{y=1}^{Y} \sum_{t=1}^{T} \sum_{i=1}^{I} \frac{O_{syti}}{(1+r)^t} + K_{syi}$$

where

NPV_S = discounted present value of net social benefits of alternative sediment control strategies (s = 1,...S)

B_S = annual benefits of alternative sediment control strategies

O_S = recurrent annual costs of alternative sediment control strategies

K_S = initial capital outlay for alternative sediment control strategies

Y = number of income classes relevant for evaluation of income distribution impacts of alternative sediment control strategies

T = time horizon or amortization period of alternative sediment control strategies

I = categories of costs and benefits associated with alternative sediment control strategies

r = discount rate, i.e., social time preference

Estimation of all the categories of financial and economic (or social) costs and benefits implied by the foregoing conceptualization for each of the many soil types and strategies for sediment management is an enormous—and perhaps impossible—task. However, by carefully delineating the methodological issues of cost and benefit estimation—both the level and distribution—as well as the situations and control strategies, a more manageable situation emerges.

MEASURING COSTS AND BENEFITS

What passes for "economic" analysis of various sediment management strategies varies widely and can be placed within an "accounting stance" continuum (discussed in Chapter 1) regarding both space and time. Costs generated from engineering data and future revenues based on current market prices can be misleading, particularly if one is concerned with societal costs and benefits. For example, the opportunity cost of labor is less than the wage rate in those situations involving under or unemployed labor. Costs based only on engineering data may also omit major technological externalities from soil erosion such as flood damage, water pollution and ditch, harbor, and reservoir sedimentation.

"Revenues" may also be overstated, particularly in those cases where local currency is overvalued, which is the case in most developing countries. Ward (1976b) discusses the use of shadow exchange rates to adjust for overvaluation of local currencies; he also discusses using the Bruno Criterion to evaluate the foreign exchange saved or earned by alternative erosion control strategies (Ward 1976a). This is particularly relevant in evaluating erosion control strategies in developing countries. Frequently these countries are dependent on hydroelectric power as a major domestic energy source. Sedimentation of reservoirs reduces power output and may lead to increased importation of oil.

A CASE APPLICATION FROM THE DOMINICAN REPUBLIC

To illustrate how the concepts introduced in Chapter 1 and the preceding section can be applied to the analysis of sedimentation problems in subtropical, Third World reservoirs, this section summarizes an evaluation of a soil conservation project for a hydroelectric watershed located in the Dominican Republic. After some background information about the study area has been presented, the method used to estimate reservoir sedimentation under different assumptions regarding land resource management upstream as well as the approach for estimating the benefits and costs of soil conservation are outlined. A more complete description of this research can be found in Veloz et al. (1984).

VALDESIA WATERSHED AND RESERVOIR

Like many other LDCs, the Dominican Republic has looked to hydroelectric development to reduce fuel oil imports. Many promising dam sites are found in the Cordillera Central, where most of the country's major rivers originate. Elevations vary in that region from 100 to 3000 meters above sea level and precipitation in many areas exceeds 1500 millimeters per year (Direccion General de Foresta [DGF] 1976).

As late as the 1950s, most of the Cordillera Central was forested. But after the death in 1961 of the country's long-time dictator, Rafael Trujillo, who owned most of the country's standing timber, many forested areas were clear cut. Peasants then settled on the newly cleared land. By the late 1970s, most of the region had been converted to rangeland and cropland (CRIES 1980). High rates of soil loss are now a problem throughout the Cordillera Central (Hartshorn 1981).

The Valdesia dam is one of several projects initiated in order to decrease the Dominican Republic's dependence on imported oil. By developing Valdesia and one other site during the 1970s, the Dominican Republic reduced the share of electricity generated at oil-burning facilities from over 90 percent to less than 80 percent by 1981 (De La Fuente 1976). However, sedimentation has been a continuous concern at the reservoir. Even before a major hurricane swept over the island in 1979, annual

sediment yield in the reservoir watershed was estimated to be 1.4 million metric tons (DGF 1976).

STUDY METHODOLOGY

Although the Dominican government has determined that the Valdesia Reservoir catchment area will be a watershed management program in the near future, a specific plan for reducing soil erosion there has not yet been developed. Without a more detailed plan, it was possible to characterize only in a general way the land uses and land management techniques to be encouraged under the project. Consultation of the literature and with professionals who have worked in the Dominican Republic, suggested the following guidelines for four slope classes:

Slope Class A (3-20 percent slope). Continue crop farming on existing cropland. Encourage mulching and contour farming. Renovate all rangeland with a slope of 13-20 percent.

Slope Class B (21-35 percent slope). Encourage mixed cropping/agroforestry enterprises on existing cropland. Renovate all rangeland.

Slope Class C (36-50 percent slope). Convert all existing cropland to agroforestry. Renovate all rangeland.

Slope Class D (over 50 percent slope). Reforest all existing cropland and rangeland.

To estimate the impacts of project implementation on resource management, a 1:50,000 scale topographic map of the 85,090 hectare watershed was consulted. The watershed was divided into 10-hectare cells, each of which was placed into one of the four slope classes. By contrasting existing land use (CRIES 1980) with recommended land use, it was found that 57 percent of the catchment area would not be affected by project implementation while 11 percent would have to undergo a change in land use. In the remaining 32 percent, soil conservation goals would be met by mulching, contour farming, and range renovation.

Reductions in soil loss resulting from compliance with project guidelines were estimated by applying the Universal Soil Loss Equation (Veloz 1982), using soil survey data and the estimates of slope that were used to categorize land into the four slope classes. In general, this approach yields conservative estimates of erosion inasmuch as the USLE explains only gross sheet and rill erosion and not gullying, streambank scour, and other types of soil loss.

Average sedimentation rates were calculated by multiplying an estimated sediment delivery ratio (Onstad et al. 1977) by estimated erosion rates. Given current land use and land management practices, it was estimated that average yearly accumulation of sediment in the reservoir is 921 x 10^3 metric tons, which is 59 percent of the rate obtained by dividing total sediment in the reservoir by the reservoir's age (Espinal 1981). However, the latter rate includes the silt deposit by Hurricane David in 1979

as well as the bed load of sediment. Thus, the observed rate probably overstates the long-term sedimentation rate. Implementation of the project throughout the watershed would reduce sedimentation by an estimated 86 percent to 130 x 10^3 metric tons a year.

RESULTS OF ANALYSIS

Sedimentation was assumed to have a negligible impact on electricity production as long as it remains possible to operate the dam (Veloz 1982). However, without any change in land resource management, it was estimated that the generator intake would be clogged with silt after 19 years. As little as a 25 percent reduction in erosion, though, would extend the dam's lifetime by about 6 years (Veloz et al. 1984).

The group affected most by project implementation would be hillside farmers. Researchers familiar with the study area supplied information about farm income without the project. Budgets for soil-conserving activities were obtained from USAID (USAID 1981) and other sources.

Economic evaluation of the watershed management project outlined above strongly suggests that the net benefits one associates with soil conservation depend on one's accounting stance. The results of private-level analysis reported in Table 8.2 indicate that some farmers would benefit from project implementation while others would lose, assuming that all use a real discount rate of 5 percent and a 25-year time horizon. Those with land in Slope Class A would, on average, benefit. The net returns per hectare they would realize by adopting improved tillage practices would exceed status quo net returns per hectare. However, full project implementation would force farmers who work on steeper land (Slope Classes B, C, and D) to make a change in land use which is, on average, not profitable for them.

Social-level analysis of soil conservation's on-site economic effects yields results that are similar to the results of private analysis of those same effects. In the former analysis, labor is shadow-priced at less than the minimum wage because of high under and unemployment in the Dominican Republic. Also, the project's exported outputs and imported inputs are evaluated using the parallel market exchange rate rather than the official exchange rate, which overvalues the local currency.

Even after these adjustments have been made, social-level analysis yields the same two conclusions as private-level analysis, assuming the same discount rate, time horizon, and accounting stance. First, as an entire group, farmers would benefit from project implementation. Second, farmers with land in the higher slope classes, who would be required to switch from traditional agriculture to agroforestry or reforestation, would lose because of project implementation.

Broadening the accounting stance so as to incorporate the off-site effects of erosion yields substantially increased estimates of the net benefits of soil conservation. Shown in Table 8.3 are the net present values of extensions in the lifetime of the Valdesia dam obtained by conforming to project guidelines in selected slope classes. For example, given project implementation in Slope Class A, the additional external benefits of

reducing erosion in Slope Ciass B (see Table 8.3) would greatly exceed the private costs of doing so (see Table 8.2).

TABLE 8.2

Private-Level Analysis of Valdesia Watershed Management Project

Slope Class	Hectares	$PNPV_i$	$PNPV_i$/Hectare
A	7,640	DR$12,500,000	DR$1,635
B	17,800	-550,000	-30
C	8,600	-1,925,000	-225
D	2,350	-1,100,000	-470
Total	36,390	DR$ 8,925,000	DR$ 245

[1]$PNPV_i$ = Private Net Present Value in slope class i
[2]DR$ = pesos; the Dominican Republic monetary unit

TABLE 8.3

Social-Level Analysis of Off-Farm Impacts of Valdesia Watershed Management Project

Slope Classes Where Project Guidelines Are Followed	Dam Lifetime	Off-Site Benefits of Compliance with Guidelines
None	19 years	0
A	20	DR$1,755,000[1]
A & B	25+	9,350,000+
D	25	9,350,000

[1]DR$ = pesos; the Dominican Republic monetary unit

CASE APPLICATION OF KEY CONCEPT

Proper conceptualization and analysis of reservoir sedimentation from an economic perspective is extremely important if optimal corrective measures are to be implemented. A core concept is the private versus social perspective or accounting stance with respect to both space and time. A social or economic accounting stance is primarily concerned with both on-site and off-site costs and returns, or with returns to the total society over the long run. Several forms of corrective or shadow pricing may be necessary in doing the social cost-benefit estimates which complicates the analysis and results in greater data needs.

Both the private and social perspectives or accounting stances are important as illustrated in the Dominican Republic case application. The private level analysis demonstrates the on-site profitability of alternative soil-conserving or sediment-reducing practices to hillside farmers, and shows those on steeper slopes as net losers. The social-level analysis includes both on-site and hydropower related off-site impacts and includes corrective or shadow prices for both labor and overvalued local currency. This analysis shows social benefits of soil-conserving practices to be substantially higher than the private costs in the Valdesia Watershed and reservoir in the Dominican Republic.

CONCLUSIONS

The private-level and social-level economic analysis of a soil conservation project planned for a Dominican hydroelectric watershed raises two major policy issues. First, if some individuals would benefit from the implementation of soil-conserving land management practices, why is voluntary adoption of those practices a relatively rare event? Second, given that changing to a more soil-conserving land use is perceived (either correctly or incorrectly) by farmers not to be remunerative, what policy tools should the government use to encourage such a change?

The lack of widespread adoption of soil-conserving practices in the Valdesia Watershed, elsewhere in the Dominican Republic, and in other Third World areas where erosion is a problem can be attributed in part to a lack of information. Research conducted in the Dominican Republic suggests that hillside farmers have little understanding of how agricultural practices affect erosion and very limited knowledge about methods for protecting soil. In addition, many hillside farmers hold insecure or limited tenure in their land which discourages them from undertaking costly measures that enhance the long-term productivity of land. Even if they were willing to adopt those measures, individuals with informal or limited tenure would find it difficult to obtain the credit needed to cover the short-term costs associated with some conservation strategies. Similarly, the tendency to overexploit rangeland, which is an open access resource in the Valdesia Watershed and elsewhere in the Dominican Republic, is very strong.

Certain public policies also tend to discourage soil conservation. In a country with an overvalued currency, for instance, there is a weaker incentive to adopt a soil-conserving land use if a large share of the output from that land use is destined for foreign markets. This is a possible obstacle to the promotion of agroforestry schemes that stress coffee or citrus production. Also, interest rate controls, which exist in the Dominican Republic and other LDCs along with an overvalued currency, make the task of reducing erosion more difficult. In the face of such controls, financial institutions tend to ration credit to borrowers who are less likely to default on loans and who can be served at a lower cost. Since they typically fall outside that set of borrowers, hillside farmers might find it difficult to finance an individual soil conservation effort when credit is being rationed on a nonprice basis.

The results of social-level analysis suggest that in order to achieve an optimal reduction in soil loss (which occurs when the off-site and on-site benefits of a marginal reduction equal the costs of making that reduction), some individuals would suffer private losses. Thus, subsidization of certain soil conservation measures might have to be considered. This possibility raises a number of policy problems. A subsidization program will have to be designed to prevent the expansion of hillside crop agriculture and grazing that would normally result if compensation were offered for conforming to project guidelines. This could entail major costs for the agency that administers the project. High administrative costs could also be associated with an attempt to foster soil-conserving activities through the use of subsidized credit.

Resettlement of individuals outside of environmentally sensitive areas is a frequently suggested policy alternative. In the Dominican Republic and most other LDCs, there exists idle cropland (e.g., land formerly planted to sugar cane) that could be given to individuals displaced by, for instance, a reforestation scheme in a watershed threatened by erosion. However, previous experience with Third World resettlement programs suggests that it is difficult to remove rural populations from ecologically sensitive areas quickly and permanently. More often than not, those populations are poorly equipped to make the transition from their familiar agricultural setting if they are moved to a radically different one. Accordingly, one should recognize that a long-term investment in the human capital of those populations is probably needed to prepare them for relocation. Given the proper diffusion of skills, more of those individuals would be capable of competing successfully in other labor markets. Similarly, individuals left in the sensitive areas would utilize land in a more sound manner. In addition, long-term reductions in population growth rates would ease the pressure on the renewable resource base.

Some data limitations qualify the results of the Valdesia case. No clear empirical evidence from the Dominican Republic about the inverse relationship between on-site crop yields and soil erosion exists. Accordingly, it was assumed that net returns per hectare would remain constant over time under the "without project" scenario. Although this leads to underestimation of the net social benefits of conservation, the assumption is not inappropriate for private level analysis. If idle land is available in each slope class, farmers will perceive that the costs of depletive land use, which equal the expense of clearing a new parcel of land once an old field is exhausted, are small and will therefore perceive that their income without the project will indeed stay constant. Also, inadequate data dictated that a simple hydrological model of the watershed—which does not reflect stream flow regime, nonsheet and rill erosion, and some of the effects of sedimentation—had to be used. Accordingly, the external costs of soil loss have probably also been underestimated.

The tools generally used to determine soil loss rates and sedimentation transport in LDCs are, by and large, rudimentary. Thus, it is hardly surprising that available estimates of the external costs or erosion (e.g., the costs of lost hydroelectricity, of reductions in irrigation water, of flood control, etc.) are imperfect. Similarly, in order

to understand better how the hillside farmer makes the decision of whether or not to utilize land in a soil-conserving fashion, better information about his institutional environment and about production functions for both traditional and less erosive agricultural activities is needed. Finally, better demographic information about the population that inhabits environmentally sensitive areas would improve our understanding of how renewable resource management problems evolve over time.

With more research on the on-site and off-site impacts of reductions in soil loss, it will be possible to perform economic analysis that is more comprehensive than the analysis described in this report. The case application estimates of the external benefits of soil conservation are probably conservative (only one type of benefit—the extension in dam lifetime—was quantified), and the per hectare returns associated with traditional agriculture have probably been exaggerated. Thus, the results of the Valdesia case argue for more research that allows for the design of better strategies for dealing with pressing soil erosion and sedimentation problems in developing countries throughout the world.

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CHAPTER 9.
ANALYSIS OF ECOSYSTEM STRUCTURE AND ENERGY FLOW IN A SOUTH INDIAN VILLAGE

T.S.P. Sundarraj
Rodger Mitchell

INTRODUCTION

Ecosystem analysis uses measures for the efficiencies of energy exchange and the transformations of materials to describe the biological relations of a community of organisms and the limits to productivity imposed by physiological constraints. Economic analysis uses measures of values to describe how individuals and communities are linked together. These two kinds of analysis can be independent. That is, a village ecosystem can be described without reference to its economy, and its economy can be defined without reference to the ecosystem. We wish to suggest that ecosystem analysis and economics are complementary viewpoints that can be used together in a way that will clarify the history of human communities and help understand the goals of farmers in developing countries. We also wish to define the biological constraints to the development of agroecosystems. While a synthesis is not yet possible, the first step toward such a synthesis involves defining what can be uniquely determined from ecosystem analysis.

Agroecosystems occupy habitats created by humans who also determine which species will be allowed to survive in the area. With continuous habitat modification, the cultivars and domesticated animals evolve genetic adaptations to the habitats created by humans and cannot survive elsewhere. The result is an evolved symbiosis between humans, and a few species of plants and animals. The adaptations of cultivars include increases in harvestable food. Human populations of increasing density depend on the coevolved yields of cultivars and genetic changes in the behavior of animals (Price 1984).

Despite adaptations to the habitats of agroecosystems, the basic physiology of domesticated plants and animals is no different from that of their wild relatives (Brody 1945, Kleiber 1961, Mitchell 1984). This means that the resource-determined limits

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to biomass production are the same for both natural and agricultural systems. It appears that agricultural development cannot be more productive of biomass than natural communities (Evans 1980, Mitchell 1984) unless it is possible to change the efficiency of the chloroplasts of plant leaves; hence, the productivity of natural communities with similar resources is a basis for a measure of the relative biological efficiency of an agroecosystem.

Through trial and error, humans have become ecosystem engineers, allocating effort and crops so as to produce a reliable and sustainable supply of biomass for food, fodder, fuel, fiber, and shelter. Until a few score years ago, the indigenous agricultural villages of Asia, Africa, and South America functioned as nearly independent agroecosystems (Calavan 1977, Moerman 1968, Norman 1979). Probably these farmers all shared the view John Buck (1930) attributed to Chinese villagers who desired to "... reduce the cost of living by becoming as self-sufficient as possible... Farmers feel it is more economical and convenient to use their own products" (p.178). Sustainable self-sufficiency was the first goal in the early evolution of agroecosystems and still has priority, even after complex economic relations develop. Villagers may cling to the tradition of meeting their demands from local biomass long after there are ways to meet these needs that the economist sees as more cost-effective alternatives.

We will attempt to develop a framework for describing the basic biological properties of a village ecosystem which includes tests for self-sufficiency and independence. The research is directed at obtaining answers to the following questions:

1. How does the productivity compare to that of natural communities with the same resource base? This is the measure of the relative intensity of cultivation and indicates whether substantial increases in biomass production might be possible.
2. What portion of the biomass is harvested and used? This is a sensitive measure of the extent to which there are multiple uses of a crop.
3. To what extent are the local needs for fuel, fodder, and food met with local biomass production?
4. How much of the biomass of the previous crop goes into maintaining the habitat and next year's production of biomass?
5. How great is the surplus production and is it likely that the village could be self-sustaining without external subsidies?

At present it is particularly urgent to take up studies of village ecosystems for two reasons. First, village life is the outcome of a very long cultural heritage which is still practiced by a large portion of humanity, and it is important to try to understand how villagers have been solving the problems of managing resources. Second, information on how a village works may well make it possible to understand change as a compromise between sustainable ecosystem management and specialized production for profit. This may explain why some technological suggestions are ignored and some are embraced, and why some are disruptive while others are constructive.

The village we will describe, Panayakurichi, is specialized in rice production and might be dismissed as having abandoned traditions that originated some hundreds of years ago in nearly closed self-sustaining managed village ecosystems. Many changes have been forced on the village by population pressures and loss of fuel resources. The availability of chemical inputs and new crop varieties have changed other aspects of village agriculture. It may be possible to evaluate these changes by reviewing earlier studies or through comparative studies. We will describe how the 994 people of Panayakurichi, near Tiruchirapalli, South India, manage the resources of labor, land, crops, and animals to obtain the food, fodder, and fuel needed to maintain the village. This ecosystem analysis, based on independent measures of all aspects of primary production, consumption, recycling, and inputs, is the basis for arguing that the village must be seen in its entirety by those who seek to understand village ecosystems. Such understanding may well be an essential point of reference for those planning to alter or improve the lives of the sizeable portion of humanity that still subsist on local resources and enjoy virtual independence of fossil fuel.

STUDY AREA AND METHODS

Panayakurichi (10.5°N; 78.4°E) occupies 257.72 hectares of flood plain along the Cauvery River. The rainfall averages 83 centimeters per year, most of which falls between August and December. Minimum temperatures are 21 to 26°C with the maxima always over 30° from March through September. Local rainfall supplies a small fraction of the water used in agriculture. Rice cultivation is possible only with water from the Uyyakondan channel of the Cauvery River, and is regulated by the Mettur dam built in 1928-34 at a cost of $13.7 million. The flow in the river and irrigation channels supplies water to 122,000 hectares. The cropping pattern is determined by the time and quantity of water released from the Mettur dam. Normally, irrigation water is available from July until late winter.

The 257.7 hectares occupied by the village consists of 6 hectares devoted to grazing lands, 155.5 hectares planted to crops, and the remainding 97.2 hectares occupied by houses, paths, irrigation canals, and farmyards which include some open land in and immediately around the village. There are 167 families totalling 994 persons of which 48.7 percent are males. Most of the population (56.9 percent) is between 15 and 59 years old, 8.4 percent is over 60 and 34.7 percent is under 15 years of age. The village is about 3 kilometers northeast of Tiruchirapalli and many of the villagers work in the city in addition to farming the land.

At the time of the census the cattle population consisted of 94 working bullocks, 15 bullocks 1-3 years of age, and 241 milking cows and buffalo. There were 189 goats.

The 155.5 hectares of cropland is divided into 312 plots, ranging from 0.004 to 2.513 hectares owned by 167 families, 2 temples, and 2 churches. Most fields (121) are less than 0.25 hectare; 108 fields are 0.25 to 0.50 hectare; 77 fields are 0.5 to 1.0 hectare and only 6 fields are larger than 1 hectare. On the average, each family

cultivates 2.5 fields totaling 0.90 hectare which is above average for India where 50.6 percent of the operational holdings were less than 1 hectare (Ministry of Agriculture 1977), or the Chingleput district in northeastern Tamil Nadu where more than 50 percent of the land holdings were below 0.5 hectare (Mencher 1972). In Bangladesh, 51 percent of the farms are below 1 hectare (Ahmed 1976).

Two high-yielding varieties of rice (*Oryza sativa*), Ponni and ADT-31, are the principle crop. The other field crop is sesame (local term *gingilly*), *Sesamum orientale*. Two plantation crops are planted; banana (*Musa*) and betel vine (*Piper betel*). All but sesame require irrigation. The production from the two field crops was estimated from haphazard square meter samples taken at harvest time. Five samples were taken from each crop, the components separated, dried at 85°C for 48 hours, and weighed.

Plantation crops were harvested at intervals over a 15 to 36-month period. The harvest was monitored to obtain average market weights for the crops. At the end of the cycle, representative plants were harvested and the components separated to obtain the dry weight. The production per plant and final standing crop were combined to estimate total yields.

The chemical composition of each of the kinds of food (Gopalan et al. 1976) and fodder (Sen 1966) is known and can be converted to kilocalories using standard values for kilocalories per gram (kcal/g) of protein (5.65), carbohydrate (4.15), and fat (9.40) (National Academy of Sciences 1966). Other caloric equivalents will be discussed where used.

Estimates for the demands for food and fodder use the census figures; estimates for labor times were obtained from observations and interviews and standard estimates of metabolic demands for Indian conditions for humans (Gopalan et al. 1976) and draft animals (Ranjhan 1976). The labor required for each farm task follows well-known norms in the village and were verified from interviews and observations. Census figures, land holdings, fertilizer usage, fuel consumption, and the whole host of data needed to determine the quantities of material and labor used in Panayakurichi were obtained with the help of the Village Karnum, D. Parimanum Pillai. The census and village records supplied by the Karnum were the basis for a complete house-to-house census of the population and land holdings for 1977-78.

THE CROPS

The input of seed, manure, water, and labor yields a mix of fodder, human food, and fuel that is used in the village. The properties of each crop are reviewed and the aggregated inputs and outputs are used to determine the extent to which the allocation of resources to crops is governed by the internal needs of the village.

RICE (112.4 HECTARES)

Most of the land (68 percent) is in high-yielding varieties of rice. ADT-31, a short-term (105 day) rice, is planted in August as a summer crop called kuruvai. In

triple cropping, the Ponni variety (135 days) is sown as the second crop and ADT-31 is the third crop. Land is committed to kuruvai in August. Some land is reserved for a mid-September planting of the Ponni variety. This "winter" crop called samba rice cannot be followed by a second crop of rice because there is no water in the spring. ADT-31 yields 9 percent less rice and less than half the fodder (bran, stems, and leaves) than Ponni (Table 9.1). Yield is only one of the factors considered in planting decisions. If the rains of the summer monsoon provide a large supply of water, then double and triple cropping with ADT-31 will produce much more from the land. If summer monsoons bring limited rain, a single kuruvai crop may be all that can be raised. Rice planted in August is nearly mature in October and November and can be destroyed by the very erratic winter monsoonal storms.

TABLE 9.1

Rice Primary Production in kg/ha[1]

		Dry kg/ha		Total Yield (138.6 ha)	
	kcal/kg	ADT-31	Ponni	10^3 kg	10^6 kcal
Paddy (rough rice)	3657	3670	4228	571.1	2088.4
polished rice	3683	(2372)	(2748)	(370.8)	(1365.7)
bran	5945	(568)	(658)	(88.8)	(527.9)
husk	1641	(730)	(822)	(111.5)	(182.9)
Straw	3330	4708	11470	1409.3	4692.9
Totals				1940.4	6781.3

[1]Based on five haphazard m² samples for above ground production and five haphazardly selected clumps to obtain the ratio of root to shoot biomass. Equivalents in combustible calories are determined from the approximate analyses of Gopalan et al. (1976) for rice, Sundarraj and Thulasides (1976) for bran and husk, and Sen (1966) for straw.

A measure of insurance is obtained by planting some samba rice between mid-September and the end of October. Only the worst of the winter storms will damage the young samba rice. The 1977-78 season followed two years of winter monsoon damage to kuruvai, and farmers feared another destructive winter monsoon. Consequently, a total of 111.9 hectares of Ponni and 26.7 hectares of ADT-31 were cropped from 112.4 hectares of paddy land. Only 22.7 hectares were double cropped and 1.7 hectares were triple cropped. The multiple-cropping resulted in an annual cropping intensity of 1.23.

Fodder demands could play a role in planting decisions. If the supply of water from the summer monsoon appears to be adequate for a summer crop but uncertain for samba, the farmers might still plant some samba because it yields twice as much fodder as kuruvai rice. The uncertainties of weather, demand for fodder, and need for rice play a role in the allocation of land to different patterns of rice culture. Sundar... (1982a) provides details of the cultural practices and labor inputs. Labor inputs for the rice (Table 9.2) range from 51 to 95 days of human labor per hectare and of

bullock days of labor. This is less human days of labor than the 183 human days and 58 bullock days reported for Uttar Pradesh (Singh and Chancellor 1975) and the 130 human days and 20 bullock days for Ungra in Karnataka (Ravindranath et al. 1980), but far below the 303 human days and 76 bullock days reported for the Central Farm at Coimbatore (Department of Agriculture, Madras 1970).

TABLE 9.2

The Input of Labor (in 8-hour Days per Hectare) for Rice in Panayakurichi

	Male	Female	Bullocks
Manuring	0.6	—	1.2
Land Preparation	35	—	59
Seedbed work	7	—	6
Transplanting	—	54	—
Weeding	—	26	—
Chemicals	5	—	—
Harvesting	12	15	4
Total	51.6	95	67.2

Farmers use all the available farmyard manure which consists of animal dung, vegetable wastes, and straw that accumulates through the year. Manure is transported to the fields during the dry season. Some fields receive as much as 1500 kilograms per hectare (kg/ha), others less than 700 kg/ha. A survey of fields suggests that 1000 kg/ha is the usual input level for a paddy field each year.

ADT-31 is seeded at the rate of 111 kg/ha, and Ponni seeding takes 86 kg/ha. Price subsidies and loans make chemical fertilizer cheap and readily available. The use of chemicals on five fields of long-term rice and five fields of short-term rice was monitored. Insecticides were applied routinely and consistently in the fields. Endrin is applied at about 1100 millileters per hectare (ml/ha) on long-term rice and 900 ml/ha on short-term rice. Both crops receive applications of about 50 kilograms of BHC per hectare.

Urea is applied to both varieties with 62 kg/ha on long-term rice and 124 kg/ha on short-term rice. Long-term varieties receive 124 kg/ha of nitrogen-phosphate-potassium (N-P_2O_5-K_2O) complex (17-17-17) and 62 kg/ha of ammonium sulphate. In terms of nutrients, this is the equivalent 62.6 kilograms of N and 21.1 kilograms each of P_2O_5 and K_2O applied per hectare of long-term rice and 56 kilograms of N applied per hectare of short-term rice.

SESAME (GINGELLY) (2.24 HECTARES)

This oil seed follows a kuruvai rice crop. The plowing of the fields in March takes 30 days for a man with a team of bullocks per hectare. Seeding at the rate of 6.18 kg/ha is done with a single pair of bullocks and takes 2 days. Sesame receives no other

care, and 10 women harvest a hectare in one day. The plants are spread on a drying surface and, when dry, 8 women work a day to thresh the 617.5 kilograms of seeds from a hectare.

