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Energy and Environmental Systems Division

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AN ASSESSMENT OF PERUVIAN BIOFUEL RESOURCES AND ALTERNATIVES

by

Jerome P. Harper, Wayne Smith,* and Eliseo Mariani†

Energy and Environmental Systems Division

August 1979

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GLOSSARY

aguaje:	tree bearing a tropical fruit
alfisolo:	clay subsurface high in base content
aridsols:	soils developed under arid conditions
bagasse:	residue of sugar cane production
berra fria:	non-frostless tropical highlands
camote:	sweet potato
cassava:	yucca
chancaca:	molasses
coppice:	to sprout from a stump of a harvested tree
entisols:	new soil without complete profile development
evaportranspiration:	loss of water from the soil by both evaporation and transportation from the plants growing therein
furfural:	a liquid aldehyde, $C_5H_4O_2$, of penetrating odor, usually made from plant materials and used in making furan or phenolic resins, and as a solvent
hectare:	(ha) a unit of area measurement equivalent to 10,000 square meters or 2.47 acres
inceptisols:	soils with initial profile development
JQ:	quadrillion joules (10^{15} joules)
maize:	Indian corn
mango:	tropical fruit; yellowish-red with firm skin and central stone
milo:	a type of sorghum
mollisols:	dark, fertile topsoil, farmed under grassland
oxisols:	clays having a loss of silicon and an accumulation of iron and aluminum oxides with 2 meters of the surface
plantain:	a banana-like plant; with short-stemmed elliphic-leaved herbs with spikes of minute greenish flowers
(quinoa) quinica:	a pigweed of the high Andes whose seeds arc ground, used as food in Peru
silviculture:	branch of forestry dealing with the development and care of forests
slash:	limbs and small stems
soles:	150 Peruvian monetary units equal to $1.00 (U.S.)
ultisols:	clay subsurface low in base content

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1 INTRODUCTION

1.1 PURPOSE

In response to the hardships placed on developing countries by soaring energy prices, the United States Government has initiated a program through the Department of Energy to assist these countries in fully developing their energy resources. Between May and September, 1978, the U. S. government and the Peruvian governments co-operated in assessing the opportunities for energy development in Peru. Four purposes of the Department of Energy were identified: (1) to quantify the energy resources available throughout Peru, (2) to evaluate the present and future energy supply/demand situation, (3) to identify alternative technological options for energy development, and (4) to propose a comprehensive program for integrating energy development with overall national development.

Energy resources assessed in this study included: oil and natural gas, coal, geothermal, uranium, hydropower, solar, wind, and biofuels. A comprehensive set of technological options for converting these resources into useful energy was identified and evaluated. This report details the results of the Peruvian Energy Assessment performed by the members of the Biofuel Resources and Technology Team which was selected for this study by the U.S. Department of Energy.

1.2 SCOPE

In this report, a comprehensive picture is drawn of the potential for the utilization of nonconventional biofuels in Peru. Current utilization of biofuel resources in Peru is identified. An evaluation then is made of the potential biomass productivity of Peru and of the present biomass supplies available from agricultural, forest, and other resources. The demand situation for biomass is assessed in terms of competitive uses and market development. A discussion of the technological avenues and resource development and management considerations for increased utilization of biofuels then follows. The assessment concludes by identifying various options for developing Peruvian biofuel resources, and by providing a regional appraisal of their applicability. The regions discussed in this report are:

the dry Costa Region;
the mountainous Sierra Region;
the wet, tropical Selva Region.

The sites visited by the biofuel team members are identified in Fig. 1.1. This method of analysis provides an evaluation of current supplies and production potential of biofuels, an assessment of the opportunities and consequences of biofuel development, and a description of promising biofuel options for Peru.

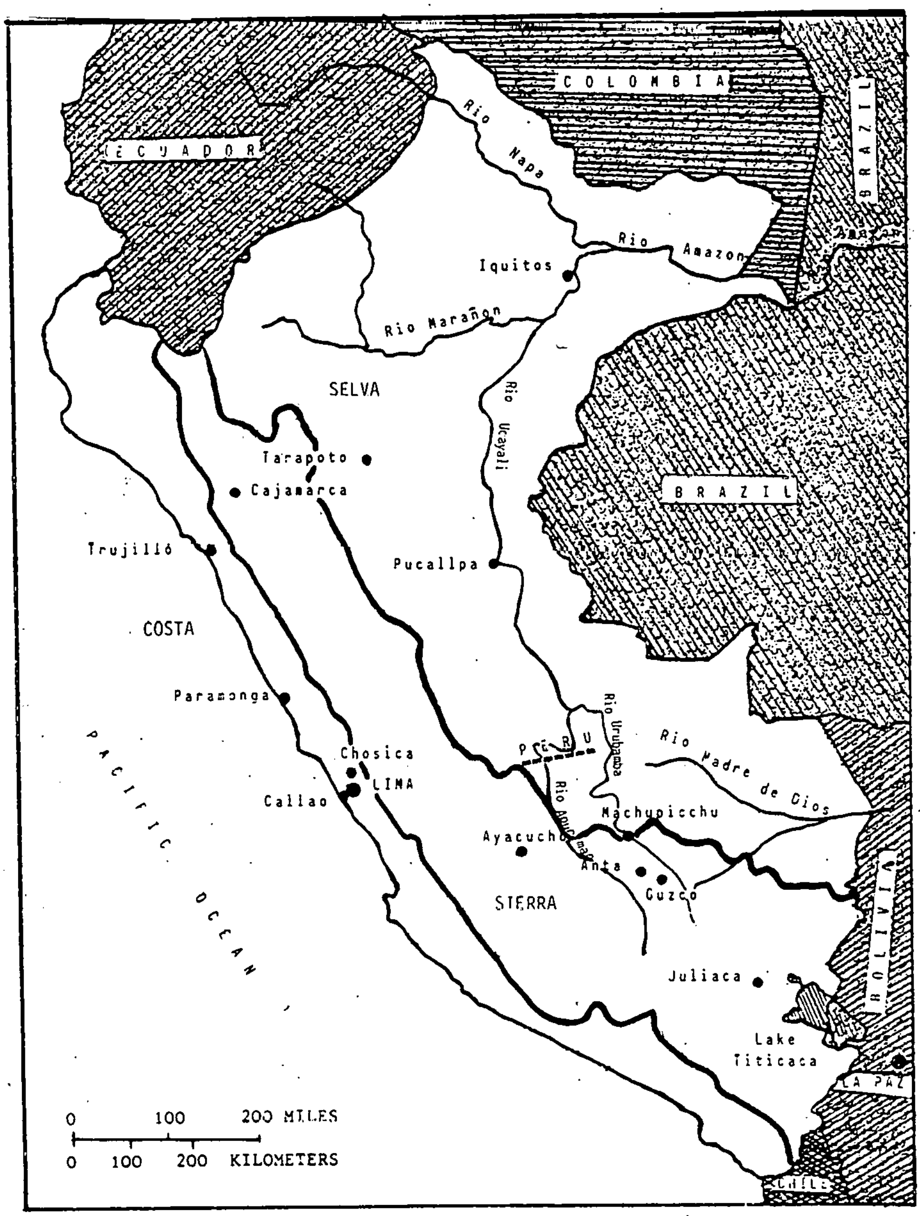


Fig. 1.1. Location of Sites Visited and Major Regions in Peru

2 CURRENT STATUS OF BIOFUEL UTILIZATION

2.1 NATIONAL PLANS

The official document outlining plans for energy development in Peru[1] makes no specific mention of expanding the use of biofuels as a future energy resource. However, individuals in the Peruvian ministries indicate a growing awareness of the importance of biofuels in the future development of energy resources in Peru, as evident from data in a recent study undertaken by the Peruvian government and the United Nations to evaluate noncommercial fuel utilization in Peru. Energy options discussed at meetings with persons from the Ministry of Energy and Mines focused on the pyrolysis of forestry wastes to produce combustible gases, oils, and charcoal; individuals from INDUPERU* expressed interest in production of charcoal from biomass to use as a substitute for imported coke and interest in the direct combustion of biomass for production of electricity; personnel from the Ministry of Agriculture were positive about developing forest plantations in the Sierra region of Peru.

Interest in biofuel energy options is also evident in other sectors of Peruvian society. There are research efforts at several universities that focus on increasing wood production. The industrial sectors, especially those involved in the forest-products or sugar-processing industries, are particularly interested in converting their processing wastes into energy resources. Thus, in Peru much consideration is now being given to developing or utilizing national biomass energy resources; however, because no formal national plan has been proposed, uncertainty exists as to the best way to develop these resources.

2.2 AGRICULTURAL SOURCES

Of all known agricultural crops in Peru, only one significantly affects the country's energy situation. Sugar cane produces bagasse for combustion, electricity, and process heat, and chancaca for production of alcohol.

These systems are very energy efficient. Electricity and steam are both produced by these power facilities (i.e., cogeneration).[2] Irrigation pumps are driven electrically utilizing power converted by their own

*Primary Peruvian mainstay responsible for industrial development.

sugar mills. Presently, these pumps use about 90% bagasse and 10% oil to fire the boilers. The amount of oil used will soon increase to 30% because of increasing use of bagasse by the paper industry[2]. The sugar industry now employs 160 million liters of oil annually.

Peru currently allocates sugar cane for production of either sugar, alcohol, or chancaca. In 1976, production of 30,404,000 liters of alcohol from chancaca was reported by the Alcohol and Beverages Department of the National Bank[3]. This alcohol was not used directly for fuel, but was converted to ethylene which then was used for production of polyvinylchloride (PVC). Thus, the alcohol in this instance substitutes directly for a petroleum-derived chemical feedstock.

2.3 COTTON-GIN WASTES

Another crop residue that is being used as an energy resource is cotton-gin waste. Stems, leaves, and other waste products remain after the ginning process. Systems in the U.S. have been developed for burning this waste to produce heat for drying cotton at the gins. A similar system was reported to be in operation near the town of Buenos Aires, Peru. The spread of these systems throughout the country would increase the energy self-sufficiency of the Peruvian cotton industry.

2.4 ANIMAL WASTE

Other major agricultral crops are not being used extensively because the distribution of these resources throughout the country is highly dispersed and thus the supply logistics are affected.

In the Peruvian highlands, dung has been used both as fuel and fertilizer since about 500 A.D.[4] As a fuel source, dung is used for cooking and heating in the highlands. The sources of dung are llama, alpaca, and cattle. Waste is collected and piled on fences or roofs or in open fields to be sun-dried as shown in Fig. 2.1.

The Peruvian highlands are harsh climatic and topographic areas in which to grow trees. For this reason, dung is used instead of firewood, particularly above the tree line. The few stands of trees that do exist in the highlands are far from most households; therefore, wood collection

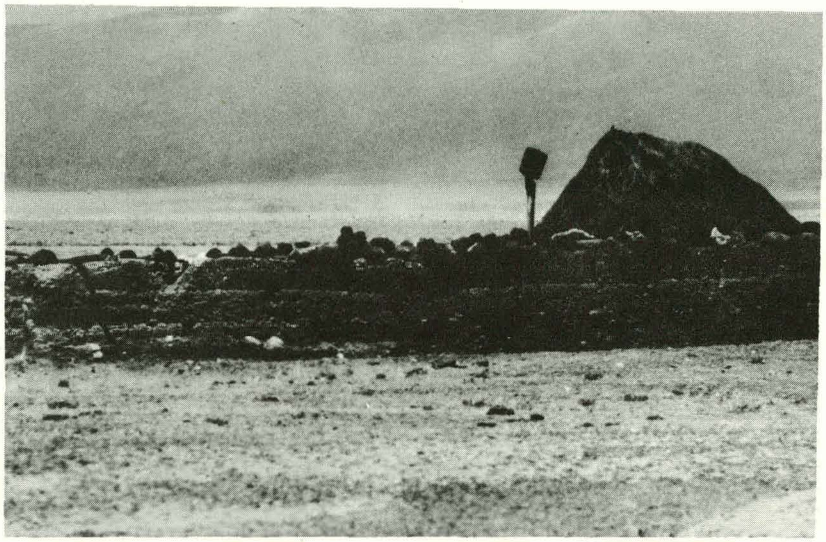


Figure 2.1. Dung Being Dried on A Fence and on the Ground in the Sierra Region (Photo Courtesy of R. Giescke, Member Peruvian Energy Assessment Team).

requires great expenditure of time and effort[4]. Families prefer cattle dung because it is the easiest to collect, and a cattle dung fire is easy to kindle and maintain. Moreover, it produces a hot fire with a minimum of smoke.[5]

Local populations have obtained sources of energy and nutrients from these high-altitude mountainous environments which permit efficient family subsistence. Currently, the amount of this type of energy available and its consumption are being investigated by the United Nations Development Program (UNDP) study group and will be reported on completion of the investigation.

2.5 FOREST SOURCES

2.5.1 Firewood

Wood is an economical and extensively tapped energy source for cooking and heating in areas below the high-altitude mountainous environment. Wood collection generally is carried out by all members of the family. The UNDP study group[5] has estimated that 20% of an adult's daily time is expanded in collecting wood. All children are instructed to bring home little pieces of tree branches or twigs and any wood waste found while playing. Of all the wood utilized in Peru, 60-85% is used as firewood. Eucalyptus is one of the most widely used species for firewood in Peru.

The Eucalyptus is a prime candidate for firewood production and harvesting because many of these trees can reach a suitable size for harvesting in a few years. Furthermore, some Eucalyptus species have the ability to sprout again from their stumps after harvesting, thereby minimizing the requirements for extensive land clearing, cultivation, and replanting operations after each harvest.[6] Several Eucalyptus trees planted on a house perimeter can supply all the firewood required for a family for many years (see Fig. 2.2).

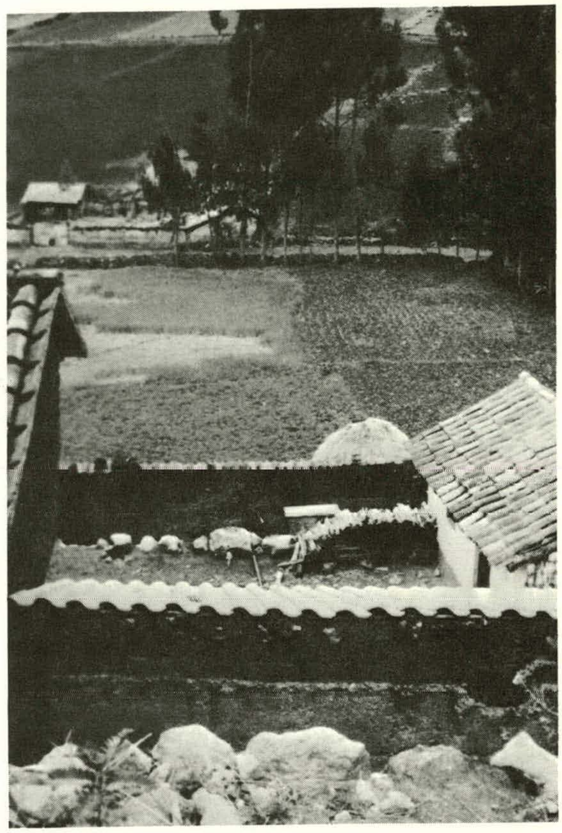


Figure 2.2. Typical Sierra Farm with Eucalyptus Border Planted for Firewood (Photo Courtesy of R. Giescke, Member Peruvian Energy Assessment Team).

2.5.2 Charcoal

Charcoal is a favorite fuel for cooking and heating throughout Peru. Because of past deforestation in the Sierra region, laws were passed many years ago prohibiting charcoal production. However, charcoal is still produced in the Sierra and Selva regions, but its cost is prohibitively high for extensive utilization. When available, it is used for cooking, particularly in restaurants.

Table 2.1 summarizes current biofuel utilization practices in Peru.

Table 2.1. Summary of Current Biofuel Usage in Peru

Biomass Resource	Biofuel Type	Conversion Technology	Energy Produced	Utilizing Sector
Wood	Firewood	Direct combustion	Process Heat	Cooking and heating (home and commercial)
Wood	Charcoal	Pyrolysis	Process Heat	Cooking (home and commercial) and heating
Sugar cane	Bagasse	Direct combustion	Process Heat, Steam and Electricity	Industrial and residential
Sugar cane	Molasses Bagasse	Fermentation	Alcohol	Industrial
Animal Waste	Dung	Direct combustion	Process Heat	Cooking and heating (home)
Agricultural Residue	Cotton Gin Waste	Direct combustion	Process Heat	Industrial

3 BIOFUEL PRODUCTIVITY -- LAND AND CLIMATE CONSIDERATIONS

3.1 TERRAIN

Peru possesses three distinct physiographic regions -- Costa, Sierra, and Selva -- each of which can be divided again into subregions. The generalized regions are characterized as follows:

(1) Costa: The range of topography in this region is represented from sea level to Andean Mountain peaks. Although some areas near the Pacific Ocean and certain inter-mountain valleys are level, much of this region is rugged. Most important, however, this area is mainly arid and is productive only when irrigation water is available. As a result, bioproduction has been limited to high value food crops under carefully managed irrigation. Productive capacity of these irrigated lands is high. Production in surplus of human food needs occurs for certain crops (e.g., sugar cane). Agricultural residues and municipal wastes are the most promising biofuel resources in these areas.

In the Costa, about one million hectares are moist enough to support forests. These occur mainly in the region of Tumbes along the north coast.

(2) Sierra: The central Andes Mountains cover most of the Sierras where the topography varies from broad mountain valleys to the steep, barren, and snow-covered peaks. Elevations in this region range from about 1,000 to 7,000 meters. Many areas of undulating landscape are not too rugged to use for the production of biomass. Much of this land is characterized by gentle-to-rugged topography supporting savanna grasslands or xerophytic forests. The valleys support food crop production; whereas much of the upland areas support livestock grazing only. About 10 million hectares in this region potentially could support forest vegetation, mainly on middle to upper slopes.

(3) Selva: East of the Andes lies the Selva which contributes the headwaters and contains the Peruvian floodplain of the Amazon River and the river's numerous tributaries. The Selva is partitioned into the high and the low regions. The high Selva which occurs at elevations between 600 and 3,800 meters, is characterized by a rolling topography with steep slopes. The low Selva indicates mostly alluvial soils in a flat topography.

Interspersed throughout this region are swampy areas that are under water for much of the year. The Selva contains most of the forested area of Peru, about 78 million hectares -- 69 million of which are in the basin and the remainder on the eastern slopes of the Andes.

3.2 SOILS

In the Costa, the absence of significant precipitation is the major restraint on biomass productivity. Without the flushing action of water, the soils often are saline and possess pH values near 8.0. The low-lying valleys possess deep alluvial soils classed as Entisols, new soil without complete profile development. Most of the remaining soils are Aridisols, developed under arid conditions. The Aridisols are differentiated from the Inceptisols, soils with initial profile development, that are characterized by the existence of saturated extract conductivities of the soil at levels greater than 2 mmhos per cm at 25^{o}C in the 18 to 50 cm layer.

Generally, soils in the Costa region are fertile and support good percolation and drainage. High fertility occurs because water has not leached bases from the profile. The soils are moderately-to-highly susceptible to erosion if in contact with excessive amounts of water. However, if properly irrigated and managed, these low-lying soils are highly productive, especially for food crops such as grains, potatoes, sugar cane, etc.

