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LAND USE ANALYSIS OF PUERTO RICO

Prepared For

THE UPR CENTER FOR ENERGY AND ENVIRONMENT RESEARCH
BIOMASS ENERGY PROGRAM

By

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Winter Park, Florida 32792

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LAND-USE ANALYSIS OF PUERTO RICO

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ABSTRACT

Puerto Rico has an area of 2,189,026 acres with 901,484 available for agriculture, a population of 3.47 million people, and 0.26 acres of arable land per person. With these dimensions to consider, every acre of land becomes important, for its use directly or indirectly affects everyone, be the land chosen for food crops, energy crops, forest, industrial plants or commerce. The outstanding feature of the landscape is its rugged topography with only about 20% of the total area having a slope of 5 degrees or less. The flat lowlands are the areas of commercial agricultural production, the mountain lands areas of forest and subsistence agriculture, and the rolling lowlands and hill lands as intermediate. The soils have been thoroughly mapped and classified with recent soil surveys (1965-80) available for land-use planning. Ecological life zone classifications are also available.

Agricultural policy and planning for Puerto Rico for about 75 years has been one of lack of continuity. Its agriculture has not become modern, nor efficient despite costly injections of funds via subsidies and programs. Agriculture has lost out to industrialization and urban growth decreasing agricultural acreage. A modern agricultural program developed by the Puerto Rican Department of Agriculture has as its major thesis to produce most of the food it now imports, improve its economy by stimulating domestic agriculture production, and provide employment. New rice, beans, and vegetable enterprises will be established on completely mechanizable land. The cattle industry will be expanded. Tobacco will disappear and sugar production will be downgraded. Commercial forests will be developed. Choices are needed between small and large size farm units.

Biomass, plant material to be used as fermentable or combustible solids for recoverable energy, is a new crop that must be considered in land-use planning for Puerto Rico which imports over 98% of its energy. Sugarcane with both combustible and fermentable solids is the most efficient energy crop with tropical grasses (Napier & Sordan 70A) and silviculture "energy plantations" offering viable energy sources. Because of limited land area, a balance must be achieved between food and energy cropping. Suggested examples of possible biomass land uses compatible with a modern agriculture program are given.

1/ Research Consultant

INTRODUCTION

Puerto Rico has a limited area with large demands placed upon it by a growing population for food and energy crops, living space, industry and commerce. It is the objective of this paper to give an analysis of past and present land uses in relation to food crops and guidance in developing Puerto Rico's biomass energy cropping.

There are simple geographic factors which must govern a land-use analysis of Puerto Rico.

Scale -- Its extent is 35 miles by 100 miles with an area of 3,435 square miles.

Insularity - Its frontier is the sea.

Density - There are 3.47 million people, 1,010 per square mile with 0.26 of an arable acre per capita.

Physiography - 80% of its surface consists of hills and mountains; 20% has to be shared by agriculture, manufacturing, highways, airports, recreational areas, and cities.

With these dimensions to consider, every acre of land in Puerto Rico becomes important, for its use directly or indirectly affects everyone, be the land chosen for food crops, energy crops, forests, industrial plants, housing, or commerce.

THE LAND

1. Physiographic and Geologic Features

Puerto Rico may be divided roughly into three principal physiographic divisions (Fig. 1) according to Roberts (1). They are the complex mountain ranges which are the most extensive, the coastal plains, and the play a (beach) plains.

An east-west mountain range divides Puerto Rico into a northern and southern part. Its crest (about 3,000 feet) is far to the south of a latitudinal line passing through the center of the Island. To the south of the crest, the relief is rugged and is characterized by many steep-walled rock cliffs, abrupt high water-falls, and jagged peaks. On the north side of the crest and extending to the coastal plain, the relief gradually becomes less rough.

The coastal plains parallel nearly the entire coastline. They range in width from a maximum of 13 miles at Lares to nil at several points along the eastern and west coasts. Most of the coastal plains are confined to areas that are covered by a thick deposit of limestone that several fluctuations in sea level in times past have caused the landscape to have a belted appearance. Erosion has produced numerous hills and valleys.

The playa plains include the level alluvial plains, lagoon deposits, and elevated beach sands. The flat alluvial plains occupy the largest area and compromise the most valuable agriculture land. They occur along all the streams, but are most extensive near the mouths of the large rivers.

Beinroth (2) uses Mitchell's seven physiolgraphic regions to describe the physiography of the Island in more detail.