The seeds yield 40 percent of their weight in oil (9.4 kcal/g). The remaining oil cake (4.34 kcal/g) is used as cattle food. The residue of stems and leaves, 12.9 metric tons per hectare (mt/ha) at 4500 kcal/kg is used for fuel.

BANANA (41.56 HECTARES)

Rhizomes of the poovan variety are planted after the fall monsoon (October, November) and produce fruit 15 months later. Land preparation requires 10 days per hectare by a man and a team of bullocks. The transportation and digging in of 2470 rhizomes requires 4 days of work from oxen and 15 man days of work. The application of 5000 kg/ha of farmyard manure 2 weeks after planting requires 19 man days and 28 bullock days to transport the manure from the village. Women disperse the manure (62 days of work), men dig the manure into the soil (55 days), and, finally, 25 man days are required to dig irrigation channels. From then on two men work one day twice a month to direct and control the irrigation. Applying a total of 123.5 kilograms of oil cake, 333.5 kilograms of ammonium sulphate, 148.2 kilograms of 17-17-17 complex, and 210 kilograms of potash to a hectare requires 100 man days. The care and harvest requires 78 days of work in February and March.

The annual yield of biomass (dry weight) is 18.78 mt/ha of which 5.81 metric tons are stem and root that have no use other than as mulch. All the other parts of the banana are used (Table 9.3). Squash or vegetables are grown as intercrops during the first few months in a banana planation. This practice varies widely and is not included in the totals here.

TABLE 9.3

Average Annual Yield of Banana[1]

Component	kcal/kg	Use	Dry (kg/ha)	(41.6 ha) 106 kcal/yr.
Output				
Fruits	4152	Human Food	7707	1330.0
Central Axis	3690	Human Food	676	103.6
Flowers	3690	Human Food	57	8.7
Leaves	4036	Fuel	4531	760.0
Root, Stem	4036	None	5806	974.8
Total			18777	3177.1
Input				
Suckers		Input for crop	472	

[1]The yields of energy are calculated with calories of combustion based on Gopalan et al. (1976) and Sen (1966) for banana leaf.

BETEL VINE PLANTATION (1.48 HECTARES)

Betel vine is part of a complex three-layered canopy involving four major cultivars that are heavily watered and manured over a 3-year cycle. Constant trimming maintains a scattered canopy of *Sesbania grandiflora* (1852 plants/ha) at 4 to 5 meters. A denser layer at 2-3 meters consists of a mixture of *Sesbania grandiflora* at 74,100 plants/ha, *Erythrina indica* at 2964 plants/ha, and 11,115 *Moringa pterygosperma* plants/ha. Betel vines are planted at a density of 37,050 per hectare and grow on the stems of these small trees. The details of cultivation are given by Mitchell (1984) and Sundarraj (1983). The plantation produces an average harvest of 51.7 mt/ha/yr (Table 9.4). Fuel is 48.3 percent of the biomass, human food 24.0 percent, and fodder 25.1 percent. Vegetable plants are irregularly scattered in the plantation; there may be 3000 to 6000 plants of banana, chilies, or eggplant per hectare. This variable production is not entered into Table 9.4.

TABLE 9.4

Average Annual Yields from a Betel Vine Plantation

Component	kcal/kg	Use	Dry (kg/ha)	(1.48 ha) 10^6 kcal/yr.
Betel vine				
leaves	4103[1]	Human Food	5770	35.0
stems	4152[2]	Fiber	2316	14.2
Sesbania				
leaves	4413[2]	Cattle Food	9568	62.5
stems	4708[3]	Fuel	21613	150.6
Erythrina				
leaves	3768[2]	Cattle Food	2408	13.4
stems	4708[3]	Fuel	617	4.3
Moringa				
leaves	4542[1]	Human, Cattle food	4440	29.8
fruits	3844[2]	Human Food	2225	12.7
stems	4708[3]	Fuel	2779	19.4
Total			51736	341.9

[1]Combustible calories based on Gopalan et al. (1976).
[2]Combustible calories based on Sen (1966).
[3]Mitchell (1979).

FODDER CROPS

The only grazing land consists of six hectares of former cropland now damaged by erosion. This is dominated by *Dactyloctenium aegyptiom* Willd., *Eragrostis plumosus* Link, and *Panicum miliare* Lam. Estimates of above ground net production based on

the harvest method (Shrimal and Vyas 1975) give yields of 3328 kg/ha. The grasses from grazing lands have an average caloric equivalent of 3803 kcal/kg (Sen 1966).

The cattle are grazed wherever there is grass. The production from fallow fields is negligible because they are grazed only in the dry season. The bunds that enclose rice paddies produce a good growth of grass, and the small field size results in the bunds occupying a significant area. The 312 fields, averaging 0.498 hectare, have a common bund 0.6 meter wide on three sides and an irrigation channel with a bund 1.06 meters wide on the remaining side. The estimate of bund length is based on the assumption that each field was square. This gives the minimum length for a bund, which is 26,012 meters for the shared bunds and 17,342 meters for the irrigation channel bunds. There is a total of 3.40 hectares of grazing land on the bunds. The grasses are similar to those of other grazing lands.

There are, therefore, 9.40 hectares of grazing lands in the village yielding a total of 119.0 x 10^6 kilocalories of forage. None of these lands could be used for other crops; hence, no tillable land is used for forage production.

AGGREGATED PRODUCTION

The total harvest (Table 9.5) consists of 27.8 percent human food, 10.2 percent fuel used by humans, and 51.9 percent could be used as forage for cattle. This is an average of 58.1 x 10^6 kilocalories harvested and used per hectare of cropland. Casual plantings and fuel gathered from the fences and paths are not included.

TABLE 9.5

Aggregated Output for Panayakurichi in 10^6 kcal/yr[1]

	Human food	Fodder	Fuel	ANP	ha
Rice (138.6 ha)	1365.7	5220.8	—	6781	138.59
Sesame (2.2 ha)	5.2	3.6	129.0	138	2.24
Banana (41.6 ha)	1442.3	—	760.0	3177	41.56
Betel (1.5 ha)	77.6	75.9	174.2	342	1.48
Grazing (9.4 ha)[2]	—	119.0	—	—	9.40
Milk	10.0	—	—	—	—
Total Harvested	2902.6	5419.3	1063.9	10438	192.3
(percent of ANP)	(27.9)	(51.8)	(10.6)	—	—
Demand	889.2	885.8	1537	—	—
(percent satisfied)	(326.4)	(611.8)	(69.2)		

[1]Data were assembled from the text and Tables 9.1, 9.3, and 9.4 and represent the outputs from the 161.6 hectares of cropland that are seeded or grazed; 31.7 hectares are multiple cropped.
[2]Includes 3.4 hectares of bunds of paddy fields.

BIOTIC INPUTS

The crops and cropping practices of most farmers in the world are strongly influenced by the portion of the biomass from previous crop that must be used to produce the current crop (Evans 1980). Biomass is used to maintain the system; it provides the propagules for replanting and the food for the humans who control and manage the crops and for the animals which are used for power. Seeds are the major energy source for humans in a grain-based agriculture. Fodder production does not compete with human food production if it is taken from the leaves and stems of the grain crop, untillable land, or weeds. The fuel used for cooking human food and other essential needs of humans must be included in the cost of running the ecosystem. Thus, biotic inputs can be separated into three categories: (1) biomass set aside for reseeding, (2) the portion of the crop and the cropland that must be set aside to supply the food and fuel for the humans and draft animals that plant and maintain a crop, and (3) food and fodder biomass from sources that do not compete with crop production. The difference between the total biomass in the first two categories and the crop production from the system is the surplus available for export or the deficit that must be imported.

SEEDS AND PROPAGULES

In the case of rice and sesame, the seeds are drawn from potential food. Two percent of the rice yield is used for the next year's crop. In sesame 1.1 percent of yield is used in seeding the next crop. The seeds and propagules of both banana and betel vine are not economically useful and do not compete with supplies of foods or nutrients. The small aggregated demand for the planting of the next crop is less than the year-to-year variation in crop yields.

LABOR

Labor is a time-limited resource determined by the size of the human and animal populations. Decisions about what to plant and how to plant are based on the availability of labor. The bullock labor is fixed as the population times the customary number of days an animal can be worked. Normally, that will be 5 days a week; hence, the 94 bullocks will provide 470 work days a week. The animals may be worked continuously during critical periods, and the dry buffaloes (52 at the census time) can be impressed to work. For a brief time, 146 animals might be worked 7 days a week to give 1022 work days a week. However, such strains on the poorly nourished draught animals are avoided if at all possible.

The portion of the population doing the farming is more difficult to explain because a person's role or potential role is a function of social status (Srinivas 1976). People of high status or with special roles, such as blacksmiths or barbers, may not farm and there are customs that limit some kinds of work to one sex. The sex of worker was distinguished, but the way social structure limited working within one sex could not be included in this study.

The annual labor requirements (Table 9.6) show that 23,421 days of male labor, 17,184 days of female labor, and 11,026 days of bullock labor are required for farming. Rainfall determines the needs for labor in each of the two systems of rice production and the other crops (Figures 9.1 and 9.2). In their anxiety to avoid losses from the winter monsoon, farmers planted much of the rice land to samba so that the peak labor demands were in September and October. Less samba and more kuruvai may be planted in other years.

TABLE 9.6

Aggregated Biotic Inputs for the Entire Crop Area in Original Units with Heat of Combustion Equivalent in Parentheses

	10^3 kg/yr (10^6 kcal/yr)			Days of work/yr (10^6 kcal/yr)		
	Seeds	Manures	Chemicals	Male	Female	Bullock
Rice	12.6	112.4	—	7622	13166	9285
	(45.5)	(195.6)	(286.9)	(13.11)	(16.59)	(73.35)
Sesame	0.01	—	—	72	22	143
	(0.01)	—	—	(0.12)	(0.03)	(1.13)
Banana	19.7	170.3	—	10888	3740	1579
	(73.3)	(307.5)	(155.8)	(18.72)	(4.71)	(12.76)
Betel	0.06	9.6	—	4839	256	19
	(0.03)	(22.4)		(8.32)	(0.32)	(0.22)
Totals	32.4	251.9	—	23421	17184	11026
	(119.2)	(525.1)	(411.16)	(40.28)	(21.65)	(87.10)

The monthly labor demands for 1977-78 can be compared to the supply that would be available (Figure 9.2) if the entire population worked a 5-day week. For bullocks that is 2081 work days a month and for dry buffaloes, 1151 days. Only in October does the labor demand exceed the potential work from bullocks. It appears that the shift of land to samba was as great as possible within the draught animal resources. If rice land were equally divided between kuruvai and samba, demands would exceed the potential bullock labor in August (3895 days) and October (3195 days), but this pattern of demand would be manageable with the use of buffaloes, small adjustments in planting times, and some 6-day work weeks.

No male buffalo are kept. The sex ratio in the cattle population is 0.97 males to 1.0 females among 1 to 3 year olds, but it averages 0.41 to 1.0 among cattle and buffalo older than 3 years (Table 9.7). There are just enough young bullocks to replace the working animals when they reach an age of 9 years. The bullock population appears to be very closely regulated to meet labor demands. All the remaining fodder supply is used for milk cattle and she buffalo that are also available as a labor supplement.

The human population is not regulated to match labor demands. Males do the heavy labor of land preparation and females have jobs that are done in larger groups,

FIGURE 9.1 ***Distribution of labor requirements for summer rice (kuruvai), winter rice (samba), and all crops combined for 1977-78.***

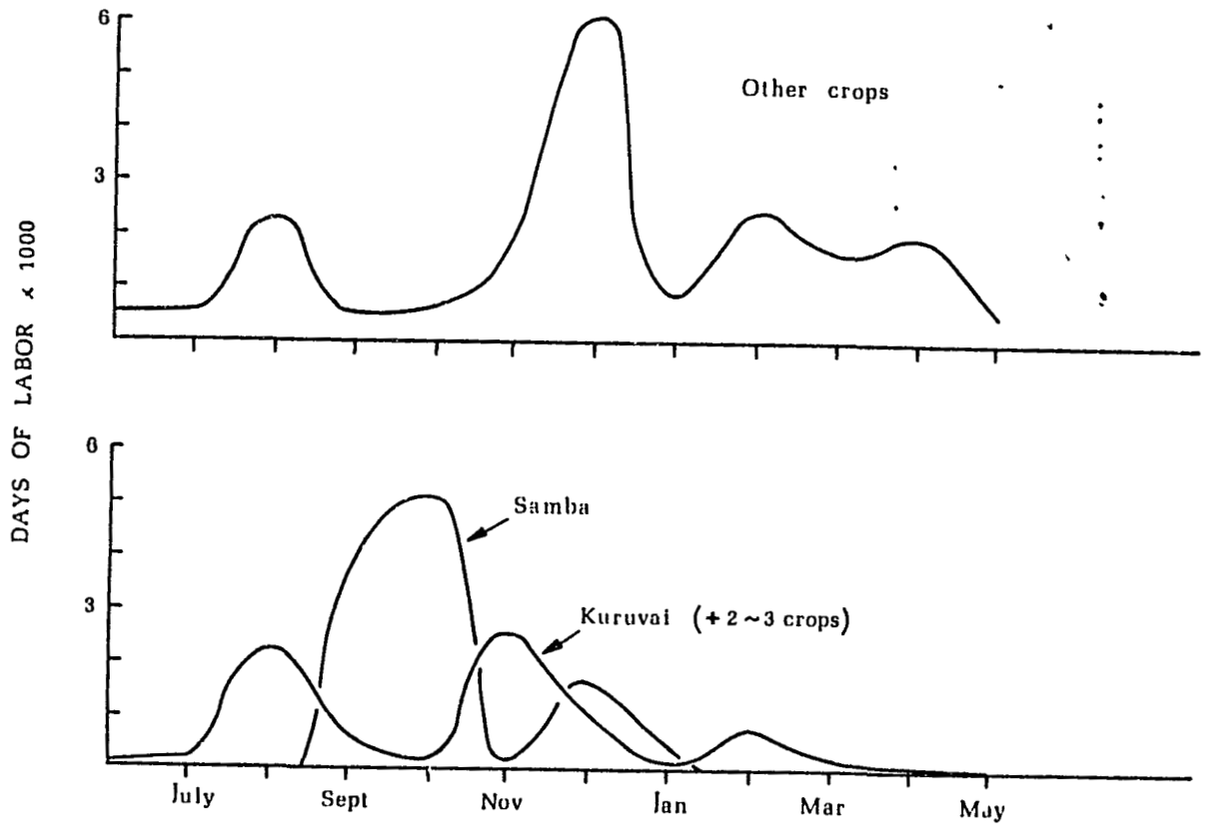

FIGURE 9.2 ***Supply and demand of human and animal labor for 1977-78.*** The horizontal lines give the supply of labor when the total population in each category works 5 days per week. The work of buffalos shown as an increment to bullock work.

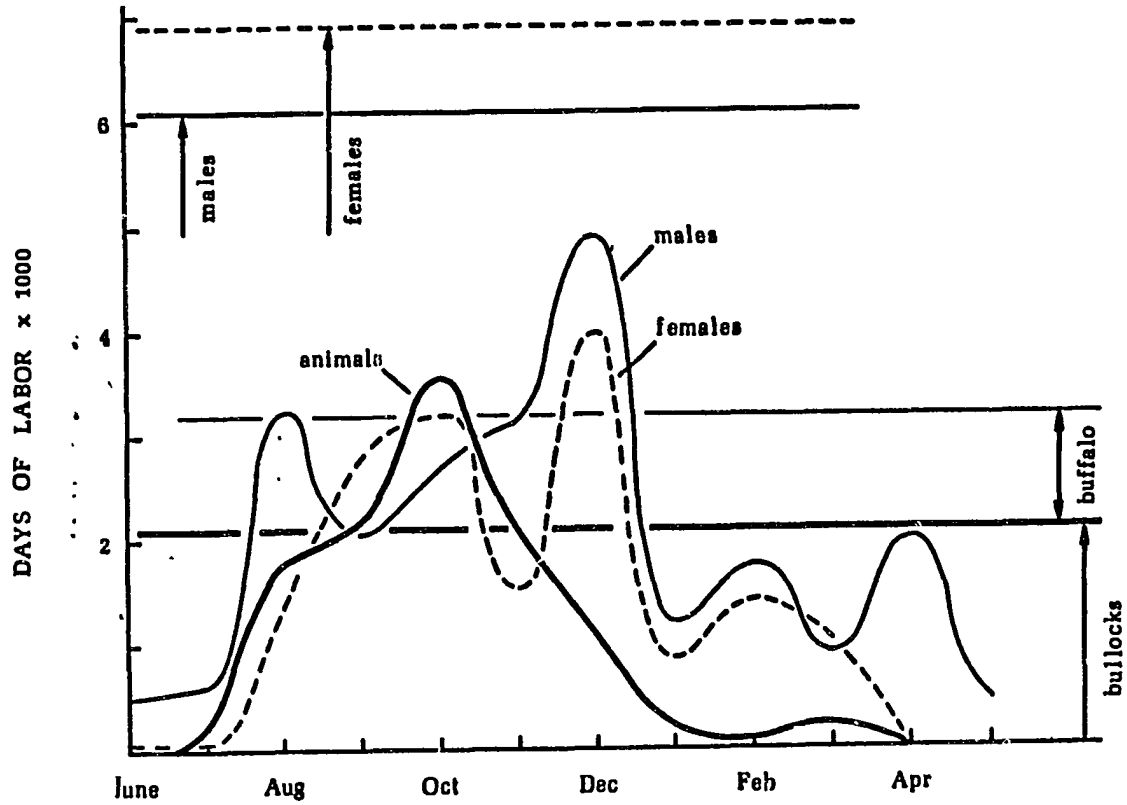

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TABLE 9.7

Numbers and Estimated Caloric Requirements of Cattle and Goats in Panayakurichi[1]

		Total Energy Inputs (10^6 kcal)		
	Census Count	Annual Maintenance	Increment	Total
Bullocks				
under 3 yrs.	15	89.79	—	89.79
over 3 yrs. (work)	94	562.10	88.11	650.11
Cows				
under 3 yrs.	36	215.35	—	215.35
over 3 yrs., dry	23	137.60	—	137.60
over 3 yrs., milking	53	316.82	106.96	423.78
Buffalo (females)				
under 3 yrs.	33	197.46	—	197.46
over 3 yrs., dry	52	310.98	—	310.98
over 3 yrs., milking	44	263.16	105.79	368.95
Goats (meat)	189	359.16	—	359.16
TOTAL				2753.28

[1]The caloric demand is equivalent to 786 metric tons of fodder. Work and milk increments were based on the cost of hard labor by a 350-kg bullock and milk production by a 350-kg cow (Ranjhan 1977). Work/milk inputs are calculated in the text.

such as planting, weeding and harvesting. In terms of work days the ratio is 1.36 males to 1.0 females and the December peak in labor can be met if 220 males and 179 females work a 5 day week (Figure 9.2). Over most of the season no more than a third to half of the villagers would have to work. It often appears that more females are at work; that is because groups of females are more conspicuous than individual males dispersed over the fields.

Time is the limiting resource in making decisions about what crops to plant and when to plant them. The farmers are acutely aware of how much time each task requires. They base their decisions on a careful consideration of the available resources and alternative schemes of planting. Figures 9.1 and 9.2 show the use of time resources in 1977-78. In another year the pattern might be quite different, but the peak demands could not be much different from those described here. Potential labor time is the limiting resource considered by the farmers managing their ecosystem, but the interrelations of ecosystem components require labor to be converted to a measure of energy. All published studies use the same widely accepted values for maintenance energy and the caloric increments needed for work by animals. The differences in the way maintenance energy is allocated result in work equivalents ranging from 200 to 900 kcal/hr (Revelle 1976). The high figures are obtained by summing the energy for annual maintenance and labor and then dividing by hours labor. Makhijani (1975) did this with assumed values for the days of labor instead of

direct measures. Intermediate values of 500-600 kcal/hr are obtained by adding the energetic cost of the hours of labor to the maintenance for the days of labor and dividing by the hours of labor (Pimental et al., 1975). The low values (200-300 kcal/hr) are the work energy (Norman 1979), which is the metabolic increment of energy for work.

The average daily energy costs for days of labor in digestible calories (Gopalan et al. 1976) have been converted to combustible calories (Mitchell 1979) of 1720 kcal/day for males and 1260 kcal/day for females. The input for work, 215 kcal/hr for males and 160 kcal/hr for females, which are lower than the common estimates, are the best data available for Indians under local conditions. The importance of using local data is made clear in Edmondson's (1979) exacting analysis which showed a two-fold difference in the instantaneous metabolic cost of work that was associated with systematic differences in diets. Farmers with diets of 2700 kcal/day had an average metabolic increment of 8.1 kcal/min at medium work. Farmers with diets of 1770 kcal had a significantly smaller increment of 6.0 kcal/minute at medium work. It is important to exercise caution in attaching significance to small differences in energy relations of various systems.

The values of Ranjhan (1976) were used to obtain a value of 7900 kcal/day for labor by bullocks in the village. Bullocks are used exclusively for labor, and the population is just large enough to meet the seasonal labor demands (Figure 9.2). Combining inputs for maintenance and labor gives a gross cost of 650 million kcal/yr for bullock labor (Table 9.7). The 90 million kcal/yr for 1 to 3-year-old male calves is an essential replacement cost.

The segment of the human population that farms cannot be distinguished from those engaged in other tasks. Perhaps a measure of the cost of a complex human society can be projected by using the ratio of energy obtained for maintenance energy of the strictly regulated bullock population as a standard ratio for the work to maintenance of a population with no social structure. To supply 88 million kilocalories of bullock work, it is necessary to put 7.4 times as much energy into maintenance (Table 9.7). For the human population, the maintenance energy is 13.5 times greater than the energy used for work (Table 9.8).

The maintenance to work ratio is twice that of bullocks and part of the larger value can be attributed to the portion of society that does no farm work, but carries out important social functions.

MANURE

Sustained agriculture requires replacement of the nutrients removed from the soil. The return of nutrients can be measured in caloric equivalents, a term needed for evaluating the completeness of the ecosystem model. The caloric equivalents also indicate how much physical effort is put into recycling. The actual effect of recycling on yields is not related to the minerals in the manure If manuring is to be compared with chemical fertilizers, then the mass of nutrients must be determined. The rate of

TABLE 9.8

Estimated Caloric Requirements for the Population of Panayakurichi[1]

	Census Count	Total energy input (10^6 kcal) Annual Maintenance	Work Increment	Total
Males				
1-14 yrs.	166	115.12	—	115.12
15-59 yrs.	277	283.09	40.28	323.37
over 60 yrs.	41	41.90	—	41.90
Females				
1-14 yrs.	179	124.14	—	124.14
15-59 yrs.	289	229.5	21.65	251.22
over 60 yrs.	42	33.42	—	33.42
TOTALS	994	827.24	61.07	889.17

[1]The constants for caloric requirements are based on the nutrient analysis given by Gopalan et al. 1976 and converted to heat of combustion rather than nutritive calories (Mitchell 1979). Work increments are calculated in the text.

TABLE 9.9

Nutrients from the Annual Application of Organic Manures and Chemicals for each Crop per Hectare per Year[1]

	Rice		Banana		Betel	
	kg	10^6 kcal	kg	10^6 kcal	kg	10^6 kcal
Farmyard manure	1000	1.74	4000	6.97	5000	8.71
Oil cake	—	—	100	0.43	1480	6.42
Total organic nutrients						
N	5	—	28	—	143	—
P_2O_5	3	—	13	—	36	—
K_2O	6	—	25	—	48	—
Chemical nutrients						
N	60	1.86	105	3.25	—	—
P_2O_5	16	0.18	25	0.29	—	—
K_2O	16	0.03	115	0.21	—	—
Manure needed to replace chemicals	12000	20.92	21000	36.60	—	—
Insecticides	50.5	4.31	—	—	—	—

[1]Farmyard manure at 1743 kcal/kg is assumed to have 0.005 N, 0.003 P_2O_5 and 0.006 K_2O (Mitchell 1979). Oil cake at 4341 kcal/kg (Mitchell 1979) is assumed to have 0.08 N, 0.014 P_2O_5, and 0.012 K_2O (Department of Agriculture 1970). The energetic costs of chemicals are from Pimental and Pimental (1979).

manuring, given under the crops (Tables 9.6 and 9.9), will total 292 metric tons for the entire area. At 1743 kcal/kg for farmyard manure (Mitchell 1979) and 4340 kcal/kg for oil cake (Sen 1966), manures equal 525.4 x 10^6 kcal/yr for all the crops.

FOSSIL FUEL INPUTS

Chemicals are used on rice and banana. The total fossil fuel input (Table 9.9) is 288 x 10^6 kilocalories for rice and 156 x 10^6 kilocalories for banana. The insecticide inputs are not substitutable, but the 444 x 10^6 kilocalories of fertilizer are equivalent to the nutrients in 2222 metric tons of manure (Table 9.9).

Nitrogen is the major nutrient for rice. Potassium is the major nutrient for banana. Each of these elements make up about 0.005 of the mass of manures. The 5 kilograms of nitrogen estimated to be in a metric ton of manure cost the farmer about 30 rupees in 1979. A ton of manure yields about 1.11 x 10^6 kilocalories of useful heat which is about the quantity obtained from 237 kilograms of wood. Substituting 237 kilograms of wood for a ton of manure would cost 80 rupees, so dung is 2.7 times as valuable as a fuel than it is as a source of nitrogen. Some of the potassium and phosphorous remains in the ash and is recycled. The way dung is used depends on the availability of fuel and the cost of alternative nitrogen sources. In Panayakurichi nitrogen costs would have to nearly triple and fuel costs remain constant before manure would be an economic alternative to chemical nitrogen. It is important to use the costs to the farmer in examining farming decisions. This accounts for local decisions, but a larger economic model is needed to decide if direct and indirect subsidies make these decisions cost-effective at a national level.

CONSUMPTION

Primary production is used as human food, cattle fodder, and fuel. The biomass used to build houses, roofs, tools, and other products is a minor fraction of production. Goats, chickens, and trained ducks are largely gleaners that feed on wastes and residues that would not otherwise be used and cannot be directly measured.

FODDER

The demand for fodder by cattle and buffalo (Table 9.7) is about 44 percent of the fodder supply (Table 9.5), but most of the potential fodder (96 percent) is low-quality rice straw. High-quality fodder represents about 36 percent of the fodder demands. This is above odend'hal's (1972) value of 25 percent cattle fodder being other than rice straw in West Bengal. The quantity of fodder is adequate, but it is still so low in quality that the herd could not be increased without serious shortages in quality forage. Goats are excluded from the analysis because they generally feed on wastelands and weeds not suitable for cattle.

HUMAN FOOD

Human food is in surplus with about 2903 x 10^6 kcal/yr harvested (Table 9.5) and a demand of 889 x 10^6 kcal/yr. Water subsidies and transport allow the farmers to put land into the most profitable crop, rice, and import the pulses, vegetables, oils, and sugar that represent about 11 percent of the calories in an average diet (Kalirajan 1976). The surplus of food available for sale is just over twice the local consumption.

FUEL

Biomass supplies the fuel. The demand is measured independently of the supply of fuel. The two common combinations of fuels—dung cakes and banana sticks, or wood and banana sticks—gave an average of 657 kilocalories of useful heat utilized in cooking for one person per day (Sundarraj 1982b) which is close to the Indian average of 650.4 kilocalories (Khadi and Village Commission 1975).

The fuels are given in Table 9.10. Banana sticks are made by twisting the fronds of the banana leaf around the central axis. Until recently, only the washermen made banana sticks to heat washwater, but this fuel is now used by villagers for cooking. There is no fee charged for the collection of banana leaves, which is usually done by children, despite the fact that it now meets over half the fuel demand (Tables 9.5, 9.10). The 12,858 kg/ha of sesame stems are assumed to provide 4500 kcal/kg and supplies about 8 percent of the fuel demand. The annual harvest of wood from betel gardens, (Tables 9.5, 9.10) meets about 13 percent of the fuel demand.

TABLE 9.10

Annual Fuel Demand and Supplies in Panayakurichi[1]

	10^6 kcal/yr	efficiency x 10^6	useful kcal/yr
Estimated demand	1537	—	238.7
Supply			
Banana sticks	760.0	0.173	131.5
Sesame	129.7	0.150	19.4
Betel Garden	174.2	0.173	30.1
Dung	438.7	0.110	48.2
Total	1502.5	—	229.2
Shortfall	34.5	—	9.8

[1]Demand and supply estimates taken from Sundarraj (1982b). All measures of efficiency and caloric content are from the Khadi and Village Commission (1975).

Surveys of the use of dung cake indicate an average use of 0.578 kilograms of dung cake a day for each person. At 2092 kcal/kg (Mitchell 1979), this yields 1209 kcal of heat or 438.7 x 10^6 kcal/yr. The cattle produce 28.87 kg/day and buffalo an average

of 2.72 kg/day dry weight (Neelakantan 1975) for a total of 538 x 10^3 kilograms of manure dry weight. The estimate of fuel consumption, 209.7 mt/yr, is 39 percent of the available manure. The use of farmyard manure (25 percent water) on crops totals 229 x 10^3 kg/yr and, together with dung cakes (at 10 percent water), gives 397 x 10^3 kilograms which exceeds the manure supply. Farmyard manure includes a great deal of rice straw from bedding and other wastes, and dung cakes are bound with about 12 percent fiber. When this is taken into consideration, the estimates seem to be within reason. Dung cakes meet about 20 percent of the fuel demand.