In the Sierra, soils occur on slopes of < 5% to as much as 70%. Just as slope varies widely, so do the soils that occur in the region. The principal soil groups are Entisols, Inceptisols, and Mollisols -- dark, fertile topsoil, formed under grassland. Mollisols are formed under cold, cool, or warm conditions in the region. Some have thin surfaces; whereas, others are deep. In some cases, clay horizons occur below the surface layer. Among the other groups, similarly wide variations occur. The major differences result from whether the soils formed under warm, humid, or seasonably dry conditions. Many of the soils occur on slopes at elevations only suitable for forests.

The second most abundant group of soils is suitable for pasture and forests growth. These soils are errosive and occur at elevations less than 3,200 meters. The fertility of the soils in the Sierra ranges from low to high. Gully erosion is a serious problem. When leaching water is present, the soils may be infertile and acidic.

In the high Selva, well-developed soil profiles belonging to the Alfisol and Ultisol soil types, clay subsurfaces, high and low in bases, respectively. Both possess clay accumulations in a subsurface horizon but differ in base content. Alfisols developed while distinctly dry seasons occur. Ultisols are highly weathered and leached of their bases. Where the soils are well-drained, the profile becomes oxidized and the iron-aluminum oxides impart a red color. In depressions and valleys, alluvial Inceptisols occur. In relatively stable upland summit positions, Oxisols occur. The latter reflect a loss of silicon and accumulation of iron and aluminum oxides within 2 m of the surface. In this group, infiltration is high and erodibility low because clays are aggregated and do not disperse readily in water.

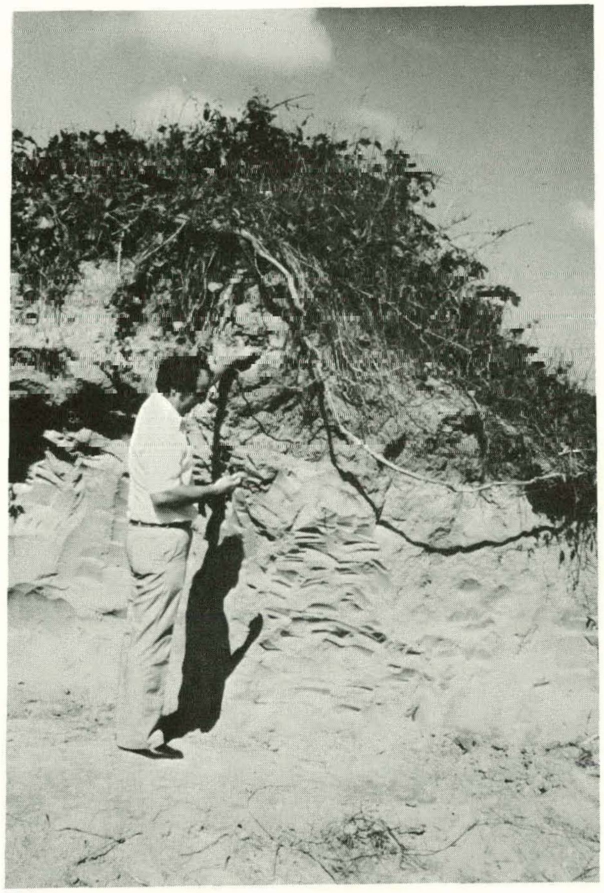


Figure 3.1. Typical Soil Profile of Selva Region

In the high Selva, where sloping land is common, erosion is a serious problem. Not only does erosion cause the loss of topsoil, but the stream sediments will adversely affect hydroelectric facilities. Because of these limitations, only about six million hectares appear suitable for pastures and two million hectares for cultivation. The remainder probably should remain in forests. Of the 70 million hectares, it is believed that as many as 25 million should be in watershed protection forests.

In the low Selva, the soils are dominated by Entisols from recent alluvial deposits from river floodings (see Fig. 3.1). The clay fraction of these soils is either kaolinitic or contains hydrous oxides -- both of which are low in exchange capacity. Thus, the soils often are low in fertility. Most nutrients occur in living and dead organic materials. Because of warm temperatures (18 to 24°C), high rainfall (1,500 to 7,000 mm), decaying vegetation, weathering in these soils is intense. The resultant clay slows infiltration and percolation. Thus, in the absence of vegetation, erosion is a serious problem. In some cases, the clays may dry irreversibly under conditions of excessive desiccation e.g., high temperatures and/or low amounts of moisture. For these reasons, many of the soils cannot persist under cultivation or support intensive cropping. When cleared mechanically, many of the soils of the Selva are compacted and depleted of vegetable ash and topsoil. This limits the feasibility of mechanical clearing and favors manual clearing.

3.3 CLIMATE

Peru provides an interesting study in climatology. The country's climate is essentially tropical and it lies between the equator and 19° south latitude. However, the topography of the region gives rise to an interesting variety of climates. Three great climatic groups are found in Peru: (1) desert; (2) tierra fria or non-frostless tropical highlands; and (3) tropical.[7] The main reasons for the existence of the various climates are the Andes mountains and the Von Humboldt ocean current. This combination has caused the development of an atmospheric weather pattern leading to the creation of a desert on the western slopes of the Andes and a tropical rain forest on the eastern side. Thus, the Andean tropical high-lands are among the highest tropical areas in the world. In Peru, these three climatic groups are present in the Costa, Sierra, and Selva regions, respectively.

The Costa is predominantly desert, but a large proportion of the country's agricultural production occurs in the coastal mountain river valleys (see Fig. 3.2). It is necessary to irrigate the crops grown in this region. The water for irrigation is obtained from snowmelts and rain in the Andes.

In the highland areas of the Andes are cool, rich, and fertile mountain valleys (see Fig. 3.3). Much of the hillside is used as pasture, and intensive agricultural production occurs on the mountain valley floors. Because of the high altitude of the Andes, many parts of the Sierra are uninhabited and unsuitable for biomass production as shown in Fig. 3.4.

Figure 3.2. Irrigated Coastal Mountain Valley in Costa Region

Figure 3.3. Cultivated Mountainside in the Sierra Region.

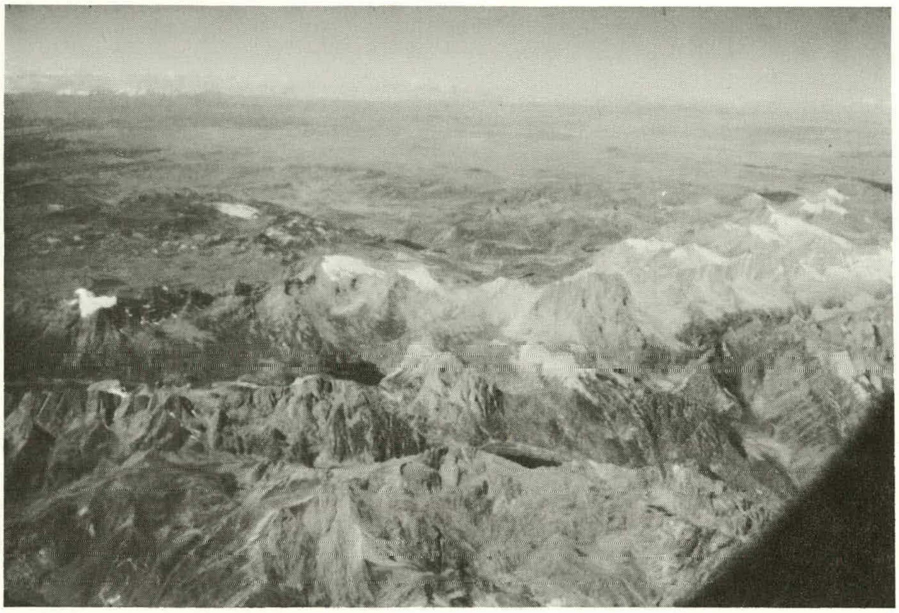


Figure 3.4. Barren Terrain Typical of the High Selva Region.

The Selva or tropical area is potentially the most productive region in Peru, and often is identified as either the high Selva or the low Selva. The high Selva or Caja de Selva (rim of the Selva) is in a mountainous tropical area with high rainfall and is shown in Fig. 3.5. The low Selva is in the flat, low-lying reaches of the Amazon River Basin and is shown in Fig. 3.6.

Thus, the two major climatic variables in determining biomass productivity in Peru are temperature and rainfall. These data are presented in Tables 3.1 and 3.2, respectively. For representative cities from the Costa (e.g., Lima), the Sierra (e.g., Huancayo), and the Selva (e.g., Tingo Maria), the typical climatic patterns are the hot-dry desert, the cool-moist highlands, and hot-moist tropics, respectively.

From an agronomic perspective, the method of climatological classification developed by Papadakis[7] can assist in understanding biomass productivity in Peru. The approach of this classification considers those environmental factors that are determinants of agricultural productivity.

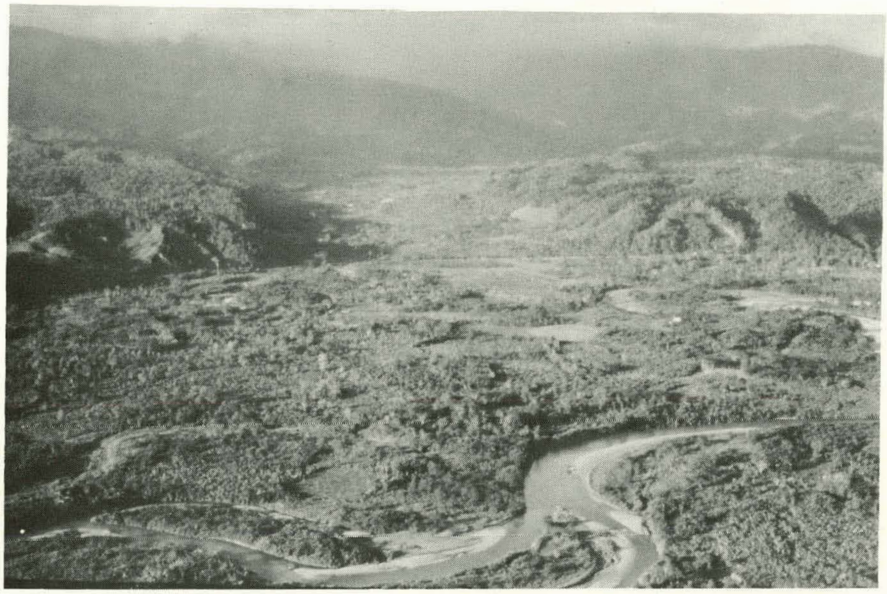


Figure 3.5. Highlands of the Caja de Selva (High Selva Region)

Figure 3.6. Low Selva within the Amazon River Basin.

Table 3.1. Monthly Mean Temperatures (°C) for Selected Stations in Peru[8]

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Arequipa	14.1	14.3	14.5	13.4	12.7	11.2	11.5	12.1	12.9	13.4	13.4	13.5	13.1
Cajamarca	14.6	14.1	14.2	13.8	13.9	13.2	13.1	14.0	14.5	14.3	14.6	14.3	14.0
Cartavio	23.0	24.1	23.8	22.0	21.0	19.2	18.3	18.0	17.9	18.2	19.0	20.7	20.4
Cerro de Pasco	2.8	2.4	3.3	2.1	1.6	2.1	1.3	2.6	2.2	2.6	3.6	3.1	2.5
Cuzco	12.0	11.4	11.9	11.4	10.2	9.5	8.8	10.2	11.5	12.3	12.9	12.4	10.9
Chacapoyas	15.9	15.7	15.6	15.4	15.8	15.2	14.5	15.1	14.1	15.9	16.5	16.2	15.6
Huancayo	12.1	12.0	11.7	11.6	10.2	9.8	9.3	10.2	11.9	12.4	12.7	12.2	11.2
Imata	4.5	4.7	4.7	3.7	1.9	1.4	1.6	1.0	2.2	2.7	3.6	4.5	2.9
Juanju	27.4	26.6	26.5	26.4	26.0	25.6	25.6	26.3	26.6	26.7	26.9	27.5	26.5
Lambayeque	25.1	26.4	26.2	24.6	22.8	20.9	19.6	19.3	19.7	20.2	21.1	22.8	22.9
Lima	21.4	22.2	22.4	19.8	17.5	15.6	15.2	15.0	15.4	16.2	17.4	19.1	18.0
Molina (La)	22.8	23.6	23.3	21.4	18.6	16.6	15.9	15.8	16.5	17.6	18.8	20.6	19.3
Piura	27.7	28.9	28.9	27.5	25.1	23.5	22.6	22.9	23.5	23.4	23.9	25.3	25.6
Puno	8.5	8.5	8.9	8.0	6.6	5.8	6.0	6.8	7.7	9.2	9.5	9.3	7.8
Tacna	20.6	20.7	19.4	17.6	15.1	13.4	12.7	13.0	14.0	14.9	17.0	18.4	16.5
Tingo Maria	22.8	22.1	22.4	22.3	22.4	21.8	22.0	22.6	22.5	22.8	26.6	23.4	22.5
Vitor	17.1	17.7	18.3	17.7	18.0	17.8	17.5	17.8	18.1	17.4	17.4	17.5	17.8

Table 3.2. Monthly Mean Rainfall (cm) for Selected Stations in Peru[8]

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Arequipa	3.1	2.6	2.9	0.1	0.0	0.0	0.0	0.01	0.1	0.0	0.1	0.5	9.4
Cajamarca	9.5	11.3	13.6	10.8	3.7	1.3	0.5	0.9	3.0	8.7	7.2	7.7	78.2
Cartavio	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.8
Cerro de Pasco	13.4	15.3	12.8	7.0	3.6	1.6	1.1	1.9	5.0	6.8	11.5	12.6	92.6
Cuzco	15.8	12.8	12.6	3.8	0.9	0.5	0.1	0.8	2.4	4.3	8.1	12.8	74.9
Chacapoyas	8.3	13.5	10.3	9.6	4.0	2.7	2.3	2.8	6.0	9.2	7.3	5.6	81.5
Huancayo	13.6	12.6	11.6	5.1	2.2	0.8	0.5	1.1	4.0	7.1	6.9	9.3	74.9
Imata	14.8	14.7	10.5	4.1	1.5	0.5	0.3	0.2	2.0	2.0	2.3	9.0	62.0
Iquitos	2.6	20.0	27.0	31.4	25.7	17.2	17.7	13.8	20.4	21.9	27.0	24.6	272.7
Juanju	9.2	15.9	14.1	20.3	12.7	6.3	8.0	6.0	12.2	16.8	15.3	10.8	147.6
Lambayeque	0.1	0.7	0.7	0.3	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.2	2.5
Lima	0.1	0.0	0.1	0.0	0.1	0.3	0.5	0.6	0.5	0.2	0.1	0.1	2.6
Molina (La)	0.1	0.16	0.1	0.1	0.2	0.3	0.3	0.3	0.2	0.1	0.1	0.1	2.0
Piura	1.1	1.7	1.9	1.5	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.6	7.2
Puno	13.5	13.8	10.9	4.0	0.9	0.6	0.5	0.6	2.4	3.7	2.7	8.8	62.5
San Ramon	24.2	24.4	24.3	20.4	12.0	5.4	7.1	11.6	12.8	16.6	12.4	21.9	194.1
Tacna	0.1	0.1	0.1	0.1	0.4	0.3	0.4	0.8	1.1	0.7	0.1	0.1	4.1
Tingo Maria	42.4	40.3	46.9	35.1	21.7	17.5	15.7	11.2	18.4	34.1	28.9	28.9	341.0
Vitor	0.8	0.8	0.2	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.1	2.2

The approach leads the development of an energy and water balance for a habitat. The energy balance is based on a combination of the severity of winters and the heat occurring during the summer, and on their relationship to agricultural productivity. An explanation of the winter severity and the summer heat classification approach is given in Appendix A and Appendix B, respectively.

The overall effect of seasonal temperature variations is described by the Temperature Regime in Appendix C, and the water balance is determined by the Humidity Regime shown in Appendix D and is based on a humidity index of the ratio of annual rainfall to annual evapotranspiration, on normal and maximum excess rainfall, and on length of humid and dry seasons. Evapotranspiration data is contained in Appendix E. The resulting climatic classification allows an estimation of the environmental variables important for biomass production. The climatic classifications of 23 stations throughout Peru are presented in Table 3.3.

The distribution of types of vegetation throughout Peru is shown in four maps, one for each interval of 4° south latitude (see Figs. 3.7, 3.8, 3.9, and 3.10). These vegetation maps, adapted from maps developed by Universidad Nacional Agraria personnel, depict eight of the vegetation zones. Table 3.4 provides a legend for interpreting these maps. The data reveal that over 42% of Peru is covered by alluvial or hilly forests, 22% by desert, 13% by protected forest area, 10% by agricultural lands, 6% by pasture, 4% by swamp-like areas, and 3% by savanna vegetation.

Table 3.3. Climatic Parameters, Regimes, and Classifications for Selected Locations in Peru[7]

Location	Humidity[a] Index	Humid[b] Season Normal Excess Rainfall (cm)	Maximum[c] Excess Rainfall (cm)	Humid Season Begin (End)	Dry Season Begin (End)	Winter[d] Severity Classification	Summer[e] Heat Classification	Humidity[f] Regime	Temperature Regime[g]	Climatic Classification
Arequipa	.10	0	4	None	Mar. (Jan.)	Citrus belt	Maize belt	Semi-arid Monsoon	Medium Tierra Fria	Medium Tierra Fria
Cajamarca	.75	11	67	Dec. (Apr.)	July (Aug.)	Citrus belt	Maize belt	Dry Monsoon	Medium Tierra Fria	Medium Tierra Fria
Cartavio	.02	0	0	None	Jan. (Dec.)	Cool tropical	Coffee belt	Absolute Desert Humid	Cool Tropical Low	Cool and Semi-hot tropical desert
Cerro de Pasco	1.54	36	>99	Oct. (Apr.)	None	Cold winter oats belt	High	Humid	Low Andine	High Andine
Chacha Poyas	1.01	18	86	Dec. (Apr.)	August	Cool tropical belt	Maize belt	Moist Monsoon	Cool Tierra Templada	Humid Tierra Templada
Chuquibambilia	.80	27	80	Dec. (Mar.)	June (Oct.)	Mild winter wheat belt	High Alpine belt	Moist Monsoon	Low Andine	High Andine
Cusco	.71	22	77	Dec. (Mar.)	June (Sept.)	Mild winter oats belt	Maize belt	Moist Monsoon	Medium Tierra Fria	Medium Tierra Fria
Huancayo	.71	20	86	Dec. (Mar.)	June (Sept.)	Mild winter oats belt	Maize belt	Moist Monsoon	Medium Tierra Fria	Medium Tierra Fria

[a]Humidity index = $\frac{\text{Annual Rainfall}}{\text{Annual Evapotranspiration}}$

[b]The difference: rainfall minus evapotranspiration during the humid season.

[c]The difference: two times rainfall minus evapotranspiration during the non-dry season.

[d]See Appendix A for explanation.

[e]See Appendix B for explanation.

[f]See Appendix C for explanation.

[g]See Appendix D for explanation.

Table 3.3 (Contd.)