2. Landform and Topography

The limitations and potentials of agricultural development are largely determined by the Island's physical characteristics. The outstanding feature of its landscape is its rugged topography. Only about 20% of the total area has a slope of 5 degrees or less. The land area by percent slope is given in Table 1.

Young (4) identified 12 different landform areas based on local relief, percentage of steep slope, and percentage of flat land. The three major landform classes defined were lowlands, hill lands and mountain lands. In percentage of total area they are as follows:

Lowland - 19%

1. Flat lowlands - 11%
2. Rolling lowlands with some flat land - 3%
3. Rolling lowlands - 4%

Hill-lands - 37%

1. Rolling hill land with some flat land - 4%
2. Rolling hill land - 22%
3. Rough hill land - 4%
4. Rugged hill land with some flat land - less than 1%
5. Rugged hill land - 6%

Mountain lands - 44%

1. Rolling mountain land - 6%
2. Rough mountain land - 15%
3. Rugged mountain land - 23%

A description of these landform areas is given by Fields (3, pp. 99-101). Fields superimposed 11 rainfall regions on Young's 12 landform regions to give seven landform-climatic regions for the Island that is meaningful from the standpoint of agriculture (Fig. 2).

At the risk of over generalization, the flat lowlands may be characterized as the area of commercial agricultural production; the mountain lands as the area of forests and subsistence farming; and the rolling lowlands and hill lands as intermediate between the two, characterized by mixed, small-scale commercial agriculture and subsistence farming.

Land area in Puerto Rico distributed by altitude is as follows (3):

Feet above sea level	% of land area
0 - 499	55%
500 - 999	21
1000 +	24

Though 55% of its land area, 1.2 million acres, is under 500 feet in elevation, the percentage of flat land is substantially less with only 400,000 acres having slopes of 5% or less. Even this acreage is subject to constraints in cultivation as a result of such factors as erosion, drainage, and climate. The significance of the flat land lies in its suitability for mechanized agriculture (5).

3. Soil Classification

The soils of Puerto Rico have been thoroughly classified. The first detailed survey of the Island was completed by R. C. Roberts and party in 1936 by the Division of Soil Survey, Bureau of Plant Industry, USDA (1). This soil survey is good, covering both crops and soils. It still serves as a handy reference for anyone wishing to know Puerto Rican agricultural status before 1936.

The Robert's soil survey was updated by the Soil Conservation Service (SCS), USDA beginning in 1965 with a survey of the Lajas Valley area. Since then additional soil conservation districts have been covered with the last, Arecibo, to be published in 1980. The districts covered and their acreages are:

District	Acres
Arecibo	402,384
Humacao (6)	470,202
Lajas (7)	102,609
Mayaguez (8)	460,836
Ponce: Sur (9) 171,790 acres	
Caribe (10) 133,613 acres	305,402
San Juan (11)	447,279
TOTAL.......	2,274,094

The recent (1965-80) soil survey is quite comprehensive, and it provides more than a mere classification of soils. The make-up of the soil survey for a conservation district contains:

1. General nature of the area and climate.

2. General soil map for broad land-use planning with map unit descriptions and soil associations.

3. Description of the soils describing each soil series in detail, and then briefly, for the layman use, each mapping unit in that series.

4. Use and management of the soils. This section contains an explaination of the system of capability grouping used by the SCS. Estimated yields for the principal crops and pasture grasses under two levels of management (local and improved) are given. Management of the soils for woodland is also discussed. Information and limitations that affect engineering practices and recreation uses are presented in tables.

5. The information and classification of the soils as to major factors of soil formation are given with the definition of the system currently used for classifying soils by the six higher categories of order, suborder, great

group, subgroup, family, and series. A table is included of the classification of the series giving the family, subgroup, and order for each series.

6. The climate of the area is described with tables for temperature and rainfall, and sometimes mean evaporation rates.

7. A guide to mapping units which contains the capability unit for non-irrigated and irrigated soils of each mapping unit as well as its woodland suitability.

8. Sheet maps of the soils with their mapping units are imposed on aerial photographs (scale 1:20,000).

The Ponce survey, made up of two publications, the Sur (9) and Caribe (10) conservation districts contain only tables on the soil properties and limitations that affect engineering and recreation uses and land capability, erodibility, and hydrological classification. The Lajas Valley survey does not contain a table on recreation uses.

The soil engineering tables presented in the soil survey have potential value in land-use classification providing such needed data on soil properties as pH, seasonal high water table levels, depth to bedrock, texture, permeability, available water capacity, drainage for crops and pasture, irrigation, and suitability for terraces, diversions, and pond reservoir areas.