SECONDARY PRODUCTION

Humans consume goat meat and milk which are secondary products. The average yield of milk from cows is 612 liters per year (l/yr) and 604 l/yr for buffalo. At 75 kilocalories per liter (kcal/l) and 128 kcal/l respectively, the yield from the herd has a caloric equivalent of 10.06 x 10^6 kcal/yr. Much of this is exported to the city.

The herd of 189 goats produces about 100 goats per year for slaughter. At 11.5 kilograms of edible meat per goat with 155 kcal/kg, this is 1.78 x 10^5 kcal for goat meat, all of which is consumed locally and represents a conversion of the weedy biomass of wastelands into usable human food.

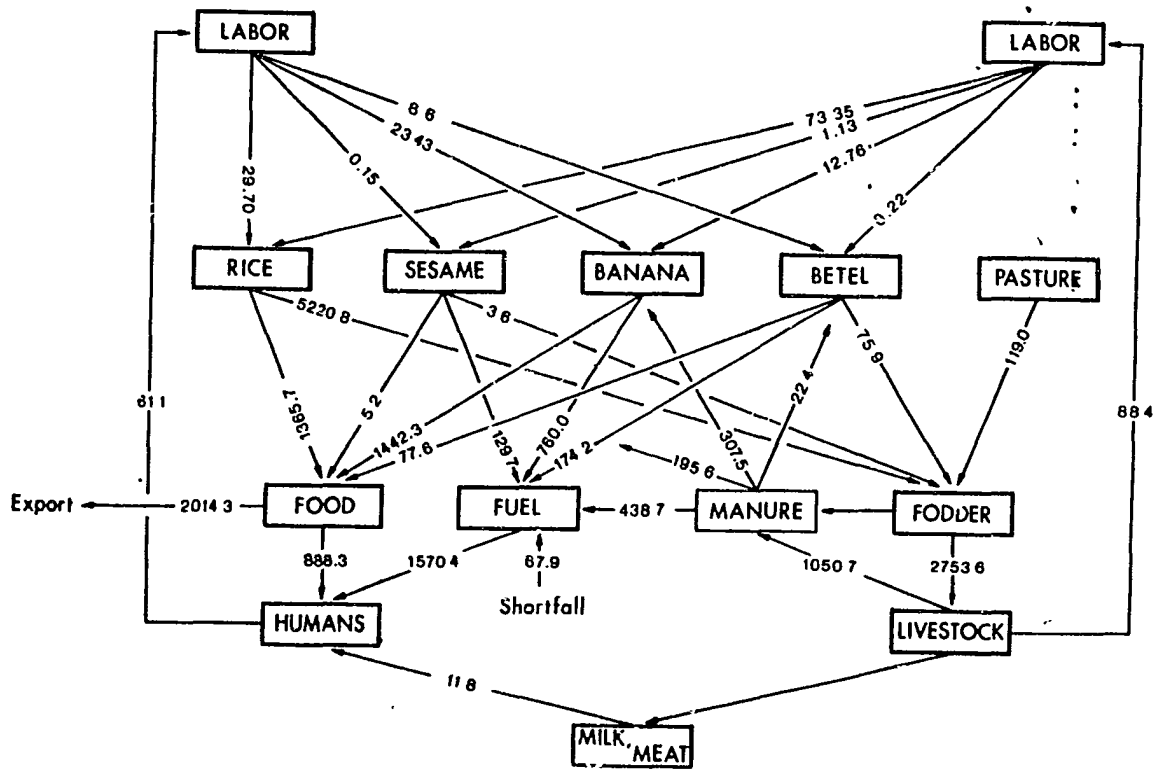
YIELDS AND SELF-SUFFICIENCY

The villagers of Panayakurichi shifted from mixed dry land agriculture to paddy rice as subsidized water from the Mettur dam became available in the late 1930s. Also, government policies have made paddy farming even more profitable by supplying cheap fertilizers and new crop varieties. Consequently, much of the land is monocropped. The ecosystem analysis shows how the resources are used (Figure 9.3) and allows an evaluation of this derived agricultural system to see the extent to which the traditional pattern of virtually complete self-sufficiency has changed in the direction of westernized monocropping. The technological extreme of western agriculture is reached when the entire crop is sold and all the food and energy needed for sustenance and farming must be purchased from the revenues.

The local yield of rice, oil from sesame, milk, and meat would satisfy 89 percent of the average diet estimated by Kalirajan (1976) for Tamil Nadu. The 11 percent defficiency in pulses, vegetables, and sugar that are not produced in the village are covered by food production equivalent to 3.3 times the total caloric demands. It is not possible to accurately estimate the vegetables obtained from small plots and intercropping which would raise the measure of self-sufficiency a few percent.

As mixed agriculture gave way to rice, there was a continuing increase in local population density which has resulted in a degradation of untillable rain-fed lands that once provided grazing areas and sources of fuel for the village. As these resources were lost, the villagers had four possible ways to solve the problem: (1) use the cash crops to

FIGURE 9.3 ***Energy flow in the Panayakurichi agroecosystem for 1977-78.***
The values are in 10^6 kcal/yr for the entire village.



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obtain fuel and fodder, (2) divert lands to fodder and fuel production, (3) obtain these from crop biomass that does not compete with food production, or (4) exercise a frugal management of the livestock herd. Options 3 and 4 have been followed with remarkable success.

Over 95 percent of the fuel demand is satisfied (Table 9.10) with the adoption of a technique for converting banana leaves into fuel sticks and a more thorough harvesting of potential fuel from crops. There is a careful gleaning of fuel from trees along paths and in waste areas. Living fences of *Prosopis* in the village are coppiced to provide more fuel. The sources of fuel have changed radically in the last generation. The villagers have put great effort into developing indigenous fuel supplies with which to maintain fuel self-sufficiency, just as Briscoe (1979) observed in Bangladesh.

The population of draft animals is barely enough for the seasonal peak demand for labor (Figure 9.2). With 109 bullocks to 241 cows and she-buffaloes, it appears that the bullock population is minimized so that as much fodder as possible can be used for milk-producing animals. Goats can glean weeds and residues without competing with cattle. Altogether the livestock consume 275.3 million kilocalories of fodder which includes an increment of 301 million kilocalories to support work and milk production (Table 9.7). All fodder demands are met from local biomass production.

HARVEST INTENSITY

The total biomass harvested and used in the agricultural system is defined as harvest intensity. Harvest intensity is the portion of the biomass production from the resource base (soil, water, and nutrients) that is used. Absolute values for above ground net production (ANP) will be used as a measure of primary production.

Harvest intensities are low in developed countries because either human food or fodder is harvested and the residues are rarely used as fuel. Much more is used in developing countries because the ANP of a food crop is also harvested for fuel and fodder. Grain can be used as a common base for comparing farming technologies because grain yields are the sole goal in the single-use monocropping of developed countries and the major goal in multiple-use village ecosystems. Rough rice yields of 3670 to 4228 kg/ha for Panayakurichi compare favorably to the averages for rice production in the United States which range from 4073 to 5295 kg/ha for long-grain rice (USDA 1980). Allowing for differences in cultivars and variations in year-to-year production, there is no reason for thinking that the animal-powered farming technology in Panayakurichi is inferior to that of mechanized American rice farming. It is generally agreed that animal-powered agriculture is as technologically efficient as mechanized agriculture (Baker and Herdt 1978, Chandler 1979, Singh and Chancellor 1974, 1975) when ANP is taken as the efficiency of trapping solar energy.

The maximization of rice yields in Panayakurichi does not seem to compete with the use of the rice biomass for fuel and fodder. Yields vary with the decisions about allocating land to ADT-31 and Ponni that are influenced by the availability of water

for multiple cropping, worries about unpredictable winter monsoons, and available draft power (Figure 9.2). The unusually large commitment to samba (winter) rice resulted in an average yield of 4.12 mt/ha seeded. With multiple cropping in rice and sesame following rice on 2.24 hectares, there was a total yield of 5.09 mt/ha from the 112.45 hectares used for rice.

The total ANP was 18.3 mt/ha for the 151.6 hectares, and 10.9 mt/ha were used. The direct use of ANP, 70 percent for banana, 53 percent for rice, and 100 percent for sesame betel plantation, averaged about 59 percent of the crop ANP.

The irrigation water makes the system biologically comparable to tropical floodplain communities though the water supply is limited in most years. Such natural communities produce an average of 20-29 mt/ha ANP so the yields of 18.3 metric tons for Panayakurichi are similar to those of natural marshes that have a seasonal water supply.

The secondary use in fuel made from dung (210 mt/yr) and the mixture of dung and vegetable wastes in farmyard manure (Table 9.6) totaling 252 mt/yr brings the total of utilized biomass from croplands to 3100 metric tons. Another 76 metric tons of forage is estimated to be taken from 6 hectares of pasture land, and goats consume about 94.4 metric tons a year mainly from weeds and wastelands. A total of 3270 metric tons of biomass is harvested and used by the villagers. This represents 2903 million kilocalories of human food (Table 9.5), 2753 million kilocalories of fodder (Table 9.7), 525 million kilocalories in manures (Table 9.6), and 1502 million kilocalories of fuel (Table 9.10).

The total land resource must be considered. Hence, if surplus land is used for spacious homesteads, wide paths, or temples, the utilized production per hectare of village land would be lower than that of a village forced to maximize its exploitation of land resources. Total energy utilization over the village area is a sensitive measure for comparing village ecosystems. The villagers harvest and use 29.8 million kcal/ha/yr of biomass from the 257.7 hectares of the village (about 8.5 mt/ha/yr).

CONCLUSIONS

Five questions were posed in the introduction. The answers to these questions provide a basis for evaluating the biotic properties of an agroecosystem and a framework for developing comparative agroecosystem studies.

1. Is the above ground net production (ANP) equivalent to that of comparable natural communities?

The utilized primary production over the entire area of Panayakurichi is 8.5 mt (29.8×10^6 kcal) /ha/yr. In terms of ANP from harvested lands, the crops range from 13.5 to 51.7 mt/ha with an average of 18.3 metric tons. The directly utilized ANP was 10.9 mt/ha for cropland. The ANP on cropland was at least equal to the ANP of seasonal floodplain tropical forests (Murphy 1975).

In the extreme case, 52 mt/ha from betel plantations, the ANP is equivalent to the highest values known for a natural community (Mitchell 1984). This is achieved with intense management and large inputs of organic nutrients. The majority of land is in rice which has an ANP about as high as can be expected for a 100 to 130-day season. The biomass production is close to the biological maximum.

2. What portion of the ANP is used?

There is a significant harvest of vegetables from casual interplantings. Also, a great deal of fuel is gathered from the living fences and scattered trees in the village which could not be monitored. For the cropland there was a direct use of 59 percent of the ANP. If secondary uses of vegetable wastes in manures and making dung cakes are included, the usage may approach 90 percent.

3. What portion of the biomass demand is met?

Each one of the 994 people of Panayakurichi need 1570 million kilocalories of fuel to cook the 889 million kilocalories of food they consume annually. The cattle and buffalo require 2393 million kilocalories per year. A ratio for food:fuel:fodder can be used to estimate the balance of ANP. The demand ratio is 1.00:1.77:1.08 and the observed output (Tables 9.5, 9.10) is 1.00:0:52:1.87, indicating what appears to be a shortage of fuel and a surplus of fodder. There is a surplus of rice that is exported. The local fuel supply meets 96 percent of the demand for cooking the food used in the village. The surplus of fodder is entirely rice straw that cannot be used because of the shortage of quality forage to supplement the rice straw.

The advantages gained from a rice surplus are great enough that the villagers are content to barter or buy the pulses, oils, vegetables, and sweets they need. Considerable effort goes into meeting the fuel demand, which has resulted in the development of banana sticks as a major fuel in quite recent times. Dung is used as a fuel because the 5 kilograms of nitrogen in a ton of dung can be purchased for 30 rupees as fertilizer while the value of dung as a fuel is 80 rupees.

Casual fodder and fuel collection form wastelands, paths, and other areas that cannot be monitored easily. Grazing and fodder is preferentially directed to cattle and buffalo. The population of oxen is restricted; therefore, the population of bullocks and dry she-buffalo is barely adequate to satisify the peak labor demands. It appears that the draft animal population is so limited that it may restrict the choices of farmers in extreme situations. The population of cows and she-buffalo is held at a level matching the fodder supply, presumably because of the value of their milk.

Villagers appear to put a great deal of effort into exploiting the local biomass to meet the human demands and regulating the herds of livestock to maximize animal protein production. The villagers keep no more than the essential population of draught animals.

4. How much of the ANP must be invested in the next season's production?

The ANP represents 10,438 million kilocalories (Table 9.5) of which 0.59 percent is the energy needed for the work increment of the human population. If it is assumed that half the population is needed to conduct farming (Figure 9.2), then the cost

would be 4.56 percent of the ANP. For draught animals the labor increment is 1.87 percent of ANP and 11.50 percent for the total consumption of working animals.

Seeds represent 1.14 percent of the ANP, and 5.03 percent is directed back to the fields as manure. Chemicals are an external subsidy that can be evaluated in energetic terms. The chemical inputs require about 411 million kilocalories of fossil fuel in their production. That caloric content is equivalent to 3.94 percent of the ANP and optimal fertilization increases yields about 20 percent (Department of Agriculture 1970). About 5 kilocalories of biomass are obtained for the input of a kilocalorie of fossil fuel. The benefits from fossil fuel subsidies are very great in animal-powered ecosystems when compared to yield of biomass relative to fossil fuel in mechanized farming (Pimentel et al. 1975, Pimentel and Pimentel 1979, Singh and Chancellor 1974, 1975, Slesser 1976).

The total biotic input is 22.23 percent, of which only 4.56 percent is human energy. Most of the biotic input is from fodder production that does not compete with human food for resources.

5. Could the village be self-sustaining? Is there a surplus?

If the external subsidy of fertilizer were removed, the village would lose its surplus in rice, but could meet all the other needs. If the water subsidy were lost, the villagers would have to return to dry-land farming and would be unlikely to meet their needs.

The subsidies have allowed this village to function like the agroecosystem with a natural water supply, but they have not resulted in the villagers diverting all their efforts into specialized cash crops. The agroecosystem continues to be managed in a way that satisfies the needs for fuel and fodder from local biomass.

Agroecosystem analysis will define the functional limits within which an ecosystem can be managed, and describe the performance of a given agroecosystem. The village considered above operates very close to the biological limit for biomass production. The intensity of biomass utilization, perhaps as high as 90 percent, attests to the ingenuity, effort, and careful attention the villagers apply to the management of their ecosystem. It is not unreasonable to dignify this management as a folk science of great sophistication that is worthy of detailed study for its own sake.

Those who would try to help in the development of agroecosystems in Third World villages would do well to consider how advice on one aspect of the agroecosystem fits into the system as a whole. Illiterate villagers cannot articulate management in scientific terms, but they may well know more about the practice of agroecosystem science than the academic specialist.

The biological limits and performance criteria developed from agroecosystem models are unique contributions that biologists can bring to a synthesis of biology with economic theory at the village level. The ways that agroecosystems fit into a society and its economy cannot be addressed by ecosystem models. We must turn to economic analysis for such wide-scale models.

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CHAPTER 10.
ENVIRONMENTAL IMPACTS OF THE ASWAN HIGH DAM: PROSPECTS AND ANALYSIS

Scot E. Smith

INTRODUCTION

When one speaks of renewable resources in Egypt, the River Nile is inevitably brought into the conversation. The Nile is Egypt's most important natural resource. The course of the history of Egypt has been inextricably linked to the Nile.

The construction of the Aswan High Dam in 1964-1971 opened a new chapter in the long and celebrated history of this ancient river with respect to its chemistry, biology, and influence on Egyptian life. Built under a storm cloud of controversy, the Aswan High Dam has been portrayed simultaneously as a symbol of the highest in engineering achievement and as one of the most outstanding examples of environmental insult. The objective of this chapter is to place in perspective important environmental issues related to the Aswan High Dam. It is fitting that these issues be addressed now after over a decade of heated debate and scientific inquiry over the relative merits of the project.

A number of reports highly critical of the Aswan High Dam project were published during the early 1970s. Because it had just been completed, reliable scientific information about the dam and its potential environmental impacts was not available. The reports were largely conjectural in their basis and failed to provide a scientifically sound means of assessing the situation. A sufficient quantity of reliable data now exists to permit a better understanding of the range and degree of impacts set in motion by one of history's largest hydrological projects.

EARLY PROGNOSTICATIONS

Concern over the possible environmental effects of a large dam at Aswan were voiced as early as 1948 when the idea of constructing a super dam at Aswan was first proposed. Until that time the established orthodoxy for providing over-year water

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storage in the Nile basin was the century storage scheme which consisted of a complex series of smaller dams located on the Nile between Uganda and Egypt. The century storage idea had been fathered and championed by H.E. Hurst, a British hydrologist and long-time Nile expert, during the early part of the twentieth century. Smaller dams, it was thought, would mitigate environmental pertubation and provide each country with the ability to control its own water supply. On the other hand, the scheme required a high degree of international cooperation and would take decades to fully implement.

The relative advantages and disadvantages of this plan were debated for over half a century. Despite reservations of a number of prominent hydrologists, plans for a large dam at Aswan were solicited by the Egyptian government. The plan offered several important advantages for Egypt that would not have been provided by any dam of lesser proportions. These advantages included the following: complete control of over-year storage, additional summer water, flood protection, and provision of cheap hydroelectric power (Whittington 1983).

A few weeks before the official ground-breaking ceremonies for the High Dam in 1960, a distinguished Egyptian hydrologist, Dr. Abdel Aziz Ahmed, warned the Institute of Civil Engineering at a meeting in London that the project was "unwise and indeed extremely hazardous" (Sterling 1971, p. 84). Dr. Ahmed's main concerns were:

- Entrapment of the annual 134 million tons of sediment carried down the Nile from the Ethiopian Highlands into the reservoir. This would not only impede the efficiency of the dam, but also shorten the reservoir's useful lifetime. Additionally, this would rob the Egyptian Delta of valuable nutrients and soil-building material.
- Riverine scour downstream from the dam resulting from high velocity of sediment-free water. This would undermine the many barrages between Aswan and the Mediterranean as well as the numerous bridges across the Nile.
- Excessive evaporation and seepage from the reservoir.

Other scientists and engineers would echo Dr. Ahmed's concern and add to the list:

- Disruption of the marine ecosystem in the eastern Mediterranean resulting from the cutoff of silt emptying into the sea.
- Erosion of the Egyptian Mediterranean coastline.
- Increase in waterlogging and salinization of the Delta's agricultural lands as a result of a higher water table.
- Rise in the incidence of waterborne diseases such as schistosomiasis and malaria.

One of the most widely circulated statements about these and other predicted environmental impacts of the Aswan High Dam was made by journalist Claire Sterling. In a well-publicized article she said:

> Of all the dams built by rich nations for poor nations hoping to grow richer that way, the one built by Soviet Russia for Egypt is in a class of its own. The High Dam at Aswan is

the biggest and most expensive in the world. The late President Nasser spent over a billion dollars on it and changed the course of history to get it: broke with the West, nationalized the Suez Canal, brought on the Suez War and so invited Soviet penetration of Egypt, the Middle East, and the Mediterranean. It made his political fortunes, but spread such ecological havoc that his country may never get over it. The dam has, in fact, greatly impoverished an already destitute nation, driven the fish from the eastern Mediterranean, expanded the whole Egyptian coast to erosion, endangered every bridge and barrier dam astride the Nile from Aswan to the Sea, robbed Egyptian soil of the silt that made it the most fertile on earth, threatened millions of acres with the blight of salinity, set off an explosion of waterborne disease and squandered the very water it was meant to save. (Sterling 1971, p. 84)

THE ASWAN HIGH DAM: A DECADE IN PLANNING

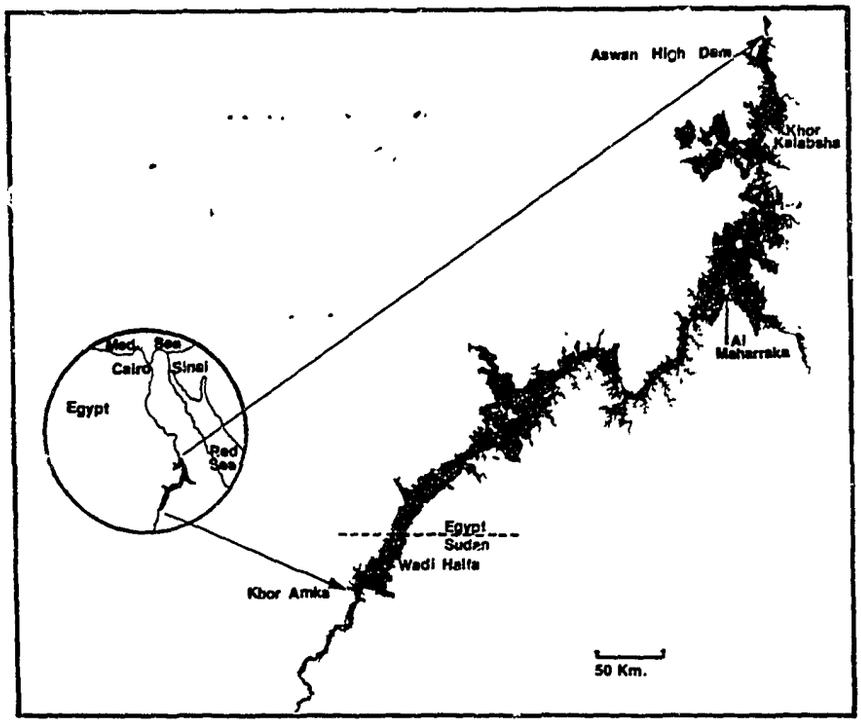
Large-scale impoundment projects have always been accompanied by sincere concern over their potential environmental impact, and this trepidation is justified. One of the most comprehensive studies of development projects may be found in *The Careless Technology: Ecology and International Development* (Favar and Milton 1972). The authors recite a large number of ill-conceived and/or poorly executed projects which have resulted in negative return on investment for the recipient country. Most of the projects cited were not fiscally sound and possessed no realistic prospect of an eventual profit. Many were also environmentally unsound and have been responsible for disastrous, irreversible damage to their surroundings.

The idea for a very large dam at Aswan to replace the one built there in the early 1900s was conceived during an optimistic era with respect to economic growth potential of lesser developed countries. But the dam still had to meet with the criteria imposed by international lending institutions today. Critics of the High Dam tend to overlook the fact that during the early to mid-1950s, western experts were repeatedly drawn into analysis of the project and consistently reported favorably upon it (Whittington 1983).

Soviet engineers reviewed the previous feasibility studies, and, with some modification, found them sound. Egypt and the Soviet Union worked out a financing scheme that called for a payment schedule acceptable to both countries. Construction of the Aswan High Dam began in 1960 under direction of the Soviet Hydroproject after a decade of technical review and planning by some of the most highly qualified engineering talent in the world (Whittington 1983). By 1964 the river was blocked by a coffer dam and the reservoir began to fill. The Aswan High Dam was completed in 1970, and the reservoir reached its operating level in 1976.

The High Dam is located about 950 kilometers south of Cairo and 6.5 kilometers upstream from the original Aswan Dam, (Figure 10.1). It is 3600 meters along the top and has a maximum height of 111 meters. The Aswan High Dam Reservoir, formally named Lake Nasser in Egypt and Lake Nubia in Sudan, is the world's second largest reservoir and provides much of the electricity consumed in Egypt.

FIGURE 10.1 THE ASWAN RESERVOIR



RATIONALE FOR A HIGH DAM AT ASWAN

Hydrological observations of the Nile date back to the ancient Egyptians who installed river gauges, known as nilometers, to determine the arrival and height of flood waters. Though not continuous, the hydrological record for the Nile is the longest and most extensive of any river in the world.

Annual discharges vary dramatically from one year to another. During the 1971-75 period, for example, the annual discharge of the main Nile at the entrance of the Aswan High Dam Reservoir varied from a low of 53 billion cubic meters in 1972 to a high of over 100 billion cubic meters in 1975.

Seasonal variations of the main Nile flow rate are even more dramatic. More than 80 percent of the river's total discharge occurs during the 3-month flood period, from August to October. This was directly discharged to the sea prior to construction of the

Aswan High Dam. The remaining 20 percent of the annual discharge occurs during the other 9 months.

The importance of the contribution of the Blue Nile is obvious: 86 percent of the Nile's annual discharge is derived from the Ethiopian Highlands, whereas only 14 percent is contributed by the Equatorial Lakes. Furthermore, the silt carried by the main Nile to form the Nile Delta originates almost exclusively in the Ethiopian Highlands of the Blue Nile watershed. The Victoria Nile and Bahr El Jebel carry much smaller amounts of silt, most of which settles out as the river flows through Lake Mobutu and the Sudd region.

In Egypt, where 95 percent of the people live on 3 percent of the land, with the rest of the land being barren desert, the availability of Nile water has traditionally been the determining factor between famine and prosperity. Similarly, northern Sudan is dominated by barren desert and the populated fertile land is limited to a narrow strip along the Nile. Egypt and Sudan occupy over 85 percent of the Nile Basin. The extreme variations in the Nile discharge make it difficult for these countries to maintain sufficient agricultural production despite land reclamation programs. Historically, high floods caused property damage and interfered with river navigation and other uses. This necessitated the construction of a number of hydraulic engineering works for flood control and for low flow augmentation; these include seven dams, seven barrages, and the Jonglei Canal.

Among the various Nile control projects, the Aswan High Dam is unique in its scale and impact. The reservoir formed by the dam has total volume of 121.3 billion cubic meters of stored water. Of this amount, 31.6 billion cubic meters are dead storage. The reservoir is 500 kilometers long and covers an area of 5000 square kilometers.

Before the Aswan High Dam, about 40 percent of the Nile annual discharge was lost to the sea. The discharge of water from the High Dam is primarily guided by downstream irrigation requirements. It is estimated that only 6 billion cubic meters of agricultural drainage water are annually discharged into the sea through the northern lakes of the Delta. Even this amount of drainage water will be reused in the near future for agricultural expansion programs. The availability of more water and low flow augmentation resulted in transforming 2.5 million acres of farmland in Egypt from basin to perennial irrigation. This enabled farmers to produce multiple annual crops, instead of one crop as dictated by the former basin irrigation scheme. In addition, the availability of more water made it possible to cultivate certain crops with high water demand (e.g. rice).

The hydroelectric power station of the Aswan High Dam has twelve turbines, with installed capacity of 2.1 million kilowatts, which can be used to generate a annual hydroelectric power output of 8 billion kilowatt-hours. The annual electric power consumption in Egypt is generally slightly over 8 billion kilowatt-hours; therefore, the High Dam could theoretically provide nearly all of the country's electric power needs.

Unfortunately, the potential electric output of the High Dam has never been fully realized. At any given time only 6 of the 12 available turbines have been in operation

due to maintenance problems. In 1985, through a grant from the U.S. Agency for International Development, all 12 turbines of the High Dam were replaced. The new turbines are more efficient and corrosion-resistant, thus effectively boosting the hydroelectric power potential of the High Dam.

The additional electricity will provide a number of opportunities for Egyptian development. Power could be used to drive the network of irrigation and drainage canals of the Delta. Currently, water is raised using diesel pumps which are more expensive to operate and difficult to maintain than electric motors.

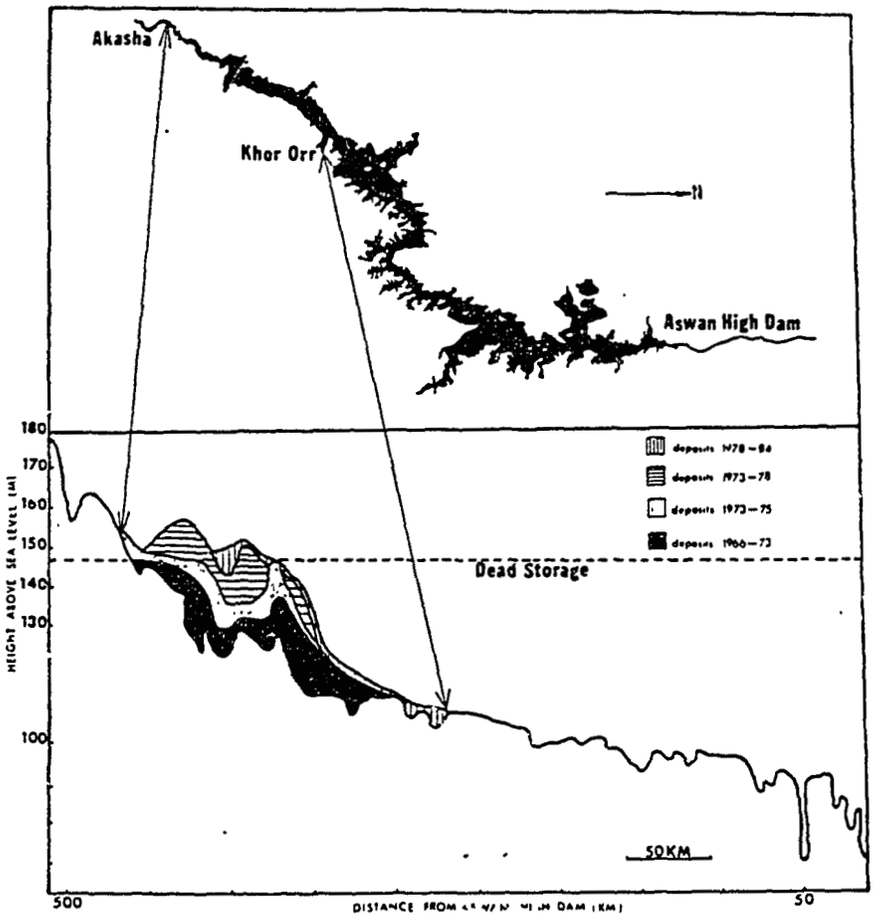
Another important use of the additional power could be in the industrialization of Aswan. The original regional development scheme for Aswan called for extensive capital investment in heavy industry (Abu El Atta, 1978). Included in the plans was construction of an aluminum factory, automotive assembly operation, and a fertilizer plant. Of the three ideas only a modest fertilizer plant has been built in Aswan. Power-intensive industrial operations such as aluminum smelting may find it advantageous to be located near Aswan in order to take best advantage of the local increased supply of hydroelectric power.