Location	Humidity[a] Index	Humid[b] Season Normal Excess Rainfall (cm)	Maximum[c] Excess Rainfall (cm)	Humid Season Begin (End)	Dry Season Begin (End)	Winter[d] Severity Classification	Summer[e] Heat Classification	Humidity[f] Regime	Temperature Regime[g]	Climatic Classification
Imata	.98	35	93	Dec. (Mar.)	June (Nov.)	Mild winter wheat belt	High alpine belt	Moist Monsoon	Low Andine	High Andine
Iquitos	2.42	187	> 99	Aug. (July)	None	Equatorial belt	Cool cotton belt	Ever-humid	Semi-hot Equatorial	Humid Semi-hot Equatorial
Juaja	.75	.17	61	Dec. (Mar.)	July (Sept.)	Citrus belt	Maize belt	Moist Monsoon	Medium Tierra Fria	Medium Tierra Fria
Lambayeque	.02	0	0	None	Jan. (Dec.)	Tropical belt	Cool cotton belt	Absolute Desert	Semi-hot Tropical	Cool and Semi-hot tropical desert
La Molina	.02	0	0	None	Sept. (Aug.)	Cool tropical belt	Coffee belt	Absolute desert	Cool tropical	Cool and semi-hot tropical desert
Lima	.05	0	0	None	Sept. (Aug.)	Cool tropical	Coffee belt	Asbolute desert	Cool tropical	Cool and semi-hot tropical desert

[a]Humidity index = $\frac{\text{Annual Rainfall}}{\text{Annual Evapotranspiration}}$

[b]The difference: rainfall minus evapotranspiration during the humid season.

[c]The difference: two times rainfall minus evapotranspiration during the non-dry season.

[d]See Appendix A for explanation.

[e]See Appendix B for explanation.

[f]See Appendix C for explanation.

[g]See Appendix D for explanation.

Table 3.3 (Contd.)

Location	Humidity[a] Index	Humid[b] Season Normal Excess Rainfall (cm)	Maximum[c] Excess Rainfall (cm)	Humid Season Begin (End)	Dry Season Begin (End)	Winter[d] Severity Classification	Summer[e] Heat Classification	Humidity[f] Regime	Temperature Regime[g]	Climatic Classification
Lomas de Lachay	.46	6	18	Jul. (Sept.)	Jan. (May)	Cool tropical belt	Maize belt	Dry Mediter-ranean	Cool Tropical	Tropical Mediterranean
Mollendo	.03	0	0	None	Sept. (Aug.)	Cool Tropical belt	Coffee belt	Absolute Desert	Cool Tropical	Cool and Semi-hot Tropical Desert
Moquegua	.00	0	0	None	Mar. (Feb.)	Citrus belt	Coffee belt	Absolute Desert	Low Tierra Fria	Tropical Highland Desert
Piura	.06	0	0	None	Mar. (Feb.)	Cool Tropical belt	Warm Cotton belt	Monsoon Desert	Hot tropical	Hot tropical Equatorial Desert
Puno	.70	20	66	Dec. (Mar.)	June (Nov.)	Mild winter oats belt	Low Alpine belt	Moist Monsoon	Low Andine	Low Andine

[a]Humidity index = $\frac{\text{Annual Rainfall}}{\text{Annual Evapotranspiration}}$

[b]The difference: rainfall minus evapotranspiration during the humid season.

[c]The difference: two times rainfall minus evapotranspiration during the non-dry season.

[d]See Appendix A for explanation.

[e]See Appendix B for explanation.

[f]See Appendix C for explanation.

[g]See Appendix D for explanation.

Table 3.3 (Contd.)

Location	Humidity[a] Index	Humid[b] Season Normal Excess Rainfall (cm)	Maximum[c] Excess Rainfall (cm)	Humid Season Begin (End)	Dry Season Begin (End)	Winter[d] Severity Classification	Summer[e] Heat Classification	Humidity[f] Regime	Temperature Regime[g]	Climatic Classification
San Ramon	1.20	51	>99	Oct. (May)	None	Tropical Belt	Coffee Belt	Humid	Tierra Templada	Humid Tierra Templada
Tacna	.03	0	0	None	July(June)	Cool tropical belt	Coffee Belt	Absolute Desert	Cool	Absolute Cool tropical desert
Tingo Maria	2.43	198	>99	Sept. (July)	None	Tropical belt	Coffee Belt	Humid	Tierra Templada	Humid Tierra Templada
Vitor	.01	0	0	None	Mar.(Feb.)	Citrus belt	Coffee belt	Absolute Desert	Low Tierra Fria	Tropical Highland Desert

[a]Humidity index = $\frac{\text{Annual Rainfall}}{\text{Annual Evapotranspiration}}$

[b]The difference: rainfall minus evapotranspiration during the humid season.

[c]The difference: two times rainfall minus evapotranspiration during the non-dry season.

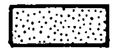
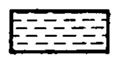
[d]See Appendix A for explanation.

[e]See Appendix B for explanation.

[f]See Appendix C for explanation.

[g]See Appendix D for explanation.

Table 3.4. Legend for Vegetation Maps of Peru

Main Vegetative Groups	Vegetative Subgroups	Symbol
Forest, Alluvial	Forest, Alluvial Class I Forest, Alluvial Class II Forest, Alluvial Class III	
Forest, Hilly	Forest, Hilly Class I Forest, Hilly Class II Forest, Hilly Class III	
Swamp Vegetation	Mangroves Aguajal Swamps Quinal	
Protected Forest	Devastated Forests Inaccessible Forests Plantations	
Savanna and Low Bush Vegetation	Dense Dry Forest Savanna Forest Chaparral Podocarpus Forest Low Bush	
Desert Vegetation	Cactus Bush	
Agricultural Vegetation	Food and Fiber Crops	
Pasture	Forage Crops	

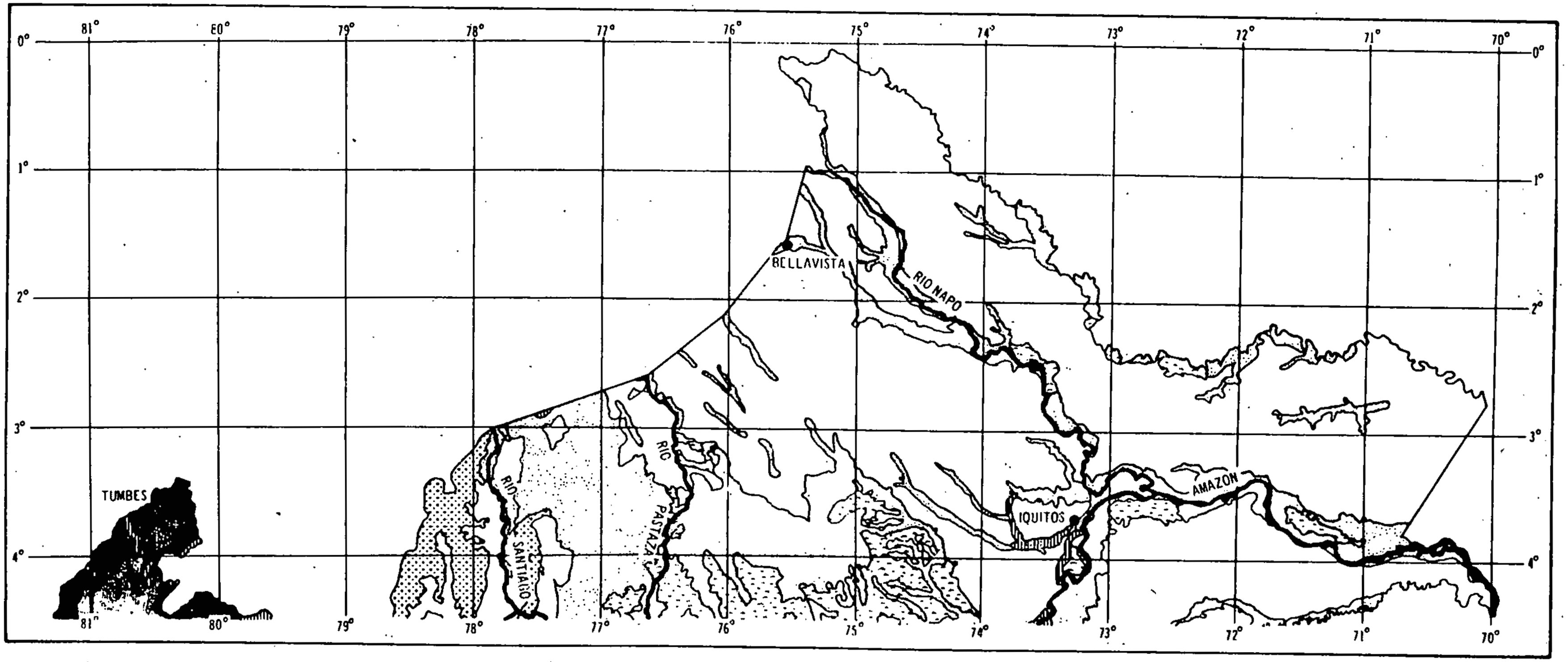


Fig. 3.7. Vegetation Map of Peru (0-4° South Latitude)[9]

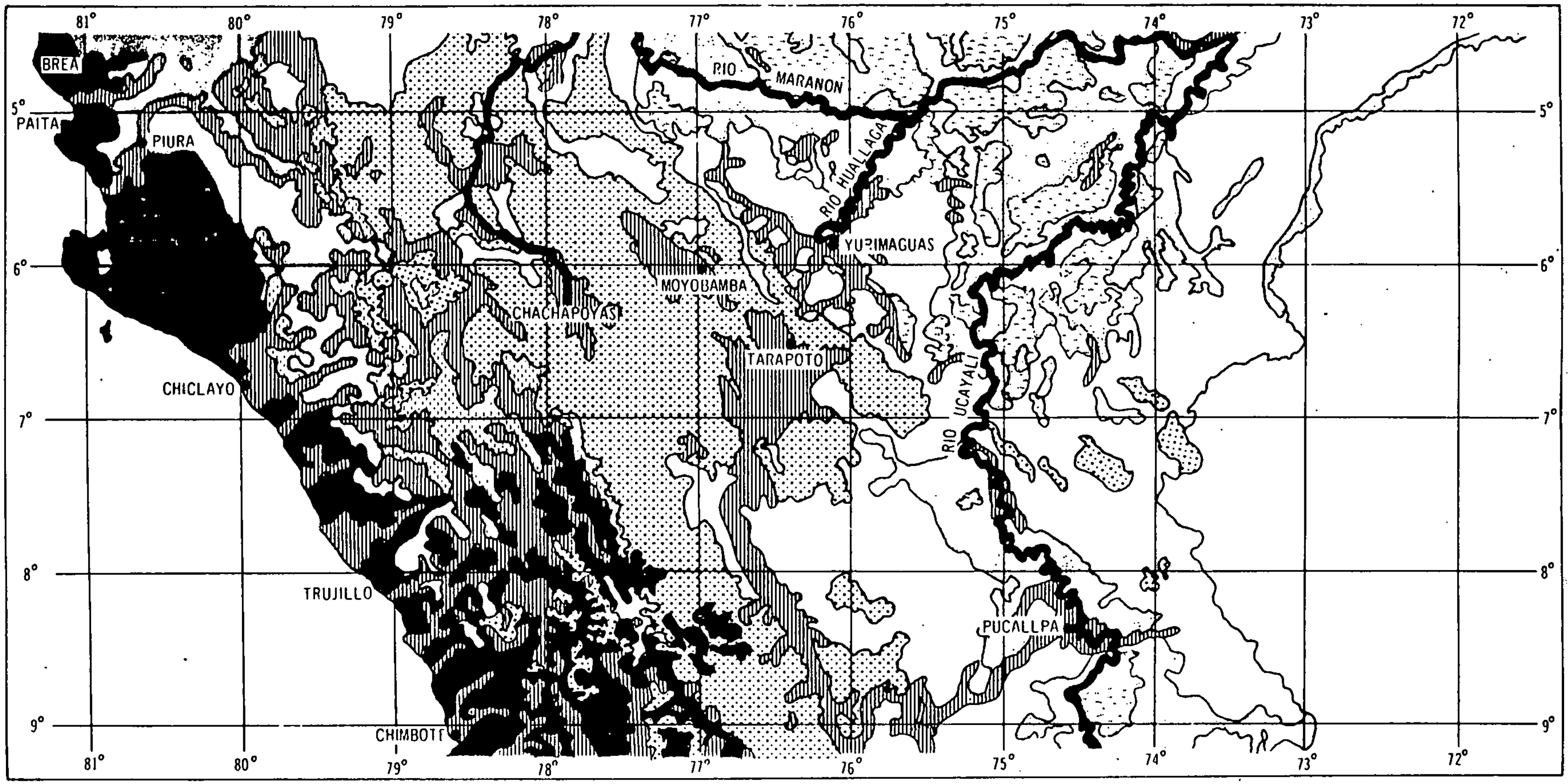


Fig. 3.8. Vegetation Map of Peru (5-9° South Latitude)[9]

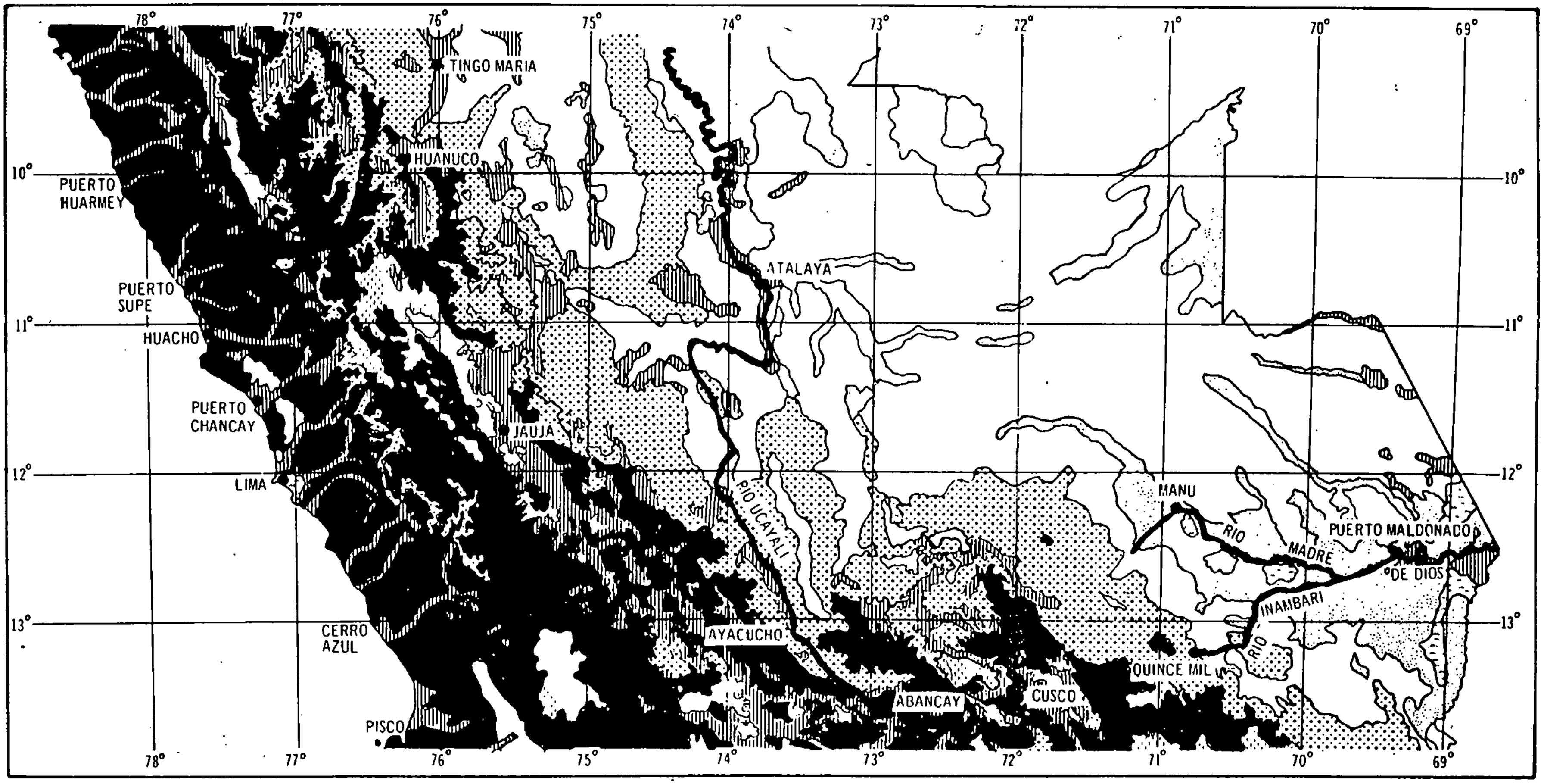


Fig. 3.9. Vegetation Map of Peru (10-13° South Latitude)[9]

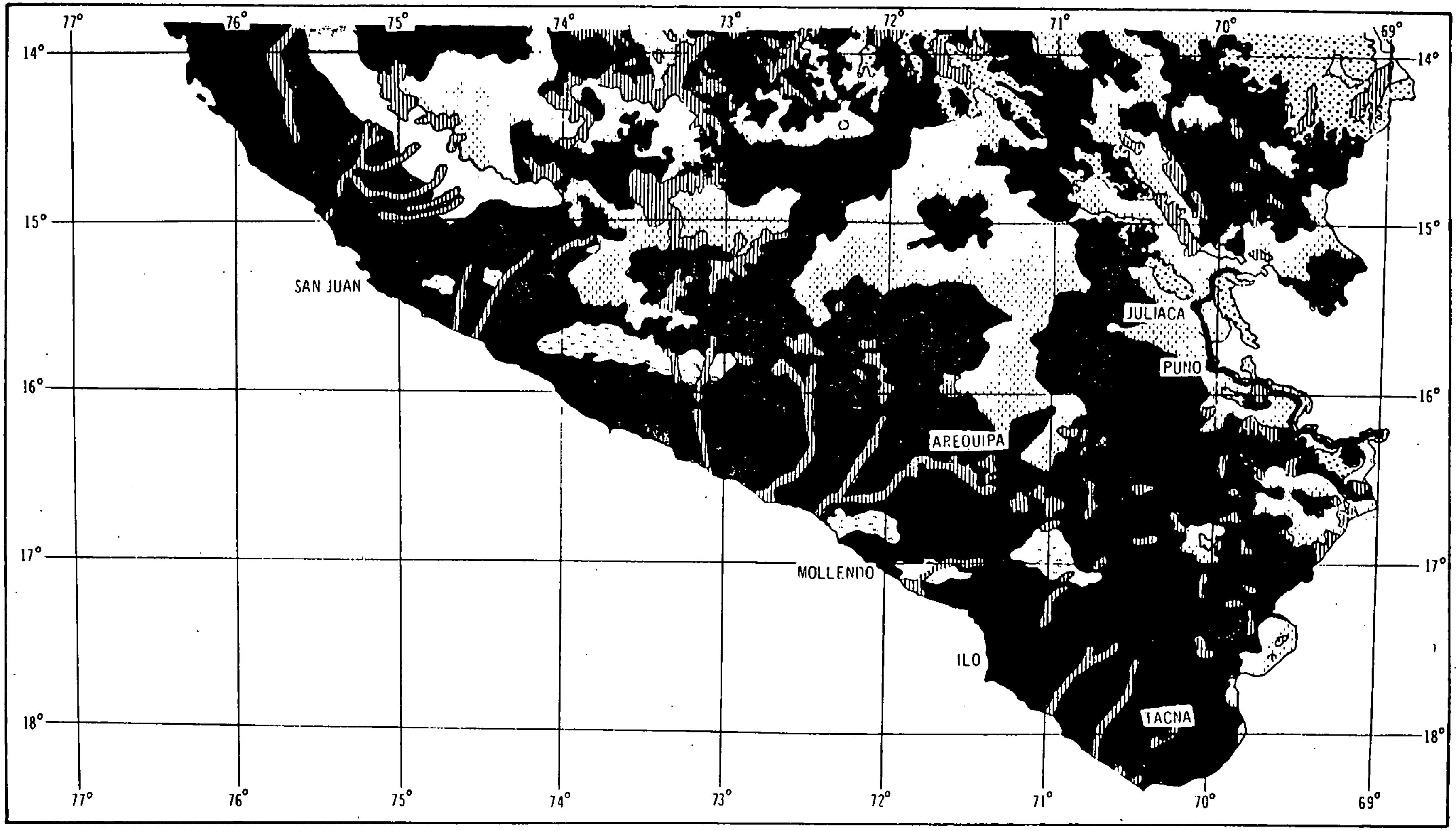


Fig. 3.10. Vegetation Map of Peru (14-18° South Latitude)[9]

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4 BIOFUEL RESOURCE BASE

4.1 CURRENT AGRICULTURAL RESOURCES

In Peru, approximately 2,600,000 hectares (2%) of a total national surface area of 128.5 million hectares are under cultivation. An additional 27.3 million hectares can be classified as uncultivated grasslands.[10] Of the land under cultivation, approximately 1.1 million hectares (over 40%) is irrigated. Cereal crops account for about 35% of the total cultivated area and 32% of the irrigated area. Tuber crops, such as potatoes, cassava, and sweet potatoes, are grown on approximately 14% of the total cultivated area and on 7% of the irrigated area. Cultivated pastures (e.g., alfalfa) and other forages cover over 15% of the cultivated area and 19% of the irrigated area. Permanent cultivars, such as lemons, olives, cocoa, tea, and coffee, provide about 10% of the cultivated area and 7% of the irrigated land; whereas, fruits and vegetables cover about 9% of cultivated land and 7% of irrigated land. Beans and assorted legumes account for over 6% of the cultivated area and 5% of the irrigated area. More than 11% of the cultivated area is used for the production of industrial crops, such as sugar cane and cotton; these crops require 23% of the irrigated acreage. Table 4.1 lists the production and yield statistics for selected crops.