The new taxonomic system used by the USDA-SCS classified 9 Orders, 22 Suborders, 37 Great Groups, 106 Subgroups, 54 Families, and 164 Series for the Island (12, p. 19). A brief description of the nine Orders of Puerto Rican soils, to aid the reader in the use of tables and maps, is given in Table 2. An excellent review and explanation of the taxonomic classification of the soils of Puerto Rico has been prepared by Lugo-López and Rivera in 1974 (13) with an update for 1977 (14). An inventory of Puerto Rican soils calculated on a percentage basis for each of the nine Orders for the six soil survey areas is given in Table 3.

4. Land Capability Classification

The capability classification used by the SCS is a grouping that shows in a general way, how suitable soils are for most types of farming. It is a practical grouping based on limitations of the soils, the risk of damage when they are used, and the way they respond to treatment.

In this system, all of the soils are grouped at three levels: the capability class, subclass, and unit. In the broadest grouping are the eight capability classes designated by Roman numerals I through VIII. In class I are the soils that have few limitations, the widest range of use, and the least risk of damage when they are used. The soils in the other classes have progressively greater natural limitations. In class VIII are soils and landforms so rough, shallow, or otherwise limited that they do not produce worthwhile yields of crops, forage or wood products.

The subclasses indicate major kinds of limitation within the classes. They are (e) erosion, (w) water as poor drainage, (s) shallow, droughty, or stony, and (c) climate too dry.

The capability classification unit for each soil is listed in the "Guide to Mapping Units" and at the end of the mapping unit description in the section, "Description of Soils" in the Soil Surveys of Puerto Rico (6-11).

The soils of Puerto Rico were grouped by Vicente-Chandler (5) in 1978 in accordance with their agricultural potential. The grouping is simple and usable within the framework of the soil mapping units of the land capability classification of the SCS. The soils are divided into five groups (Table 4). This grouping has served as the basis for the modern agricultural program now being carried on by the Commonwealth Department of Agriculture. It is a very useful grouping that can be used as a base for land-use assignments of crops, silviculture, and other agricultural enterprises including energy crops.

A knowledge of the status of the land-use inventory of Puerto Rico is of help in future planning. The Department of Natural Resources made a land-use inventory of the Island in 1973 (15). The inventory was made from aerial photographs and two computor programs which allowed determination of the land use to a detail of 62 acres. They obtained agricultural acreages of 1,174,816 and forest 702,378.

The acreage of agricultural land suitable for mechanization is an important factor in land-use decisions. Vicente-Chandler (5) estimated 337,000 total acres (270,000 available acres allowing 20% off for roads, housing, etc.) of land that can be used for full mechanization. This is primarily class I land and has irrigation or adequate rainfall available. Bonnet (12) stated that some 523,191 acres, about 24% of Puerto Rico's total soil area, are suitable for mechanized planting of sugarcane, whether for sugar or for total biomass (Table 5). This includes classes I, II, and some III lands with slopes 20% or less.

5. Ecological Life Zones

The Puerto Rican ecosystems are extremely important, because they form a substantial component of the life-support system for over three million people. Ewel and Whitmore (16) mapped the ecological life zones for Puerto Rico according to the Holdridge system. They identified six distinct life zones which are also widely represented in Central and South America. Detailed emphasis was given to ecological zone features, water balance, and biotemperature theory, so that research done in Puerto Rico, Central America and South America will be mutually beneficial.

The areas occupied by the ecological life zones in Puerto Rico are (16):

Subtropical dry forest	300,578 acres
Subtropical moist forest	1,316,103 "
Subtropical wet forest	525,047 "
Subtropical rain forest	3,262 "
Subtropical lower montane wet forest	26,959 "
Subtropical lower montane rain forest	3,039 "

The subtropical moist and wet forest zones occupy 85% of the total land area in Puerto Rico.

More thorough study has been given to the ecosystems of Puerto Rico and the Virgin Islands than to most other tropical regions. The ecological studies made of Puerto Rico prior to 1900 were summarized by Wadsworth (17) in 1960. Murphy (18) was one of the first to provide detailed descriptions of Puerto Rico's forest in 1916. A classical description of the Island's plant communities was published by Cook and Gleason (19) in 1926, which still serves as a standard reference work. In 1966 Dansereau (20) published physiognomic and floristic descriptions of more than 100 vegetation types in Puerto Rico. He designated six principal vegetative zones conditioned primarily by climate and secondarily by either physiography or plant material. Publications with accompanying maps of vegetation were issued by Little and Wadsworth (21) in 1964, by Williams (22) in 1967, and by Odum and co-workers (23) in 1970.