RESERVOIR SEDIMENTATION

During the flood period, the Blue Nile brings large amounts of sediment load, in the range of 80 to 130 million tons annually, into Egypt (Ball 1939). Since 1975, four years after completion of the High Dam, virtually all of this sediment has been deposited in the Aswan Reservoir. As is typical in newly formed reservoirs, during the first years of operation, sediment-laden water traversed the entire length of the reservoir. As the reservoir filled, the velocity of the water slackened as the volume increased. Sediment was then laid down progressively farther away from the dam. Surveys of sediment deposition in the reservoir have been conducted since 1971. The survey results, in conjunction with satellite remote sensing analysis of sediment distribution, confirm the characteristics of sediment in the reservoir (Smith 1983). As illustrated in Figure 10.2, sediment-laden water is confined to the southern third of the reservoir during flood. Most of this sediment consists of lighter clay and silt particles with sand being deposited farther upstream.

At the present time, the zone of significant sedimentation extends between 260 and 480 kilometers south of the dam. Most of this region is actually Sudanese territory, not Egyptian. Sediment depth ranges from virtually nothing up to 300 kilometers from the High Dam to over 30 meters in the zone between 350 and 450 kilometers from the dam. Deltas are being formed in the area between 360 and 450 kilometers from the dam. At the moment, the deltas do not impede the flow of the Nile due to the depth of the river channel at this point. The deltas do, however, pose a potential threat to the long-term storage capacity of the reservoir should an extraordinarily large flood displace them into the reservoir proper.

FIGURE 10.2 SEDIMENTATION PROFILE IN ASWAN RESERVOIR



The recent drought of the Ethiopian Highlands has affected sediment distribution in the reservoir. Since 1980, the average total inflow of the Nile to the reservoir has been 43 billion cubic meters—less than half the normal amount (Shalash 1982). Satellite and ground-based monitoring show that only finer sand and clay particles are entering the reservoir. This finer material, along with previously deposited sediment, are moving forward toward the dam (Shalash 1982).

Another aspect of the drought affecting sedimentation has been an increase in the water's salinity due to high evaporation. Normal floods would add a sufficient supply of water low in salt concentration to dilute the reservoir. Lack of this input has

increased salinity by an estimated 5 percent in the past 5 years (Whittington 1983). Higher concentration of salts in water causes more suspended matter to precipitate rather than stay in the water column. This point has not been quantitatively examined, but could have a significant impact on sedimentation rate and pattern.

The shoreline adjacent to the region of high sedimentation is almost entirely barren of vegetation due to a lack of arable land. Given this scarcity of arable land, the idea of dredging the southern portion of the Aswan Reservoir and using the dredged spoils for land reclamation is attractive. Land reclamation projects are common along both the White Nile and the Blue Nile in the Sudan. Most are found in the semiarid zone south of Khartoum, but experiments are now being conducted in the desert. The Ethiopian-derived alluvium would provide an excellent soil base and, from the point of view of the Sudanese, could be considered a renewable resource due to the reliable supply coming down the Blue Nile from the Ethiopian Highlands each fall. Sediment traps could be established along the main Nile between Khartoum and the southern extreme of the reservoir to facilitate transfer onto the shore. The economic feasibility and long-term effects of such an extensive land reclamation effort using relocated river sediment are not certain.

DOWNSTREAM DEGRADATION

Due to the reduction of suspended material and increased velocity of water released from the High Dam, riverbed degradation and coastal erosion are problems downstream from Aswan. Evidence indicates a significant amount of degradation and scour in the river stretch between Aswan and Cairo. A small amount of clay is found in the discharge of the dam, and some aeolian matter (sands and silts) enter the river along its course between Aswan and the Mediterranean, but the system is far from balanced.

Riverbed erosion is evident throughout the river in the form of local scour at meander points. The Egyptian Ministry of Irrigation has a program to monitor riverbed erosion and the stability of hydraulic structures, and to repair damages from scour. At least one barrage, the Esna Barrage, has recently been reinforced. Also, water releases from the reservoir are carefully controlled in an attempt to limit river scouring. The recently completed Tushka relief canal in the southern end of the Aswan Reservoir appears to offer the needed security against excessive water release from the dam. The government considers the problem of downstream scour control a manageable one.

Coastal erosion along the Mediterranean, on the other hand, is a more immediate, pressing concern requiring timely remedial action. Many agriculturally important areas are threatened with inundation by the sea and need protection.

The northern Delta has lost land to the Mediterranean since the beginning of recorded time. The sea's level has risen about 2 meters since Roman times and the Delta itself seems to be subsiding at approximately the same rate (Waterbury 1979).

The annual contribution of new alluvium deposited on the Delta before the High Dam was built mitigated some of this loss. Entrapment of the sediments by the reservoir upset that balance and has caused an acceleration of the erosion rate on the Delta.

The Nile has two outlets to the Mediterranean, the Rosetta to the west and the Damietta to the east. Both peninsulas of the tributaries have retreated by several hundered meters and could breach into either the brackish water lakes fringing the coast or across agricultural fields. During heavy storm events in the winter months, seawater does invade the coastal lands causing a number of environmental problems.

The primary concern over seawater intrusion is for protection of groundwater quality. Groundwater is used both for drinking and irrigation and lies relatively close to the surface (El Shazly 1974). Seawater contamination of any portion of the aquifer would pollute freshwater supplies and increase reliance on the already overtaxed Nile.

Another potential environmental impact which would result from seawater intrusion is loss of the fishery practiced in the brackish water lakes that fringe the coast of Egypt. Approximately 90 percent of the fish consumed in Egypt are taken from these lakes, and most of the species would not tolerate significantly higher concentrations of salt.

A number of detailed studies of the coastal erosion problem have been made since 1978, although no official action has occurred to remedy the situation. It is likely that without assistance from an international organization, the problem will continue to be a serious one in the future.

ECOSYSTEM ALTERATIONS

RIVERINE CHANGES

The Nile has historically been considered a relatively clean river due to an absence of any major industrial activity along its banks. Anthropogenic sources of pollution consist primarily of domestic sewage from local villages. The self-cleansing ability of the Nile is thought to be sufficient for even today's large population within the Nile valley (Ramadan 1978).

Two changes in the river's use resulting directly from the Aswan High Dam are responsible for a deterioration of water quality in the river. The amount of agricultural drainage water returned to the river increased considerably as basin irrigation was phased out. Additionally, farmers began to apply more chemical fertilizers to replace the nutrients formerly brought in each year by the silt. This nutrient-rich water has resulted in serious seasonal blooms of aquatic vegetation throughout the irrigation and drainage network as well as the main Nile. The density of phytoplankton has increased more than tenfold since predam conditions (Ramadan 1978).

Perhaps the most worrisome development has been the recent introduction of water hyacinth (*Eichhornia crassipes*) to the lower Nile. Water hyacinth can be

found in all slow-moving water on the Nile and impedes navigation and operation of the Delta barrages. Mechanical harvesters are used to remove this aquatic weed at several points along the river; the government is reluctant to use chemical herbicides in the river.

The second use change in the Egyptian Nile since construction of the Aswan High Dam has been an increase in boat traffic. Both commercial and pleasure boat activity has gone up sharply due to the reliable water level afforded by the dam. There has been a significant increase in petroleum pollutants, especially at tourist sites (Mancy 1978). Large tour boats run between Cairo and Aswan on a regular basis year-round. Prior to the High Dam, only a few such tour boats operated, but by 1984 there were over 25 in operation.

There exists no systematic water quality monitoring program to test for petroleum-based products in the river. The sporadic data that have been collected indicate that hydrocarbon levels have increased and merit constant monitoring (Mancy 1978).

IMPACT ON RESERVOIR ECOSYSTEM

The Aswan High Dam and its reservoir are located in one of the most arid regions of the world. The reservoir has created a unique microclimate within this region characterized by a higher incidence of cloud cover directly over the water, lower air temperature, higher wind velocities, and an increase in relative humidity near the reservoir. These meterological anomalies do not extend far from the immediate vicinity of the reservoir.

The impoundment is monomictic and has a long season of stratification during the summer that parallels the air temperature regime. The breakdown of the stratification begins with the incoming floods in the southern region and the gradual cooling of the climate in the northern region. The northern two-thirds of the reservoir is lacustrine in nature, while the southern third varies from riverine to semi-riverine and lacustrine conditions depending on the magnitude of the annual flood (Fead 1981).

Remote sensing analysis of Landsat satellite imagery was used to monitor the spatial distribution of plants in the reservoir (Smith 1982). The satellite images clearly showed that algae, aquatic macrophytes, and aquatic hydrophytes concentrated along the near-shore zone of the reservoir. The analysis indicated that while the main channel of the reservoir remains relatively clear of vegetation, phytoplankton is distributed throughout the central area of the reservoir. High densities of vascular aquatic vegetation are found within the embayments.

The highest concentrations of aquatic vegetation occur during the summer months when insolation is greatest and water volume is low. Analysis of the Landsat images revealed that in June, for example, up to 52 percent of the surface area of the reservoir's embayments may be covered with a matte of vegetation. The flood has a flushing effect on the reservoir's aquatic vegetation. During the peak flood period, vegetative cover decreases to less than 20 percent in the embayments and less than 10 percent for the reservoir as a whole.

An immediate and permanent downstream impact of the High Dam was the loss of the Mediterranean sardine fishery. Suspended silt carried by the river fed the fishery with nutrients and supported a large, diverse biota. Closure of the river at Aswan trapped the silt and caused loss of the fishery.

Advocates of the High Dam project reconciled this loss with the argument that a new freshwater fishery could be developed in the Aswan Reservoir. Fish could be taken from the reservoir with substantially less effort than that required of the sea fishery. Also, the species, primarily Nile perch and tilapia, would be of higher nutritive value than the sardines.

The reservoir's fishery potential is quite high. Initial prediction of commercial fishing, made during the early stages of reservoir development, was 20,000 tons annually (Abdel-Latif 1980). The actual landing of fish was somewhat better, peaking at 28,000 tons in 1979. Total catch has levelled off in recent years at a sustained yield of approximately 24,000 tons.

There are a number of economic limitations in the Aswan Reservoir fishery practices. The main economic limitation of the fishery as a whole is an inadequate delivery system for shipping the catch to market. Currently the fish are transported by rail to Cairo and other large urban markets in the Delta. The rail cars are not refrigerated; consequently, a large percentage of the catch spoils on route. There is little question that if a more efficient means were provided for delivery of the fish, a much larger net benefit could be realized from the reservoir fishery.

IMPACT ON AGRICULTURAL LANDS

Of all the original environmental concerns raised about the potentially deleterious impacts of the Aswan High Dam, excessive groundwater may well prove to be the most significant problem. Drainage projects throughout the Nile Valley and particularly in the Egyptian Delta have been ineffective in reducing waterlogging and subsequent soil salinization. Agricultural productivity per acre has fallen in recent years due to increasing accumulation of salt in the soil. Overall production of food has increased in Egypt over the past decade only because perennial irrigation allows for multiple cropping during the year (Waterbury 1979).

Part of the problem relates back to the farming practices perfected before construction of the dam. Basin irrigation encouraged capturing as much water as possible during the flood period. The water would be diverted from the river and inundate the fields until, eventually, it would either seep into the ground or evaporate. Suspended and dissolved minerals and nutrients would be deposited to replenish the soil. This practice, when used in a perennial irrigation scheme together with a drastically underpriced (or free) supply of water, usually results in overwatering. The problem is further exacerbated by the presence of the year-round high water table resulting from high water levels in the channel. Prior to the Aswan High Dam, these levels fluctuated seasonally, becoming lower in summer and higher after the fall flood.

Evidence that the water table has risen along the Nile Valley since construction of the High Dam is confirmed by piezometric readings. According to the Egyptian Ministry of Irrigation, the water level has increased significantly throughout the valley. In low-lying areas, the water table reaches close to the ground surface.

Extensive drainage projects in the Nile Valley are designed to alleviate this problem for arable land. Conceptually, the implementation of this type of drainage network is not a difficult task. However, the problem is complicated both by the size of the affected area and by the lack of mechanized equipment available. Currently the Ministry of Irrigation is in the process of installing tiled drainage for the entire delta and hopes to accomplish the task sometime in the next decade.

PUBLIC HEALTH

The World Health Organization and a number of other international health agencies expressed concern about the possible effect of the Aswan High Dam on incidence and prevalence of waterborne diseases such as malaria and schistosomiasis. Other large-scale impoundment projects in tropical climates had created suitable environmental conditions for the spread of these and other diseases.

Schistosomiasis has spread with the gradual conversion from basin to perennial irrigation since the last century (Miller et al. 1978). With basin irrigation, snails, which are an intermediate host to the parasite, could not survive the dry season during low water. Longer contact time associated with perennial irrigation enhances the chance for infection. Consequently, the conversion of over three-quarters of a million acres in Upper Egypt from basin to perennial irrigation resulting from the High Dam was expected to be accompanied with an explosive rise in the incidence of the disease.

Public health surveys throughout rural Egypt have found a generally declining prevalence of schistosomiasis since the early part of this century (Miller et al. 1978). The decline is due to a number of factors including public health programs, protected water supplies, medical treatment, and health education programs.

Similarly, malaria is spread through open water. Since time immemorial, the harshness of the Nubian Desert and narrowness of the valley acted as a natural barrier protecting Egypt from invasion of the African malaria vector, *Anopheles gambiae*. This mosquito has, however, succeeded in advancing northwards and in establishing itself twice within the past 40 years. The first time, it invaded Upper Egypt in 1941-42, when it reached 600 kilometers downstream from the Sudan. In 1950, it again appeared and reached Abu Simble in Upper Egypt. In both cases successful vector eradication of this species was accomplished.

Currently, the northern limit of *Anopheles gambiae* is the Dal Cataract at the southern extreme of the reservoir. Favorable breeding conditions occur when the reservoir water level falls between December and July, leaving numerous pools in the rock side channels. Any slackening in the vector control programs conducted by the

Sudan and an increase in human population along the shores of the reservoir could potentially permit the advance of malaria northward.

LAND USE CHANGE IN THE NILE DELTA

DESERT AND URBAN ENCROACHMENT ONTO ARABLE LANDS

Throughout its recorded history, Egypt has fought against desert encroachment onto arable land. References to the engulfing of entire cities by shifting sands are found in writings over a thousand years old. Efforts to predict sand dune movement have been largely unsuccessful because of the stochastic nature of local wind patterns which dictate the depositional pattern of aeolian material. Some progress has been made by Egypt toward retarding or redirecting dune movement. Given the size of the problem, these efforts have proven inadequate. Land reclamation projects have attempted to balance some of the losses, but they represent a small fraction of the valuable land lost.

Egypt is still predominantly a rural country even though approximately 40 percent of its population now resides in cities of more than 2 million inhabitants. As is true in many lesser developed countries, the society is rapidly becoming more urbanized. Its urban population is growing at a much faster rate than the rural component (Waterbury 1979). Much of the urban growth may be attributed to greater public expectations for economic prosperity which indirectly resulted from the project. Prior to the High Dam, Egypt's economy was largely dictated by the varying flow of the Nile. After completion of the dam, however, the source of the Nile for Egyptians effectively became Aswan. For the first time in history, Egypt had nearly absolute control over its water supply. This confidence was reflected in accelerated economic growth and a dramatic population increase.

Cairo, the nation's primary city, exhibited the highest growth rate. Located near the apex of the Delta, Cairo has expanded in all directions including toward the desert to the east and arable lands to the north, south, and west. The greatest amount of urban development has taken place on arable land. Despite the fact that the government has encouraged growth on desert land and levied penalties for developers on farm land, people prefer the flatter alluvium of the Delta for both residential and commercial use. In addition, many of the settlements that sprang up around Cairo as a result of the 1967 war with Israel have now been effectively institutionalized as public housing projects. The vast majority of those settlements were located on arable land rather than in the desert.

Other large cities such as Zagazig, Mansoura, and Tanta have grown at almost the same rate as Cairo. These cities are "locked" into arable land and have had no option but to expand over the alluvium. This has resulted in the loss of several thousand feddans of agricultural land. Each has approximately doubled its size in the past 20 years, and they collectively account for a proportionally larger total loss than that created by growth in Cairo.

CONCLUSIONS

The Aswan High Dam has influenced virtually every aspect of Egyptian life. Some of the impacts of the project have been negative while others have certainly resulted in enrichment. The High Dam has succeeded in providing a reliable supply of water and power to Egypt without bringing on the environmental disaster predicted by some analysts; it will probably serve in the future as a good example of international cooperation for the betterment of living standards.

It should not be forgotten that the primary purpose of the High Dam is for water storage. This task has been performed admirably. In 1973, low rainfall in Ethiopia brought a pitifully small flood into Egypt. If not for the High Dam, drought conditions would have dramatically lowered agricultural production in the Delta and caused hardship in every sector of Egypt's economy. The flood of 1975, on the other hand, was extraordinarily large. If not held back by the High Dam, it would have had a devastating impact downstream in terms of scour and waterlogging of soil.

Two small examples, however, cannot be used to assess the ultimate wisdom of a project. Many variables go into the final judgment of its worth; without agreement on how to assign relative weights to these variables, no consensus can be reached on a project's value. There exists no final chapter on the Aswan High Dam story. We can only make periodic observations and try and make sense of the overall situation. As it stands now, the evidence suggests that optimism should prevail for the future of Egypt and its dam. The environmental problems associated with the project are well understood and manageable within the constraints of Egypt's economy.

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PART III
IMPLEMENTING RENEWABLE ENERGY SYSTEMS

CHAPTER 11.
IMPLEMENTING AGROFORESTRY IN A PHILIPPINE VILLAGE: AN ANTHROPOLOGICAL ANALYSIS

Robert C. Salazar
Daniel T. Hughes

INTRODUCTION

In the last decade, agroforestry has become a popular concept in forestry and development circles. It is a land use system which holds the promise of arresting the destruction of tropical forests and contributing to rural development. As a broad development strategy, agroforestry involves the integrated management and use of forest and agricultural resources. Whereas forests were previously managed primarily for conservation and industrial purposes, through agroforestry forest resource use is now proposed to complement the agricultural activities of rural populations, especially those in marginal lands. This is to be done by combining annual food crops with perennial forest plants and sometimes with livestock, either simultaneously or sequentially on the same unit of land, in ways that are compatible with the sociocultural, ecological, and economic conditions of the area and its people (Combe and Budowski 1980; King and Chandler 1978; Vergara 1983a, 1983b). Through this system of land use, it is hoped that local consumption needs may be met and additional incomes generated, while simultaneously sustaining agricultural productivity, maintaining ecological stability, and encouraging community participation (FAO 1981).

With the institutionalization of international support for agroforestry, interest has gone beyond the classification of specific technologies and small-scale experimentation and demonstration research, to actual project implementation in rural communities. While this trend is encouraging, it is also important, as Hamilton and King (1983, p.107) put it, "not to be seduced by a mystique that has arisen about the widespread applicability of agroforestry and its ability to solve all land use problems in the tropics." The need to take stock of the lessons of agroforestry implementation, therefore, has become more urgent. Indeed, only through continuing assessment can

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agroforestry avoid the fate of becoming another highly touted "miracle technology" that failed.

In this chapter, we focus on an agroforestry project in the Philippines, the Buhi-Lalo Upland Development Pilot Project (BLUDPP). Our discussion is centered around four main concerns in project implementation: (1) the formulation of general implementing strategies; (2) the channeling of resources into and for the project; (3) the development of the management capabilitites at the local level; and (4) the mobilization of demand for agroforestry and for community development among the farmers. Essentially, we argue that the implementation of agroforestry is influenced as much by the strategic interventions adopted by the project in each of these areas, as by the political, economic, and social contexts of implementation. The data for this study were gathered from project records and reports, through focus group discussions and formal interviews, and through the method of participant observation. Fieldwork was conducted from August 1983 to July 1984.

THE PROJECT

The BLUDPP was established in 1979 as a 5-year agroforestry/watershed management project of a regional program in southern Luzon, the Bicol River Basin Development Program (BRBDP). The long-term impact expected of the Buhi agroforestry project was the protection of a wastershed area that drained into the lake of Buhi, a town in the Bicol region. Set in the watershed were three contiguous villages (about 4161 hectares in area) which comprised the project's geographical focus. The project's more immediate objectives, however, were the following: (1) increased agricultural production and productivity; (2) increased productive employment opportunities; (3) increased farmer participation in development activities which affect them; and (4) the reversal of the deterioration of upland watershed areas. The project was also designed to test a community-based approach to agroforestry development, and to develop the capabilities of government agencies in agroforestry management.

The project had two major components: (1) reforestation, which was directed toward portions of the watershed which were in the public domain; and (2) agroforestation, designed for lands considered "alienable and disposable." Farmers were encouraged to plant forest and agricultural crops, establish firewood lots, and implement soil conservation measures such as bench and vegetative terracing, and contour ditching. Other programs included technical training for farmers, organization of farmers' associations, backyard livestock raising, and field experiments in agroforestry. The project was in operation from May 1979 to December 1984, and was funded jointly by the Government of the Philippines (GOP) and by the U.S. Agency for International Development (USAID), the latter having extended $220,000 in loans and grants.

Other studies have evaluated the project's implementation and performance, particularly during its first 3 years (Aguilar 1982, Silverman et al. 1982). It is

interesting to note, however, that the principal problems which these reports had identified and for which recommendations were proposed had continued to plague the project until the end. The flow of funds and material supplies was often delayed, and farmer participation was limited in many ways. Given the benefit of having the information from these earlier studies and of seeing the project through its closing years, we shall discuss some of these problems anew, along with the other concerns mentioned earlier. Our intention, we might add, is not to have the last word but to further broaden our understanding of the implementation process.

FORMULATING GENERAL STRATEGIES OF IMPLEMENTATION

A significant strategy which the planners used was to divide the project into a 2-year pilot phase (Phase I) and a 3-5 year expansion period (Phase II). Given the novelty of agroforestry projects, it was felt that a pilot phase could yield some lessons from which subsequent projects could learn. Planners thus emphasized a "learning process" approach to development administration (Korten 1980, Pressman and Wildavsky 1984). Indeed, the strategy resulted in some important revisions for the second phase. Plant species which were acceptable to the farmers were identified, and inappropriate regulations and procedures were modified.

It appears, however, that the effectiveness of any learning process depends heavily on the skills and resources of the learner. Throughout the design and pilot stages, the USAID consultant effectively fulfilled this role. Although his affiliation with the USAID already gave him some amount of power, his personality and his social and managerial skills further allowed him to mobilize support effectively from central and regional administrators alike. Local-level leaders and farmers were also impressed by his *pakikisama*, or his ability to get along well with others. Of course, not everyone agreed with his views. The regional hierarchy of the Bureau of Forest Development, for example, felt that some of his reports were biased and quite inaccurate, thus subsequently straining the relations between the BFD and the USAID. Nonetheless, his political and diplomatic skills were valuable to the projects. His absence during Phase II was felt particularly in terms of the project's articulating its lessons. Without the monthly reports which he sent to the agencies and officials involved, the project had less feedback to go by. Lacking his power and diplomatic skills, the project had more difficulty securing resources from outside. Some degree of dependence had undoubtedly developed between planner and implementer.

Phasing had other practical merits. Fearing possible delays in the negotiation process and needing ample time to prepare the basic inputs (e.g., nurseries and seedlings) before the onset of the planting season, planners divided Phase I further into a start-up phase of 6 months and a follow-on period of 18 months. This way, funds for the initial phase were gotten immediately, while financial and administrative arrangements for the later phase were being negotiated. Accordingly, the start-up

period was financed under a direct grant from USAID ($55,000) and the follow-on phase from other sources. Phase II remained as a loan-funded project ($165,000).

Given the combined goals of agroforestation, reforestation, and community development, what overall management structure was deemed appropriate in terms of agency involvement? For the first 2 years, the overall administrative reponsibility for the project was assumed by the Bicol River Basin Development Program Office (BRBDPO). The management of field operations, however, was assigned to a representative from a line agency, then the Ministry of Local Government and Community Development (MLGCD). This set-up did not function well because the project manager did not have full authority over the project and was not fully accountable to the interagency program office. Of course, this structure was only temporary, for the BRBDPO's long-term plan was to transfer responsibility for the project to a line agency. Several agencies were considered.

The first choice, the MLGCD, was eventually dropped from consideration reportedly because of the poor performance of its first designated project manager. An alternative choice, at least for the BRBDPO, was the Bureau of Forest Development (BFD), ostensibly because of the project's reforestation component. The USAID consultant, however, felt that the BFD had limited experience with the major components of agroforestry; namely, orchard development, soil conservation management, and farmer extension services. The consultant further argued that the BFD regional director himself expressed interest only in the reforestation component, for the agency was undermanned and already too loaded with work to even manage agricultural development activities. Instead, the USAID at first wanted the National Irrigation Agency (NIA) as the lead agency, but later proposed a division of functions between the NIA and the BFD, the former for agroforestation and the latter for reforestation. After all, 80 percent of the target areas were classified as "alienable and disposable" lands, and thus outside the BFD's jurisdiction. Furthermore, the NIA was in charge of most other activities in the loan package and had more extensive experience with community organizations. The stalemate was finally resolved in favor of the BFD taking full responsibility for the project as the lead agency. The basis for such decision is not clear, but what is apparent is that the BFD was chosen despite its expressed disinterest in the project at that time.

CHANNELING OF RESOURCES INTO THE PROJECT

The timely delivery of resources into the project was BLUDPP's most serious drawback. This is exemplified by the frequent delays in payment of salaries, at times for 2 months, and at other times for as long as 6 months. A number of factors seem to have contributed to this problem. First, with the transfer of the project to the BFD, more structures, channels, administrative levels, and regulations had to be taken into account, thus complicating the flow of resources. Secondly, in a number of cases, administrative procedures were not properly and promptly followed because planner

and implementing officials alike were not fully aware of such rules. In their evaluation report, Silverman et al. (1982, p. 80) even allege that key administrators from the BFD were "ill-prepared" and "ignorant of important GOP and USAID regulations concerning implementation of the Project and have, therefore, been surprised by bureaucratic obstacles which have frequently confronted them." Finally, as BFD officials argued in response to this criticism, the project design, in the first place, did not provide for a support staff (e.g., administrative officer, bookkeeper, supply officer, property custodian, cashier, and planning officer), thus preventing the BFD from decentralizing the financial management of the project.

To be sure, attempts were made to overcome these problems. The support of local and regional government officials was sought. A simpler transfer-of-payment scheme between the USAID and the project was devised. Adjustments in the financial administrative structure and procedures at the regional and local levels were introduced. Despite these changes, however, delays continued until 1984, thus indicating the influence of other variables. Indeed, the delivery of resources was affected as much by the overall implementing structure and the organization's managerial capabilities, as by the nature of the social and political ties among the project's key participants. For one thing, in addition to the transfer of the project from the BRBDPO to the BFD, the high turnover in important positions affecting the project undermined continuity and stability. In 1980, a new mayor was elected; in 1982, the USAID consultant took a new job and was replaced by another, while a new BFD regional director was also appointed; and from 1979 to 1984, a total of six managers had been assigned to the project (five from BFD and one from MLGCD). For another, there was the continuing process of conflict and competition among various key participants.

First, there was the competition between the newly elected town mayor and the deputy project manager, both members of the local elite but from different alliance groups. In some cases, the use of their respective networks benefited the project. Once, for example, the deputy project manager hastened the release of the delayed funds by calling on his social allies in the national bureaucracy. In turn, the mayor once flexed his political muscle by notifying the Office of the President of the Philippines about the financial delays, thus prompting immediate action from regional officials. On the whole, however, the project did not fare well under this political one-upmanship.

Second, the USAID and the BFD representatives also had their share of major differences. It may be recalled that the BFD did not find favor with the USAID consultant right from the start. The latter's critical reports worsened this already tenuous relationship by keeping the BFD on the defensive, thus perhaps reducing whatever support might have been available from the regional level.