The Costa region contains 27% of the total cultivated area in Peru and 66.6% of the irrigated land. Virtually all agricultural land on the coast is irrigated; this area accounts for 75% of rice production, 58% of corn production, 86% of sweet potato production, 99% of cotton production, and over 99% of sugar production in Peru (see Table 4.2). The biofuel potential of this area, as estimated from the crops listed in Table 4.2 is approximately 53 JQ's (10^{15} joules) per year, two-thirds of which comes from sugar cane production. Much of the sugar cane residue currently is being utilized by the sugar industry as boiler fuel. Moreover, over 30 million liters of ethanol are produced in the sugar districts, as shown in Table 4.3. Table 4.4 shows that an additional 18 JQ's of biofuel energy could possibly be obtained from the livestock population in the Costa region.

The Sierra region contains 50% of the area cultivated in Peru and 30% of the land irrigated. Continuous cultivation in this region is rare, and a fallow system of crop rotation usually is followed. One estimate shows

Table 4.1. Total Production, Residue, and Energy Estimates of Crops Grown in Peru[11]

Commodity	1976 Production (Metric tons)	1976 Yield[11] (Metric tons/ Hectare)	Annual Residue Production Estimate (Metric tons)	Estimated Residue[a] Energy Value (10^{15} Joules)
Rice	570,415	4.28	855,623	11.47
Oats	741	.83	1,482	.02
Barley	149,517	.92	224,276	3.00
Milo	465	.85	465	.01
Maize	725,659	1.88	725,659	9.72
Quinoa	8,676	.58	21,690	.29
Sorghum	45,945	3.13	68,918	.92
Wheat	127,497	.95	191,246	2.56
Soybean	2,869	1.42	4,303	.06
Plantains	711,065	11.45	106,660	1.42
Camote	162,547	11.51	24,382	.32
Potatoes	1,167,000	6.59	250,050	3.25
Yucca	402,486	11.23	402,486	5.23
Cotton	164,511	1.67	164,511	2.20
Peanut	3,647	1.26	3,647	.05
Sugar cane (For sugar)	8,791,542	159.86	3,077,040	33.85
Sugar cane (For Alcohol)	185,170	54.14	64,810	.71
Sugar cane (For Molasses)	233,050	53.88	81,568	.90
Coconut	1,311	7.95	1,967	.03
Aguaje	5,460	21.00	5,460	.07

[a]See Appendix F for explanation.

Table 4.2. Total Production, Residue, and Energy Estimates of Crops Grown in the Costa Region of Peru[11]

Commodity	1976 Production (Metric tons)	1976 Yield[11] (Metric tons/ Hectare)	Annual Residue Production Estimate (Metric tons)	Estimated Residue[a] Energy Value (10^{15} Joules)
Rice	426,431	4.88	639,647	8.57
Oats	---	---	---	---
Barley	2,570	2.37	3,855	.05
Milo	---	---	---	---
Maize	417,444	3.45	417,444	5.59
Quinoa	---	---	---	---
Sorghum	45,145	3.16	67,718	.91
Wheat	3,824	2.04	5,736	.08
Soybean	2,301	1.42	3,452	.05
Plantains	113,020	12.84	16,953	.22
Camote	119,313	13.34	20,897	.27
Potatoes	156,948	13.85	23,542	.31
Yucca	50,932	10.67	50,392	.66
Cotton	162,869	1.69	162,869	2.18
Peanut	967	2.54	967	.01
Sugar cane (For sugar)	8,761,542	159.90	3,066,540	33.73
Sugar cane (For Alcohol)	41,958	59.58	14,685	.16
Sugar cane	67,350	84.19	23,573	26

[a]See Appendix F for explanation.

Table 4.3. Production of Absolute Ethanol in Peru by Sugar Producing District[3]

Station	FY 1972				FY74				FY 1976			
	Absolute Ethanol Production (1000)	Yeast Recovered (Mt/Yr)	Yeast for Fodder (Mt/Yr)	CO_2 Produced (Mt/Yr)	Absolute Ethanol Production (1000)	Yeast Recovered (Mt/Yr)	Yeast for Fodder (Mt/Yr)	CO_2 /Produced (Mt/Yr)	Absolute Ethanol Production (1000)	Yeast Recovered (Mt/Yr)	Yeast for Fodder (Mt/Yr)	CO_2 Produced (Mt/Yr)
Paramonga	4,996	71	749	2500	5,184	74	852	2590	5,065	72	760	2530
Pomalca	881	13	132	440	1,104	16	166	552	1,414	20	212	707
Pucala	---	---	---	---	3,795	54	569	1900	3,540	51	531	1707
Tuman	3,341	48	501	1670	2,831	41	425	1415	2,863	41	430	1431
Chucarapi	728	10	109	364	868	12	130	434	627	9	94	313
Sta. Maria	4	.05	.55	2	---	--	---	---	---	—	---	—
Cartavio	10,590	151	1588	5295	10,717	153	1608	5358	11,235	161	1685	5617
Casa Grande	7,942	114	1191	3971	8,941	128	1341	4470	4,968	71	745	2484
Laredo	---	---	---	---	1,143	16	171	571	692	10	103	346

Table 4.4. Residue Production and Energy Potential From Livestock in Peru[11]

Animal By Region	1976 Population[11] (1000 Head)	Annual Residue Production Estimate (1000 Metric Tons)	Estimated Residue[a] Energy Value (10^{15} Joules)
Alpacas			
National	2,445	318	4.64
Sierra	2,445	318	4.64
Poultry			
National	37,681	42	.61
Costa	28,374	32	.46
Sierra	6,671	7	.10
Selva	2,637	3	.05
Goats			
National	2,021	222	3.24
Costa	728	80	1.17
Sierra	1,278	140	2.04
Selva	16	2	.03
Horses			
National	1,327	1,991	29.07
Costa	123	185	2.70
Sierra	1,138	1,707	24.92
Selva	66	99	1.45
Llamas			
National	1,361	23	.34
Sierra	1,361	23	.34
Sheep			
National	15,294	1,682	24.56
Costa	241	26	.38
Sierra	15,025	1,653	24.13
Selva	27	3	.05
Pigs			
National	2,142	236	3.45
Costa	587	65	.95
Sierra	1,309	144	2.10
Selva	246	27	.40
Cattle			
National	4,189	7,121	103.97
Costa	509	865	12.63
Sierra	3,327	5,656	82.58
Selva	353	600	8.76

[a]See Appendix F for application.

500,000 hectares, approximately 20% of all cultivated land in Peru, lies fallow each year.[12] Land typically will lie fallow 1-2 years per year of crop production, depending upon the soil type. Cereal and tuberous crops account for over 60% of the cultivated land, 40% and 20% respectively, in this mountainous area. Table 4.5 shows that over 98% of the barley, 10% of the oats, 33% of the corn, 100% of the quinoa, 99% of the sorghum, 97% of the wheat, and 90% of the potatoes in Peru are grown in this region. The potential biofuel energy available from the crop residues of the Sierra is approximately 16 JQ's.

The animal population of the Sierra is large. Table 4.4 shows that virtually all of the country's alpacas, goats, horses, llamas, and pigs and 80% of the cattle in Peru are found in this region. The manures produced by these animals provide approximately 140 JQ's of energy annually. Much of this energy is used for heating and cooking, or as fertilizer.

- In the Selva, which is potentially the most productive agricultural area of Peru, 23% of the area is under cultivation. Shifting cultivation predominates in this region, with the particular sequencing of crops dependent upon locale. A typical sequence would involve: (1) slashing and burning a hectare of jungle; (2) planting maize or rice; (3) planting yucca (cassava); and (4) planting bananas and mangoes or some other fruit tree. The land then is allowed to return to jungle. The major crops, as shown in Table 4.6, are plantains (78% of Peruvian production), cassava or yucca (78% of Peruvian production), and rice (25% of Peruvian production). The total biofuel energy that is potentially contained in crop residues of the Selva is 6 JQ's; including that from animal wastes, it is approximately 11 JQ's. Comparatively lower biofuel production from agriculture in this area is due to the type of crops grown and the lower yields of the crops. Agricultural production in this area is currently developing. Eventually the Selva could become the major agricultural region of Peru.

In summary, it has been estimated that 246 JQ's of energy are produced by agricultural production in Peru; approximately one-third (76 JQ's) from crop residues and two-thirds (170 JQ's) from animal residues. Currently, sugar cane residues in the Costa and animal waste (dung) in the Sierra are utilized the most.

Table 4.5. Production, Residue, and Energy Estimates of Crops Grown in the Selva Region of Peru[11]

Commodity	1976[11] Production (Metric tons)	1976[11] Yield (Metric tons/ Hectare)	Annual Residue Production Estimate (Metric tons)	Estimated Residue[a] Energy Value (10^{15} Joules)
Rice	1,593	4.55	2,390	.03
Oats	741	.82	1,482	.02
Barley	146,947	.91	220,421	2.95
Milo	465	.85	465	.01
Maize	236,915	1.07	236,915	3.18
Quinoa	8,676	.58	21,690	2.91
Sorghum	---	2.00	---	---
Wheat	123,673	---	185,510	2.49
Soybean	---	.94	---	---
Plantains	45,219	---	6,782	.09
Camote	17,149	9.41	2,572	.03
Potatoes	1,449,792	5.80	224,969	2.93
Yucca	37,749	6.26	37,349	.49
Cotton	126	7.43	126	.00
Peanut	---	.97	10,500	---
Sugar cane (For sugar)	30,000	150.00	---	.12
Sugar cane (For Alcohol)	34,400	67.45	12,040	.13
Sugar cane (For Molasses)	97,710	54.44	34,199	.38
Coconut	---	---	---	---
Aguaje	---	---	---	---

[a]See Appendix F for explanation.

Table 4.6. Production, Residue, and Energy Estimates of Crops Grown in the Selva Region of Peru[11]

Commodity	1976[11] Production (Metric tons)	1976[11] Yield (Metric tons/ Hectare)	Annual Residue Production Estimate (Metric tons)	Estimated Residue[a] Energy Value (10^{15} Joules)
Rice	142,391	3.13	213,587	2.86
Oats	---	---	---	---
Barley	---	---	---	---
Milo	---	---	---	---
Maize	71,300	1.66	71,300	.96
Quinoa	---	---	---	---
Sorghum	800	2.00	1,200	.02
Wheat	---	---	---	---
Soybean	568	1.40	852	.01
Plantains	552,806	11.40	82,921	1.08
Camote	6,085	8.34	913	.01
Potatoes	10,260	5.70	1,539	.02
Yucca	314,345	12.07	314,345	.09
Cotton	1,516	.75	1,516	.02
Peanut	2,680	1.07	2,680	.04
Sugar cane (For sugar)	---	---	---	---
Sugar cane (For Alcohol)	88,390	61.38	30,937	.34
Sugar cane (For Molasses)	67,990	39.30	23,797	.26
Coconut	1,311	7.95	1,967	.03
Aguaje	5,460	21.00	5,460	.07

[a]See Appendix F for explanation.

4.2 AGRICULTURAL RESOURCE POTENTIALS

The need to provide food for the Peruvian people of the nation will restrict the capability of the agricultural sector to provide biofuels to satisfy the future demand for energy. In 1976, 13% of the GNP was from agriculture and 40% of the labor force worked in this sector. An unfavorable balance of payments in agricultural trade amounting to a $33 million deficit was registered in that year. Most likely, increases in agricultural production will be offset by increases in population. Thus, the use of agriculturally productive land for energy production does not currently appear feasible.

Agricultural alternatives for providing alternative energy resources by 1985 rest primarily in the development of the agro-industrial base in the country. For example, increasing sugar production would simultaneously increase the availability of bagasse for energy conversion. Development of other agro-industries could similarly provide processing wastes that could be readily converted into a biofuel resource.

However, the use of marginal lands and the development of new agricultural approaches -- such as fertilization to allow more fallow land to be cultivated -- could brighten the outlook of a biomass production for energy uses. Certain high-residue crops, such as Chenopodium quinoa shown in Figure 4.1) can be grown on marginal lands. This crop has utility as a food crop and potentially as a fuel crop. It can be naturally self-propagating, and, if it is planted in the marginal highland areas of the Sierra, it can also provide protection from erosion. Other food/fuel crops similar to C. quinoa should be identified for future biofuel applications. Other candidates are potato and cassava, which could be sold as food or fermented into ethanol in times of surplus.

Figure 4.1. Chenopodium Quinoa: A Crop Which Could Provide Both Food and Fuel

Double or multiple cropping practices could significantly increase crop production. The identification of multiple cropping schemes for various areas in Peru should also consider the feasibility of a food/fuel crop rotation. Thus, by employing multiple cropping for energy production, no additional land effectively would be removed from food production.

Developing the Selva for crop production could increase greatly the area of Peru under cultivation. This approach could open new lands for the production of biofuel crops. However, it should be seen as a long-term venture because environmentally sound approaches for agricultural production in this tropical area still need to be developed.

In summary, three avenues appear open for agricultural approaches to biofuel production:

(1) the use of marginal or underutilized lands for the production of food/fuel crops;
(2) the development of multiple cropping approaches of alternating crops for food and crops for fuel in a single year; and
(3) the development of the Selva for agricultural production.

4.3 CURRENT FOREST RESOURCES

Peru possesses over 128 million hectares of land (Table 4.7) divided among 23 land types supporting vegetation. Although most of the forests are natural, plantations are becoming increasingly abundant and well-dispersed as shown in Table 4.8. Unfortunately, most of the forest growth occurs far from the major population centers. Of the total acres in forests (84.5 million hectares), about 75.5 million hectares are in the Selva as shown in Table 4.9. Table 4.8 shows that the number of plantations, mainly of eucalyptus, are increasing rapidly in the Sierra. For example, the area planted in 1973 was about 8,000 hectares; in 1976, it was 37,800 hectares, bringing the total acreage in Peru to 106,140 hectares (as shown in Table 4.8).

The Peruvian Amazon represents the greatest potential for forest products in South America other than Brazil. Two regions in the Amazon -- the low-lying alluvial forests and the humid forests on the slopes of the Andes (Ceja de Selva) -- are hilly but support high wood volumes, (Table 4.7). This region has annual rainfalls from 1,500 to 7,000 mm, but the soils are low in fertility. Temperature averages range from 18oC for the

Table 7. Distribution of Land Types in Peru by Area, Region, Productivity, and Dominant Species (1973)

Land Type	Area (Millions ha)	Volume (m^3/ha)	Number (Trees/ha)	Most Abundant Species	Costa (ha)	Sierra (ha)	Selva (ha)	% Total Area
Forest, Alluvial Class I	3.612	140-180	120(a)	Cumalo, Moena, Machimango, Shimbillo, Copal, Quinaquina	-	-	3.612	2.81
Class II	7.375	100-130	100(a)	Cumalo, Copal, Machimango, Zapote, Huimba, Shimbillo, Moena	-	-	7.375	5.74
Class III	5.071	80-100	65(a)	Oje, Palo Azufre, Requira, Cumalo, Lagarto, Caspi, Cetico	-	-	5.071	3.94
Forest, Hilly Class I	12.754	140-180	110(a)	Tornillo, Moena, Quinillo, Cumalo, Mashonaste, Copal, Pashaco, Chimieva	-	-	12.754	9.92
Class II	16.169	120-150	90(a)	Tornillo, Moena, Quinillo, Cumalo	-	-	16.169	12.58
Class III	9.841	70-120	70(a)	Tornillo, Moena Quinillo, Cedro, Pashco	-	-	9.841	7.66
Mangular	0.028			Mangle, Deli, Avicenia, Conocarpus	0.028	-	-	0.02
Forest, Dry Dense	0.525	40	110(b)	Guayacan, Palo, de Vaca, Amarillo, Sanchez, Zapote, Pasallo	0.525	-	-	0.41

(a)
(b)

Table 4.7. (Contd.)

Land Type	Area (Millions ha)	Volume (m^3/ha)	Number (Trees/ha)	Most Abundant Species	Costa (ha)	Sierra (ha)	Selva (ha)	% Total Area
Forest, Savanna	1.121	12-15	30(b)	Algarrobo, Zapote, Huarango, Hualtaco, Palo Santo, Ceibo	1.121			0.87
Chapparel	0.898			Algarrobo, Zapote, Sauce, Acacias	0.898			0.70
Quinual	0.006	20-50	500	Quena		.006		0.005
Forest, Podocarpus	0.408	70-75	65(a)	Romerillo, Ulcumano, Moena, Cumalo, Puma, Maqui, Paltron, Roble			.408	0.32
Palm Forests	1.053		580	Aquaje, Huasai, Ungurahui			1.053	0.82
Bush Land	1.086			Tara, Pallilo, Mito, Sauce, Molle	1.086			0.84
Land Suitable for Plantations	2.336			Shrubs, Grasses		2.336		1.82
Swamp	3.502			Aguaje, Palms			3.502	2.72
Forests Devastated by Agriculture Class I	5.191	70	100				5.191	4.04

Table 4.7. (Contd.)