6. Climate

A meaningful land-use analysis of Puerto Rico should include a brief discussion of its climate. For its climate, primarily as related to rainfall and evaporation, influences a great deal of the agricultural usage of the land.

The Island has a tropical, uniform, oceanic climate, and nearly ideal conditions exist for a heavy precipitation over most of the area. The highest peaks and the northern and eastern sides of the mountain ranges receive the highest rainfall (Fig. 3). The southern side, northwestern corner, the eastern shoreline and the interior valleys receive the least.

The average annual rainfall ranges from less than 30 inches in the southwestern part of the Island to nearly 200 inches on the highest peaks in Sierra de Luquillo (Fig. 4). There are no definite seasons, but rather a rainy period from May to November and a dry period the other 6 months. Throughout the winter, however, many showers occur, but the heaviest torrential rains take place in the summer.

The high evaporation rate combined with high temperatures, low relative humidity and constant winds tends to cause semiarid conditions even where the average annual rainfall is 45 inches. A rainfall of 30 inches in Puerto Rico is equivalent in effectiveness to about 15 inches in the United States. Many of the agricultural areas on the southern coastal plain have evaporation rates much higher in comparison to their rainfall during the dry weather than at other seasons, and irrigation is necessary even in areas having an average annual rainfall of 65 inches (Fig. 5).

The water available from dams, wells, and rivers must face competition with domestic and industrial consumption, thus depleting supplies available for irrigation. A water balance for the semiarid southern region reveals an average 5 million gallon per day deficit (Table 6).

The mean monthly temperatures range no more than 5°F from summer to winter with a yearly mean average temperature of 77-79°F on the coastal plains to 71-74° in the mountains. The temperature seldom rises higher than 90 and even in the highest, coolest parts of the Island, it seldom falls below 50°F. Sunshine occurs daily over most of the Island with the exception of a few days each year.

Temperature and sunlight are not limiting factors for agricultural production in Puerto Rico. Rainfall is limiting in some areas of the south and southwest coasts during the winter months, but irrigation, when available, compensates for this water deficit.

LAND-USE POTENTIALS

1. History of Puerto Rico's Agricultural Policy

Puerto Rico's past was centered in agriculture. Since the days when the Island was first settled by the Spanish, the people have been concerned with producing agricultural crops. Up until the twentieth century, the agriculture in Puerto Rico, as in most of the Caribbean, was based on large farm or plantations, owned by a few, growing sugarcane, tobacco, cotton, and fruits for export. Domestic food was grown on small plots by the farm laborers.

In 1900, when Puerto Rico became a U.S. possession, Congress passed a law limiting land holdings to no more than 500 acres by any individual or corporation. The law was not enforced, and large land holdings continued. Some of the agricultural policies of the U.S. government in the early 1900's were applied to the Island, with soil and water conservation programs beginning in 1923, the WPA programs in the 1930's, and the Farm and Home Administration program of family farms of 30 to 40 acres in 1948.

The change of political climate in the early 1940's, with the beginning of the Popular Democratic Party of Muñoz-Marín, marked the start of the local Puerto Rican agricultural policy. In 1941, the Island's legislature passed the land law (Ley de Tierras). It reafirmed the 500-acre limitation law.

At this time, sugarcane occupied over 70% of the crop acreage with the major part being controlled by companies whose shareholders were not in Puerto Rico.

The 1941 land law established the Land Authority of Puerto Rico, a semi-autonomous corporation, part of the Puerto Rico Department of Agriculture. Its task was to end large corporate land holdings, help small farmers, ecourage new farmers and make best use of the lands for public good under efficient and economic production. The Land Authority handled the disposal of the large land holdings by creating Proportional Benefit Farms (Title IV) consisting of large commercial farms and sugar mills organized and run by the Authority devoted mainly to sugarcane; small plots (1-3 acres) were distributed to low-income families (Title V); and family farms of up to 25 acres were sold to farmers (Title VI).

After the creation of the Land Authority in 1941, the Island's agriculture was subjected to many plans, programs, and reports evolved to help formulate a sound and dynamic agricultural policy. High points identified by year, are summarized as follows:

1953 - "A Comprehensive Agricultural Program for Puerto Rico" drawn up by Dr. N. Koening, USDA, with the cooperation of the Commonwealth of Puerto Rico (24). This study was most thorough in its examination of soil erosion, water use and control, reclamation, forest and grassland resources, as well as its analyses of agricultural credit, marketing problems, farm size, unemployment in rural areas and the problem of land use and taxation. Many of the technical findings and conclusions recommended remain useful and valid today. Nevertheless, the study's usefulness as a guide to the formulation of a development strategy for agriculture was weakened, because it incorrectly assessed the impact of factors external to agriculture, mainly industrialization. Wrong conclusions were drawn, because it divorced agricultural planning from the mainstream of development decision for the Island as a whole.