Third, a veiled conflict also seems to have lingered on between the BFD's regional hierarchy and the deputy project manager. For reasons unclear, the BFD had apparently excluded the position of deputy project manager from the project's plan and budget. Threatened by this move, the deputy project manager denounced the

BFD for alleged mismanagement, citing the overpricing of tools and supplies and the delayed payment of salaries and wages. Although by 1982 many of those who had either inflicted or received the wounds had left, the bruised feelings between the USAID consultant and the BFD regional director, and between the latter and the deputy project manager, remained and had spread within each of their organizations. Consequently, attitudes and interests were less enthusiastic, and support less active. Finally, the lack of cooperation between the regional auditor and the BFD representatives has also been cited as a plausible cause for the delays (Silverman 1982). Although we do not have the data with which to confirm or refute this, our experience with other development projects in the area indicate that auditors are indeed important gatekeepers whose support must be secured. The process of implementation, therefore, is influenced not only by the complexity of organizational structures but also by the degree of political pressures which participants bring into play. Accordingly, resource flows can be hastened by simplifying channels and procedures, by mobilizing the support of key gatekeepers in the system, and by activating various sociopolitical networks of influence. Finally, implementation requires participants with considerable political know-how and diplomatic skills in orchestrating these moves.

IMPROVING MANAGEMENT CAPABILITIES AT THE LOCAL LEVEL

A few strategic interventions of the implementing organization were also instituted by the project at the local level. In view of the long-term plan to let the community itself manage the project, most project employees were local residents. Thus, a number of farmers were trained in nursery development and maintenance, while others were trained as extension workers. To establish a link between the local government and the project, an advisory "promotions committee" was also formed, with the town mayor as chairman. Finally, project activities were organized into two major components, with reforestation supervised by the BFD-assigned manager, and agroforestation by the deputy project manager. The planners' intent was to have a so-called nonhierarchical authority-structure in which the BFD, as the lead agency, was expected primarily to coordinate with and provide administrative support to the agroforestation unit, rather than manage it directly.

Although these interventions encouraged the development of local capabilities, they also provided participants with the opportunities for extending their respective networks of influence and support. In this context, the town mayor, the project manager, and the deputy project manager emerged as the principal patrons. The acquisition and allocation of resources, therefore, was done essentially through these lines of patronage, often with discouraging results for the project. In some cases, management decisions to hire or fire were made less on the basis of qualifications and job performance than on the strength of the client's social-political loyalties. A

farmer's wife, incensed by the nonrenewal of her husband's contract, remarked with pungent sarcasm:

> They should have told us during the training seminars that being a compadre (or a co-godparent in baptism or marriage) is an important criterion for employment. Look at _____, he is so inefficient yet he's still on the job because one of the managers is his compadre. Of course, my husband is too old to give me a child, but why, I could have flirted with some other guy in order to get pregnant, and I could have had the child baptized with the managers as godfathers! This way, my husband would have kept his job!

Organizational performance, thus, depended on the balance of power among the patrons. Personnel adjustments and other interventions which could have tilted the balance in favor of a rival were avoided, while those that strengthened one's own position were pursued. For this reason, inefficiencies in such critical areas as budget and personnel administration, community organization, and project monitoring were exacerbated.

At the same time, however, these patron-client ties also created pressures for compliance which hastened the attainment of other project objectives, especially those which patrons themselves pursued. Local norms of reciprocity dictated that subordinates give their loyalty and support in exchange for various favors from their patrons.

Otherwise, one would be criticized for having no sense of shame (hiya) and gratitude (utang na loob). From the perspective of many employees and farmers, for instance, the deputy manager had substantial control of and access to a wide variety of resources. He had lands to farm in the village, and he extended interest-free loans. As a former town official, he had many connections, and as deputy manager, his evaluation was crucial for promotions and for travel and training opportunities. It is no surprise then that despite the salary delays and some threats of a sit-down strike, the deputy was able to mobilize the farmers. With his authoritarian and paternalistic management style, however, cooperation was not really elicited but compliance extracted. This certainly was not the kind of participation the project had idealized.

MOBILIZING THE DEMAND FOR AGROFORESTRY AND FOR PARTICIPATION

The project's objective for agroforestation was to implement the following land development activities (LDAs): development of orchards (245 hectares); development of firewood lots (85 hectares); and soil conservation measures such as bench and vegetative terraces and contour ditches (56 hectares). To increase the demand for agroforestry, the strategy was to integrate the inputs and to facilitate access to them. Thus, seeds and technical assistance were provided free, tools were lent out, and labor subsidies were granted. Support systems and structures for the delivery of these inputs

were set up. Nurseries were established in accessible locations; farm development plans were drawn up; training seminars for farmers were conducted; a cadre of nursery workers and extension leaders from among the farmers was trained; and marketing networks were also explored. Economic incentives were also provided through short-term work contracts and through the distribution of livestock (swine, goats, and chickens) for backyard raising. On the other hand, the project was also expected to enlist at least 284 farmers as project "cooperators." To ensure their participation, farmers' associations were formed, and access to the project's inputs was made contingent upon membership in these groups. Social events such as singing contests and community dances were also held to foster community interest.

The project's outcome has been quite varied. By December 1983, originally the project's expected date of completion, four community associations had been organized with a total membership of 425 farmer-cooperators. Of these, 62 percent had at least one LDA while 38 percent had none whatsoever. Orchards and firewood lots were generally perferred by farmers (56 and 26 percent, respectively). A number of cooperators, in fact, reported additional incomes from the firewood lots which they had established 5 years earlier. Less acceptable were the soil conservation technologies. Bench terraces were constructed by only 11 percent of the farmers, vegetative terraces by 5 percent, and contour ditches by 2 percent. In terms of the total hectarage developed for each of the LDAs, the target for firewood lot development had been surpassed (103 percent), for orchard development almost completed (90 percent), and for soil conservation barely achieved (33 percent).

Other indicators, however, suggest that the project's accomplishments were more apparent than real. Most LDAs, for instance, were poorly maintained after the crops had been planted. Bench terraces in particular were still uncultivated 3 years after they were constructed. It was also discovered that some of the reported LDAs were done with much assistance from laborers hired by the project, at times with little or no help at all from the farmer himself. Finally, it appears that the distribution of subsidies may in fact have reinforced an existing economic gap inasmuch as the cooperators who received them had relatively higher incomes than the rest (Aguilar 1982). Additional data from our study also show that although there were more tenants than owner-cultivators in the associations (205 and 191, respectively), a significantly greater percentage of owner-cultivators than tenants received the subsidies (3 and 20 percent, respectively).

Community involvement in the project has also been limited. On the one hand, farmers may be said to have participated in the project insofar as they had contributed their time, their money (by way of membership dues), and their labor. They had also shared in the various benefits provided by the project.

Participation in decisionmaking and in evaluation, on the other hand, was much less evident. In the first place, the initial decision concerning the need for an agroforestry project as well as its goals and strategies was made not by the farmers themselves but by outsiders. Secondly, their involvement was limited to a few operational decisions such as the kinds of crops to be procured, or the manner of

distributing the livestock and the short-term work contracts among the members. Finally, when controversial decisions were at issue, farmers ultimately depended on the political elite. During the tense period when salaries were delayed and funds were allegedly being misused, for example, it was by informally mobilizing their communication networks and by having their complaints reach key political figures that farmers brought pressure on the management. Having shifted the responsibility for direct intervention to these leaders, farmers then expressed their views more willingly in the general assemblies. It was through these processes, therefore, that the decision to grant farmers access to accounting records was reached. As a result, the management saw the need to present periodically the project's financial reports to the staff and the associations.

This indirect, nonconfrontational approach was again followed in July 1983 when numerous complaints and allegations about the distribution of subsidies led the management to consider ending the subsidy scheme altogether. To legitimize this decision, the management asked the farmers to submit a formal petition seeking to use the funds for a seed bank instead. In general, therefore, farmers' associations functioned more as channels for implementing the management's decisions and for distributing the project's benefits, than for articulating the farmers' needs and demands.

Thus far, we have seen that the demand for agroforestry and for community participation has been low despite the project's strategic interventions. A number of factors seem to have contributed to this outcome. We shall limit out analysis, however, to the following aspects: (1) the delivery system; (2) the project's technology and its strategy for mobilizing participation; and (3) the economic, political, and social conditions in the village.

DELIVERY SYSTEM

The farmers' frustration over the project resulted in part from deficiencies in the delivery and distribution system. Early in the project, farmers complained that the criteria for choosing the recipients of the subsidies were unclear. They claimed further that some farmers even got their reimbursements despite inadequate improvements on the land. Allegations of favoritism were inevitably made. Late reimbursements led to further distrust in the organization and added to the tension caused by the salary delays and to other interorganizational conflicts. To avoid further problems, and as some farmers themselves suggested, the project ceased providing the subsidies and reallocated the remaining funds to establishing a seed bank.

The dispersal of livestock was also faced with similar difficulties. At the first dispersal of the sows, for example, all but one of the recipients were officers of the associations, again prompting allegations among members that officers were being unfairly favored. Subsequently, the management transferred the allocation decision to the farmers' associations themselves. Within the organizations, distribution decisions were made at times by drawing lots, in most cases through consensus and bargaining.

In this context the social and political relations among the officers and members were very much at play.

The untimely delivery of adequate and appropriate seeds was another source of discontent. While fruit and fuelwood species were supplied free to the farmers, the annual crops (grains, root crops, and pulses) that were needed for the bench and vegetative terraces were not. In fact, planners were uncertain whether subsistence crops were more appropriate than cash crops, and in either case whether the project was allowed to provide these inputs. As it turned out, the management had wrongly assumed that funds allocated for seeds could be used only for the perennial crops (fruit and fuelwood). It was only after 4 years, in August 1983, when the seed bank was proposed, that the farmers' request for annual cash crops such as ginger, garlic, and peanuts was heeded. But then again, the response was further delayed because the seeds were not delivered for 8 months.

TECHNOLOGIES AND STRATEGIES

Contrary to the experts' expectations that the LDAs would be easily adopted because they had been tried and tested elsewhere, most farmer-cooperators had left their bench terraces idle, the majority did not follow the suggested cropping patterns for their orchards, many were not satisfied with the project-preferred firewood species, and quite a few still practiced slash and burn cultivation. Certain features of the technological innovations themselves appear to have influenced these responses. Farmers explained that the terraces could not be cultivated immediately and were thus left to fallow because the fertile topsoil had been removed in the process of terracing. They also noted that compared to the more popular local firewood species ("bugus" or *Acalypha stipulacea* and "palo maria" or *Calophyllum inophyllum L.*), the project-introduced species ("ipil-ipil" or *Leucaena leucocephalis*) took more time to dry. Also, because of its texture, the latter species had certain limitations as building material. Cooperators were hard pressed in explaining why they did not plant their orchard crops in clean, orderly rows as the design had called for, or why some of them continued to burn the cut vegetative cover before planting anew, a practice which the project frowned upon. As some scientific studies have confirmed, however, the practices of burning and of planting a mixture of crops at random do have some ecological merits (Van Nguu 1982), and it is perhaps these results which reinforced the farmers' behavior.

The limited participation in decisionmaking and evaluating, on the other hand, may also be attributed to the project's understanding of and strategy for community mobilization. To begin with, the project design did not provide enough guidelines on how to achieve the goal of "improving farmer participation and developing self-reliance in developmental activities." Other than specifying the number of seminars to be conducted and the number of farmers to be enlisted, the planners seem to have left the project implementers to their own decisions on the "what, who, and how" of participation (Uphoff, Cohen, and Goldsmith 1979). For the most part, these

decisions reflected an equally unspecific and unprogrammatic strategy for mobilizing participation, though perhaps guided only loosely by the staff's interests and assumptions. The deputy manager, for example, impressed outsiders with his views on community organizing as empowerment and with his experiences with farmers' cooperatives. Contrary to these claims, however, the project in fact implicitly pursued the strategy of consensus-building and followed a "topdown" approach to community mobilization. The many conflicts in the project were resolved not by encouraging the farmers to organize themselves and articulate their demands as a group but by mobilizing traditional patron-client networks. In this respect, the project essentially followed the traditional model of community development rather than the "bottom-up" strategy of community organizing and its emphasis on confrontation and mass action. The latter, it appears, has been more effective in genuinely mobilizing community participation in the Philippines (Hollnsteiner 1979).

THE VILLAGE CONTEXT

The project's experience finally illustrates the bearing of economic, political, and social structures and processes within the village on the effectiveness of various interventions. In the first place, the village households have been faced with considerable ecological and economic uncertainties. Droughts, floods, and typhoons have alternately ruined the farmers' paddies and crops as well as the fishermen's corrals and cages in the lake. Technological changes in both farming and fishing have displaced farm labor, delimited the fishing grounds, and hastened the depletion of the lake's fisheries, including what used to be part of the poor man's diet, the "sinarapan" (*Mistichthy luzonensis* Smith) (Beveridge 1983). Uncertainty has come from outside the village as well. The market price of the farmers' crops has not kept pace with the increases in the prices of farm inputs and primary goods and the cost of education and health care.

Given these uncertainties, therefore, it seems only practical for the villagers to have been more interested in the subsidies and in income from wage labor, than in the LDAs. After all, the benefits from the latter were neither certain nor immediate. The farmers' decisions, however, were not simply the result of expediency but the outcome of a rational calculus of costs and benefits. This was evident in the farmers' selective preference for certain cash crops because of market price and storage considerations, in their interest in swine raising because of its lower labor and cash input requirements and higher returns, or in the low-priority most farmers from one village gave firewood lot development due to transport costs and difficulties. The project's technology, in effect, did not sufficiently address the people's short-term needs nor did its strategy adequately consider the variations in economic activities among the villages. Indeed, agroforestry's goals cannot be uniformly imposed on communities which vary in their use of agricultural and forest resources.

The farmers' decision to participate in agroforestry activities also appears to have been influenced by the demands and uncertainties in the system of land tenure. Many

tenants explicitly stated that they found no reason to develop the land whose fruits they would not be reaping anyway. Others introduced improvements only when they were confident that their relationship with the landowners was stable. These concerns are reflected in the fact that a significantly higher percentage of owner-cultivators than tenants (64 and 49 percent, respectively) had actually engaged in orchard development.

Finally, as the following examples indicate, project implementation is further influenced by village-level politics. It may be recalled that the project hired and trained upland extension leaders (UELs) from among the farmers themselves in order to improve service delivery. These UELs helped other farmers plan and implement their LDAs and encouraged them to participate in other project activities. They also provided feedback to the management and thus served as the principal links between the project and the farmers. This structural intervention had mixed effects. Although it provided the project with better access to village resources and kept it in closer touch with local developments, it did not necessarily lead to wider farmer mobilization. Apparently, the UELs' position and performance in the community sociopolitical structure constrained as much as it facilitated their effectiveness. For example, one UEL felt that her status as "barangay captain," or village head; her ownership of the only launch in the village; and her ties with other political factions all worked to her advantage. Conversely, another, UEL felt that his poor achievements as a village head even soured the farmers' view of him as an extension leader.

The farmers' associations also became an arena for village politics. In one association, for instance, the officers who got elected were active political leaders who belonged to the same party and who had previously run on the same slate for the village council elections. In another, two of three leaders who had served as presidents also had at one time or another been a barangay captain. Participation in the associations' activities also depended on the nature of the alliance structures within the villages. In one village where households "came from the same womb" as they said, mobilization in terms of attendance in meetings and adoption of LDAs was easily made along kinship lines. Patterns of participation in the other associations, on the other hand, also reflected the more diverse and relatively distinct sociopolitical alliance groups in the communities. Consequently, the project's scarce resources were inevitably converted to social and political capital inasmuch as allocation decisions were often governed by kinship and political considerations.

Irregular as all this may seem, for peasants everything was merely following its normal course. Many other village associations introduced by the government had all come to pass, leaving a few pockets full here and there. Besides, they argued, even the once successful farmer's cooperative which town-dwellers themselves established eventually failed despite the help of the nuns. Even the country's economy was in sad shape because of graft and corruption, they added. "So why have any illusions about village agroforestry associations?" they asked.

CONCLUSIONS

The Buhi agroforestry project had designed important strategies for implementation. Appropriate structures were set up to ease the flow of resources into the project and to mobilize the support of the local government and the farmers (see Table 11.1). The project thus seemed to have had the essential ingredients for success.

TABLE 11.1

Some Major Innovations in Project Design and Implementation

Formulating general strategies of implementation
1. Pilot strategy and a "learning process" approach
2. Phasing
3. "Lead" agency in a "nonhierachical" authority relationship with other government agencies

Channeling of resources into the project
1. Mobilization of support from local and regional government officials
2. Simplified transfer of payments scheme between the USAID and the project
3. Adjustments in the financial administrative structure and procedures at the regional level
4. Decentralization of financial management

Improving management capabilities at the local level
1. Hiring of employees from the community itself (including the deputy project manager, upland extension leaders, and nursery farm workers)
2. Formal linkages with the local government
3. Structural division into reforestation and agroforestation sections

Mobilizing demand for agroforestry technologies and for community involvement
1. Simple technologies
2. Use of economic and social incentives
   - integration of inputs (seeds, labor subsidies, tools, and technical assistance)
   - increased physical accessibility to nurseries
   - supplementary sources of income: livestock raising, construction work
   - social festivities (serenades, singing contests, community dances)
3. Formation of community associations for demand articulation and for the eventual take-over of the project

Although these management interventions achieved certain benefits for the project, they did not significantly affect the status quo. The formal and informal structures and procedures of implementation in both the wider bureaucracy and the donor agency showed limited flexibility in accommodating the needs of a small-scale project. Project resources and activities, in turn, were easily embroiled in the political competition among the local elite, the project officers, and the village leaders. Finally, the mixed results of the project in terms of land developments and organizational participation strongly reflected existing variations in the access to and use of political, economic, and sociocultural resources.

Clearly, agroforestry cannot be expected to yield significant changes in the people's lives and in their environment unless many of these variables that constrain implementation and participation are confronted. Some of these seem tractable, at least at the project level. Adjustments in structures and procedures may be made to allow a wider distribution of resources. Political leaders with the skill of orchestrating the support of diverse actors at various levels may also be designated. Other variables, however, are much less tractable, mediated as they are through the social structure. In order that changes in the latter can be realistically achieved, the political will to implement them is essential. Given these contraints, therefore, development planners and practitioners should be more modest in their claims regarding agroforestry's benefits to rural communities.

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CHAPTER 12.
THE POLITICAL ECONOMY OF DEFORESTATION IN COSTA RICA

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INTRODUCTION

Costa Rica presents a microcosm of the deforestation problem which currently plagues the tropical world. At one time, 99.8 percent of the country was forested; by 1977, this proportion had shrunk to 31 percent, with half of the loss having occurred since 1950 (Tropical Science Center 1983, p. 28). By 1984, the forested proportion was down to 26 percent. In recent years, Costa Rica has been losing its remaining forest cover at a rate faster than any other Latin American country. Of the 13,338 square kilometers of forest remaining in 1984, some 300-500 square kilometers are being lost per year (Myers 1980, p. 132). Forest reserves, Indian reserves, and national parks, respectively, protect 2788, 4338, and 4183 square kilometers, at least nominally (Tropical Science Center 1983, pp. 30-31). The remaining "unassigned" areas face extinction within a matter of years, and the nominally protected areas are by no means immune to destruction.

The rate of forest loss is actually accelerating throughout Costa Rica (Oficina de Planificacion Sectorial Agropecuaria 1978, p. 45). The only localities in which deforestation has been arrested are those where there is little forest left to lose. So, for example, in the heavily populated Central Region (home to 57 percent of the country's population), the remaining forest cover is confined to inaccessible and rugged patches of land. Even this scant cover might have disappeared in recent years were it not for the fact that the government housing construction monopoly in the Central Region has been too short of funds to clear this land for residential construction. At the other extreme, the Atlantic Region still possesses substantial forest cover, but expansion of road networks and growth in the banana industry in this region have spurred forest loss in recent years.

Beyond the primary environmental consequences, the social, economic, and political ramifications of deforestation are severe. Economically, systematic destruction of the nation's forests leaves watersheds unprotected, causing soil erosion,

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periodic soil dehydration (as the forest's capacity to buffer water release is lost), siltation behind the dams which currently provide 99 percent of Costa Rica's electricity, threats to potable water supplies, increased frequency and severity of flooding in low-lying areas, and problems for irrigation projects (located mostly in Guanacaste, in the northwest of the country). National topsoil loss in this primarily agricultural country is about 680 million tons annually. According to a recent report, 17 percent of Costa Rica is now severely eroded, and 24 percent is modestly eroded (Tropical Science Center 1983, p. 58). Eroded soil is deposited near the mouths of rivers, thus damaging the potential of coastal fisheries, and imperiling drainage from some of the low-lying banana growing areas. Less obviously, the genetic resources of tropical forest species are lost, too—some even before they are discovered or recorded.

At its worst, forest loss is irreversible. Once its forest cover has been stripped, the thin layer of soil erodes rapidly. Thus, the land can lose not only its ability to regenerate the original ecosystems, but also any potential for productive uses, such as commercial forestry. Indeed, despite the rate of forest clearance—or perhaps because of it—Costa Rica is on the verge of becoming a net importer of lumber for the first time in its history.

Deforestation in Costa Rica does present a pessimistic picture. Destruction of the ecological resources on which Costa Rica depends, threatens the prosperity of the country, and, by implication, threatens a degree of social stability, democratic government, and political tolerance unmatched in Latin America (Field 1982).

This study will proceed at the national level of analysis. This level of analysis is appropriate because of substantial commonality in the etiology of deforestation throughout the country. The entire country's forests are subject to similar incentive systems and resulting human behaviors, economic pressures, systems of property and land tenure, governmental rules, public agency jurisdictions, and central government policies. Costa Rica's small size, social and political homogeneity, and virtual absence of local or regional government add validity to a national level of analysis.

We will analyze deforestation in Costa Rica by making extensive use of the concept of a natural resource management regime. According to Young (1982), a resource regime is a set of institutional arrangements providing a structure for actors to operate and an incentive system composed of specific rights, rules, regulations, compliance mechanisms, and transformation mechanisms. A regime can have both formal (de jure) and informal (de facto) elements, which (as we shall see in the Costa Rica case) are not always consistent. The most important kinds of rights are property rights, which specify who may use a resource and what kind of use they may undertake. Rules and regulations are the obverse of rights, imposing restrictions on permissible behavior. Compliance mechanisms are the means for enforcing rights, rules, and regulations. These mechanisms can be carried out informally, through general acceptance of social norms, or formally, through administrative and legal systems. Transformation is the means through which a regime's rights, rules, regulations, and compliance mechanisms change over time.

In these terms, Costa Rica's forest resources are subject to a virtually uniform national regime. We hope to show that this regime is largely to blame for current deforestation problems, and we will explore the prospects for two alternative kinds of regimes that are sometimes proposed. But first, on what basis may we evaluate the existing regime and potential alternatives?

EVALUATION CRITERIA

We have already alluded to the problems associated with deforestation in Costa Rica; but what, precisely, is amiss? Clearly necessary at this juncture is some concise criterion or criteria of evaluation.

Given that deforestation in Costa Rica is primarily an ecological problem (i.e.,it occurs at the intersection of human and natural systems), its amelioration or resolution demands two primary qualities of social institutions such as resource regimes (Dryzek 1985). The first—usually stressed by ecologists (e.g., Odum 1983 pp. 47-50 and 288-89)—is negative feedback, which is the capacity to produce deviation-counteracting outputs in response to shortfalls in ecological life support capacity. The second—more usually emphasized by economists and political scientists—is coordination, which is the ability of individual and collective actors to operate in unison toward collective ends. Without coordination, the system succumbs to collective action problems such as the "tragedy of the commons" and under-provision of public goods (e.g., Hardin 1982). Negative feedback and coordination will constitute our evaluation criteria for the existing resource regime and its possible alternatives.

THE EXISTING REGIME AND ITS SHORTCOMINGS

In terms of the elements of resource regimes outlined above, the existing regime pertaining to deforestation in Costa Rica may be characterized as follows.

PROPERTY RIGHTS

Virgin forest lands in Costa Rica have historically been treated as common property. That is, any individual could make use of these lands as he or she pleased. This arrangement made obvious sense in an era of seemingly limitless "unused" forest and a small population. The idea that forest land is common property generally still applies today. Moreover, reforested land is often subject to similar treatment.

Costa Rica common law from the nineteenth century recognizes property rights based only on land occupancy and "improvement" (such as clearing trees or planting crops). If the land is occupied for 10 years in good faith, then the individual occupier receives legal title. However, if another party purchases the improvements, that second party can obtain "good faith" title immediately (Tropical Science Center 1983, p. 28).

Land can therefore change hands as a result of squatting, which is blessed by a 1942 law giving possessionary rights based on one year's occupancy. This process can affect private as well as public land, including land nationally protected in reserves or national parks. Indeed, squatting and subsequent land transfer have become an organized business in Costa Rica. Squatters are in the business for the profits to be made from establishing and selling improvements, rather than out of land hunger or any desire to establish themselves as farmers.

Invasions of public lands are, in principle, prohibited under a 1969 Forestry Law. This law has proven ineffective; not only does the Forest Service (Direccion Forestal General [DFG]) lack the resources to enforce the law, but the boundaries of public lands are often unregistered.

One widely advocated general solution to the tragedy of the commons is the conversion of abused commons resources into parcels of private property (Demsetz 1967), on the grounds that individual owners will take better care of resources if they can expect to receive the full benefits of good husbandry—and to bear the full burden of mismanagement. The trouble with this general solution as applied to the Costa Rica case is that the very mechanism for the establishment of private property rights—land clearance—requires destruction of the resource in question. Moreover, even having secured title to a piece of land, a landholder may pay scant attention to good management if he knows there is a tract of unclaimed forest nearby to which he can move once the soil on his present tract is exhausted. Thus, a peculiar set of incentives stems from a combination of existing laws and the circumstances of tropical forest ecosystems, whose soil is often too poor to support crops for more than a season or two under traditional farming practices.

Any possibility of more permanent returns might lead to better land management under private property. However, further skepticism concerning the purported benefits of a system of private property is warranted based on field observations suggesting that the individuals clearing forests for their own agricultural purposes lack the financial incentives as well as agricultural and ecological knowledge to manage land on a sustainable basis.

RULES AND REGULATIONS

As should be clear from the previous subsection, many laws of long standing support squatting and, hence, forest clearance. There are, however, a number of laws which appear to be more sensitive to the deforestation problem. For example, the Forestry Law of 1969 specifies that any clearing of forest land must receive a permit from the Forest Service, which is to be issued only if the land has sustainable agricultural potential (Tropical Science Center 1983, p. 30). Indeed, cutting permits were suspended for part of 1983. There is a good deal of sentiment in the legislative assembly in favor of stronger forest laws. Costa Rica's environmental laws are extensive; there are thousands of pages of environmental legislation on the statute books. However, there is little point in our describing these laws, even in the most

general terms, for their content is irrelevant to the operation and performance of the existing resource regime. The reasons are described below.

COMPLIANCE

The formal content of environmental legislation pertaining to deforestation is irrelevant inasmuch as the laws in question are simply neither enforced nor obeyed. In a study conducted by the Institute of Legal Research at the University of Costa Rica (Instituto de Investigacion Juridica 1981), a survey of seven cases actually tried under the Forestry Law revealed only one conviction, resulting in a 1-month prison sentence. In the remainder of the cases, three times the court accepted that the accused was ignorant of the law (even though this defense is legally impermissible), twice the court accepted that the accused had verbal permission from a forestry inspector to cut trees, two cases were lost under the statute of limitations, and in one case the wrong party was brought to trial. Thus, even when cases do end up in court, little sanction results from transgression of the law. Most transgressions, however, do not even get close to the legal system. Law enforcement is minimal. While this situation clearly benefits many individuals such as professional squatters, landowners complain that they receive no protection against land invasions, trespassing, or timber theft. This lack of enforcement exacerbates the "commons" aspect of forest resources.

Responsibility for the wholesale lack of compliance with existing laws or regulations rests to a large extent on the weak enforcement capabilities of Costa Rica's legal and administrative systems. This outcome is not surprising, given the lack of financial, administrative, and institutional capabilities Costa Rica shares with most less developed countries.

TRANSFORMATION MECHANISMS

Extensive reforms in the systems of rights, rules, regulations, and compliance mechanisms we have described are unlikely, given the weakness of the transformation mechanisms in the existing regime. A number of powerful organized interests frustrate reform; timber and cattle interests especially are powerful lobbies in support of the status quo. The economic (and hence political) hand of cattle interests is strengthened by the low-interest loans they receive from the nationalized banks to finance operations (Tropical Science Center 1983, p. 30). Moreover, pressure from cattle interests is hard to resist, given the importance of beef exports to the economy. In 1983, beef constituted Costa Rica's third largest category of exports, earning essential foreign currency at a time when demand for coffee, banana, and sugar exports was slack.

INCENTIVE STRUCTURE

The net result of the regime we have described is a rather perverse incentive structure. There is a continuous incentive for squatters to invade "unused" land.