Land Type	Area (Millions ha)	Volume (m^3/ha)	Number (Trees/ha)	Most Abundant Species	Costa (ha)	Sierra (ha)	Selva (ha)	% Total Area
Forests Inaccessible	8.667	100-120	100				5.191	4.04
Desert	28.709				28.709			22.34
Grassland	7.929				*	*		6.17
Agricultural Use -- Trees and Cultivated	12.201			Various Crops, and Casuvina, Eucalyptus, Cypress	*	*	*	9.49
Palm Forests	1.053		580	Aquaje, Huasai, Ungurahui			1.053	0.82
Forest Plantations	0.038			Eucalyptus,		*	*	0.03
	128.521							100.00

*Not proportioned

high Selva to 24°C for the low Selva. In the undisturbed state, these conditions favor rapid growth.

Inventory statistics (Tables 4.7, 4.8, 4.9, 4.10) reflect the massive commercial volumes of Peruvian timber, especially in the Selva. For biofuel assessment, these statistics have limited value. Only a few of the several hundred tree species comprising these forests are used commercially (see Table 4.10). In addition, because of the abundance of forested hectares, only the largest trees are chosen. Generally, only trees with a top diameter of 40 cm or larger are included in inventories. Because logs are often transported by river rafting, only the species that float are usually chosen. Generally, only about 25 species are used, 44% of these belong to four species. Where mechanical harvest and over-the-road transportation is possible, additional species are exploited.

Table 4.8. Forest Plantation Development in Peruvian Departments[13]

	Year				
Department	1964	1968	1973 Hectares	1976	TOTAL
Tumbes	1.0	3.0	68.4		463
Piurra		10.0	109.3	300	2,201
Lambayeque	4.0	10.0			552
Cajamarca		165.0	670.0	549	7,261
Amazones			411.0		2,913
La Libertad	5.0	17.0	326.5	500	5,053
Ancash	6.0	634.6	706.0	500	9,395
Ica		15.0	13.0		323
Arequipa	19.0	24.0	71.0	30	992
Tacna			12.0	22	567
Lima	15.0	40.0	28.0		1,090
Moquegua			5.0		242
Junin	485.2	411.0	274.0	169	18,798
Huanuco		370.5	451.7	300	5,433
Pasco		117.0	29.5	140	2,353
San Martin					6
Huancauelica		1.0	81.5		1,447
Loreto					708
Ayacucho		65.7	368.0	100	2,462
Azeo	482.6	660.8	1,943.0	2,013	27,416
Apurimar	15.0	326.4	2,286.4	1,084	15,758
Madre de Dios			3.5		70
Puno		10.0	150.0	10	637
Total	1,032.8	2,881.0	8,005.8	5,717	106,140

NOTE: Eucalyptus comprises about 98% and other species the remainder.

Table 4.9. Natural Forest in Peru and Land Capable of Supporting Forest Plantations (1976)[14]

Region	Natural Forest	Plantations	Land Suitable For Planting	Total
	Hectares			
Costa	950,000	6,683	493,317	1,450,000
Sierra	50,000	97,672	7,402,328	7,550,000
Selva	73,000,000	1,785	2,498,215	75,500,000
Total	74,000,000	106,140	10,393,860	84,500,000

Table 4.10. Production of Sawn Forest Products by Species[14]

Species	1968	1972	1975
	Year		
		m^3	
Alfaro	3,411	3,884	7,890
Caoba	18,312	21,176	26,094
Cafahua	178	105	7,220
Cedro	70,815	83,997	68,513
Congoma	1,511	---	5,135
Copaiga	2,470	2,292	17,898
Cumalo	1,222	13,311	10,780
Diablo fuerto	2,025	3,637	3,088
Ishpingo	1,330	1,538	3,783
Lupuna	15,787	8	1,665
Marupa			1,330
Moena	2,642	11,814	20,753
Mogal	1,600	1,258	1,827
Roble amarillo	4,466	7,084	7,467
Roble corrienta	68,472	13,797	108,608
Tornillo	5,756	30,003	59,263
Ulcumano	3,855	3,884	4,398
Eucalypto	17,134	67,026	85,047
Others	48,341	114,812	52,881
Total	269,327	379,626	513,640

Currently, no more than 2.7% of the forests are exploited and of that amount, only one m^3/ha, or less, is harvested.[15] This usage represents less than 1% of the annual growth -- about 0.006% of the standing volume.

Estimates of the standing volumes vary widely. In this report, only the conservative estimates were chosen (Table 4.7). Vast amounts of commercially unused biofuels are left in the forests because ways to use them are not known; the wood will not float, or wood is lost to decay awaiting high water. This, added to unused slash (limbs and small stems) from commercial trees, suggests that much biomass which potentially could be used for fuel is left in the forest.

After logs are delivered to a mill site, they are processed -- mill waste may represent from 50 to 70% of the overall amount of lumber processed.[15] Although these wastes often are burned for disposal purposes, it appears that they could be used as biofuels. To illustrate this waste, compare the data for harvested volumes (Table 4.11) and for processed volumes (Table 4.12). From these data, the waste generated by the Peruvian forest products industry can be calculated. For 1975 production, waste volume was approximately 503,000 m^3. Assuming a density of 500 kg/m^3 and a heating value of 18,000 million joules per metric ton, this waste is the equivalent of 4.5 JQ's of energy.

Increasing numbers of plantations, mainly eucalyptus, are being planted in Peru (Table 4.8), especially in the Sierra. These cultured forests grow from 10 to 18 m^3/ha/yr and now cover over one million m^3 (Table 4.13). During this study on Peru, large eucalyptus plantations were observed in the highland of Cusco. E. globulus was observed at 400 m (12,000 ft). In Cajamarca, E. globulus, E. camaldulensis, and E. salignas were growing at 2500 m (7,000 ft) on an experimental plantation belonging to the Servicio Silvo Agropecuario U.N.T.C. A successful establishment and rapid growth of E. deglupta was observed on a plot on the experimental farm operated by the Ministerio de Agricultura, Zona Agraria IX, Tarapoto. In the City of Lima, many eucalyptus, mainly globulus, are planted along major avenues and parks.

These natural forests are estimated to grow about 10 to 30 m^3/ha/yr.[14] Assuming that the average Selva forest is useful for forest production and 60% harvestable, these 43 million hectares would grow between 430 to 1,290

Table 4.11. Extraction of Round Wood for Processing in Peru[14]

	m3		
	1968	1972	1975
Sawn Timber	490,175	690,919	934,825
Parquet	20,086	30,943	20,189
Plywood	27,931	58,832	39,068
Veneer	27,441	51,630	73,545
Particle Board	11,881	9,799	10,594
Decorative Hardboard	1,539	2,079	2,081
Rail Ties	2,830	3,604	1,507
	581,883	847,806	1,081,809
Firewood	2,081,960	2,369,215	2,580,185
Charcoal	27,951	31,112	19,206
Pulpwood		54,333	22,450
Rural Construction (homes and Fences)	268,743	329,678	370,006

NOTE: See Table 4.8

Table 4.12. Production of Forest Products in Peru[14]

	m3		
	1968	1972	1975
Sawn Boards	268,327	379,626	513,640
Parquet	5,624	8,664	5,653
Plywood	12,144	25,579	16,986
Veneer	11,931	22,448	31,976
Particle Board	9,139	7,538	8,149
Decorative Hardboard	810	1,094	1,095
Rail Ties	1,555	1,980	8,288
	310,530	446,929	578,327
Firewood	2,081,960	2,369,215	2,580,185
Charcoal	27,951	31,112	19,206
Wood Pulp	*	54,333	22,450

*Information not available.
NOTE: See Table 4.8

Table 4.13. Wood Production[a] By Plantations in Peru[14]

Year	Volume of Wood in Plantations
1964	208,200
1966	163,800
1968	579,200
1970	737,200
1972	1,532,400
1974	1,940,800
1976	1,143,400

[a]Assuming 10 m^3/ha/yr for 20 years.s.
NOTE: See Table 4.8

million m^3/yr. This wood could be used for energy without reducing the current standing forest stock. This growth represents 3,900 to 11,000 JQ's.

Despite Peru's massive potential for forest growth, the country increasingly imports forest products, as shown in Table 4.14), and has not developed its export potential. Among the imports is a considerable volume of coniferous wood (Table 4.15), probably to meet the softwood fiber needs, especially for pulp. Currently, only one pulp mill uses Peruvian wood (Table 4.16), while the rest use bagasse. A well-developed forest industry could generate substantial amounts of biofuels and lend support to efforts to manage forests; currently, exploited forests are rapidly being degraded by timbering and shifting agriculture.

Peruvians use only 0.25 m^3 of wood per capita/yr but import pulp and paper valued at 900 million soles/yr.[15] In the remainder of Latin America, 1.2 m^2/capita/yr of wood are used; whereas inhabitants of developed countries use more than 2 m^3. Wood is an energy-efficient building material compared to the energy requirements for concrete, steel, aluminum alternatives. The potential for expanding wood use and the energy content of the commercial wood volumes in Peru is shown in Table 4.17. The energy content of this wood volume is estimated to range from 78,370 to 97,620 JQ's.

Table 4.14. Importation and Exportation of Forest Products in Peru[14]

	m^3	
Year	Imports	Exports
1968	54,926	7,902
1970	55,082	19,191
1972	62,228	15,946
1974	60,448	18,120

NOTE: See also Table 4.8

Table 4.15. Importation of Forest Products by Peru[14]

	m^3		
	1968	1972	1975
Charcoal	107	6	38
Roundwood			
Conifer	297	12,415	422
Non-Conifer	472	2,934	1,610
Mine Timber	3,597	317	
Post and Piling	25		3,299
Sawn Wood			
Conifer	40,393	42,142	56,043
Non-Conifer	459	99	268
Rail Ties	6,131	174	26,093
Parquet	5		781
Veneer	209	1	32
Wood Terciada	756	1,661	511
Laminated Board	43		
Manufactured Wood	1,772	1,912	2,993
Fiber Board	658	567	1,077
Total	54,924	62,228	93,167

NOTE: See also Table 4.8

Table 4.16. Location of Forest Products Mills by Product in Peru[14]

Location	Saw Mill	Parquet Plant	Veneer Mill	Lamina Doras	Encha Pes	Particle Board	Cajune Fas	Paper Mill	Total
Piuna		7					19		26
Tumbes		4							4
Lambayeque		2					8	1	11
Chachapoyas	18								18
Cajamarca	2						2		4
Jaen	6	6					5		17
Trujillio	7							2	9
Lima	3							9	15
Iquitos	31	3	2	2					38
Pucallpa	45	6	4					1*	56
Tarapota	3								3
Yurimaguas	4								4
Tingo Maria	34					1			35
Moyabama	7								7
Huancayo	49								49
Oxapampa	12						11		23
San Ramon	16	2					11		29
Satipo	33	4							37
Villa Rica	20						10		30
Cusco	17								17
Puerto	14		1						15
La Convencion	8								8
San Gaban	5								5
Ayacucho	3								3
Apurimac	4								4
Total	341	34	7	2	3	1	66	13	467

*Only mill using wood -- others use bagasse.

Table 4.17. Area, Wood Volume, and Energy in Wood Inventory of Peruvian Forests

Land Type	Area Million ha	Commercial Wood Volume m^3/ha	Total m^3 X 10^6	Wood Biomass mTons X 10^6	Energy[b] Joules X 10^{18}
Alluvial Forests					
Class I	3.612	140-180	505.7- 650.1	252.8-325.0	4.6 -5.9
Class II	7.375	100-130	737.5- 958.8	368.7-479.4	6.6 -8.6
Class III	5.071	80-100	405.7- 507.1	202.8-253.5	3.6 -4.6
Hilly Selva Forests					
Class I	12.754	140-180	1,785.6-2,295.7	892.8-1,147-8	16.1- 20.7
Class II	16.169	120-150	1,940.3-2,425.4	970.1-1,212.7	17.5- 21.8
Class III	9.841	70-120	688.9-1,180.9	344.4- 590.4	6.2- 10.6
Dry, Dense Forests	0.525	40	21	10.5	0.19
Forests/Savana	1.121	12- 15	13.4- 16.8	6.7 - 8.4	0.12- 0.15
Quinoal	0.006	20- 50	0.12- 0.3	0.06- 0.15	0.001-0.003
Podocarpus Forests	0.408	70- 75	28.6 - 30.6	14.3 - 15.3	0.26 -0.28
Forests Abandoned from Agriculture	5.191	70	363.4	281.7	5.1
Forests (Inaccessible)	8.667	100-120	866.7-1,040.0	433.3- 520.0	7.8- 9.4
Forest Plantations	106,140		1,143.4	571.7	10.3

Note: Calculated from data in Table 4.7.

[a]Assumes density of 500 kg/m^3.

[b]Assumes heating value of 18,000 million joules per metric ton.

4.4 FOREST RESOURCE POTENTIALS

The forest resources in Peru are immense and will remain so even if exploitive forestry should continue. Although local plantings could be made in the Costa primarily for fuelwood and rural use, efforts to expand forests in this area show little promise. Climatic conditions are unsuitable except in a small area of the extreme north, where forest management should be implemented to sustain the resource base. Plantation management shows promise in much of this region.

In the Sierra, considerable opportunity exists to expand forest resources. Current estimates predict that 10 million hectares could be forested in this region. Recent trials show that both Eucalyptus and pines will grow rapidly in this region. Establishing such forests here seems urgent while there still is land available, an acute need for forest products, and excess labor to accomplish the task. Moreover, reforestation will help control erosion.

Expanding the forest resource in the Sierra involves certain policy questions. A choice in objectives must be established between targeting plantations only for biofuel production and developing a viable forest products industry with energy opportunities evolving from wastage and non-merchantable trees.

The eucalyptus, which is native to Australia, emerges as a prime candidate for fuel production and because many of these trees can reach a suitable size for harvesting within approximately seven years. Peru has over 100,000 ha planted in eucalyptus. Furthermore, some eucalyptus species which range from approximately 450 to over 700 ha, depending upon the source,[6] could be grown on marginal land like deserts, swamps, etc. They also have the ability to sprout again from their stumps after harvesting, thereby minimizing the requirements for extensive land clearing, cultivation, and replanting operations after each harvest (see Figure 4.2).

The principal industrial products of eucalyptus and their uses are:

-- <u>Roundwood</u> - Small poles and large poles for telephone and transmission.

-- <u>Sawnwood</u> - Construction timber and flooring, railway sleepers.

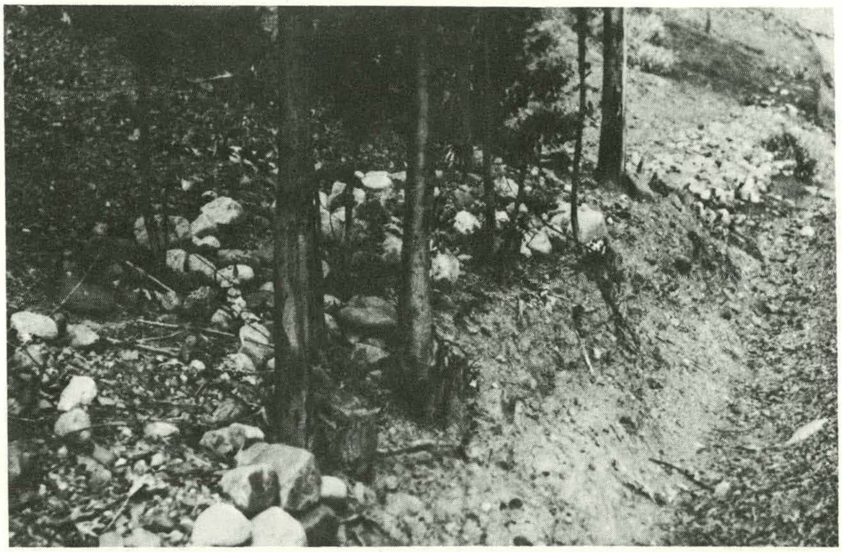

Figure 4.2. Coppiced Stand of Eucalyptus (Photo Courtesy of R. Giescke, Member Peruvian Energy Assessment Team

-- Pulpwood - Hardboard, softboard, and paper.

-- Plywood - Laminated wood products.

-- Charcoal - Home or restaurant cooking. To be burned in blast-furnaces, in charcoal-iron industries.

Eucalyptus in Australia, South Africa, and other countries are known to provide other valuable minor products, including:

-- Honey - Australia exports 17,000 metric tons annually.

-- Essential Oils -- Nearly all species of Eucalyptus have oil producing glands in their leaves which produce oils. The main essential oils and their uses are:

(a) Cineol - Used in pharmaceuticals, stain removers.

(b) Phellandrene - Used in the industry as a solvent and flotation for metals.

(c) Terpineol - Used in perfumery.

(d) Eudesmol - Used as a fixative for perfumes.

(e) Piperione - Used as a raw material for synthetic thymol and menthol.

Eucalyptus trees could provide substantial amounts of biomass in the Costa, Sierra, and Selva regions of Peru. These trees are an important resource in future forest development.

The dependency of much of the population on concrete and other construction materials that require more energy to produce and process than wood, and the importation of woods (especially softwood pulp and mine timbers) suggest that a viable forest industry would serve the national interest. Such an industry would: (1) reduce imports, (2) substitute low energy materials for high energy alternatives, and (3) generate biofuels to meet energy needs as a byproduct, or in certain cases as a principle raw material. Even in developed countries, about 40% of the harvested wood cannot be used for conventional forest products and is diverted to other uses, e.g. energy production, or disposal. Noncommercial trees also may be used for energy wood.

Each hectare of trees planted in the Sierra region will grow from 10-20 m^3/ha/yr during an 18-yr growth period. At this rate, 90 to 180 x 10^9 J of energy are fixed in merchantable wood (assuming 500 kg/m^3 and 18,000 million J/MT of wood). Half of this probably would be waste wood useful for energy production. Should the biomass in such noncommercial components be used, the amount of energy obtained from wood could be increased from 15 to 25%.

The Selva possesses about 8.7 million hectares (Table 4.7) which needs reforestation following shifting agriculture. Plantations could be established before abandonment and restore the biomass to a useful crop.

Currently only 2.7% of the forests is exploited, with only an average of 1 m^3/ha harvested. However, the harvest targets only certain prized species (Table 4.10). Removing only these trees without deliberate attempts to regenerate the choice species will degrade the forest and its products. Proper management could maintain both the high productivity and the supply of useful species.

Amazonian forests grow from 10 to 30 m^3/ha/yr. If 40 million hectares were deemed accessible for harvests, then the equivalent of 2.7 to 10.8 x 10^{18} joules of energy would be produced annually as commercial wood, without reducing growing stock. Half of this would be mill waste if processed for forest products, and a similar quantity would be potentially available as noncommercial biomass at the harvesting site. Assuming wise management, this quantity could be maintained or increased. As new technologies for harvesting and transporting are developed, the area used for biofuel production could be expanded.