1964 - "The Agriculture of Puerto Rico: Situation and Possibilities" (25) presented by the Secretary of Agriculture M. Hernández-Agrosta in collaboration with various local scientists. The report made recommendations concerning agricultural policy and outlined a program of action for development of many aspects of agriculture including zoning of farm lands, conservation of water, soils, and forests, drainage projects, and increasing the agricultural budget. Parts of the program were put into action, but not with unified long-range planning. Folowing this period, various agricultural secretaries have given impulse to distinct parts of this program in accord with his criteria and the compelling situations of his time in office.

1968 - "The Preservation of Agricultural Land in Puerto Rico", a study by R. M. Fields (3) submitted to the Island Planning Board and Agricultural Council. The reports was drawn up to examine the problems affecting agricultural land ownership and to recommend appropriate measures as to zoning or non-zoning laws for its preservation. A productivity index was developed to serve as a basis for farm classification. Time permitted the study to develop only the index for 1963 data with details for the Mayaguez area. The report contains a good general description of crops and topography (3, pp 101-131) and a review of soil area characteristics (3, Appendix C). No apparent action was taken on this report by governmental authorities despite the dire need for a clear policy on zoning to preserve the good agricultural lands of Puerto Rico.

2. Agriculture

It appears that the agricultural policy and planning for Puerto Rico for about 75 years has been one of lack of continuity. The past policies were limited to responding to a succession of crisis in different sectors rather than any long-range planning. The Island's agriculture has not become modern, nor efficient, despite costly injections of funds via subsidies and programs to revive it as it emerges into the last quarter of the twentieth century. Agriculture has lost out to industrialization. An attempt to bring agriculture into balance was begun in 1977 with a plan for modern agriculture (5).

A comprehensive report, "Concepts, Plans, and Program for a Modern Agriculture in Puerto Rico" (5) was developed by J. Vicente-Chandler with the aid of mainly local scientists and submitted to the Commonwealth Department of Agriculture as a guide in developing a complete long-range plan for agriculture. The major thesis of the plan is that Puerto Rico requires a modern program to fully utilize its natural resources of soils, water, and year round warm weather, produce most of the food it now imports, improve its economy by stimulating domestic agricultural production, and provide employment, but not at the price of rasing food costs.

The report does not rely on generalities. It presents definite recommendations as to crop and forestry acreages, water needs, economic demands, farm employment, and a time-frame for development by 1988. Its primary objective is to stimulate food production and minimize imports. It sets production goals based on modern farms with agronomic supervision to bring the modern technologies directly to the farmer.

The plan has designated some drastic changes in land use, as the modern agriculture develops over the next 10 years (Table 7). The area in sugarcane will be markedly reduced and will be limited to completely mechanizable lands. The new rice, vegetables and bean enterprises will be established on completely mechanizable land. Pineapple and hay production will be expanded on the mechanizable lands where they are now concentrated. The production of pigeon peas and starchy vegetables will be transferred from sloping lands to mechanizable soils. The cattle industry will expand. The tobacco industry will disappear. The production of coffee, citrus, bananas, and plantains will be concentrated on moderately steep soils. The new fruit industry will be developed on rolling land in the semiarid region. The production of poultry, pigs, and ornamentals will expand mostly on soils with moderate slopes in the mountain region and on mechanizable but very sandy soils. Commercial forests will be developed mostly on steep, deep soils which are at present largely abandoned. Aquaculture will be developed in appropriate areas and the very steep and very shallow soils will be kept in natural woodlands for recreation and wildlife.

In Table 8, the total acreage for each agricultural enterprise, the production goals projected for 1988, and the farm values are presented. Total value of agricultural production at the farm level is projected to increase from $421.8 million in 1976 to $793 million in 1988. The plan presents yearly production costs of labor, materials and other items for the different agricultural enterprises in 1988 (5, Table 143). They point out that enterprises with high labor costs have a greater impact on the economy of the Island than do those whose costs are mainly for materials. They estimate that every dollar in farm wages has a 1.8 multiplier effect on the Island's gross product, and that each job in agriculture creates another opportunity for employment in other phases of the economy. Attention has been given in the plan as to the needs of the farmer for credit, direct incentives, services and materials, marketing and food conservation and processing.