Cattlemen with an eye on eventually acquiring title in some cases finance the activities of squatters. Fearing invasion, many private owners of forested land try to pre-empt squatters by clearing land themselves, thus securing control. Alternatively, they may sell land to the Institute of Land Colonization (ITCO) for use in land reform programs, and hence eventual clearance. Some large landowners go so far as to sponsor "armies" of squatters to protect the fringes of their property. Countervailing "armies" are organized too, in some cases under the auspices of political movements. Land is often acquired by the best-organized of these armies.

For those who control the land, the incentives are such as to promote forest clearance followed by a year or two of crops and then establishment of cattle pasture. Deforestation occurs in large measure not because of the returns from cropland or timber, but because of the returns from conversion to cattle pasture. Although information on land classification is unreliable, the Tropical Science Center (1983, p. 68) estimates that between 1950 and 1973 the proportion of the country under pasture increased from 35 percent to 50 percent. Unfortunately, pasture that was once rainforest has a short life span, due once again to the poor quality of soils. One particularly stark example may be found in the Coto Brus Valley, where there are large areas of abandoned pasture that were once forest. The land is now trampled, flooded, eroded, and not even usable for the cattle for which it was originally converted from forest.

Perverse incentives extend not just to private individuals, but also to government agencies. Thus, ITCO receives income from the "improvement" of lands under its jurisdiction, and hence encourages clearing. DGF claims ITCO-sponsored colonists are responsible for up to half the illegal deforestation occurring (Tropical Science Center 1983, p. 30).

However, some attempts have been made to provide incentives to promote reforestation. For example, under a plan initiated in 1979, any individual purchasing land and planting trees upon it may offset the cost against taxes owed to the government. The individual in question keeps any future profits from the operation. By 1981, around 1638 hectares had been planted under this program (Tropical Science Center 1983, p. 34). Unfortunately, the major effect has been to promote the planting of fast-growing softwoods such as pine and cypress, which yield quick financial returns but little contribution to ecological integrity. Occasionally, landowners cut natural forests in order to replant and receive the tax reduction. Any reforested land also becomes vulnerable to the encroachment of squatters. The net result is that reforestation proceeds at a minimal rate. Total annual reforestation of around 2500 hectares may be compared with the forest loss of 30,000-50,000 hectares.

An intended incentive to protect existing forests comes from the government's granting of tax credits on current assets for any land donated to the national park system. This program has had limited effect because payment is made in the form of long-term government bonds, which probable inflation and currency devaluation render unattractive.

Overall, it is clear that the existing incentive structure promises substantial short-term private gain from deforestation, which overwhelms the minimal threat of punishment for engaging in illegal activities. At the same time. miniscule financial incentives for reforestation and protection are offered.

ASSESSING THE EXISTING REGIME

We are now in a position to evaluate the existing regime in terms of the two standards of evaluation introduced earlier: negative feedback and coordination. Performance is wanting on both criteria.

NEGATIVE FEEDBACK

Ecologically destructive individual behavior does not result in nature imposing a significant short-term penalty on the individuals involved. As soon as a crop will not grow or a pasture will not support cattle, the squatter can move on to virgin land, and the rancher can buy exhausted cropland. Operating here is, in fact, a vicious circle of positive feedback (deviation amplification): The more ecological destruction an individual causes (by improper land management), the more land he will go on to spoil. There is insufficient individual reward for conservation practices as long as there is new land to move on to—regardless of how little forest remains in toto. The worse things get, the worse they become.

The activities of the government in Costa Rica do little to inject any effective negative feedback into man-nature systems. There is little wrong with the reception of feedback signals in government. Responsible officials are frequently highly aware of the scope and severity of deforestation problems.These signals are often translated into policy adoption—witness the voluminous amount of environmental legislation and hopeful reforestation programs that exist. There is some obstruction of feedback at the point of policy adoption. Note, for example, the persistence of systems of property rights more appropriate to a past era of abundant forests, with little attempt to change the content of these rights. Moreover, countervailing pressure from timber, cattle, and colonizing interests can impede policy adoption. But it is on the response side of the feedback cycle that government really breaks down, with the inability of administrative and legal systems to ensure either effective implementation of policies or compliance with laws and regulations.

The various administrative agencies of the Costa Rican government generally do little to enforce laws or promote adherence to the principles of effective natural resource management. The Forest Service is not able to prevent the 60 percent of annual forest clearance that is illegal. Even with the best intentions, the DFG simply lacks the staff and funds to police forested areas. In practice, the DFG attends only to timber cutting and ignores clearance for agriculture or pasture. Squatters tend to cut and burn forest quickly in order to secure their rights; there is little the DFG can do to stop them.

In contrast with the "turf expansion" motivation found in many governmental agencies in industrial societies, administrative agencies in Costa Rica often seek to assign responsibility to others. The result is often inaction. For example, the DFG believes that the Costa Rican Electricity Institute (ICE) should do more to protect forests located in watersheds above hydroelectric dams. ICE has more political influence and a larger budget than DFG. Though it does engage in some protective activities in watersheds where its investments are large, ICE regards high-altitude forests that catch much of the rainfall as outside its jurisdiction. Recently, ICE requested that a forest reserve be created to protect the watershed of one of Costa Rica's largest hydroelectric projects in the Arenal area of Guanacaste. More generally, ICE believes responsibility should rest with the Ministry of Agriculture (MAG), inasmuch as a large amount of cutting is now taking place in lowland areas, rather than in watersheds above dams..

COORDINATION

As with the feedback criterion, substantial failure is also evident with coordination. The preservation of ecological integrity may be in the general long-term interests of all who are involved (except perhaps, for foreign investors in agribusiness operations), yet degradation of forest resources continues. Systems of land tenure and property rights facilitate an effective tragedy of the commons, as each self-interested individual scrambles to maximize his share of the returns from an ever-declining common resource—forest land.

Government has proven unwilling or unable to promote coordination. Indeed, the Costa Rican government is thoroughly uncoordinated internally. A plethora of agencies has interest in the deforestation issue. Some of these agencies pursue ends directly counter to ecological life-support values. For example, the Agrarian Development Institute (IDA) views forests as "idle" lands and encourages squatting by redistributing large areas of land among small landholders. ITCO sees empty land in terms of opportunity for its colonizing mission.

Equally serious, though, is administrative confusion and a lack of coordination between the activities of agencies which should not, in principle, be antagonistic to one another. We have already noted differences between DGF, ICE, and MAG over who is responsible for protection of forested watersheds. A coordinating body for environmental policy was created in 1981—the National System of Environmental Protection and Improvement (SINAPROMA). But SINAPROMA has proven ineffective. Agencies are jealous of their prerogatives, and reject guidance and resent oversight. Yet, none currently exhibits any desire to take a more activist stance on environmental policy, and any interagency cooperation which does occur takes place in a sporadic and informal manner.

OPTIONS

The picture we have painted is bleak. Entrenched property rights, perverse incentive structures, and weak implementation and compliance mechanisms combine to violate minimal preconditions for effective resource management. What kind of resource regime could improve this dismal state of affairs? More to the point, what is the feasibility of constructing such a regime? We will consider two broad options, centralized and decentralized reforms, respectively.

CENTRALIZED REFORMS

There is a school of thought which recommends strong doses of central authority and planning as a solution to any commons-type environmental problem of the kind outlined in this chapter (e.g. Hardin 1968, Ophuls 1977). This position is adopted by many observers who have studied tropical deforestation in Costa Rica and elsewhere. For example, the Environmental Profile of Costa Rica written by the Tropical Science Center in 1983 is replete with centralizing recommendations: Laws should be enforced more stringently; more scientific studies should be conducted to provide the information necessary for effective management; government should direct reforestation programs; an integrated national environmental policy should be adopted; power should be concentrated in the hands of SINAPROMA; the DFG should exercise more effective control over cutting permits; funding for the various agencies should be increased; and effective control over public lands should be exercised.

There are a number of good theoretical and practical reasons why any such system of expanded central control could expect little success in Costa Rica.To begin with, wholesale centralization for environmental management of this sort has rarely worked elsewhere. The effectiveness of centralized environmental policy depends crucially on control being exercised by an ecologically motivated political elite. It is hard to point to the existence of any such ecological mandarins anywhere in the world. Members of governing elites exhibit a variety of motivations, some selfish and some public-spirited, but they are rarely thoroughly committed to a single overreaching goal in the way effective ecological administration demands.

Centralized administrative structures by their very nature have poor negative feedback sensitivity. Structures of this sort may be adept at certain kinds of tasks, especially those involving mobilization of resources toward simple goals while attending to a limited number of variables. Examples include fighting a war, moving the mail, and forcing industrialization (Lindblom 1977). Centralized structures are far less competent when it comes to interpreting and acting upon multiple, subtle, and locally variable feedback signals from a complex environment, such as that composed by the interaction of human and natural systems in the deforestation problem. The internal culture of a bureaucratic structure frequently distorts feedback interpretation.

Centralized administration perhaps promises more in the way of coordination than of negative feedback, though even here its promise may be illusory. Coordination through administration imposes a huge burden of calculation on the upper levels in a hierarchy, which must allocate tasks and responsibilities within the structure and ensure that actions in the various parts produce a coherent whole. Implementation studies frequently reveal that subordinate units in an administrative structure often exercise substantial independence from nominal superiors. Note, for example, the frequent clashes between the Department of Watersheds and Land Classification, and the Forest Service of which it is nominally a component part—not to mention the "passing of the buck" between different agencies we noted earlier.

As a practical matter, it is clear that Costa Rica, in common with most Third World countries, lacks the institutional, intellectual, and fiscal capabilities which would be required for stronger central analysis, oversight, and control in resource management. Strong-willed, public-spirited, and single-minded bureaucracies are not a Central American forte. While Costa Rica's government is already highly centralized, that centralization does not translate into effective control in resource mangement or elsewhere. Strong policy statements on environmental issues made by political leaders (up to and including the presidential level) are therefore rarely converted into action. One suspects that any alternative of centralized structure would produce only more of the same.

Despite our negative prognosis on centralized reform, such an approach might have some potential if it were confined to a small number of well-defined areas. Given the Costa Rica government's weak enforcement and compliance capabilities, the organizational resources it does have at its disposal would be best utilized if concentrated on a few areas, such as the national parks. In those areas, inspections from ground and air could be used to detect illegal encroachment on the forest. Inasmuch as organized business is involved in such cases, there might be some possibilities for property confiscation (which could, ideally, be put to good use in financing enforcement and perhaps even reforestation). But there is little reason for optimism concerning even such limited expansion of effective central control.

DECENTRALIZED REFORMS

The basic premise of a decentralized strategy is that the people closest to a problem are, given the right incentives and motivation, the people best qualified to solve it. Negative feedback signals have an immediacy which is hard to ignore, given that any worsening of ecological conditions will have a clear impact on the livelihood of the people involved in making collective decisions. The institutional design challenge is, then, simply one of coordinating the choices of these individuals to their common good. By definition, a decentralized regime involves dispersed power and authority; but to what kind of structures should they be dispersed?

At least two options are available here. The first would involve a modification of private property systems—to make private property secure once established, and

immune from the encroachment of others if it were not put to productive use. The usual incentives of private profit would then act to avert the tragedy of the commons, though private property owners might still choose to engage in destructive behavior if the financial return were great enough. Such behavior, while advantageous to the property owner (at least in the short term), could have substantial negative externalities (e.g., in terms of private and social costs of adverse watershed effects). Furthermore, any strategy emphasizing private property would involve a radical transformation of systems of property rights in Costa Rica. Moreover, its decentralization may only be superficial, because the enforcement of any such rights would require a stronger administrative and legal system than is currently available in Costa Rica.

A second decentralized option would involve local communal control. This option would be similar to the idea of "social forestry," which has been tried (with mixed results) in some Asian countries (Barnes and Allen 1981). Social forestry has not been attempted in Costa Rica, though it would be consistent with the sporadic "communal" land reforms which have occurred in a few localities (Seligson 1979). The land of an "empresas comunitarias de autogestion" is held in common by the community, and those who work it receive a salary. Communal control would also require the establishment of meaningful local governments.

Decentralized reform of this sort is no panacea. While it might work in a few isolated cases, any more widespread application would require little short of a revolutionary restructuring of the Costa Rican political economy. More gradual institutional reform would simply be too little, too late. Costa Rica's forest cover could virtually disappear in the years it would take to get a coherent decentralized structure in place. Any such communal restructuring would require some massive changes. Truly effective decentralist reform (or, for that matter, any kind of effective reform) would demand a thorough shift in the locus of decision-making power, wholesale change in the structure of property rights, and undermining of the power of cattle and timber interests and perhaps even sharp restrictions on the scope of market forces in the economy. In the context of the last of these points, it is noteworthy that Shiva, Sharatchandra, and Bandyopadhyay (1982) trace failure of social forestry programs in India to their subversion by people with an eye on financial profit rather than community ecological well-being.

DIVERTING ATTENTION

Given our pessimism concerning the efficacy of decentralizing reforms in the short term, and of centralizing reforms on any time scale, the future of the deforestation problem in Costa Rica might seem unremittingly bleak. The only positive short-term solution we have to offer is one that would divert attention and energies away from forest clearance. If such diversion could be accomplished effectively, then some of the remaining forest cover might be allowed to regenerate in those cases where soil and

nutrient loss has not made deforestation irreversible. The trick here is to devise a set of incentives which would make it advantageous for people not to deforest because the rate of return on alternative activities would be higher.

Clearly, any such approach would have to provide a high level of employment, so there would not be large numbers of individuals with nowhere to go but the forest fringe. One possibility along these lines would be a program of intensified farming production, based on nontraditional and labor intensive crops on land suitable for sustainable agriculture. Appropriate crops might include fruits and vegetables, spices, ornamental green plants, and flowers, which all require a high degree of care and attention. Local processing facilities would be needed for dehydration, freezing, canning, or fresh packing. Further, a substantial degree of education in agricultural techniques would be required. Foreign expertise would initially be necessary. Given the weakness of the Costa Rican government, this program would require finance from private interests and international aid agencies.[1] Its success would be contingent on the development of international markets for the agricultural products in question. Such markets would exist if the U.S.-sponsored Caribbean Basin Initiative were to come to fruition.[2] Costa Rica is well placed in this respect, for it is close to the United States, its internal communications are highly developed, and its climate is conducive to crops of the kind we have described.

Any such program would provide a number of incentives for the participation of private corporations and the Costa Rican government. The advantage to private businesses would lie mainly in the low operating costs in Costa Rica compared with costs of similar operations in the United States. With such financial advantage in mind, businesses might be induced to set up local processing facilities and educate Costa Rican agronomists and small farmers in appropriate agricultural techniques. The advantage to Costa Rica's government would be that such a program would promote exports, and also expand the tax base. On a long-term basis, any successes in this area would reduce the country's dependence on multi-national corporations.

CONCLUSIONS

The diversionary measures we have described may be capable of reducing deforestation pressures in the short or medium term, insofar as these pressures come from the rural poor. They would do little to inhibit the large-scale, organized deforestation engaged in by businesses. The latter kind of deforestation might require more draconian measures of the kind we described in our discussion of centralized

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[1]Over the past 15 years, the Latin American Agribusiness Corporation, S.A., and the U.S. Agency for International Development have undertaken a number of projects of the kind we are outlining here in several Caribbean countries.

[2]Costa Rica's industrial sector cannot readily seek any advantage from the Caribbean Basin Initiative because of the high average industrial wage compared to that of other Central American countries.

solutions; however, there is little cause for optimism concerning the effectivness of any such centralized strategy. Such a strategy may, though, be effective if it is confined to protection of relatively small, well-defined areas, such as the national parks. On a long-term basis, decentralized proposals might offer considerable promise, but in the meantime diversion of attention away from deforestation activities is perhaps the best that can be hoped for.

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CHAPTER 13.
SOCIOLOGICAL FACTORS IN NATURAL RESOURCES MANAGEMENT IN A TROPICAL WATERSHED

David O. Hansen
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INTRODUCTION

The primary objective of the Ocoa Natural Resource Management Project (NARMA) is the introduction of land conservation practices. Reforestation is a major component of this effort because, as is true for most mountainous tropical countries of Latin America, hillsides and steep slopes are increasingly being brought under intensive cultivation. Rapid population growth in rural areas, absence of uncultivated arable lands, and land concentration in the hands of a rural elite literally force the rural poor to avail themselves of these lands. Deforestation ensues as does soil erosion.

If, as many argue, it is unfeasible to transfer these populations to other areas, then it is incumbent on development planners to create programs that conserve nonrenewable resources while rationally exploiting renewable energy and other resource bases. In the case of mountainous terrain, this implies maintaining vegetative cover, including perennials, in addition to reforesting steep slopes.

Although the Ocoa is not currently dammed for hydroelectric power production, the topographic, edaphic, and land use characteristics of its watershed are illustrative of several major watersheds in the Dominican Republic which feed hydroelectric dams. Hydroelectric power is particularly important to the Dominican Republic because of the dearth of fossil fuels in the country. Traditionally, it has depended on imported oil to fuel electricity generators. Hydroelectric power has become an increasingly important centerpiece of the national economy because escalating oil prices have reduced foreign currency available for other needed imports. Soil erosion in catchment areas of these dams has seriously reduced the estimated life of these systems because of the excessive siltation of the artificial lakes on which they depend.

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This is one illustration of the complex interaction between natural resource conservation on hilly terrain and the sustainability of renewable energy systems. Ultimately, the viability of many renewable energy sources depends on the relationship between natural resource bases, technology, human populations, and the cultures which they possess. It is this set of factors and their interrelationships which are analyzed in this chapter. Particular emphasis is given to the human factor.

The analysis is divided into two parts. The first, titled "Social Analysis of the Ocoa Watershed," presents and analyzes data from the field study of the Ocoa River watershed. Principal conclusions and recommendations from this section follow. Data were gathered in early November 1981 by the authors and technicians from the Ministry of Agriculture's Department of Soil and Water and the AID Mission. Thirty-nine farmer interviews and 17 farm leader/agent interviews were completed throughout the watershed. The second part, titled "Implications for Project Design," presents comments on organizational facets of the project delivery system.

SOCIAL ANALYSIS OF THE OCOA WATERSHED

HISTORY AND LAND USE IN WATERSHED

Most steep slopes were not brought under cultivation until they were deforested by lumber companies that entered the area in the early 1950s after completion of a major highway that traverses the upper slopes of the watershed. Farmers from the lowlands followed the lumber companies. They possess farming technology inappropriate for steep lands and have unwittingly facilitated massive losses of topsoil. Hurricanes, like David and Frederick in 1979, intensify the soil loss problem.

LAND TENURE

The Catastro Rural (the Dominican Census Department) completed a census of rural establishments in Ocoa County prior to the field study, but the data had not been processed. These data have the potential to yield accurate and complete information on land tenure and land use by seccion and paraje (microregions), and could be of use in designing a project for the entire watershed.

Small and medium-size farms predominate in the watershed, and they contribute most to the natural resource degradation problem on the hillsides. The average amount of land per farmer in the survey is 10.35 hectares and the average amount of land cultivated or in pasture per farmer is 8.4 hectares. There is considerable unemployment and chronic underemployment in rural areas. There is insufficient land to support adequately the large rural population. Changes in productive systems to be promoted by NARMA must allow for intensive farming practices if a substantial proportion of this population is not to be relocated.

Forms of land possession vary considerably. Of those surveyed by the Soil and Water Department on another occasion, 41 percent held titles; 32 percent claimed

possession by inheritance; and another 27 percent claimed possession by occupation. Land titles are certified using the Torrens system (Clausner 1973, 200). Much state-owned land, which requires reforestation, is or will soon be occupied. It will be important to use the *Catastro Rural* data in elaborating plans to reforest them and reclaim other state-owned lands.

PRODUCTION SYSTEMS

Most farmers are at or near the subsistence level. Therefore, some form of compensation would probably be necessary before they would accept conservation practices that imply short-term reductions in income and/or farm production. Most farmers grow red beans and pigeon peas as cash crops and for consumption; they grow corn, manioc, and sweet potatoes for consumption. Farmers do not raise hogs because they were eliminated as part of the African Swine Fever Eradication Program. Many farmers raise a few chickens and some raise cattle. Farmers should be encouraged to grow beans, potatoes, and peanuts on flat lands. Intercropping systems which would permit farmers to continue to grow crops on steep slopes with less water runoff should be investigated. Farmers should be encouraged to leave plant foliage on the land after harvest, particularly legumes with high nitrogen content. They should also be encouraged to pen animals and bring them feed. This could help correct overgrazing on many of the slopes.

Typically, adult males carry out land clearing and cultivation activities which require heavy manual labor. Children over 12 years of age and wives participate in other cropping activities, as do other males who either work for wages or through convites.The convite is a form of labor exchange which is commonly practiced in rural areas. It occurs primarily at planting and harvest times. A farmer invites neighbors to help him undertake these activities on his property; the property owner provides the neighbors with meals while they work on his farm. Changes in farming systems implied by more intensive cultivation of perennial crops probably will not alter the division of family labor greatly. However, once planted, these crops will require less nonfamily labor. This may result in a weakening of the convite tradition unless other activities are introduced that require intensive labor sharing, or unless perennial crops are farmed collectively. The Institute for Agrarian Reform (IAD) experiences with collective farming suggest that this is probably not a desirable option.

Responsibility for farm animals is more or less equally distributed among the husband, wife, and children. Small-animal production can be increased substantially without greatly modifying other farm practices. Small-animal production will increase the role of women in small-farm production.

The introduction of natural resource conservation practices, including those that directly impact on small-farm production systems, will not affect the division of labor manifest in household chores. Family authority is centered in the adult male head of household which suggests that project activities should be directed primarily to him.

Few families have off-farm sources of income because of lack of opportunities. Several perform labor on other farms, but wages are low (DR$3.00-DR$3.50/day). Only 23 percent of the respondents of the recent survey produce charcoal, and most of them reside in the southern region of the watershed. Charcoal production is considered to be a last-resort attempt to subsist in the region.

The lack of arable state-owned lands and off-farm employment opportunities in the watershed has implications for project-design activities. To the extent that they imply less intensive agricultural production, they should be accompanied by programs of population relocation or programs that provide adequate off-farm employment.

SOCIOCULTURE FEASIBILITY OF POTENTIAL PROJECT ACTIVITIES

It is recommended that the convite tradition be used in promoting conservation activities in the Ocoa watershed. The Community Development Council (a local voluntary organization) and regional Soil and Water Office have used it to promote them in the past.

Effective reforestation projects will probably require changes in current Forestry Department policies which prohibit the cutting of trees for any purpose. Tree nurseries should be established in rural areas so that farmers have ready access to seedlings. Farmers should be allowed to cut timber, at least those trees which they plant themselves, or the economic incentive for planting will be absent. Reforestation of steep slopes should also require relocation of families that depend exclusively on their cultivation for livelihood.

Farmers will be more receptive to partic[illegible] forestation of steep slopes if they are simultaneously permitted to cultivate them. This alternative should be researched; and the cultivation of manioc, pigeon peas, and other perennial crops that provide greater ground cover encouraged.

Many farmers of small farms will resist the introduction of artificial pastures because animal husbandry is not a feasible option for them. They lack sufficient land and capital for purchasing animals, fencing, and so on. Further, they lack alternative arable lands to produce crops consumed by the farm family.

Soil conservation practices currently being introduced by the Soil and Water Department are compatible with existing production systems and are, thus, readily accepted by the small-farm farmer. They include erosion barriers, drainage ditches, and contour farming. Inanimate erosion barriers are the most popular because stones and tree trunks must be moved in any event, and because they require little or no maintenance once in place.

The introduction of coffee and fruit trees will be accepted by farmers if suitable climatic and marketing conditions exist. Alternative sources of income will have to be guaranteed while trees are still not in production. Ideally, these trees would be

intercropped with traditional crops. This alternative should be researched to determine which intercropping systems optimize soil conservation.

FARMER PERCEPTIONS OF CONSERVATION MEASURES

Farmers are aware that productivity levels have decreased. However, 49 percent attribute it to decreased soil fertility while only 23 percent attribute it to erosion. The relationship between soil loss and decreased soil fertility is not readily apparent to them; therefore, they propose "feeding the soil" as the solution. Educational programs should emphasize the soil erosion process, its causes, and its effects on productivity.

Over three-fourths of surveyed farmers are willing to introduce soil conservation practices on their properties and on community lands. All are willing to contribute labor in introducing them. However, only 13 percent said they would be willing to invest capital in conservation measures on their properties, and only 5 percent were willing to do so on community lands.Most do not have working capital of their own, but are willing to use credit to introduce conservation practices. Eighty-three percent indicated that they would need technical assistance in addition to credit; 44 percent indicated tools; and 18 percent indicated food. These inputs are currently being provided by Soil and Water technicians and the Community Development Council for conservation activities. It is recommended that this practice be continued.

Because many farmers are at the subsistence level, they may perceive the implemention of conservation practices as an unacceptable risk. Minimizing short-term reductions in food production and individual capital outlays may help reduce this perception. When the conservation practices entail some short-term reductions in food production, it may be necessary to provide alternative income-generating employment, if they are to be accepted by the small farmer.

RURAL ORGANIZATIONS

Principal rural organizations in the Ocoa watershed are the German/Dominican potato cooperative "Santa Cruz," farmer associations, housewife clubs, and youth clubs. The potato cooperative was organized to provide technical assistance in potato production and to market potatoes. It has 970 members of which about 400 are active. Plagued by internal problems several years ago, it almost failed. However, it appears to be regaining the confidence of its members. It jointly provides technical assistance in production and soil conservation activities to farmers with technicians from the local federal extension office.

There are 53 farmer associations in Ocoa county that are affiliated with the Farmer Federation. Several may be in communities outside the watershed, but there are also nonaffiliated associations. The Federation's goal is to secure arable land for farmers which makes it highly political, and, therefore, probably less qualified to undertake NARMA activities. Local farmer associations, on the other hand, are organized to obtain credit and farming inputs, as well as land, and to promote community development projects. They are led by elected officers, typically a president, a

vice-president, a secretary, a treasurer, and several council members. Each association also has working committees that are organized to address pressing local problems. Natural resource conservation committees should be promoted in each association by the Soil and Water Department. Ideally, the leader of this committee would be a community leader, and act as a paratechnician in natural resource conservation. Most farmers in communities with associations belong to them, attend meetings frequently, and feel that the associations are useful. Women generally do not participate in them; when they do, it is to attend meetings as heads of households.

Associations have undertaken community projects such as road or bridge repair, school construction, and so on. Normally, farmers have participated in convites to carry out these projects, providing labor, while the Community Development Council has provided them with tools, food, and technical assistance. Recently, the Soil and Water Department has promoted conservation activities using the same mechanism. Use of this mechanism to carry out future individual and community conservation projects should be encouraged.

There are fewer housewife and youth clubs in rural areas than in urban areas. Young men and women typically participate in the latter. These clubs are directed by an elected president, a secretary and a treasurer. Youth clubs promote recreational and cultural enrichment activities. Housewife clubs teach homemaker skills to young men and women, thus enabling them to secure nonfarm employment. They can also be used by Agricultural Extension and the Public Health Department to teach conservation, and nutritional and family planning concepts and techniques, all of which should be part of a comprehensive watershed development project.

Conservation practices should be introduced through farmer associations and possibly through youth clubs. Association leaders favor setting up demonstration areas on land owned or borrowed by them from members. Ideally, lands would be worked by members using the convite tradition.

GOVERNMENT SERVICES

The Ministry of Agriculture (SEA) and the Agricultural Bank are two most active agencies in the watershed. SEA provides services through its Agricultural Extension and Soil and Water Offices. The Agricultural Bank provides credit to 81 percent of the farmers surveyed, and the Extension Office provides technical assistance and seeds to 63 percent of them. Some seeds are loaned to the small farmers. These services are directive. They are determined a priori by the agencies and provided to farmers, if farmers request them. The Soil and Water Department promotes soil conservation and irrigation projects. It builds on past efforts by the Community Development Council and cooperates with the Council in carrying out many of them. Thus, it is more responsive to farmer needs. It has concentrated on introducing relatively simple conservation practices that are easily understood by the small farmer and have been accepted by him. Emphasis is given to "demonstration" areas. Its projects have maximized farmer participation.

Most farmers would like to have a Cooperative Service Center installed in San Jose de Ocoa. Its greatest perceived value would be to market their products and to provide cheap farm inputs. Many would be willing to invest in it, although the extent of investment would be limited by "their ability to do so."

FAMILY PLANNING AND NUTRITION

Population pressure on land in the watershed is great. Among respondents in the November survey, the average family size is 7.5 people, and the average amount of land worked per family is only 8.1 hectares. Most arable land is currently under cultivation; therefore, pressure on the land will increase unless there is considerable outmigration or drastic reductions in human fertility.

Seventy-one percent of the surveyed farmers know about family planning; however, only 41 percent practice it. Families that practice family planning have fewer children. Most farmers have heard about family planning from public health agents who give talks in their community or from radio broadcasts. Direct contact by public health agents is the most effective source of information. Most couples are willing to practice birth control, particularly after having several children. Rural women are more receptive to these ideas than are men. Men in geographically isolated areas are more likely to adhere to traditional sexual mores.

Hunger is ever present in rural areas. Many families eat only twice a day; some eat only once a day. Diets emphasize carbohydrates—rice, beans, plantain, sweet potatoes, and cassava; protein intake is inadequate. A Peace Corps Volunteer working on nutrition in Ocoa estimates rural diets to be 60 percent deficient in protein intake.