In summary, biofuel supplies from forest resources appear abundant even if much of the forest biomass is converted to forest products (which could also replace other energy uses).

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5 RESOURCE DEVELOPMENT AND MANAGEMENT

5.1 HARVESTING

Harvesting systems are a primary determinant of successful development of forest resources. The best systems to use in Peru will vary due to the diversity of the forests and the terrain supporting them. However, three typical systems now commonly employed are:

(1) Axe, hand-rolled with cart hooks, and hand winch (most common);

(2) Chain saw, cart hook, and winch;

(3) Chain saw and rubber tire articulated skidder (company extractors).

In the Sierra, harvesting would target primarily plantations of exotic trees planted on deforested lands or lands not in grass and bush. These forests could be harvested and the wood handled largely by hand because of relatively small tree sizes and well-drained soils. However, power saws could be used advantageously in large-scale harvests. Wood harvesting for domestic fuel use could easily be done manually by employing surplus labor. However, when siting access roads and skid-trails, this must be done with care to prevent soil erosion during the wet periods.

Forest harvesting in Peru is regulated by the Ministry of Agriculture. The Agricultural VIII zone office in Iquitos manages about 2,000 contracts using 20 staff members, five of whom are foresters and the remainder technicians. The length of the cutting season there is six to seven months. All-weather logging is not possible, and water transport in small creeks is unreliable. Rivers flood five to six months each year.

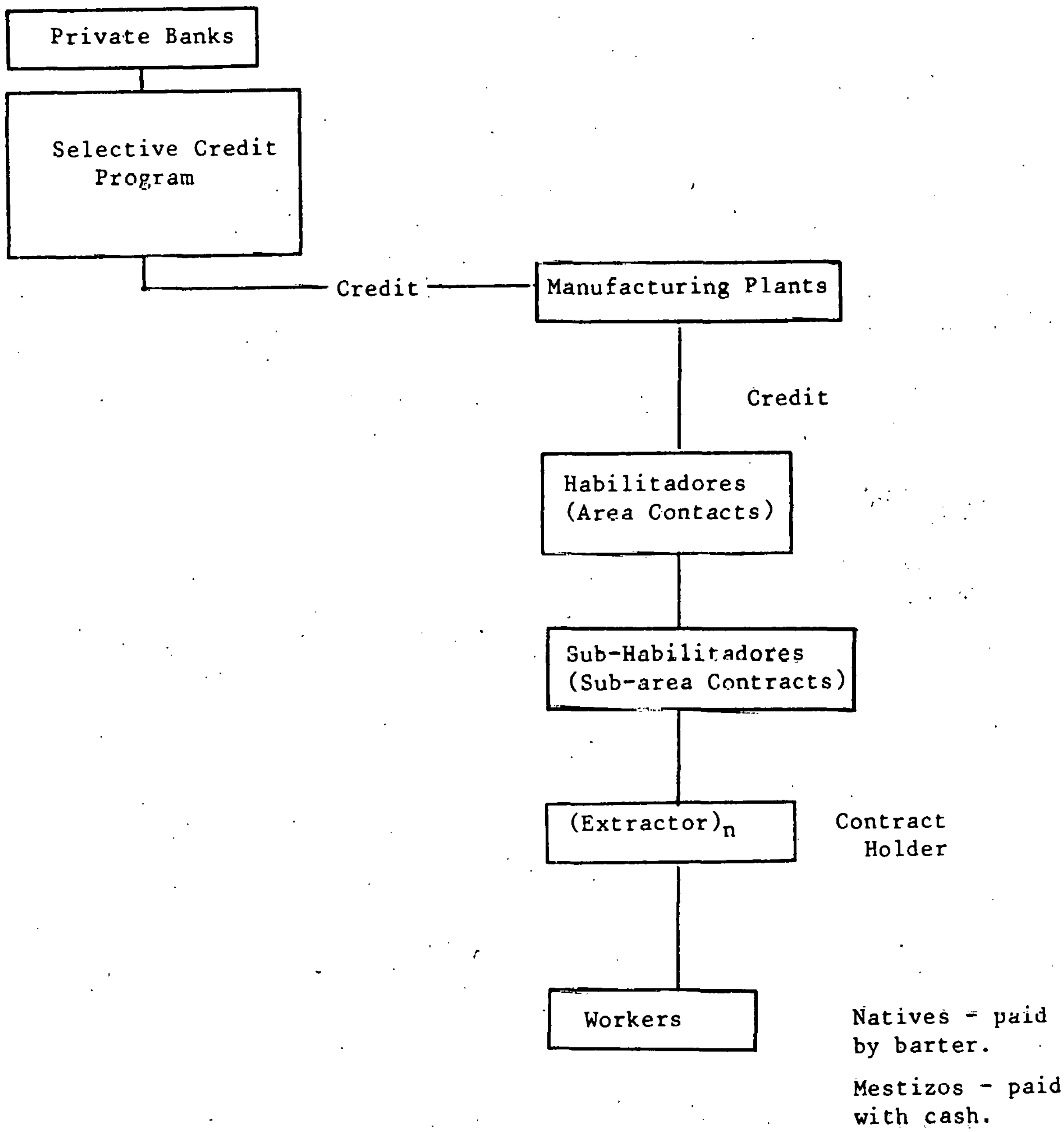
The zone office signs contracts with extractors for the harvesting of six species. Because there is little enforcement, extractors seldom follow these contracts. Thus, Cedro and Mahogany are usually the species taken, and the others are left. Standing wood usually is sold as follows:

Cedro and Mahogany: 500 Soles/m^3

Other Species: 50-70 Soles/m^3.

Twenty percent of the estimated pay scale is received in advance by extractors. The remainder is received after scaling the log rafts at the river mill site.

Credit is a serious problem for extractors. A typical credit scheme is shown below:



Although The Agrarian Bank could make credit available, it does not, mainly because extractors provide incomplete inventories. An absence of credit retards improvement of logging methods.

In the Selva, the large size of the trees and the need to free harvesting from dependency on river transport systems suggests the use of mechanical harvesting aids. This does not preclude the use of manual harvests.

The use of wood for biofuels does not recognize current quality constraints. All species can be useful -- not just those that will float or perform well in current, conventional uses of forest products. Greater introduction of mechanical felling devices -- skidders, loaders, and haulers -- would allow all trees to be removed and permit year-round operations in many cases. Moreover, insect and disease decay losses would be reduced because timber would not be left in the forest awaiting stream-rise. This way, trees suitable for forest products could be sorted out from those useful only for biofuels.

The development of efficient harvesting systems requires the proper selection of equipment along with the use of other harvesting approaches and would take additional study of soils, seasonal site conditions, labor availability, other power systems, the educational level and attitudes of workers, and support systems. The development of these harvesting systems would affect how forest resources are utilized in both forest products industries and energy production.

5.2 REFORESTATION

Currently, the forestry law in Peru requires extractors to plant two trees for each m^3 of trees extracted. However, there is little law enforcement, and the extractors do not know where, when, and how to plant. Furthermore, the Forestry Department has only one nursery for the entire Loreto zone in the Selva (50 million ha). To ensure the future productivity of forest resources, adequate reforestation is necessary.

In the Sierra, tree planting or artificial forestation with Eucalyptus and/or Pinus seems to be the only reasonable alternative. Considerable attention must be given to pre-planting site preparation. Brush removal and terraces could possibly be used to stabilize hillsides. A nursery

Figure 5.1. Experimental Nursery Operation for the Production of *Eucalyptus* and *Pinus radiata* of the National Technical University of Cajamarca.

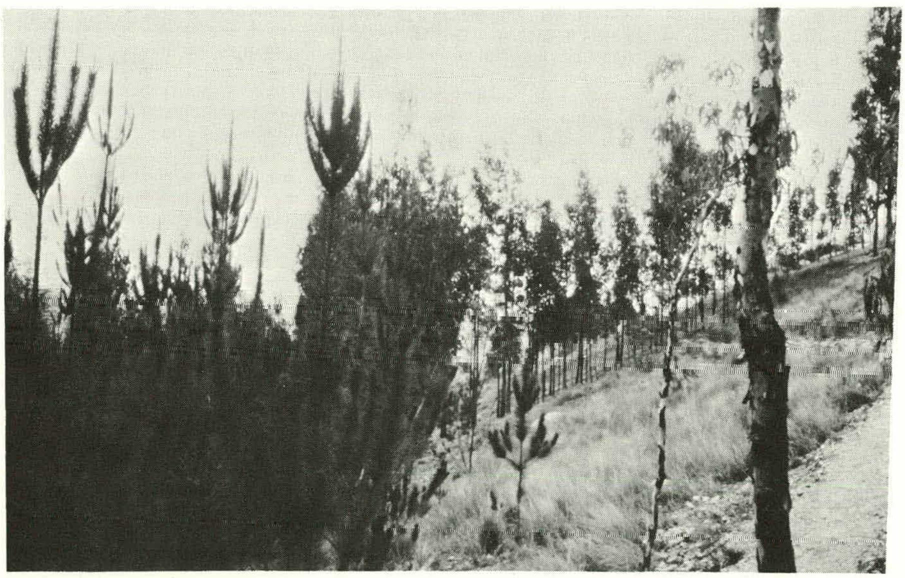


Figure 5.2. Experimental Plantation of *Eucalyptus* and *Pinus radiata* Operated by the National Technical University at Cajamarca.

support system network would need to be established close to reforestation areas. Worldwide, nursery production techniques are well advanced. The technology is easily transferable as shown in Fig. 5.1).

Many nursery support system trials of different species have been conducted in Peru. From these, Eucalyptus globulus and Pinus radiata appear well suited to local conditions. However, additional tests are desirable to ascertain the best species for the variety of growth sites available (see Fig. 5.2).

In general, eucalyptus displays growth superior to other species. Although this tree will meet many domestic needs for sawn timber and fuelwood, it does not supply pulp used by Peruvian paper manufacturers. Pinus radiata or P. caribaea, oocarpa, pinasta, eldarica, or others may prove useful in meeting softwood production goals. Pinus radiata performance to date suggests that it will grow quite well on many sites in the Sierra.

Another advantage to using Eucalyptus, besides its rapid growth, is its capacity to coppice. Pines do not coppice. A disadvantage of eucalyptus use, however, is the minimal grasses and species growth underneath the canopies of these trees. Because of the need to provide forage for domestic animals, pines often may be more desirable.

For either species, soils and species requirements must be matched to ensure that each hectare produces its fullest biomass potential. Soil surveys and species tests on each major soil association need completion before extensive plantings are begun. Chemical, physical, and biological soil properties will determine the success of the species planted.

In the Selva, a number of reforestation opportunities are available. Artificial reforestation in areas abandoned after shifting agriculture could immediately produce tree growth. Although the feasibility of this practice has been demonstrated, the best species to use and management practices have not been fully investigated. Although numerous species trials have been conducted in the Sierra, few have been made in the Selva. Certain eucalyptus and pinus species are potentially suited to the Selva's wetter conditions. In addition, other exotic species (e.g., Gmelina) and several native species may prove useful for this purpose.

In specific sites in the Selva, where all commercially useful trees have been harvested, reforestation is urgently needed. For example, the forests along the river near Iquitos are depleted of commercial species. However, due to changes in species utilization since this area was first logged, Lupuna, a tree previously unused, is now available in some places and is a prized specie for plywood. In most cases, the desired species will not reestablish under the shade of the remaining worthless trees. Developing a demand for wood biofuel products would create a market for these cull trees and would supply the necessary impetus to reforest these sites.

One method which shows promise is used at the preliminary trial on the Von Humboldt National Forest. It involves strip removal of all trees, planting with choice native species, and cleaning for two years. The cleaning operations (mechanical or chemical) are necessary to allow the crowns of planted trees to grow above the competing vegetation. Another alternative may involve cutting all residual trees and using them for biofuels. This would be followed by site preparation by scarification, and then establishment of plantations. Mechanical preparation must be done carefully to prevent site quality deterioration from topsoil removal and from the loss of nutrients stored in tree foliage and twigs remaining from harvest.

Natural regeneration using standard silviculture systems, such as selection cutting, shelterwood, and strip cutting, may prove useful, but these need extensive investigation before one or more systems are selected. However, a wise choice, if properly implemented, could ensure the sustained productivity of these forest lands and the utilization of their immense growth capacities. A serious restraint is the worldwide lack of knowledge about silviculture systems suitable for the tropics.

5.3 TRAINING

Achieving the objectives outlined above will require preparation -- through education and training -- about forest resource development activities of a large supply of professionals and para-professionals. Unlike fossil fuels, forest supplies should never run out if forests are managed properly.

By expanding use of wood as a principle building material in Peru, the housing industry will be less dependent on fossil energy. However, this notion must be introduced into Peruvian culture. Historically, the population has used clays for adobe; the use of concrete and masonry was easily accepted because of their similarity to adobe. However, in the housing industry, woodworking is not as well-developed. Public education about the value of using wood is needed and woodworking skills must be taught to encourage the use of wood. Thus, Peru could take advantage of one of its most abundant resources, reduce its need for energy-intensive materials, and aid the development of a viable forest industry.

For a highly professional nucleus of forest managers, several disciplines need to be introduced. Silviculturists with competencies in the area of species ecology, soils and nutrition, genetic selection and breeding, and nursery management. Protection specialists also are important to keep pests under surveillance, to promote fire as a management tool and to prevent wildfires.

Utilization specialists are needed to expand the use of the many under-utilized species. They need to develop quality grades and standards to protect consumers from inferior products and to develop means of seasoning and processing woods to meet these standards. Testing of woods, to ensure their proper performance, also is essential.

Forest engineers are needed to develop harvesting and other forest operations that are most economical, yet environmentally acceptable. These studies should be complemented with a consideration of the attitudes and aptitudes of the forest labor pool.

For development of the Selva's forest resources, forest ecologists who are keenly sensitive to the problems unique to this region are urgently needed. It appears that most forestry professionals in Peru are educated in the Costa and have limited tropical forestry experience. Typical ecosystems (e.g., in the Selva) are very productive but also very fragile and sensitive.

5.4 ENVIRONMENTAL FACTORS

The major environmental factors associated with land use in Peru are soil and water. Intimately tied to these are nutrients. Forest cover mediates the effects of climatic events, so that forest removal or establishment can sharply change ambient conditons and affect water behavior and soil properties.

Lands affected mainly by grazing (e.g., the Sierra) receive intense solar radiation, causing the surface soil temperatures to be high and nutrient mineralization to be rapid. Over-grazing can reduce the infiltration rate of water and result in water runoff. Establishing a forest canopy will reduce soil temperature and restore desirable hydrologic functions which involve infiltration and percolation. Moreover, raindrop energy is lessened and erosion reduced. When fully stocked with trees, forests will probably undergo increased evapotranspiration. This in turn will increase the soil water storage and the level of the storm hydrograph in streams associated with the watershed. Stream water levels can be regulated by controlling the proportion of the lands which have been harvested, recently generated, or fully stocked.

Excessive erosion proceeds only when there is no crop canopy. Thus, management schemes must be devised to minimize erosion and must be properly phased with appropriate climatic events. Forests are nutrient conservers because they filter atmospheric depositions and store nutrients in their biomass. Because only the woody component is used in biofuel production, proper management of the logging slash is essential to prevent nutrient losses. For example, excessively hot fires in the dry season could have serious effects on soil conditions and result in losses of nutrients and water.

Roads and skid-trails used in harvest must be properly sited and constructed to minimize erosion. Contour roads could serve as terraces by increasing water infiltration.

In the Selva, a different set of problems is present, although these problems involve the same key factors. Humid, tropical forests differ from temperate forest ecosystems in that most of the nutrients are contained in the biological material. This phenomenon has been exploited for generations in these regions by the practice of shifting agriculture -- felling of trees and burning the vegetation to release the nutrients so that crop production is possible. Figure 5.3 shows shifting agricultural practices in the Selva. After a few crop years, the area is allowed to grow back to native

Fig. 5.3. Shifting Agricultural Practices in the Selva (Forepart of clearing contains drying trees, back part of clearing has been burned.)

vegetation before repeating the process. Erosion is a problem only when the soil is bare. Wise practitioners of this form of agriculture keep bare soil intervals to a minimum. Where such practices have not been followed, soil erosion (as much as 150 t/ha/yr) has been severe. Losses of 2-3 cm of topsoil can cause yield reductions of 50%.

Forest removal and cropping result in:

(1) reduced infiltration,

(2) accelerated decomposition of organic matter,

(3) increased bulk density,

(4) increased soil nutrients (temporary), and

(5) increased surface water flow.

After crop yields decline, forest regrowth is permitted, and these trends are reversed and the soil is ameliorated. Allowing forest regrowth also prevents pest populations that develop on monocultures from reaching serious levels.

Site preparation can be associated with serious problems, as shown in Fig. 5.4). In areas too wet for burning, bulldozing can reduce soil productivity -- by compaction, topsoil removal, and removal of nutrients contained in the slash from felled trees. Infiltration is reduced dramatically by acceleration of mechanical disturbance and erosion. Where possible, the felled material should be viewed as a mulch for the new forest. In seasonally dry areas, proper timing of felling, burning, and piling of debris can be done mechanically without serious adverse affects. Soil moisture contents during the period of activity should be chosen when puddling and compaction are not problems.

The object of any reforestation scheme should be twofold: (1) to get the new forest reestablished as quickly as possible, and (2) to keep the period of exposed soil as short as possible. In this way, environmental problems will be prevented and forest growth ensured. Comprehensive reviews of cropping systems in the tropics indicate that growing trees (e.g., forest, nut, or rubber) seems to be a feasible alternative for these lands, providing that processing facilities for the crops are nearby.

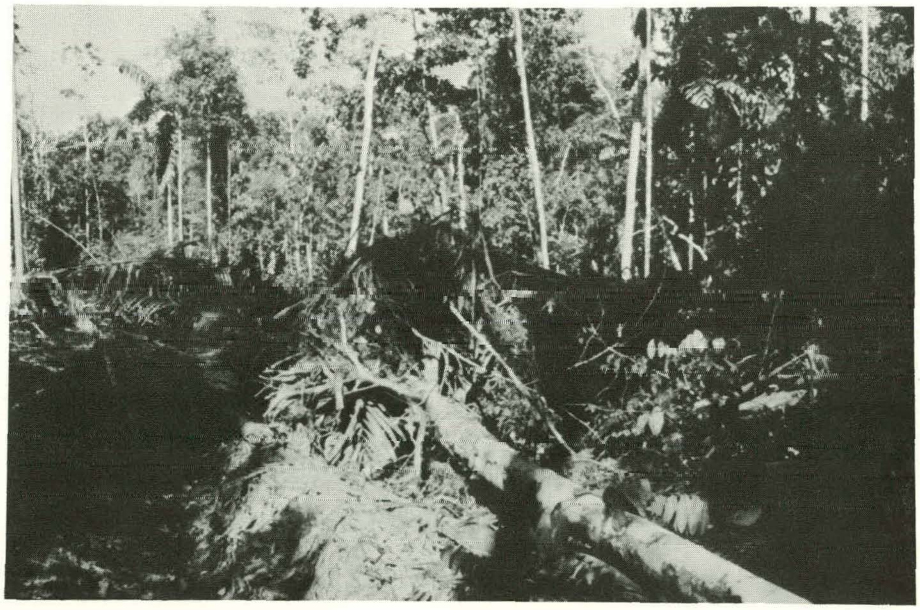


Figure 5.4. Mechanically Harvested Site in the Selva Tropical Forest

Woody waste is now burned or dumped in the countryside or rivers. Air and water pollution may result from these operations. Creating a use for these materials could go far in alleviating problems associated with this disposal procedure.