As one reads the modern agricultural plan, the thought comes to mind, "If only this had been done years ago". In the context of normal times, this agricultural plan appears to provide a definite plan with proper regard to land use and the people, both country and urban. Possibly two obstacles may be difficult to overcome in the near future, despite the recognition and allowances made by the planners. They are a shortage of water for full agricultural potential and a need for more highly trained, motivated, and disciplined farmers and farm laborers.

Unfortunately, we are not in a context of normal times. An energy crisis affects all of our planning. Thus, the modern agriculture must try and bring the present and future energy needs of the Island into its concepts, plan, and program. This important matter will receive further attention in the Biomass part of the report.

(a) Human Resources: Puerto Rico's human resources comprised a poulation of 3.47 million in 1979, projected to an estimated 3.58 million in 1988 (5). Its land area is 3,435 sq. miles and will not grow any larger. This gives a population of 1,010 people per sq. mile, giving it a population density greater than Japan and about the same as Taiwan. It becomes impossible to make any decisions in land use for agriculture without consideration of this awsome population density.

An average of 47,000 out of 718,000 persons employed on the Island work in agriculture. The majority of the 41,000 men employed in agriculture are over 44 years old and have an average of 4 years of schooling. On the other hand, more than half the population of the Island is less than 19 years old and more than 400,000 workers are high school graduates.

The modern agricultural program in 1988 will employ at reasonable salaries about 47,000 persons throughout the year (Table 8) including farm workers, farmers, and farm managers. An additional 40,000 jobs will be generated from this agriculture giving a total of 88,000 jobs.

The modern agriculture plan concludes that Puerto Rico has the necessary human resources to develop it, but that an effective and continuous effort is required to train people in the required disciplines and skills. As pointed out before, this lack of skilled and disciplined labor presents an obstacle to accomplishing the modern technologies called for in the program.

(b) Farm Size: The various agricultural policies of Puerto Rico since 1900 have tried to deal with farm size. Historically, because of its agricultural past, the best lands were formed into large holdings with small farms being major in number, but small in total acreage. Various administrations have tried to deal with the problem of large versus small land holdings. The government via the Land Authority attempted to create small farms using Title V and VI grants. At present, aided by the severe decline of the sugar industry, the government is now the largest land holder.

The farm sizes for the Island in 1974 are given in Table 9. Over 86% of the farms were below 50 acres, but this represented only 24% of the total farm acreage. There were 572 farms (2.9% of total number of farms) over 260 acres or more in size, yet they represented 50% of the total farm acreage. Interestingly, compared to 1950, the number and acreage of small size farms are decreasing and the large-size farms increasing.

Modern agriculture requires large-size farms for certain crops (sugarcane, rice) and small-size farms can do well in intensive and specialized crops and enterprises (ornamentals, poultry). The modern agricultural plan appears to be searching for a blend of various farm sizes suited to the crop or enterprise. The political advantage of small-size farms must be weighed against the practical reality of the skills of the farmer, his resources, and the viability of the agricultural market he must deal in.

3. Forests

The forests of Puerto Rico have played an important role in protecting soil and water resources by minimizing floods, reducing the amount of soil material lost as sediments in rivers, and prolonging runoff into periods of dry weather. When the Island was colonized in the early 1550's, it was completely covered with forest, but clearing land for farms was soon begun. By 1930, most of the forests had been cut. Some of these areas were abandoned and were taken over by inferior volunteer species.

About 1.1 million acres of land are available for forest cover in Puerto Rico (27). In 1973, a land resource inventory (15) showed fine wood growth at 682,000 acres, large scattered crown 32,066 acres, solid crown cover 264,493 acres, and public forests 125,628 acres. Commercial and non-commercial forests including the Caribbean National and Commonwealth forests requires about 50% timber stand improvement or reforestation.

Woodland-suitable groups have been compiled by the SCS in their soil surveys for Puerto Rico to assist in planning the use of the soils for wood crops. Woodland management tables include such specific data as woodland suitability, soil group and map symbol; potential productivity giving suitable trees and average yearly growth per acre in board feet; and the hazards and limitations that effect management, including seed mortality, erosion hazard and equipment limitation. Using the soils for forests involves care in changing of some natural non-commercial forests to commercial, the protection of other non-commercial forests in their natural state, and the planting of non-forested areas.