Many farmers recognize the value of protein food sources such as eggs, milk, and meat. Most said that they had learned about food nutrient values from their parents; 21 percent had learned about them from public health agents.

Probably the most effective way to teach family planning and nutritional concepts and practices would be through direct contacts by public health and SEA extension agents. Ideally, they would use housewife and youth clubs, and farmer associations to make presentations and to organize horticultural, animal, and food conservation projects.

MASS MEDIA USAGE

Most farmers listen to the radio; many of them listen daily. Most farmers are illiterate and, therefore, do not read newspapers. Agricultural technologies are disseminated over the radio. Farmers frequently listen to programs such as "Talking to the Farmer" which is broadcast by "Radio Ocoa." These programs should be expanded.

Geographically isolated farmers are more likely to question the validity and reliability of information obtained over the radio and in newspapers. Technical

information is more readily accepted by farmers, particularly if they hear it from other farmers on the radio.

It is recommended that the SEA Department of Environmental Education become more actively involved in the Ocoa watershed. Slide shows that teach environmental practices and that are based on experiences in the Ocoa watershed, should be prepared for use with the farmers. Attractive wall posters and other educational materials that farmers and rural merchants are likely to display in their residences and/or places of business should be elaborated and disseminated in the region.

MIGRATION

Relocation of farmers cultivating steep slopes will be an important facet of NARMA. These slopes should be taken out of production and in many cases reforested.

Young people with above average education typically migrate from the area in search of a better life elsewhere. They do not identify strongly with rural places of origin and typically move to regional urban centers such as San Jose de Ocoa and Bani. Some migrate directly to Santo Domingo, although step migration appears to be the norm. Most men in this group find menial employment such as work in the construction industries or as street vendors. Young women encounter more limited opportunities and most work as housemaids.

Most less educated young people continue to reside in rural Ocoa or migrate to other rural areas. Few are fortunate enough to obtain land. Some migrate to irrigated agricultural areas such as Azua where they sharecrop, while others work as farm laborers or in sawmills in the central mountain range.

Willingness to migrate varies. Those who own land will not migrate without guarantees of arable land and credit elsewhere. Willingness is associated with aversion to risk; the closer to the subsistence level of farming, the greater the perceived risk in migration.

Preliminary contacts should be made with the Institute for Agrarian Reform (IAD) concerning the possibility of relocating farmers to agrarian reform settlements. Vocational training for young farm men and women should also be emphasized. It is clear that they will migrate from the area because of lack of opportunities. Their migration should be encouraged, but they should be provided with job skills that will allow them to obtain gainful off-farm employment. It is recommended that the Plan Sierra experience with vocational training be evaluated by NARMA project designers.

IMPLICATIONS FOR PROJECT DESIGN

SITE SELECTION AND PROJECT FLEXIBILITY

Selection of areas for undertaking project activities should take into account the local population's awareness of natural resource depletion and willingness to address

the problem. These factors are highly associated with the level of degradation of the natural resource base. Priority should be given to areas of the Ocoa watershed that solicit the assistance of Soil and Water technicians. Farmers must be willing to mobilize themselves for participation in watershed development activities. Although a watershed development design that includes all areas should be prepared, priority ranking of them should be based on farmer interest. Complete coverage of the watershed should be considered secondary, and is likely to occur in any case as spread effects occur. For land conservation activities, it may be desirable to continue working with farmer associations that have already received technical assistance from Soil and Water technicians.

Local participation is maximized by assuring that project activities address the needs of each site. This requires that the project be flexible. It will be necessary for project designers to conduct site-specific research, and sufficient leeway should exist in the budget to attend to the particular needs of each area. Project activities should undergo continuous evaluation and adjustments should be made when problems with the original design surface. Planners and technicians must be mindful of the long-range time frame of project activities, and the fact that it is a pilot project. The ability to adjust the project design is one indicator of pilot project success.

DELIVERY OF SERVICES MECHANISM

The Current Situation

The service delivery mechanism proposed in the Project Identification Document consists of three major components. First, farm management plans are to be prepared for each farmer with the assistance of SEA technicians. Second, the Agricultural Bank is to provide credit for carrying out these plans. Third, the plan will be implemented with the assistance of Soil and Water technicians and farmer associations.

The mechanism is appropriate for this type of project. However, to be effective, several important factors must be considered before implementation. First, it will be important to review past conservation practices and the way they have been carried out. The project will not commence in a vacuum. Positive and negative aspects of past activities as well as farmer attitudes towards these activities should beanalyzed. Second, it will be necessary to review traditional agricultural practices in the region. Farm plans should be compatible with current practices, or the farmer is apt to reject them. Third, the plans must be intelligible to the small farmer who, in most cases, is illiterate. They must minimize use of reading and writing skills which most farmers do not possess, and in some cases, do not appreciate. Fourth, it will be necessary to consider the intentions of SURENA regarding how the plans are to be developed and implemented.

Two major types of conservation activities are currently underway in the Ocoa watershed. The Soil and Water Office is introducing soil conservation measures along the San Jose de Ocoa-Constanza road. These activities build on past efforts by the

local Community Development Council to increase farmer awareness of the soil erosion problem. Soil and Water agents have been working in the area for approximately 1 year. During this period they have given assistance to individual farmers and to groups of small farmers which have sought their help.

The latter assistance merits review, for it indicates how farmers of small farms are now being taught through organizations. Farmer associations provide labor which is used to build irrigation canals, drainage ditches, and so on. Most farmers are willing to participate in collective efforts for 1 or 2 days per week, except at planting or harvest time. Soil and Water agents provide the technical assistance needed to undertake these projects. An agent indicates the appropriate technique to be introduced and supervises the work. The Community Development Council provides food for the workers who participate in the projects. This food is given to them by CARITAS. Picks, shovels, and other tools are supplied by the Soil and Water Office and by the Community Development Council. Worker brigades have also been formed by the Council to carry out hurricane reconstruction activities in other parts of the region. There is a potential to form brigades to carry out reforestation and land conservation practices on state-owned land.

The second major activity is educational. Soil and Water technicians promote conservation practices at periodic meetings of farmer associations in the watershed and over the local radio station. Interviews with farmers throughout the watershed suggest that both practices have been very effective.

Normally, farmers participating in a convite rotate from property to property until all of them have been visited. This custom has been used by the Community Development Council and the Soil and Water Office to satisfy the labor demands of conservation activities.

The Soil and Water Department intends to continue activities currently being realized in Ocoa with funds from NARMA. It will amplify them and build on earlier experiences. Priorities for additional inputs into the area will be defined by the detailed project design which will be elaborated during the coming months. Technical criteria will be used to rank areas in priority.

Regional Structure

Conservation activities currently underway in Ocoa are important and valuable. Further, they are well received by the local population and have built on customs and traditions of the region. It is important that they be encouraged and strengthened. Soil and Water technicians have developed a rapport with small farmers which has improved their effectiveness.

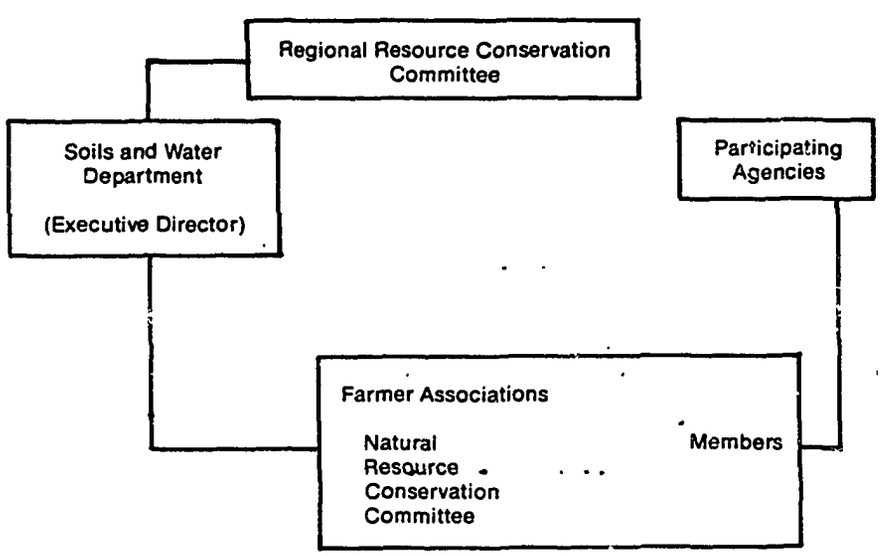
However, these activities have not been systematic. They have originated largely from individual contacts by farmers and farmer associations with the Soil and Water agents. A complete inventory of the natural resource base of the watershed does not exist. In the year of activity in the watershed, Soil and Water agents have not visited less accessible, but critical, regions. There is little communication between them and

representatives of other agencies dealing with natural resources such as INDRHI (Hydraulic Resource Institute), *Obras Publicas* (Road Maintenance), and *Salud Publica* (Public Health). These factors inhibit effective watershed development planning and activity.

Therefore, it is recommended that, in addition to strengthening ongoing activities, simultaneous attention be given to developing a comprehensive watershed development plan that will incorporate and systematically expand these activities.

Local organizational structures which would probably best facilitate planning and coordination of activities are found in Figures 13.1 and 13.2. The structure represented in Figure 13.1 is appropriate for a program that is limited to soil and water conservation activities; that in Figure 13.2 is appropriate for a comprehensive watershed development program. Each recommends the creation of a regional committee to establish policy and facilitate coordination of activities among various agencies concerned with natural resource conservation and use; each also maximizes grassroots participation of farmers in project activities.

FIGURE 13.1 ***Organization option 1 for watershed development program.***



Under Option 1, an overall Resource Conservation Committee would be established. Its members would represent the local community and divisions of SEA that are directly involved in program activities. The committee would be advised by representatives of other agencies concerned with the conservation and rational use of the natural resource base.

The committee members would consist of the following:

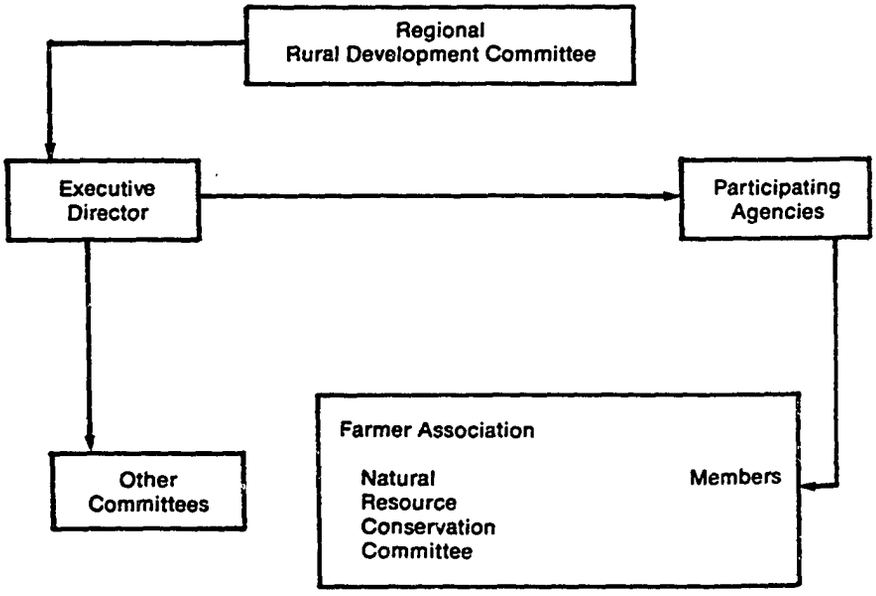
1. Mayor of Ocoa County
2. Three Farmer Association representatives
3. Community Development Council representative
4. Regional Director of SEA
5. Director of Soil and Water Department
6. Project Executive Director (from Soil and Water Department)

The advisors would consist of the following:

1. Dominican/German "Santa Cruz" Project representative
2. Public Works Department representative
3. INDRHI (Instituto National de Recursos Hidraulicos) representative
4. Forestry Department representative
5. Agricultural Bank representative

The committee would be responsible for making policy for the program. Ideally, it would review the program design prior to its implementation, make recommendations for changes, and advise on priority listing of activities. It would coordinate activities of the various agencies related to the program.

FIGURE 13.2 ***Organization option 2 for watershed development program.***



Executive responsibility would rest with the Soil and Water Department. Farmers would participate in the program through farmer associations to which they are affiliated. The associations provide for greater program coverage with limited resources, and build on indigenous social organization. A natural resource conservation committee (NRCC) would be created in each association. The committee would provide a direct link between Soil and Water agents and the Regional Conservation Committee. Heads of NRCCs would be trained by Soil and Water technicians. They would act as paratechnicians, responsible for developing the farm management plans of association members, for supervising conservation activities in which they participate, and for promoting conservation education. They would be paid for their work in this capacity, and would be assisted by Soil and Water technicians assigned to their region.

The advantages of Option 1 are as follows:

1. The program is more easily managed because it is limited in scope to soil and water conservation activities and only includes agencies dealing with them.
2. The structure maximizes the participation of farmer associations.
3. The structure maximizes the participation of various agencies in policy formulation and project execution.

The disadvantages of Option 1 are as follows:

1. The structure lacks an executive capacity that is independent of participating agencies. Thus, it may be perceived as less legitimate by several agencies and encounter difficulties in eliciting their participation in program execution.
2. The program ignores watershed development activities not related to soil and water conservation, per se, such as research, marketing, migration, population control, and vocational education.

The organizational structure found in Figure 13.2 is appropriate for a comprehensive watershed development program that simultaneously deals with farm technology development, the reducion of population pressure on the land, and soil and water conservation activities. Under this option, an overall Rural Development Committee would be established. It would consist of representatives of the local community and SEA departments most integrally involved in the program. As true for Option 1 the committee would be advised by representatives of agencies undertaking development activities in rural areas.

The committee members would consist of the following:

1. Mayor of Ocoa County
2. Three Farmer Association representatives
3. Community Development Council representative
4. Director of Soil and Water Department
5. Director of Agricultural Extension Department
6. Director of Agricultural Research Department
7. Executive Director

The advisors would consist of the following:

1. Dominican/German "Santa Cruz" Project representative
2. Public Works Department representative
3. INDRHI representative
4. Forestry Department representative
5. Agricultural Bank representative
6. SEAPLAN (Subsecretaria de Planificacion Agropecuaria) representative
7. Public Health Department representative
8. Dominican Agrarian Institute representative

This committee would also be responsible for policy formulation and would exercise responsibilities attributed to the Regional Resource Conservation Committee of Option 1.

Executive responsibility would be given to an executive director who is independent of the participating agencies. The executive director would coordinate activities of the various agencies who would in turn carry out project activities with participating farmer associations. Their link to the associations would be through committees organized to receive assistance and facilitate interaction between agencies and association members.

The advantages of Option 2 are as follows:

1. The program and structure treat all facets of a watershed development program, including soil and water conservation practices, research and measures to reduce population pressure (migration, off-farm employment, family planning).
2. The executive director has greater legitimacy in that he is not associated with any one institution.
3. The structure maximizes the participation of farmer associations.

The disadvantages of Option 2 are as follows:

1. The program is more comprehensive; therefore, activities will be more complex and costly.
2. Executive control is independent of government agencies and, therefore, will not be institutionalized.

Viability of Farm Management Plans

The concept of a farm management plan is new to most farmers and is not well adapted to slash and burn agriculture. It is important for many farmers to become familiar with the concept because they cultivate lands continuously.

It will be important to emphasize two facets of the methodology that is followed. First, instruction should be easy to understand and should provide for assistance by another person. Second, the farm management plan should be comprehensive, including not only conservation practices, but also appropriate land use techniques.

That is, it should emphasize crop production, pasture management, and reforestation where appropriate.

In keeping with past practices, activities should be labor intensive and capitalize on the convite tradition. Once farm management plans are prepared for members of an association, they should collectively participate in carrying out programmed activities on each other's farms. They should be supervised by the paratechnicians who in turn are advised by Soil and Water technicians. Food for the workers may be provided by property owners or by the Community Development Council, in which case it should be considered a gift.

If credit is extended to farmers for conservation activities, it will be unwise to associate it only with conservation and/or reforestation. Farmers are apt to question how the credit will yield additional income to pay the loan. Given the short planning horizon of subsistance farmers, it is unlikely that assurance of long-range benefits will convince them of the merits of this credit use. Thus, credit for conservation should be combined with credit for agricultural production, and money allocated through the Agricultural Bank should not represent a separate line of credit. The regional office of the Agricultural Bank has a capacity to handle additional loan volume.

SPREAD EFFECTS

The degree to which conservation practices will be accepted by farm communities and associations adjacent to communities that participate in project activities partially depends on how the project is carried out. Judging from the year of activity of the Soil and Water Office in San Jose de Ocoa, the potential for diffusion to neighboring areas is excellent. For example, several farmers built drainage ditches prior to hurricane Allen. Their crops remained intact while the rains washed away the soil and bean crops of neighbors. Now all farmers are requesting help to install drainage ditches in their fields. Wealthier farmers of the region are paying laborers to dig them.

This example clearly demonstrates that conservation activities do spread. Several factors are likely to facilitate this process:

1. Working with farmer associations.
2. Maximizing the use of farmers in the diffusion process.
3. On-site visits.

Initially, cooperation should be only with those farmer associations that are anxious to undertake conservation activities. In Ocoa, they have already been identified. As they complete conservation projects, members of other associations should be invited to speak with their members and visit project sites. Project activities will probably be interpreted as a status symbol; indeed, if successful, they will also yield economic benefits. This will probably result in a "keeping up with the vecinos (neighbors) effect" among associations. Other associations will not want to be left out. Members of the Department of Rural Organization/SEA have indicated that they

used this effect to great advantage in other promotional activities (personal communication, Mr. Enrique Chalas).

Ideally, farmers who have been involved in project activities should be used as change agents. Other farmers are prone to accept new ideas if respected leaders of their community and/or surrounding communities are proposing change. Leaders should be used as paratechnicians in which case they can also provide technical advice on how to implement conservation activities and information about their economic benefits. A second use of farmers in the diffusion process is through radio broadcasts. Programs such as "Speaking with the Farmer" of the Ocoa radio station should be strengthened by the project and the use of farmers on the program maximized.

There are two strategies that can be employed to maximize diffusion effects. The first alternative is to work with the most receptive communities in several watersheds. The second alternative is to concentrate activities in one watershed and bring in farmers from other watersheds to observe the results.

Major advantages associated with the first alternative are as follows:

1. It will permit the program to reach a broader population more quickly.
2. The most receptive farmers will be most immediately impacted.
3. It will make possible the most efficient use of resources in the short run.

Major disadvantages associated with the first alternative are as follows:

1. The project would not be a comprehensive watershed development project in the strict sense of the word, because it would deal with individual communities only.
2. The project would not deal with population pressure on the land, but only with soil and water management and reforestation.

Major advantages associated with the second alternative are as follows:

1. It will allow for a comprehensive watershed development project. Natural resource management methodologies can be elaborated and tested, and it will be possible to develop a rational soil and water management project for an entire watershed.
2. The watershed management project can be used as a model once sufficient activities are underway.

Major disadvantages associated with the second alternative are as follows:

1. The project will take longer to develop in that it will be more comprehensive.
2. The project will require the coordination of various agencies which will require a more cumbersome administrative structure. Coordination is likely to be costly and will delay realization of project activities.

DISTRIBUTION OF BENEFITS

Obviously, a detailed analysis of benefit distribution is not possible at this time because specific activities and the watershed areas in which they will be undertaken have not been identified, nor have strategies for implementing components of the project. However, it is possible to speculate on benefit distributions for specific project activities. Analyses of benefit distribution will be needed during the project design and implementation stages.

Reforestation

Reforestation of private lands will mostly benefit farmers with large farms because benefits will be in proportion to the amount of land owned. This, of course, assumes that rational exploitation of forests will be permitted by the Department of Forestry. If not, a program of this nature will have negative consequences for large landowners.

Most lands requiring reforestation are state-owned and are currently being exploited by farmers with small farms. Their reforestation will impact negatively on landed and landless small farmers in the short run, because they will lose temporary use of the land. "Temporary" is emphasized because soil erosion is inevitable and limits the use of these lands to several years when they are brought under cultivation. If these activities provide opportunities to earn off-farm incomes and/or alternative farm lands for farmers affected by the project, short and long-run benefits will accrue to the farmers.

Agroforestry

Agroforestry on steep slopes will benefit landed and landless small farmers in the short run. It will permit them to continue growing subsistence and short-cycle cash crops while at the same time reducing soil erosion. However, depending on the tree spacing, the availability of arable flat lands, and forestry policy, the long-run effects may be negative. Dense forest cover will not permit cultivation. If trees cannot be cut for commercial purposes and arable flat lands are not provided them, small farmers will be jeopardized in the long run.

Pasture Improvement

Many hillsides in the Ocoa watershed have highly eroded soils that can be rehabilitated by seeding with artificial pastures. This activity will benefit large and small landowners alike. However, large owners are likely to benefit more because they have additional resources for fencing and sufficient land to feed several cattle and/or other large animals.

SOIL CONSERVATION PRACTICES

Agronomic practices will benefit large and small landowners in proportion to the amount of land they own. They reduce soil erosion and therefore help maintain soil fertility.If they are labor intensive, they will benefit poorer landed and landless farmers by providing them with nonfarm incomes.

Mechanical practices will provide similar types of benefits to the extent that they are also labor intensive.

Coffee and Fruit Trees

These will benefit larger farmers to the extent that they require more land. Coffee is grown in the region, but on extensive plantations. There are many fruit trees native to the area, but none are currently being raised commercially. Raising them commercially will benefit small farmers by providing them with alternative sources of income at planting and harvest times.

Nonhillside farmers of the Ocoa watershed and the population in general will benefit from the project. Revegetation of the watershed will increase the volume of water in the river and, thus, facilitate irrigation of the valley. Methodologies and conservation techniques developed by the project will be used in other major watersheds of the country. Thus, farmers of these other watersheds and those with lands irrigated by their major rivers will benefit indirectly from the project.

CONCLUSIONS

Natural resource and energy conservation programs will fail if participating communities are not integrally involved. Success will depend on community members becoming increasingly aware of conservation practices and the need for them, and participating in the undertaking of these practices. Activities will probably have to be subsidized by government because farmers of the central mountain region are at or near the subsistence level, and because many activities may imply temporary reductions in the level of agricultural productivity. Farmers are able to supply labor. The government will have to provide capital and technology.

There are five options to follow in undertaking a watershed conservation program. First, small farmers cultivating the steep slopes might be induced to relocate, or their off-spring might be encouraged to do so. If it is decided to relocate farmers, the Dominican Agrarian Institute will probably need to supply them with alternative farm land. If focus is placed on their off-spring, provision of job skill training for off-farm employment may be required. The second option is to provide these farmers with off-farm employment. Private capital would have to be induced to invest in the region, or the State would have to invest in artisan or other labor intensive industries. The third option is to introduce farm technologies such as hybrid seeds that increase food production with less intensive land use. The fourth option is to introduce land

conservation practices and reforestation. The third and fourth options will involve changes in the production systems of small farmers. A fifth option is to reduce population growth in the region by introducing family planning concepts and techniques. This would require the participation of public health and other educational agencies.

An effective program that addresses the repair of damaged soil and water resources, and which maintains or increases land productivity, will probably require simultaneous attention to all five options. A balanced eco-cultural system represents the complex interaction of the natural resource base, the human beings exploiting it, and the technology they use in production activities.

The population of the southern slopes of the Central Mountain range, including the Ocoa watershed, is too large to maintain with existing technology without depleting the resource base. Because the resource base is constant, either technologies will have to be improved to increase production and conserve natural resources, or the population will have to be reduced or held constant, or both will be necessary. Programs that act exclusively on natural resources will not correct improper use of them. Rather, system disequilibrium will continue because several of its causes will be neglected.

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CHAPTER 14.
ENVIRONMENTAL MANAGEMENT EDUCATION: A MODEL FOR SUSTAINABLE RESOURCES DEVELOPMENT

Robert E. Roth

INTRODUCTION

Global concern about environmental problems, quality of human life, and the impact of development led to the convening of the United Nations Conference on the Environment in Stockholm, Sweden, in June 1972. The recently concluded tenth anniversary of the Stockholm Conference stressed the need and role for environmental education.

Recommendation 96 of the Stockholm Conference called for the establishment of an international program in environmental education that would be interdisciplinary in appproach, formal and nonformal, encompassing all levels of education and directed toward the general public.

In separate action, the U.S. Agency for International Development initiated a Title XII program that was designed to assist U.S. colleges and universities in the development of faculty expertise to conduct education, research, and public service on food and nutrition-related matters in developing countries while concurrently improving the quality of education within the participating institution. The historic involvement of the United States with developing countries was continuing but was in growing need of additional trained faculty with interests in international work. A general aging of participating faculty was occurring without the opportunity to train and interest younger faculty in international work. . .

Against this backdrop, the focus on resources, economics, and the abilities of developing countries to cope with escalating problems was increasing. A USAID analysis (1979) concluded that "the critical environmental resources of developing countries are today subject to stresses of unprecedented magnitude. Because the health, nutrition and general well-being of the poor majority are directly dependent on the integrity and productivity of these resources, the capacity of governments to

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manage them effectively over the long term may well be the single most important prerequisite to the eradication of poverty, the fulfillment of basic human needs, and the ultimate achievement of sustained development." (p.1)

The natural resources of most developing countries are being rapidly depleted by general deforestation, habitat destruction, desertification, soil erosion, and the pressures of rapid population growth. Government agency and nongovernment organization ability to educate and inform the people about the effective management of natural resources may be a most critical prerequisite to achieving a quality life.

AN ENVIRONMENTAL MANAGEMENT EDUCATION MODEL

A model for the strengthening of developing countries' environmental education and information capabilities for building an appropriate institutional framework to deal with conservation problems and sustainable renewable resource and energy development is presented. Examples from the Dominican Republic and Barbados will be discussed. Public environmental management education and training programs will be discussed in relation to the establishment of sound renewable resource management plans, developmental goals, and the establishment of an environmental ethic. Evaluative approaches are suggested for program and workshop effectiveness, and for knowledge gain and attitude shift in relation to selected environmental management and energy issues.

ENVIRONMENTAL MANAGEMENT EDUCATION DEFINED

Environmental management education is concerned with an individual's self-understanding, with an understanding of the co-inhabitants of the Earth, and with interrelationships within and among each of these constellations of concern. A major goal is to encourage the individual to develop the ability to make thoughtful decisions which will create an environment that allows one to live a quality life. Specifically, environmental management education is concerned with developing a citizenry that is:

1. Knowledgeable about the biophysical and sociocultural environments of which man is a part.
2. Aware of environmental problems and management alternatives of use in solving those problems.
3. Motivated to act responsibly in developing diverse environments that are optimum for living a quality life (Roth 1969).

Thus, environmental management education is concerned with knowledge of natural systems, society, and the individual. It not only attempts to provide the individual with environmental understandings, but also views one as a potential creative being and encourages acceptance of the responsibility for decision making.

Another characteristic of environmental management education is that it deals with the attitudes people hold about themselves, toward other individuals and groups of individuals, and toward their environment. These constellations of ideas greatly affect our level of living and quality of life.

Environmental management education is not just ecology, resource use, sociology, art appreciation, philosophy, or management. It is an interdisciplinary focus that embraces the sciences, humanities, social sciences, and technology for purposes of developing cognitive understanding, belief and attitude change, and providing motivation for behavioral change and effective action.

A first step towards an agreed upon body of concepts appropriate for environmental management education was taken when a list of 112 concepts was produced (Roth 1969). Scholars from 40 professional areas and 12 ecological regions of the United States agreed on the majority of concepts to be emphasized. The concepts delineated represented a useful and appropriate structure of conservation concepts.

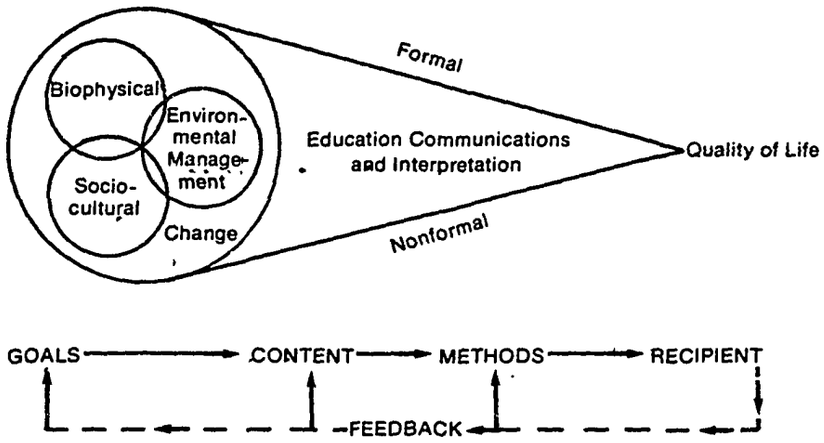
The list of 112 concepts was subsequently submitted to a panel of experts (comprised of Ohio State University personnel) representing the various disciplines, organized according to topic, and arranged in the order of importance on the basis of Qsort response (Brooks 1970). A consensus was reached both as to placement in a major area and as to degree of importance (Bowman 1972).