5.5 INTEGRATED UTILIZATION

Developing forest biofuel cropping systems that are compatible with other needs of the people can have positive benefits to the development of this energy resource. Thus, public acceptance is essential.

Firstly, the virtues of a renewable energy supply must be advocated. Secondly, choosing forest cropping that is compatible with other human needs must be investigated. For example, public acceptance would be high in the Sierra if the use of forests for fuel could be interfaced with grazing opportunities on the land. Where this is desirable, pines probably will be the chosen species. Moreover, these forests must be managed to ensure the supply of high quality water which often is a limiting resource in the Sierra.

In the Selva, forest production, in many cases, must be integrated into a multicropping scheme. A diverse flora will reduce pests and also produce a variety of other commodities. Rotation with annual crops, grazing crops, and periodic reforestation could prove economically and environmentally acceptable.

In areas not intended for agricultural production, forest harvesting should be done using similar principles. Clear-cut harvest areas should be sized to prevent excessive water loss and erosion. Where strip cutting is employed, clearing by environmentally acceptable chemicals may prove useful if manual labor is not available. Where selection cutting is used (e.g., removing certain large trees for timber products and culling trees for energy), an ample number of young trees of desirable species must be left and protected. It is also recognized that certain forests cannot be harvested for any purpose because of overly steep terrain, erosive soil or remote location of mills.

Knowledge of soil, site, and species requirements and of the interactions of management practices with these and climatic events can ensure productive use of the land without adverse environmental problems.

6 MARKET CONSIDERATIONS

6.1 IMPORTATION

Importation of agricultural and forestry commodities into Peru significantly affects the country's development of biomass resources for energy production. For example, in 1975 over 90% of the internal demand for oats, 35% of the internal demand for corn, 85% of the internal demand for wheat, and 95% of the internal demand for soybeans was satisfied by imports.[17] In 1975, a deficit in agricultural trade of $12 million occurred. In 1976 the deficit increased to $33 million due to a drop in world sugar prices. In 1972, 62,288 m^3 of wood was imported, of which 87% was soft, coniferous wood.[18] Because Peru's forest resources are mainly hardwood, continued importation of softwood can be expected in the future.

Until significant increases in agricultural productivity occur, especially in cereal crop production, governmental resource development can be expected to emphasize food production. This position is entirely justified. In 1976, the total agriculture production index was 103 (1961-1965 production equalled 100); the 1976 total food production index was 119.[19] This gives an average annual increase in total agricultural production indexes for years between 1965 and 1976 of only 0.3%; whereas, that for the food production indexes was 1.6%.

On a per-capita basis, the situation is less encouraging. The 1976 per-capita index for total agricultural production was down to 70, and that for total food production dropped to 81. For the years between 1965 and 1976, this amounted to an average annual decrease of 3.2% in the per-capita agricultural production indexes and a decrease of 1.9% in the per-capita food production indexes. The situation over the past few years has begun to stabilize, and the total food production indexes have begun to increase at a rate of 3-4% per year, roughly the same as the population growth; as a consequence, the per-capita food production index has remained at 81 for several years. However, overall agricultural production has not increased as rapidly, thereby resulting in lower per-capita indexes.

Development of biomass energy resources must be incorporated into the overall development of food and agriculture in Peru. Some basic strategies for Peruvian agricultural development were identified in a 1971 study undertaken jointly by the Peruvian Ministry of Agriculture and the U.S. Agency for International Development.[10] These approaches and new ones that have since been identified need to be related to plans for overall national energy development, and particularly to biofuel resources development.

Peru is a net importer of forest products. On the average, 280% more forest products were imported than were exported in the years 1968 and 1974 (see Table 4.14). Much of this is a result of a scarcity of soft wood in the Peruvian forests. However, importation of processed materials indicates that the forest industries sector should expand production for internal markets. The import situation points out that increased attention should be given to development of soft wood resources and to expansion of wood processing capabilities.

6.2 MARKET DEVELOPMENT - INTERNAL

The housing industry in Peru has principally used adobe-type materials, later replacing those with steel-reinforced concrete. Early settlements were established in areas without forests such as the Costa or the Sierra valleys. In the Selva, which was sparsely populated, palm thatch was used for housing. Thus, the use of wood products for housing never became an integral part of Peruvian culture.

As a result, energy intensive materials, such as cement and steel, are now used for housing. Considerable energy could be conserved if the nation's vast wood resources were used for home building and other construction projects. The development of markets for wood is necessary and could be done by developing domestic uses. New wood products could increase the utilization of wood in the manufacture of inorganic bound wood-cement boards. These boards, which are termite-, weather- and fire-resistant, could be used in wood framed houses. Wood waste in the manufacture of inorganic bound wood-cement boards could be converted to biomass fuels and used in the cement plant to reduce petroleum-derived fuel consumption.

6.3 MARKET DEVELOPMENT - EXTERNAL

With the second largest forestry resources in South America, Peru can be a significant world exporter of forest products. Currently, Peru exports plywood panels and veneers to North American and European markets.[20] However, based on trends in other parts of South America and in the world as a whole, the market for plywood may decline in the 1980s. To protect and expand its current share of the world market, Peru should vigorously develop and expand its internal wood-processing capabilities. The manufacturing of inorganic bound wood-cement boards, mentioned above, could create new external markets and could be exported to neighboring countries (e.g., Bolivia, Brazil and Chile). Thus, expansion of Peruvian forest product industries is essential for both internal and external market development.

6.4 MANPOWER

Wood in Peru is abundant, and the energy used in producing wood is low relative to alternatives; thus, this avenue needs to be advocated and the skills for working wood need to be developed among the people. Wood, unlike fossil fuels, is renewable and, if managed properly could be an inexhaustible resource.

Forestry activity and wood working (i.e., saw mills, plywood plants, etc.) could be labor-intensive operations providing employment opportunities). Mills and plants would be located in the rural areas near the resource base. Increasing employment opportunities here could help to stem the movement of workers towards urban areas. However, housing, schools, and medical care should also be developed concurrently with this industrial base. The extent of the impact of forest products industry expansion on national unemployment will depend on the degree to which both the internal and external markets for forest products are developed.

Coordination between forestry operations (i.e., harvesting, forest products manufacturing) and agricultural operations could improve utilization of manpower to avoid critical shortages or over-supplies during the wet and dry seasons. Forest operations, if well managed, could provide year-round employment, cash crops, and a livelihood for members of the local population. This would lessen the movement of these workers from the country to heavily populated areas like Lima.[5]

Presently, forestry professionals are educated without much experience in the humid tropics, which is where the majority of Peruvian forest resource and growth potential occurs. Most resource professionals are educated in the Costa without extensive exposure to the productive forest region of Peru. More contact between field and university personnel can enhance forest management approaches.

An absence of electricity in most isolated rural villages also aggravates the population drift. It is virtually impossible to develop saw mills, carpentry shops, and maintenance shops without electrical supplies. Difficulties in providing minimum education facilities for grown-ups is another consequence of the lack of electricity.[21] Biomass-derived petroleum substitutes could economically and profitably generate the required electricity and, at the same time, improve the socio-economical systems in the rural areas. Means to use forest or agricultural waste to produce biofuels without damaging the environment, forestry, or agricultural systems should be available.

6.5 ENERGY POLICY AND PRICING

Current governmental pricing and regulatory policies are often counterproductive for expanding biofuel utilization. The primary substitute for firewood or dung is kerosene, which is heavily subsidized. The retail price of kerosene ranges from 17S/gal. in Lima to 16S/gallon in Tarapoto. This is about 9¢/gal. at an exchange rate of 180S/$. The world market price is approximately 30¢/gal.

To a lesser extent, a similar situation for diesel exists. The price of diesel in Tarapoto is 32S/gal. or about 18¢/gal. in Electroperu.[22] Such subsidies may be justifiable. However, the kerosene subsidy seems politically motivated. The impact of such pricing policies create a situation where firewood purchased for cooking is more costly than kerosene in many parts of the Selva and Sierra. Careful consideration needs to be given to the consequences of energy pricing policies and biofuel development.

Governmental energy policy makes charcoal production illegal. This policy complicates programs to develop production of this promising biofuel option. Officially, charcoal production is not allowed; however, an expansion of production appears to be occurring in the Sierra. Another official policy is to increase bagasse utilization.

In the future, competing energy development approaches for electrical generation are biofuel or small-scale hydroelectric sources. The High Sierra seems to be a region where such conflicts could readily occur.

Uncertainty regarding future oil production also could complicate decision-making about biofuel development. Peru, which is now a net exporter, may have to import oil in the future. This would significantly affect pricing of various energy resources throughout the country. With the variety of energy policies and alternatives present, biofuel development should be integrated into governmental energy policy and decision-making to the greatest possible extent.

6.6 TRANSPORTATION

Transporting forest resources from the source of supply to the site of utilization is a serious problem at all levels of distribution. The collection and transportation of firewood by the rural population in the Sierra region consumes considerable time and effort. Typically, firewood is collected and carried home by the people themselves as shown in Fig. 6.1. Distances of 20 km are not unocmmon for persons to carry firewood. This level of effort for persons whose diet may be marginally sufficient causes great physical stress. Biomass energy strategies for Peru should consider approaches that would alleviate these collection and transportation problems.

Figure 6.1. Firewood Being Transported Home in the Sierra (Photo Courtesy of R. Giesecke, Member Peruvian Energy Assessment Team)

On a national level, transportation is a limiting factor in forest resource development. The Andes Mountains create a massive barrier for the transportation of Selva forest products to Costa markets. Within the Selva, transporting the wood from deep in the forest to the mills is a considerable problem. Novel approaches such as the construction of a floating mobile plywood plant as shown in Fig. 6.2 offer promising solutions. However, lack of adequate transportation systems may be the most significant factor governing the development of biofuel resources in Peru.

Figure 6.2. Floating Plywood Plants Waiting to be Conveyed to Forest Harvesting Site on the Amazon River.

7 BIOFUEL TECHNOLOGY OPTIONS

7.1 DESCRIPTION OF CURRENT TECHNOLOGIES

Current approaches to biomass conversion can be categorized as either thermal, thermo-chemical, chemical, or biological. Each of these processes is described below.

7.1.1 Thermal Process

The thermal approach is the most straight-forward and involves the direct combustion or incineration of biomass for the generation of heat. If combustion occurs in a specially designed boiler, such as that used in the sugar-processing industry, pressurized steam can be generated from the heat. Using steam turbines, this pressurized steam can be used to generate electricty and then serve as a source of process heat. If a steam engine is used in place of a turbine, mechanical energy also can be produced. A simpler approach involves the incineration of biomass to produce process heat for direct industrial application, e.g., for cotton drying or crop drying.

7.1.2 Thermochemical Processes

Thermochemical conversion approaches typically are a combination of pyrolytic and combustion processes. Pyrolysis is the thermochemical alteration of organic matter in agricultural and forestry residues in the absence of air. The first material pyrolized by man was most likely wood, and the product was charcoal, a clean-burning fuel. This is an ancient and simple approach to pyrolysis but is still one of the most practiced biomass conversion strategies in the world today. Brazil has an intensive national program to increase charcoal production. Today, 40% of the energy needs of Brazilian steel industry (approximately 2 million tons annually) are supplied by charcoal.[23]

Pyrolysis also produces other forms of energy in addition to the carbonized charcoal. This conversion process can also produce an oil-like substance known as pyrolytic oil and a low-to-medium BTU, combustible gas. The quantity of charcoal, oil, or gas produced depends primarily on the chemical composition of the feed, its preparation, the reaction temperatures, the reaction pressure, and the residence time of the material in the reactor.[24]

7.1.3 Chemical Processes

Chemical approaches involve either acid hydrolysis or the use of other chemicals to extract particular organic materials from biomass -- materials that can be used in place of petroleum derived compounds. Typical products obtained from this approch include oils, resins, and other assorted organics. Perhaps the most industrially important of these is furfural.

Furfural, identified in 1832 by Dobereiner, is an aldehyde with the -CHO group in the α position.[25,26] It is obtained from pentosan which contains agricultural residues, and its production was commercialized in 1922 by the Quaker Oats Co. Primarily it serves as a chemical intermediate for the production of furfuryl alcohol, tetrahydrofurfuryl alcohol, furan, tetrahydrofuran or polytetramethylene ether glycol, or as a precursor of pyrrole, pyrrolidine; these products have many important applicatons. Furfural is used: (1) as a selective solvent in the refining of lubricating oils to increase their stability during processing; (2) as an extractive distillation medium in the manufacture of butadiene from petroleum; (3) as a decolorizing agent for wood resin; and (4) as a resin former.

7.1.4 Biological Processes

Biological conversions of biomass offer numerous avenues for the production of biofuels, by the biochemical alteration of the substrate during the metabolism of a microorganism. The two most widely used bio logical conversion processes are the fermentation of carbohydrates to produce ethanol and the anaerobic digestion of organic matter to produce a methane-containing gas.

Fermentation is essentially a hydrolytic process. Beginning with one six-carbon sugar molecule (glucose), the enzymes produced by faculative microorganisms (usually a yeast known as Saccharomyces cerevisiae) sequentially break down the sugar molecule into two molecules of ethanol and two molecules of carbon dioxide. In additon, the microorganism obtains metabolic energy from the biochemical hydrolysis of the sugar. This process has been used throughout the centuries to produce fermented beverages.

A process has been developed for the industrial production of ethanol from molasses using various references on industrial ethanol production.[25,28,29] The first phase of the process involves dilution of the molasses and adjustment of the pH. Other nutrients usually are not required if blackstrap molasses is used because it contains non-sugar nutrients. The mash (as the acidified diluted molasses is called) is then transferred to the fermentation vat.

After inoculation with yeast, fermentation begins and continues for 28 to 72 hr (an average of 45 hr), producing an alcohol concentration between 6 and 10%. The optimum temperature for fermentation varies between 25° and 35°C. During fermentation, carbon dioxide gas is produced in equimolar quantities with ethanol. The fermentation liquor then is centrifuged, and a yeast-rich stream is precipitated. Part of the yeast will be returned to the yeast vat for reuse; most will be dried and sold.

The light stream from the centrifuge is passed through a heat exchanger and into the still. From this still, it passes through a condenser; the condensate contains 60% ethanol and a mixture of aldehydes. The condensate then is charged into the aldehyde column where these and other highly volatile compounds are boiled off. The ethanol fraction comes off after the aldehyde and then enters the rectifying column. The lower fraction is known as fusel oil, which is a complex mixture of higher alcohols. Water known as Lutter water, leaves the system from the bottom of the column.

The final step in the process is the production of anhydrous (water free) ethanol. To achieve this product, benzene is added (10 times the quantity of water present) and a binary system of ethanol-benzene is formed that distills until essentially all of the benzene is exhausted. Typically, for each ton of molasses (with a 55% sugar content) fermented, 68 gal of ethanol, 340 lb of CO_2, 1.02 lb of yeasts, 1.6 lb of fusel oil, and 435 lb of stillage is produced.

Another commonly practiced biological conversion process is anaerobic digestion.[27] Anaerobic degradation of organic matter for the production of methane involves three general groups of interacting bacteria. The first operates on cellulosidic wastes to produce organic acids, alcohols, H_2, CO_2, NH_3, and sulfide; the second oxidizes the longer chain organic acids to acetate and H_2; and the third utilizes the H_2, CO_2, and acetate to produce methane.[20] Temperature greatly affects the rate of conversion. For optimum production, the temperature of the reactor should be kept between 33°-38°C. To ensure stability of the process, sudden temperature changes should be avoided. This technology has been successfully adapted to conditions in developing countries.

7.2 PERUVIAN BIOFUEL TECHNOLOGY OPTIONS

Peru has extensive and diverse agricultural and forestry resources. As a result of the meetings between Peruvian and U.S. biofuel team members after assessment studies, specific biofuel technological approaches were identified as promising options. These are discussed below.

7.2.1 Option A: Small-to Medium-Scale Gasification

U.S.-Peruvian development and demonstration of small-to-medium-scale gasification systems for low-BTU gas production from the pyrolysis of biomass is a promising venture. Such systems could power various types of machinery, e.g., diesel generators or irrigation pumps, and provide a substitute for petroleum-derived fuels. Proposed projects would adapt existing technologies to local conditions and identify potential application and feasibility through demonstration projects.

7.2.2 Option B: Wood Waste Inventory

Most estimates fix the processing plant waste wood production at about 50 percent of the wood delivered to the mill. In Peru there are 230 sawmills, eight plywood and veneer plants, and several other plants that produce pulp and paper, particle board, and flaving. However, logging slash resides and non-commercial tree residues are only crudely estimated. Quantitative biomass inventories need to be made to assess these biofuel resources. Such studies would require destructive sampling and determination of areal weights and species and components distribution. These inventories should be made for the array of land productivity classes within each physiographic region and major soil associations within each region. With these data available, precise appraisals of woody biomass supply for energy uses would be possible. Investments in biofuel utilization opportunities can be planned. Proposed projects would undertake an extensive survey of wasted or unutilized forest residues generated by agricultural, forestry, or industrial activity that could provide low-cost and readily available sources of biomass for energy conversion.

7.2.3 Option C: Stationary and Mobile Charcoal Production Systems

Assessment of the potential of using mobile (i.e., tractor mounted or rail-mounted) charcoal kilns for the production of charcoal at the forest harvesting site is a promising biofuel technological option. The development of such a system would allow greater utilization of forestry wastes and non-commercial wood species by mitigating the transportation problems associated with shipping biomass to a conversion site, and the production of a valuable fuel resource. Similarly, stationary sites would permit conversion of biomass residues at forest and agricultural processing sites. A small-scale objective for increasing charcoal production is the substitution of charcoal for kerosene used for cooking in rural and small urban areas and in secondary cities. A large-scale objective is the subsitution of charcoals for imported metallurgical coals. A proposed project would develop small-scale systems (both mobile and stationary) for production of charcoal for cooking, or for other domestic or industrial uses.

7.2.4 Option D: Wood Distillation

The destructive distillation of surplus and waste wood in Peru appears to be an attractive option. Some by-products of this process are: methanol, cresote, acetone, tar, and charcoal. These byproducts have certain definitive advantages in the national economy, mainly because they could be substituted for oil sold to the international market. A feasibility study could determine the practicality of implementing such a wood distillation system in Peru. The need for charcoal resource has been identified in the iron-industry in the Chimpote area. There is a proposed effort to adapt existing technology for a pilot plant demonstration of the process and provide market penetration studies.