About $250 million worth of wood products are imported yearly; yet, there is no local wood industry. The modern agricultural program recomends that 220,000 acres of the 280,000 acres of the mountaneous steep, deep soils be established in commercial forests over the next years. Forestry experts have recommended that Honduras pine (Pinus caribaea var. hondurensis) as best for commercial growth in Puerto Rico. These forests will produce wood with a farm value of $83 million yearly and will create 4,000 jobs in the field.

BIOMASS

1. Introduction

Up until the 1970's any land-use analysis study of Puerto Rico would concern itself with acreages of food crops, pastures, and forests for its various soils. The world energy crisis has added a new dimension to any planning, be it political, economic, or agriculture. To agricultural crops, a new word has been added: biomass. Biomass can be defined as plant material which has the ability to convert the radiant energy of the sun to chemical energy and to store this energy in recoverable forms (fermentable and combustible solids). Thus, biomass as an agricultural crop gives man a renewable energy source to replace dwindling supplies of fossil fuels.

There are two principal groups of biomass: herbaceous annual species and woody perennial species. The herbaceous group includes the major part of our agricultural crops such as sugarcane, forages, grains, vegetables, and starchy root crops. The perennial group includes such crops as coffee and citrus, but most woody plants are forestry (or silviculture) species.

Biomass becomes available for energy sources by burning its combustible solids as a boiler fuel, converting its fermentable solids to alcohol based fuels, use of pyrolitic methods to produce gas and liquid fuels, and development of chemical conversion of cellulose and hemicellulose complexes to alcohol or chemical feedstocks. Thus, agricultural planning in Puerto Rico must consider such crops as sugarcane, tropical grasses, and silviculture, not only for their conventional uses, but for their energy potentials.

Puerto Rico imports over 98% of its energy requirements as oil. With the world energy crisis sending oil prices soaring, the expenditure for oil in 1976 was 1.4 billion (28). Food expenditures for imports amounted to $500 million for the same period. However, oil prices are rising at a more rapid rate than food crop prices. As a country which does not have the resources to produce both its total energy and food crop requirements, choices will have to be made. Any adequate land-use analysis for Puerto Rico must give serious consideration to biomass as part of its presentation.

2. Biomass Energy Sources

The consideration of traditional crops as biomass energy sources requires that traditional agronomic practices be replaced by new agronomic practices which seek to obtain highest yields per unit area of energy-potential materials, rather than traditional uses as food, fiber, or construction material. For example, economic feasibility for biomass is not possible with conventional yields of 30 tons of millable cane per acre, but biomass managed cane yielding 90 tons per acre reaches economic feasibility. Non-traditional energy cropping includes non-intensive biomass crops on marginal lands with minimum tillage and use of weeds and grass clippings as energy sources.

With each crop presented in the following section, an estimate is given of the maximum possible acreage and soil regional location available within limits of sound agronomic practices including erosion and water control. The suggested acreage allocation (Table 10) does not imply that total biomass conversion of Puerto Rican agriculture is recommended; rather, they serve as guides to the reader for possible use in planning studies. Nor does the acreage given mean that all of it is suitable for the mechanization needed in planting, harvesting, drying, and transporting the biomass crop. Where possible, the dry-matter biomass production per acre and totals will be given, as well as potential BTU's equivalents of the material produced (Table 10). No attempt is made to give direct economic evaluations, as it lies beyond the scope of this report.

(a) Sugarcane: As has been shown by Alexander (29,30), sugarcane is the most efficient biomass producer in Puerto Rico. Maximization of tonnage was achieved with changes in management that gave a 3-fold increase over the average yield for the Island's sugar industry (29). The use of cane tops and leaves contribute about 30% more biomass than just millable cane stalks. The fiber content for boiler fuel ran about 17%, but new varieties can give higher fiber values. The fermentable solids can be used for alcohol production directly from the cane juice or from molasses. Thus every 100 tons of green millable cane becomes 130 tons of biomass cane (30% additional for leaves and tops) which gives 22 dry tons of biomass capable of producing 360 million BTU's, equivalent to 36,000 KWH of electricity, plus about 1,600 gallons of alcohol from cane juice or enriched molasses, sufficient to replace 1,600 gallons of gasoline.

(b) Tropical Grasses: Tropical grasses, other than sugarcane, hold promise as maximum biomass producers. Napier grass (*Pennisetum purpureum*) has been shown by Alexander to be capable of producing actually more biomass tonnage than sugarcane in a 6-month harvest interval (31). It can be designated as an intermediate rotation crop suited in areas not appropriate to sugarcane, because of length of growing season available or other growing conditions such as rainfall.