The concepts important to know in environmental management education were grouped into four categories: biophysical, sociocultural, environmental management, and change. Each cluster of concepts is viewed as existing on a continuum and the four areas are interrelated (Figure 14.1). The conceptual core is applied through "educational and communication processes," comprising a range from formal education to nonformal communication strategies. The major goal described on the right side of the model is "quality of life" which can also be interpreted as the individual's conception of achieving a workable environmental ethic.

The organization and validity of environmental management education concepts was deemed to be appropriate for program development and curriculum organization.

The proposed model in Figure 14.1 has the advantage of being concise, graphic, and logical in its application. It provides an easily visualized guide to the process of program development in both formal and nonformal educational settings regardless of cultural and national context. The program developer is reminded that the identification of appropriate environmental management/education goals, objectives with a behaviorial or measurable orientation, and well-defined and implemented communications or teaching strategies is essential for achieving a quality life. Evaluative feedback of both an in-process or summary nature is to be utilized in relation to impact on the recipient or target audience. Through rigorous evaluation strategies involving pre- and post-testing of concepts and attitudes assessment of skills and performance, and the achievement of anticipated goals in documentable form, it will be possible to demonstrate achievement of intended goals in relation to the improvement of the quality of life.

FIGURE 14.1 ***Conceptual model for environmental management education.***



Source: Roth, 1973.

Townsend (1982) conducted an investigation into the underlying structure of the domain of environmental mangement education concepts. A refined list of 54 concepts drawn from the works mentioned above was submitted to a randomly selected panel of experts and practitioners in the field for a review of accuracy and validity for environmental management education. The underlying dimensions (factors) of the concepts studied were identified as (1) ecology: interdependence and living things; (2) culture: interaction with environmental considerations; (3) ethics: humankind's moral responsibility for environmental considerations; (4) natural resources management and use; and (5) population: interactions with environmental conservation. While differences in perceptions of concept categories exist between this work and those proposed previously by Roth (1969) and Bowman (1972), such differences can be explained by the general nature of the concepts which leaves them open to multiple categorization possibilities. Townsend's work provided a necessary update and expected categories.

A DOMINICAN REPUBLIC EXAMPLE

The Dominican Republic's natural resource base is deteriorating at an alarming rate. As indicated in the recently completed Country Environmental Profile (Hartshorn et al. 1981), erosion rates per hectare in most of the nation's watersheds are estimated to average 300 metric tons per year. The report concludes, "Since soil erosion rates of 10 to 30 metric tons/hectare/year are normally considered excessive, the erosion rates in the Dominican Republic are little short of catastrophic." (p. 97)

This massive destruction of the watershed areas is exhibited throughout the country. Every year millions of tons of the nation's productive soil are washed away as hillside areas are denuded and covered with massive scars from landslides, washouts, and deforestation. The color of the rivers is now a bright brown indicating increased silt loads in the water. Due to the lack of hillside vegetation cover, the unusually heavy rainfall from two hurricanes (21 inches of rain in 7 days) took on calamitous proportions causing major flooding throughout the country. Sedimentation is filling up the reservoirs. The useful lives of multimillion dollar hydroelectric facilities have already been cut to less than half by siltation. In addition, siltation damage to hydroelectric facilities often results in lower-than-planned power output levels and frequent power outages.

The hillside farmer is at the center of this problem. He is forced by population pressures to cultivate on the only land available: hillside areas which are highly vulnerable to erosion. The agricultural practices the farmer uses are often the principal cause of erosion which results in lower productivity, and most probably contributes to his poverty. The hillside farmers are trapped in a vicious cycle which, unless broken, will result in increased destruction and increased suffering for the hillside poor.

Fortunately, the situation can still be reversed. The degradation of the country's watersheds can be brought under control before the point of irreversible environmental degradation is reached. Time is short, however. It is estimated that within 20 years, the landscape of the Dominican side of the island of Hispanola will resemble that of its neighbor, Haiti, if corrective action is not immediately implemented.

The Natural Resources Management Project (NARMA) will assist the Dominican Republic in building an institutional framework to deal with the natural resource conservation problem. This project will form part of a broader USAID strategy which aims to have in place, during this decade, the necessary institutional capacity and field experiences to confront effectively the country's natural resource problems.

A major activity under this component will be the strengthening of the Dominican Republic environmental education program. Under this activity, the efforts to generate more public and target group awareness of the natural resource problem and ways to deal with it are being strengthened and expanded. Training workshops are being carried out to teach school teachers, local leaders, and small farmers to increase local participation in conservation activities. A viable approach to changing hillside farming behavior patterns which can be replicated in other critical watersheds is the goal. It is expected that the project and the spread effects from project activities will cause sufficient numbers of hillside farmers to implement improved conservation practices so that stabilization of the soil and a reduction of the rate of natural resource degradation can be accomplished within the target watershed, within the coming decade in a cost-effective manner.

Objectives of the Environmental Management Education component of the NARMA Project in the Dominican Republic include the following:

1. Development of a comprehensive national plan for environmental education.
2. Development and testing of alternative communication techniques to strengthen awareness of resource issues.
3. Training of teachers, leaders, and farmers in conservation concepts.

Specific inputs include:

1. Short courses for teachers, leaders, and farmers.
2. A total of 225 one-day workshops for farmers.
3. Purchasing of educational equipment, electrical generators, buses, and vehicles.
4. Development of a training center at Jimenoa.
5. Providing three person-months of technical assistance.
6. Receiving four persons from SURENA (Subsecretaria de Estado de Recursos Naturales) to enroll in long-term training in environmental education and communications.

The environmental education component of the project utilizing the proposed model for Environmental Management Education is making significant progress both at the national as well as at the watershed levels. Posters, written bulletins, pamphlets, radio programs, T-shirts, bumper stickers, and a video tape of the project have been prepared for the mass media program. Curricula for targeting specific concepts for children in grades 1-6 have been designed, although this goes beyond the orginal project activity. A number of short courses are being designed with different target groups in mind. Construction of a National Environmental Education Training Center at Jimenoa is nearing completion.

Evaluation of work completed to date reveals that the educational program appears to be a major stimulator of interest in conservation practices. Prior to the project, a study by the Office of Environmental Education revealed that only 40 percent of the campesinos used conservation practices like composting; a recent survey indicated more than 80 percent used conservation practices. The program has been very active in organizing courses and in participating in workshops/courses organized by other groups such as the Junta de Desarrollo. Success can be attributed to:

1. Use of existing associations and committees to mount courses with farmer groups in different areas.
2. Trainers' knowledge of local people and their ability to relate positively to the people's production as well as conservation concerns.
3. Preexisting knowledge of conservation methods.
4. Availability of transport and adequacy of materials.
5. Willingness of personnel from other programs, including military units, to participate.
6. Support from the headquarters staff in Santo Domingo and acknowledgement and recognition of the importance of the program.

Initial evaluation of farmers' responses to the training programs indicates that there is more interest in specific conservation training than in general exposure to the concepts of environmental protection. Preliminary evaluation of school students by the Office of Environmental Education staff, on the other hand, revealed that they are very responsive to more general concepts and to wildlife protection, but not as interested in agricultural conservation practices.

A further advantage of the training effort lies in the ability to relate concern for conservation with concern for production systems. If conservation techniques are treated and presented in isolation, farmers appear to be much less interested in their possible relevance to their situation than when practices like composting or building terraces are utilized as educational activities. Participants are highly receptive to hands-on demonstrations like composting and reforestation.

A BARBADIAN EXAMPLE

The Caribbean is a region with 15 island nations. Barbados is one of the countries of the eastern Caribbean that has a strong dedication to education and an enlightened management of her natural resources. Barbados faces environmental problems because of agricultural practices, tourist trade, and population growth. The development of educational approaches has moved from a tentative involvement with innovation stressing such issues as discovery learning, child-oriented instruction, and scientific literacy to a positive Caribbean-controlled thrust involving science and technological education for national development. Several educational models are described by King (1979) as being useful in achieving educational and national development.

The motivation for curriculum development is derived from:

1. The march to independence and other forms of internal self-government sparked by a surge of nationalist feeling and dissatisfaction with colonialism.
2. The attempt to provide a type of education enriched both qualitatively and quantitatively to meet the new demands on society.
3. The desire to produce a type of manpower in keeping with the technological demands being made on the system.
4. The hope of developing an inquiring people, with the goal of producing a scientifically literate citizenry.

Emphasis of the Environmental Management Education approach utilized in Barbados was on science teachers in year one of the project and social studies teachers in year two. The workshop goal was to utilize the proposed model to portray concepts related to international resources and environmental management education, and simultaneously to train faculty for international development work.

The project in year two consisted of developing, implementing, and evaluating a workshop for secondary social studies teachers in Barbados. Social studies in

Barbadian schools is a composite of geography, history, economics, and political science. The interdisciplinary nature of the curriculum lent itself well to providing opportunities to learn about the environment. Environmental education does not appear as a distinct subject in the schools of the island, but an integrated approach across the disciplines has been well accepted.

Coordination of the workshop was accomplished by a representative of the Caribbean Conservation Association, with the assistance of the Barbados Community College and the Ministries of Education, Agriculture, and Housing and Lands. Twenty-seven teachers attended sessions and field trips. As a follow-up each teacher developed an activity that could be used in his or her current teaching situation, thus applying immediately what was gained from the workshop.

Informal evaluation of the experience revealed that teachers deeply appreciated U.S. involvement in this type of development. Participants left with a new excitement and a wider perspective of what instructional materials and techniques were effective for environmental education. Programs such as this benefit not only the teacher participants, but the OSU faculty who learn more about international development, and the OSU students who may learn to think more globally by association with those whose classroom is the world.

EVALUATION STRATEGIES

Evaluation strategies that would seem to be useful in assessing the effectiveness of the Environmental Management Education model are proposed below.

A determination of appropriate concepts and content is a useful first step. As indicated previously, the sequential works of Roth (1969), Bowman (1972), and Townsend (1982) provided a sound basis for identification of concepts and an organizational structure for their presentation. As the conceptual organization was applied in the Dominican Republic and Barbados, it was possible to speculate on knowledge gained, some attitudes that may have been shifted, and skills that were acquired and employed.

Subjective evaluation is another evolving strategy that was employed by a team of independent reviewers in the Dominican Republic Environmental Education portion of the NARMA project. Surveys completed and in progress indicate that conservation practices are being implemented as a result of project activity, especially in relation to workshops and radio programs. The use of video-taped documentaries that provide observation of a visual change in the landscape further supports the contention that the goals of the project are being achieved. In addition, preliminary evidence of concept gain and attitude shift resulting from pre/post-assessment of participants in the workshops and mass media campaigns exists. This preliminary evidence will provide the basis for more detailed and rigorous pre/post-studies presently under design.

Fortner (1986) conducted a study to evaluate the environmental education programs across the two cultures of Barbadian and U.S. workshop participants by

comparing teacher characteristics and adaptive potential of existing materials. It was found that both groups had positive attitudes toward teaching and responded enthusiastically to the varied techniques of the workshop activities. School curricular limitations were viewed to be restrictive for adoption of materials in Barbados. But in the United States, school curricula were viewed to be more accommodating of materials adoption. The workshops in all cases appeared to achieve the intended objectives and pre/post-test evaluations revealed an increased awareness of availability of materials, enhanced knowledge of techniques, and motivation to adopt activities experienced.

CONCLUSIONS

The proposed model for Environmental Management Education has been utilized in both the Spanish and English speaking Caribbean for the implementation of training and education programs. Concepts appropriate for the development and implementation of both conservation and environmental management education appear to be relevant. The variety of methodologies employed for the formal and nonformal education settings appear to be effective. The established goals and objectives of the program examples are being achieved as evidenced by the various preliminary evaluative strategies. It is suggested that the model for Environmental Management Education be considered as a guide for the development of either formal or nonformal environmental management/education programs in developed as well as developing countries.

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CHAPTER 15.
SUMMARY AND CONCLUSIONS

OVERVIEW

Renewable energy sources have taken on increased importance in the non-OPEC developing countries with the rapid increases in gas and oil prices and the declining availability of fuelwood. Deforestation is progressing at a rapid rate in much of the world with a five-fold gap between harvest and planting rates forecasted by 2000 for the developing countries as a group (World Bank 1980).

Conservation of existing energy sources and the development of new renewable and sustainable sources of energy are frequent recommendations. Worldwatch Institute has developed estimates for future worldwide consumption of energy. Renewable energy sources are expected to increase from 16.5 percent of worldwide consumption in 1980 to 23.9 percent by the year 2000 (Brown and Shaw 1982). Within the renewable energy subset (which is relatively more important to most developing countries), wood is almost half and hydroelectric power one-third of the total. Thus, this book placed primary emphasis on these two dominant renewable sources of energy in terms of production and use characteristics, feasibility analysis, and project implementation in selected developing countries (Dominican Republic, Costa Rica, Barbados, the Philippines, India, Ghana and Egypt).

The chapters in Part I, "Renewable Energy Production and Use Characteristics," focused on improved methods for estimating yield and heating value of standing biomass, seedling survival and growth rates of fuelwood plantations, the end use of energy in rural households, and the potential of unconventional renewable energy sources such as solar ponds. The chapters in Part II "Feasibility Analysis of Renewable Energy Options," illustrated financial and economic analysis, energy accounting, and environmental impact assessment. The chapters in Part III, "Implementing Renewable Energy Systems," dealt with concepts such as delineation of property rights, political competition and patronage, centralization, and the role of local farmer organizations. The following sections briefly describe each of the general methods and findings from the chapters.

PRODUCTION AND USE CHARACTERISTICS

A comprehensive biomass inventory sys[illegible] the dry forest areas of the Dominican Republic was developed by Kasile[illegible]field (Chapter 3). The system consists of two stages supported by biomass regression equations and e[illegible]lues. A stratification was conducted based on the visible human interventi[illegible] within the forests and the subsequent degradation and removal of biomass. Within each stratum, sample plots were established in a randomized pattern and all trees greater than 5

centimeters in diameter were measured at 0.5 meters (DKH). Regression equations were developed for each species specifically, and for all species combined that relate DKH to fuelwood biomass weight and total biomass weight. Energy values per pound of biomass were developed to determine the yield of energy in fuelwood per hectare by each stratum. Such information permits the development of a utilization plan that will ensure continued production of these fuelwood sources.

Larson reported on applications of hormones to nursery stock for the production of seedlings of tropical trees for reforestation projects (Chapter 3). Application of certain hormones to nursery stock of several north temperate species has been shown to stimulate root regeneration and early growth. Despite its potential value to tropical forest and plantation management and reforestation, similar studies with major tropical tree species have been lacking. In a preliminary trial reported here, indoleacetic acid (IAA)/kinetin mixtures were applied to stump seedlings of pochote (*Bombacopsis quinatum*) and melina (*Gmelina arborea*). In additional trials, indolebutyric acid (IBA) was applied to roots of stump seedlings and stem cuttings of the two species. Seedling root regeneration increased as concentration of IAA increased in root soak solutions, but kinetin had no effect. At the highest IAA level (320 ppm), both pochote and melina seedlings formed over twice as many roots as untreated seedlings. Several IAA/kinetin treatments increased shoot growth above that of untreated trees (based on dry weight of leaves per tree). The IBA-ethanol solution treatments of seedlings roots or stem cuttings of the two species did not significantly improve growth, and at highest concentrations (3000 ppm) growth was reduced relative to controls. Cuttings made from the pruned-off tops of pochote stump seedlings quickly rooted and grew vigorously, effectively doubling the number of plants available for outplanting.

Fynn and Bailey discussed some design issues in producing electricity from solar ponds, a relatively new concept (Chapter 4). The Dominican Republic has experienced growing expenditures for imported oil, deforestation, soil erosion, and urban migration. The use of solar ponds as a heat source as well as a source for electric energy generation can contribute to overcoming these interrelated problems. This source of energy is renewable, improves rural conditions for living and working by increasing the availability of electricity and heat, and can help reduce the demand for wood and oil as fuel. Appropriate solar pond design for the Dominican Republic, within the context of the nation's energy resources and its economic security, is discussed. This includes site selection, a preliminary pond design coupled with an organic Rankine Cycle electrical generator engineering cost analysis, and a discussion of the future potential of solar ponds in the Dominican Republic and other tropical areas, as well as the potential of advanced pond designs.

A survey of fuel use in rural households in the Central Philippines was completed and evaluated by Hunt and Ponce (Chapter 5). Where commercial forms of fuel are not affordable or available for household needs, dependence for necessary (cooking) energy is entirely upon wood and agricultural residues. Firewood and charcoal are

used extensively by city households, street food vendors, and commercial establishments such as bakeries as well as in rural areas in many developing countries, including the Philippines. Observations of household and community fuel use in rural villages on Leyte are discussed. In addition, data are reported on amounts of traditional and commercial fuel used by 150 households in a rural area of Central Philippines, fuel costs, what it was used for, types of stoves used, preferences for fuels, and where and by whom household fuels are obtained. Choice of energy technology can have long-term impacts on regions. Some observers suggest that the single most important development in terms of household energy conservation would not be a new source of energy but a more fuel-efficient stove than is commonly used.

FEASIBILITY ANALYSIS

Hitzhusen and Boakye-Dankwa reported on a private and social cost-benefit analysis of pulp and fuelwood options in the Ghana Subri Forest Project (Chapter 6). In the early 1970s the Ghana Forestry Department embarked on an intensive reforestation program with the aim of converting about 100,000 hectares of degraded forest reserves to plantations of fast-growing species. To achieve this, exploited areas were clear-felled and the trees and other ground cover burned. To eliminate this waste of existing resources, the government of Ghana proposed a charcoal production and utilization project. One of the areas selected for this program was the Subri Forest Reserve in the high forest zone situated 45 kilometers to the east of Takoradi in the western region. Financial (private) and economic (social) analyses of pulp and fuelwood alternative management strategies for the Subri Forest Reserve are compared. Under the two decision criteria used, net present value (NPV) and internal rate of return (IRR), the financial analysis shows the fuelwood option to be superior to the pulp option. The economic analysis includes consideration of shadow wages and shadow exchange rates, and concludes that the fuelwood option is also socially preferred.

The economic and political feasibility of establishing a sugar-cane-based alcohol industry in the Caribbean Basin was examined by Rask (Chapter 7). Both Caribbean domestic use plus fuel alcohol export to the United States are considered. The national security and economic benefits of an alternative energy source that diversifies energy supply away from OPEC are clear. In addition, positive elements of the Caribbean Basin Initiative (CBI) are identified. They include increased employment, increased exports, reduced petroleum imports, and emphasis on the comparative advantage of sugar cane to produce a unique commodity (alcohol) that offers the clear possibilities for one-way trade, private investment opportunities, and technical assistance. The projected level of U.S. alcohol production plus potential CBI imports together will meet only a fraction of projected U.S. fuel alcohol demand, thus there is little economic basis for domestic U.S. producer objection to alcohol imports. U.S.

sugar and corn sweetener producers should benefit from less sugar import price pressure.

Hitzhusen, Macgregor, Southgate, and Veloz present an analysis of the hydroelectric power and land use trade-offs in the Dominican Republic (Chapter 8). A conceptual model contrasts private and social levels of economic analysis from an accounting stance perspective. These concepts are then applied to the Valdesia watershed and hydropower reservoir in the Dominican Republic. The first phase of the case application involves assistance from agronomists, engineers, and foresters in making detailed estimates of current ("without project") soil erosion and sediment delivery ratios. Best erosion control practices are established by slope class, and "with project" estimates are made of erosion and deposition rates. The second phase of the Dominican case involves financial (private) and economic (social) estimates of the on-site and off-site costs and returns with and without the project. Financial analysis of on-site costs and revenues to soil conservation by slope class shows benefits to some, but not all, farmers. When the on-site and off-site (foregone hydropower) economic or societal net returns are estimated, the net present value of the project increases substantially. Foreign exchange savings (primarily from reduced oil imports) are also significant.

Ecosystem structure and energy flow were analyzed by Sundarraj and Mitchell in a South Indian village (Chapter 9). Using supplementary irrigation water from the Mettar dam and less than 260 hectares of land, the people of Panayakurichi produce 3.3 times as much food energy as they consume, 96 percent of the fuel they burn, and the fodder for 539 head of livestock. The draft animal population matches the demand, and about 70 percent of the adult human population must work at critical times. There is a surplus of rice and moderate deficit in pulses, oils, vegetables, and sweets. With the growing fuel shortage, the villagers have devised alternatives from agricultural wastes and burn dung because market value of dung as a fuel is six times greater than the cost of nutrients in chemical fertilizer. The surplus of rice is obtained with an input of fertilizer equivalent to 1034 million kilocalories of fossil fuel. The villagers have a comprehensive view of their system and regulate resources so as to harvest an average of 9 tons (29.8×10^6 kcal) of usable biomass from each hectare. This relatively closed ecosystem is an entity that can persist so long as adequate irrigation water is available.

Smith reviewed the environmental impacts of the Aswan High Dam and hydroelectric power station (Chapter 10). Primary areas of concern include 80 to 130 million annual tons of reservoir sedimentation, riverbed degradation and coastal erosion, riverine changes in terms of water quality, changes in the reservoir ecosystem such as fishery development and aquatic weed problems, waterlogging and soil salinization, and the potential spread of malaria through open water.

IMPLEMENTATION OF PROJECTS

Anthropological perspectives and research techniques were applied by Salazar and Hughes in a study of the implementation of an agroforestry project in the Philippines (Chapter 11). Intervention processes and their response to technological, ecological, political, economic, and sociocultural variables at the national, regional, and local levels are examined. Analysis begins with the factors that led to the establishment of the project and the choice of objectives, implementing structures, and strategies. The interests, resources, and capacities of the donor agency; the implementing agencies; and the local government are discussed. Problems with the mobilization of financial resources constrain the procurement and delivery of supplies from the center to the periphery. Overcoming this constraint requires activating political and social networks both within and outside the project. The mobilization of human and organizational resources within the implementing unit relates to a system of patronage which constrains rather than facilitates project performance, particularly with respect to the goal of community participation. Community participation is more apparent in the areas of implementation and benefits than in decision making and evaluation. Furthermore, participation is affected by some factors inherent in the project, such as inappropriate land use techniques, insufficient seeds, and inadequate extension services, as well as by other factors among the farmers and their community, such as land tenure, land use patterns, economic diversity, and relations of power and influence.

Dryzek and Glenn applied the concept of a regime for natural resources management in a national-level study of the political economy of deforestation in Costa Rica (Chapter 12). A resource regime is composed of specific rights, rules, regulations, compliance mechanisms, and transformation mechanisms. The existing regime does not promote ecological sustainability in forest management; the systems of property and weak transformation and compliance mechanisms embedded in this regime are actually largely to blame for the severity of current deforestation problems. In the unique context of tropical forest ecosystems, the incentive structures yielded by this regime promote ecologically destructive use of land on the part of squatters, cattle ranchers, and other private landholders.

Several options are evaluated by Hansen and Erbaugh in a social analysis of a natural resource conservation project concerned with soil erosion and deforestation in the Ocoa Watershed of the Dominican Republic (Chapter 13). Options include relocation of hillside farmers, off-farm employment, output increasing technology to reduce land use intensity, land conservation practices, and reductions in population growth. Involvement of local farmer associations is critical to the diffusion and adoption of new natural resource conservation concepts.

Roth presented a model for the strengthening of developing countries' environmental education and information abilities for building an appropriate institutional framework to deal with conservation and development problems (Chapter 14). He used examples from the Dominican Republic and Barbados. Public environmental management education and training programs were discussed in relation to the establishment of sound renewable resource management plans, developmental goals, and an environmental ethic. Evaluative data are discussed in relation to program and workshop effectiveness; knowledge gain and attitude shift are discussed in relation to selected environmental and energy issues. The ability to educate and inform people about the effective management of natural resources may be an important prerequisite to eradicating poverty, fulfilling basic human needs, and achieving a quality life in developing countries.

KEY FINDINGS AND IMPLICATIONS

Several key findings and policy implications emerge from the 13 individual studies and 10 academic disciplines represented in this multidisciplinary research effort. They can be summarized as follows:

1. Kasile and Maxfield have developed a useful methodology for estimating both biomass volume and heating values in a dry forest region typified by acute scarcity of fuelwood. They also found up to a three-fold increase in energy availability when dry land forest species are air dried to 14 percent moisture content. This methodology and evidence can be readily generalized to similar regions throughout the Third World.
2. Dieback and death of seedlings is a serious problem in efforts to establish wood energy plantations to off-set rapid rates of deforestation. Larson found a threefold increase in seedling root regeneration in pochote and melina from soaking roots in indoleacetic acid (IAA) at about 300 ppm, which may facilitate increased feasibility of plantations.
3. Solar ponds for electricity production have relatively high capital outlay requirements, but their operating costs are much lower than most conventional methods of producing electricity. They may also reduce some of the deforestation pressure on fuelwood-short regions. Some unanswered technical and economic questions remain, however.
4. In developing countries as a group, household energy consumption is more than 50 percent of total consumption, and household energy needs consume a significant portion of poor household resources. Hunt and Ponce found that (a) fuel preference varied with type of cooking which increases the opportunity of substitution to reduce deforestation; (b) clay and steel stove predominate which makes adoption of other types difficult; and (c) many Central Philippines villagers fear that community woodlots could be a source of trouble in the community which should help focus implementation strategies.

5. Private and social cost comparisons of pulp and fuelwood options in the Subri Forest of Ghana found fuelwood superior even when shadow pricing labor which would be expected to favor the more labor intensive pulp option. Shadow pricing foreign exchange made the import substitution oriented pulp option relatively less attractive. Thus, shadow pricing has important implications for both economic efficiency and income distribution.
6. Many developing countries are experiencing balance of payments problems from low prices of sugar exports and high prices of oil imports. The analysis by Rask of a sugar-cane-based ethanol industry in the Caribbean Basin builds on comparative advantage and offers the possibility of increased trade and foreign exchange generation as well as reduced dependence on OPEC by a number of developing countries.
7. When off-site impacts on hydroelectric power in the Valdesia watershed of the Dominican Republic are included in the economic analysis of soil erosion control practices, very high rates of return are found. However, steep slope farmers will need to be compensated for the private losses they incur. Also, policies of overvalued currency, interest rate controls, and ill-defined property rights need revision.
8. A South Indian village is found to be a relatively sustainable ecosystem in an energy flow context. However, the system is dependent on external irrigation water and off-farm jobs as well as subsidized insecticides and fertilizer. Measuring labor value in calories of energy also ignores peak demands for labor and the opportunity cost of off-farm jobs.
9. A review of environmental impacts of the Aswan High Dam finds that water storage and hydropower objectives have been met but that waterlogging and, to a lesser extent, sedimentation are major negative impacts. A management plan to address these impacts would require considering the high soil erosion rates in the Ethiopian Highlands (a major sediment source at Aswan).
10. The literature abounds with examples of problems in implementing renewable energy projects. Salazar and Hughes bring an anthropological perspective to an agroforestry project in the Philippines and find the constraints to implementation include political competition and patronage, omission of ethnic minority groups in planning, fear of controls, and poorly defined property rights. A similar analysis in Costa Rica done from a political science perspective by Dryzek and Glenn adds an additional factor of weak enforcement capability. And the social analysis in the Dominican Republic by Hansen and Erbaugh finds local farmer organizations critical in diffusion and adoption of tree planting, etc., for soil conservation. Explicit consideration of these factors will make education efforts more effective in implementing future renewable energy projects.

The importance of a multidisciplinary approach to renewable energy issues in developing countries is highlighted by the complementarity of the alternative

disciplinary perspectives in addressing critical production/use, feasibility, and implementation issues. The following are illustrative:

1. The use of more productive fuelwood species may never be implemented without attention to property rights and socioeconomic incentives, and inefficient stoves and end uses may off-set gains from any realized increased fuelwood production potential. An integrated approach is essential.
2. Energy flow analysis provides a useful complement to socioeconomic analysis (including shadow pricing) of energy systems, particularly if existing prices understate the marginal social values of nonrenewable energy sources. However, attempts to formulate an energy theory of value presume that saving finite energy is the only consumer preference and that energy is the only constraint to development. This approach could lead to options with low energy inputs, but excessive costs of other resources.
3. Effective physical and biological soil erosion control practices in watersheds above hydroelectric power installations will not be adopted by hillside farmers because they are not profitable. This is true even though the benefits to society from reduced sedimentation of hydropower reservoirs greatly exceed the costs of soil erosion control. Physical and biological concepts of soil erosion control must be combined with concepts of social benefits and costs (a longer and wider accounting stance) as well as socioeconomic and political incentives for adoption if resolution of hydropower reservoir sedimentation is to occur.

This book was not intended as an exhaustive treatise on all aspects of renewable energy in developing countries. Rather, it has presented results from some recently completed research by physical, biological, and social scientists at the Ohio State University on selected production/use charateristics, feasiblitiy analysis, and implementation constraints to renewable energy projects in developing countries. Case applications from seven countries were used to illustrate concepts and formulate policy recommendations.

The authors hope that the book has presented a convincing case for the validity of and need for a multidisciplinary evaluation of Third World natural resource development programs. Clearly, the state of the art in development and project evaluation has not yet progressed to where such an approach is routine or formalized. It is increasingly evident that multifaceted resource problems require multidisciplinary—ideally, truly interdisciplinary—evaluation if development plans or proposed solutions to critical resource problems are to be viable. It is toward this goal that this volume has been directed.

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