7.2.5 Option E: Forest Resource Development, Management, and Utilization

Forest biomass can provide massive amounts of biofuels for Peru while also generating export commodities and reducing imports. Forest management is grossly inadequate in tropical areas, in both humid and seasonably humid regions where bio-production potentials are great. Tropical ecosystems are fragile and senitive. Examples of catastrophic results of improper management in other countries document this. Procedures for reforestation and the introduction and culture of exotic species are advanced in other countries which lack a softwood resource and rely on forest products for both energy and economic values. In Peru, a broad-based forest resource program needs to be developed to emphasize:

(1) reforestation and management of the humid tropical forests following harvesting, and development of soil-site specificity of management practices;

(2) determination of properties of all tropical woods, i.e., how to group them in utilization classes, establish grades and standards, and develop uses -- especially in housing -- to reduce the dependence on energy-intensive alternatives, such as concrete and metal for structures;

(3) evaluation of potential species and their site requirements for forestation of idle lands in the Sierra; introduction of a genetic solution and cultural practices and integration of management of forest, range, and wild animals resources. Eucalyptus and Pinus species could be used in forestation of about 10 million hectares in which lands are underused, a labor surplus exists, and energy needs are great;

(4) development and expansion of the use of forest products in Peru, especially in the construction industry.

The experience and success of forest management and wood products industries in the United States provide a sound basis for U.S.-Peru cooperation in the development of the above program. The proposed project would:

(1) identify and develop effective forestry management programs;

(2) identify and initiate forestry development projects;

(3) identify, develop, and initiate forest management training programs;

(4) develop new uses for forest products; and

(5) train individuals in woodworking.

7.2.6 Option F: Electrical Cogeneration

Plywood and milling operations in Peru can provide a site for the demonstration of a system for the conservation of electricity and process steam as currently practiced by the U.S. forest industry. Moreover, an assessment should be made of the energy plantation concept of providing biofuels for the generation of electricity and process heat for small towns in the Selva. A feasibility study could determine the practicality of using locally available wood for firing the steam boiler and could assess whether this form of renewable energy source could make an important contribution to Peru's future energy consumption. Proposed projects would adapt existing technology (wood-fired steam boiler design) and provide small-scale electrical generation (0.5-2.0 MW) and process steam for local uses to be defined.

7.2.7 Option G: Chemical Production and Market Penetration

An assessment and evaluation should be made of the resource and economic factors relevant to the development of industrial chemical technologies (e.g., furfural production) which uses biomass as the primary material input. Development of a pilot plant would provide the appropriate vehicle to accomplish such an assessment, e.g., of industrial solvents and chemical intermediates derived from biomass. Market penetration studies would identify the potential of a national effort to develop this resource and its use in both internal and external markets.

7.2.8 Option H: Anaerobic Digestion Technology

The development of anaerobic digestion systems for rural Peruvian localities and possibly urban areas would be undertaken. The construction and field-testing of the model system then would follow. An assessment of strategies for introducing such systems for home use in rural Peru and the training of personnel in the construction and operation of the units would be done.

7.2.9 Option I: Development of Ethanol Production Capabilities

Expansion of ethanol production in Peru should be explored as a viable process for development of Peruvian biofuel resources. Ethanol could provide fuel for transportation, cooking, and other industrial uses. Alternatives for recovering and utilizing the fermentation byproducts, such as CO^2, yeast, fusel oil and stillage, also would be identified and appraised. Such projects could assess the feasibility of and options for increasing ethanol production at existing fermentation plants. A research and development program could be started to explore the use of other biomass resources, e.g., potatoes or yucca as substrates for fermentation and recovering and utilizing byproducts of the process.

7.2.10 Option J: Agricultural Strategies For Fuel Production

In the foreseeable future, the objective of agricultural production in Peru will continue to be increased food production. However, certain agricultural strategies could be initiated that could increase the availability of agricultural residues, or perhaps even whole crops, for energy production. One such strategy is the increased practice of multiple cropping. This approach could be used to increase the production of agricultural residues for energy conversion. Another possible alternative is the utilization of marginal lands for the production of agricultural fuels. Such strategies need to be assessed further.

8 POTENTIAL REGIONAL APPLICATIONS

Each of the biofuel technology options described in Section 7 has particular regional applications because of differences in vegetation, climate and industrial capabilities. The Costa Region has its own particular set of applications that are specifically defined. The Sierra and Selva also have individual applications. These are described below.

8.1 COSTA REGION

8.1.1 Costa Option A-I: Gasifier Powered Irrigation Systems

This option utilizes agricultural residue, particularly sugar cane field residue, to fuel a gasifier in the production of a low-Btu gas to power an irrigation pump.

8.1.2 Costa Option E-I: Eucalyptus Plantation Development

Eucalyptus plantations in the Costa are a potential source of firewood, charcoal, and waste wood. These products then could be used to produce electricity or biofuel for use in water-pumping engines on the coastal irrigation projects; these normally use large amounts of gasoline or fuel oil.

8.1.3 Costa Option F-I: Expanded Cogeneration From Field Residues

Cogeneration from the burning of bagasse is commonly practiced at sugar processing plants. Bagasse could be substituted or electrical generation could be expanded if field residue were used.

8.1.4 Costa Option G-I: Development of Furfural Production

If processing facilities are constructed, bagasse, rice hulls, corn cobs, or other pentosan-containing residues available in the Costa Region, could be used for feedstock in the production of furfural.

8.1.5 Costa Option H-I: Rural Anaerobic Digester Development

If anaerobic digester equipment were available, livestock manures, produced by farm animals in the Costa Region, could be used to produce methane for farm use.

8.1.6 Costa Option H-II: Anaerobic Municipal Waste Treatment

The construction of an anaerobic digester for the treatment of municipal sewage for the major coastal cities could provide waste treatment and produce methane.

8.1.7 Costa Option I-1: Increased Ethanol Production

Use of residue from brewery wastes could produce ethanol or increase utilization of molasses. Bagasse use could also increase ethanol production.

8.1.8 Costa Option I-II: Recovery and Utilization of Fermentation Byproducts

A potential annual savings of 40,000 barrels of diesel oil in the Lima area could be realized if a system to liquify the carbon dioxide (CO^2) that is discharged into the atmosphere by fermentation were installed, to replace the manufactured CO^2 that presently comes from fossil fuel feedstock. Manufactured CO^2 currently is used in the fabrication of dry ice and beverages. Sugar mills are sincerely interested in selling other fermentation byproducts, now wasted.

8.1.9 Costa Option J-I: Assessment of Multiple Cropping Strategies

The overall agricultural productivity of the Costa could be increased by the introduction of multiple cropping approaches. The potential of employing such practices to increase available residue for energy conversion should be assessed and strategies developed for its introduction.

8.2 SIERRA REGION

8.2.1 Sierra Option A-I: Small-Scale Gasifier Development

The development of small-scale gasifier units to power machinery or generators is a viable biofuel option for the utilization of crop residues in this area.

8.2.2 Sierra Option C-I: Plantation for Charcoal Production

The possibility of developing Eucalyptus plantations for the production of charcoal for home and other commercial uses is an alternative.

8.2.3 Sierra Option E-I: Plantation Development

An additional 10 million hectares of land in the Sierra could support either Eucalyptus or Pinus plantations. Development of such plantations would not only make firewood more available but also would help control erosion and stimulate the development of local wood product industries.

8.2.4 Sierra Option E-II: Wood Frame Construction

Wood frame construction would permit the incorporation of passive solar systems (e.g., better insulation) in new housing construction plans. Wood uses the least energy of all housing materials in converting raw construction material into a finished product. With Eucalyptus as a wood source, the opportunities for an additional cash crop and employment for the local population make introduction of wood frame construction in Peru a viable option.

8.2.5 Sierra Option F-I: Cogeneration

For many years, Eucalyptus trees have been planted in the Sierra, particularly in mining areas where Eucalyptus wood was used as structural members in mining tunnels. These Eucalyptus plantations should be expanded to produce wood that could be used to generate electricity or used for water heating. Currently at the Buenaventura mines, 1.5 million gal. of diesel oil are used annually to generate 4,000 kWh.[30] Biofuel could contribute to a substantial savings of this fossil fuel.

The Cusco area could be benefited by large plantations of Eucalyptus trees. Evidence of good growth of E. globulus can be seen on the mountainous area and along the Urubanba River Valley. Observed shortages of electricity in this area could curtail the construction of hotel accommodations that are badly needed in this highly visited spots.

Tourism is another important source of foreign exchange, and biofuel could contribute to its development if Eucalyptus plantations were established 20 km from Machupicchu, where great quantities of flat land, water, and manpower exist. The present railroad system could be used to transport wood and charcoal for electrical generation at the end of the railroad. This is hypothethical, however. At present, enough Eucalyptus trees are planted to generate only 1,000 kWh.

8.2.6 Sierra Option H-I: Rural Anaerobic Digester

Introduction of small-scale anaerobic digesters into the Sierra would provide an alternative to the use of dung as a fuel. The fuel produced would be clean burning and could also provide lighting.

8.2.7 Sierra Option I-1: Potato Fermentation

The feasibility and practicality of using potatoes as a feedstock for fermentation and ethanol production should be addressed. Development of such an industry could provide an expanded and stabilized market for the potato in Peru.

8.2.8 Sierra Option J-I: Chenopodium Seeping

Consideration should be given to promoting the seeding of Chenopodium Quinoa in above-treeline areas in the Sierra. This material could provide food grain and a residue that would be a readily accessible fuel.

8.3 SELVA REGION

8.3.1 Selva Option A-I: Gasification for Electrical Generation

In areas of the Selva, such as Tarapoto, present forest resources are sufficient to supply a gasifier that could power the town's 2 MW power plant. Use of waste wood from land clearing in the area could provide an inexpensive source of fuel for the gasifier and also be compatible with agricultural development.

8.3.2 Selva Option B-I: Wood Waste Inventory

A serious need exists to identify the amount of wood waste generated at forest harvesting sites, sawmills, plywood plants, and other wood processing sites.

8.3.3 Selva Option C-I: Large-Scale Charcoal Production

The biomass resources available in the Selva are able to support the large-scale production of charcoal for use by Peruvian industries. The feasibility of such an approach should be addressed.

8.3.4 Selva Option D-I: Wood Distillation

If developed, wood distillation industry in the Selva could supply organic substitutes for petroleum-derived materials and fuels. The development of this industry should be assessed for the production of alcohols, tars, and charcoal.

8.3.5 Selva Option E-I: Training and Extension

Expansion of on-site training of forestry personnel and development of a forest extension service would help ensure the future productivity of Selva forest land.

8.3.6 Selva Option E-II: Forestry Research

Research on tropical forests and the environmental consequences of their utilization needs to be expanded.

8.3.7 Selva Option E-III: Forestry Management

Alternative forest management approaches should be identified and developed if greater utilization of forest resource is planned.

8.3.8 Selva Option F-I: Cogeneration

The use of Selva biomass for generation of electricity, steam, and process heat (possibly for district hot water use) should be studied further.

8.3.9 Selva Option G-I: Palm Oil Utilization

Palm oil is a promising substitute for petroleum-derived fuel, especially the Brazilian babacu palm, Orbignia speciosa that grows in relatively poor soil and in areas too wet for food crops. A palm oil plantation producing 3,000 t*/yr is located near the town of Juanjuy, south of Tarapoto. This oil could partially replace some lubricant oil or fuel derived from petroleum. The feasibility of using this resource should be explored.

*t = metric ton

8.3.10 Selva Option I-I: Ethanol From Cassava (Yucca)

The development of cassava for both food and fuel (ethanol) purposes should be seriously assessed. Other South American countries, e.g., Brazil, are pursuing this approach. It could prove to be a viable option for Peru.

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APPENDIXES

Appendix A. Explanation of Winter Severity Classification[7]

Winter Severity Classification	Mean Annual Minimum Temperature	Coldest Month -- Average Daily Temperature	Other Temperature Requirements
Mild winter wheat belt	-29 to -10 C (-20 to 14 F)	>0 C (32 F)	Mean annual minimum may be higher if cold month ave. dly. max. is <5 C(41 F)
Cold winter oats belt	-10 to -25 (14 to 27.5 F)	5 to 10 C (41 to 50 F)	Mean annual minimum may be higher if cold month ave. dly. max. is <10 C(50 F)
Mild winter oats belt	-10 to -25 C (14 to 27.5 F)	>10 C (50 F)	
Citrus belt	>-2.5 C (27.5 F)	10 - 21 C (50 - 69.8 F)	Not entirely frostless. Cold month average daily max. may be higher, if mean annual temperature is <19 C (66.2 F)
Cool tropical belt	<15 C (59 F)	<21 (69.8 F)	Entirely frostless. Cold month average daily max. may be higher if mean annual temperature is <19 C (66.2 F)
Tropical belt	<15 C (59 F)	>21 C (69.8 F)	Entirely frostless. Mean annual temperature is >19 C (66.2 F)
Equatorial	>15 C (59 F)		

Appendix B. Explanation of Summer Heat Classification[7]

Summer Heat Classification	Average of the Average Daily Maximum Temperature of n Warmer Months	Frost-Free Season	Other Temperature Requirements
High alpine belt	>10. C(50. F); n=4		Average daily max. of coldest month > 17.8 C (0. F); too cold for low alpine
Low alpine belt	>-10. C(50. F); n=4		Average of the lowest each month of 1 or more months >0 C (32 F)
Maize belt	>21. C(69.8 F); n=6	4-1/2 months	Too cold for coffee or cool cotton
Coffee belt	>-2.5 C (77 F); n=6	Minimum > 5 months[a]	Average daily minimum of all months >20. C(68. F); summer too cold for warm cotton
Cool cotton belt	>25 C(77 F); n=6	Minimum > 5 months[a]	Summer nights too warm for cotton -- too cool for warm cotton
Warm cotton	>25 C (77 F); n=6	Minimum = 5 months[a]	Average daily maximum of warmest month > 33.5 C (92.3 F)

[a]This time period is reduced to 1 1/2 months when average daily maximum of the warmest month exceeds 33.5°C (92.3°F).

Appendix C. Explanation of Temperature Regimes for Peru[7]

Temperature Regime	Winter Severity Classification	Summer Heat Classification
Hot equatorial	Equatorial belt	Warm cotton belt
Semi-hot equatorial	Equatorial belt	Cool cotton belt
Hot tropical	Tropical belt	Warm cotton belt
Semi-hot tropical	Tropical belt	Cool cotton belt
Cool tropical	Cool tropical belt	Warm wheat belt, maize belt, coffee belt, or cool cotton belt
Tierra templada	Cool tropical belt, tropical belt, or equatorial belt	Coffee belt
Cool tierra templada	Cool tropical belt, tropical belt, or equatorial belt	Warm wheat belt, or maize belt
Low tierra fria	Mild winter oats belt, or citrus belt	Coffee belt
Medium teirra fria	Mild winter oats belt, or citrus belt	Maize belt
Low andine	Mild winter wheat belt, cold winter oats belt, mild winter oats belt, or citrus belt	Warm wheat belt
High andine	Mild winter wheat belt, cold winter oats belt, mild winter oats belt, or citrus belt	High alpine belt
Semi-hot subtropical	Citrus belt	Cool cotton belt

Appendix D. Explanation of Humidity Regime[7]

Humidity Regime	Annual Humidity Index	Water Surplus	Other Humidity Requirements
Always humid	> 1.0	>20% evapotranspiration	All months humid
Humid	> 1.0	>20% evapotranspiration	One or more months not humid
Dry Mediterranean	Between 0.22 and 0.88	>20% evapotranspiration	Winter rainfall greater than summer
Moist Monsoon	> 0.88	>20% evapotranspiration	July-August (Jan-Feb southern) have higher humidity indices than April-May (Oct-Nov southern)
Dry Monsoon	Between 0.44 and 0.88	>20% evapotranspiration	July-August (Jan-Feb southern) have higher humidity indices than April-May (Oct-Nov southern)
Semi-arid Monsoon	< 0.44		July-August (Jan-Feb southern) have higher humidity indices than April-May (Oct-Nov southern)
Absolute desert	< 0.09		Average daily max. for all months > 15 C -- all months are dry
Monsoon desert	< 0.22		All months are dry-humidity index of July-August greater than April-May

Appendix E. Evapotranspiration (cm) for Selected Stations in Peru[7]

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Arequipa	8	8	9	10	12	11	10	11	12	11	11	9	122
Cajamarca	7	8	7	7	8	7	9	9	8	8	9	8	95
Cartavio	8	9	8	7	6	5	5	5	5	5	6	7	76
Cerro de Pasco	4	3	4	5	4	5	4	5	4	4	4	5	51
Chachapoyas	6	6	5	6	6	6	6	7	7	7	8	7	77
Chuquibambilla	6	6	6	7	7	8	8	8	8	8	8	7	87
Cusco	8	8	9	9	9	10	10	10	10	10	11	9	113
Huancayo	14	13	11	4	2	1	1	1	4	7	6	8	72
Imata	5	4	4	5	6	6	6	7	7	7	8	6	71
Iquitos	11	10	11	10	9	10	10	12	13	12	12	11	131
Juaja	5	6	5	6	6	6	7	7	7	8	8	6	77
Lambqyeque	9	12	12	9	8	6	6	5	6	7	9	9	98
La Molina	11	12	10	10	7	5	4	5	5	7	7	9	92
Lima	9	9	9	8	6	4	4	3	4	6	6	7	75
Lomas de Lachay	5	5	5	3	3	2	1	1	2	2	3	4	36
Mollendo	9	9	8	7	6	5	4	4	4	5	6	7	74
Moquegua	13	14	14	14	14	14	15	15	15	15	15	14	172
Piura	20	20	22	18	15	13	12	14	15	15	16	17	197
Pumo	5	6	6	7	7	8	8	8	8	9	8	7	87
San Ramon	22	21	21	15	12	8	8	6	9	16	14	21	173
Tacna	11	13	12	11	8	6	6	7	7	8	10	11	110
Tingo Maria	11	10	11	11	12	13	11	13	13	12	12	11	140
Vitor	14	15	15	16	16	16	16	17	18	17	16	15	191

Appendix F. Annual Residue Production Factors and Energy Value

Commodity	Animal Residue Production Factors Ton Residue / Ton Production	Energy Value of Residue (10^9 Joules)
Rice	1.5 MT/MT Production	13.4
Oats	2.0 MT/MT Production	13.4
Barley	1.5 MT/MT Production	13.4
Milo	1.0 MT/MT Production	13.4
Maize	1.0 MT/MT Production	13.4
Quina	2.5 MT/MT Production	13.4
Sorghum	1.5 MT/MT Production	13.4
Wheat	1.5 MT/MT Production	13.4
Soybeans	1.5 MT/MT Production	13.4
Plantain	0.15 MT/MT Production	13.0
Camote	0.15 MT/MT Production	13.0
Potatoes	0.15 MT/MT Production	13.0
Cassava	1.0 MT/MT Production	13.0
Cotton	1.0 MT/MT Production	13.4
Peanut	1.0 MT/MT Production	13.4
Sugarcane	0.35 MT/MT Production	11.0
Coconut	1.5 MT/MT Production	13.4
Aguaje	1.0 MT/MT Production	13.0
Alpacas	0.13 MT/Head	14.6
Poultry	1.1 MT/1000 Head	14.6
Goats	0.11 MT/Head	14.6
Horses	0.14 MT/Head	14.6
Llamas	0.11 MT/Head	14.6
Pigs	0.11 MT/Head	14.6
Sheep	0.11 MT/Head	14.6
Cattle	1.7 MT/Head	14.6