A crop appropriate for a short rotation is the hybrid forage, grass, Sordan 70A, a cross between sweet sorghum and sudan grass. Alexander (31) has obtained an average of 3.4 tons per acre projected oven-dry biomass in 2-month harvest intervals and 4.3 tons in a 4-month harvest interval. Sordan 70A is versatile in its short cropping period to fit into rotations with many food crops.

"Wild" *Saccharum* clones (US 67-22-2 and SES 231) and Johnson grass (*Sorghum halapense*) have been suggested for minimum-tillage candidates for marginal soils where lack of water is predominant (30). They can produce moderate yields with the barest minimum of production inputs.

(c) Silviculture: Yield potential for Puerto Rico's forests have never been realized when managed as "energy plantations". However, Whitmore and Alexander (32) foresee a new dimension and challange in the production of total dry matter for energy conversion rather than lumber. A pilot research project has been submitted to the USDOE, Fuels from Biomass Systems Branch. Potential yield projections of 18 tons dry matter/acre/year for tropical rain forests and 11 for subtropical forests have been suggested (33). Species thought to have genuine potential as biomass energy sources include *Eucalyptus robusta*, *E. tereticornis*, *E. camaldulensis*, *E. grandis*, *Cassia siamea*, *Albizia procera*, *Leucaena leucocephala*, *Casuarina equisetifolia*, *C. glauca*, *Syzygium jambos*, and *Pinus caribaea* var. *hondurensis* (32).

Certain species of the genera *Euphorbia*, *Calotropis*, *Cryptostegia*, and *Parthenium* might also be grown on marginal lands because of their high contents of plant hydrocarbons (32) rather than as a boiler fuel.

3. A Balance: Food and Energy Cropping

Agricultural planners in Puerto Rico must weigh carefully the merits of energy planting versus food planting for the Island's available land resources. There are about 270,000 acres of level, mechanizable land for either cropping system or a combination of both. This is the best land and is capable of producing the highest yields of food or energy crops. Yet compromise can prevail to give a rational combination of both.

Some suggested examples of possible biomass land uses compatable with a modern agriculture program are:

1. The proposed 70,000 acres for sugarcane in the modern agriculture plan can produce, instead of sugar at a loss, boiler fuel (bagasse) and enriched molasses sufficient to supply all the needs of the Puerto Rico rum industry, with an appreciable surplus which can be converted to alcohol for gasohol, saving on imports of both molasses and motor fuel.

2. The use of tropical grasses such as Napier on the humid, deep soils with 20-25% slope could provide more BTU's of energy as a boiler fuel than all of the 522,000 acres of soils that could be planted to sugarcane (Table 10) including the best acreages for mechanization. Of course all of the 554,000 acres of the humid, deep soils with 20-25% slope can not be used for Napier; but aside from slope, the soils and climate are good for Napier grass production.

3. The use of Sordan 70A, not only in the semiarid gentle rolling hills for three crops per year, but in any cropping area where there is a fallow of 2-3 months before planting the next crop (such as for vegetables).

4. The use of silviculture to produce boiler fuel instead of lumber. There are about the same number of BTU's available on these non-food croplands as on those available for sugarcane energy crop production (Table 10). The steepness of some of the 736,000 acres would prevent its use for biomass production. If we allow 20% of the land as inaccesible for harvest, we would obtain 589,000 acres of woodland yielding 4,712,000 dry tons of biomass fuel. Of course, logistics and economics of handling the woody material will have to be developed, but this energy crop can not be ignored in a balanced food: energy crop program.

5. The use of certain species of genera Euphorbia, Calotropis, Crystotegia, and Parthenium to produce plant hydrocarbons on marginal lands in the semiarid area with about 230,000 acres in steep and shallow soils. More research is needed on the yields, convertability, and economics of this type of crop for energy. At present these soils are not productive for any economic crop.

6. The use for boiler fuel of grass clippings and weeds collected from the grass median barriers and borders of the Island's autopista system rather than being left on the roadside or trucked to the nearest municipal dump. There are about 1200 acres available that could give yearly 4800 tons of dry-biomass fuel (35).

7. The use of the rice straw in the proposed rice enterprise for boiler fuel in the rice drying and processing plants (34). One thousand acres in rice can produce 4,000 tons of dry rice straw equal to 60 million BTU's.

REFERENCES

1. Roberts, R. C. 1942. Soil Survey of Puerto Rico. USDA series 1936 in cooperation with Univ. PR-AES, 503 pp + soil maps.

2. Beinroth, F. H. 1969. An outline of the geology of Puerto Rico. AES-UPR Bull. No. 213.

3. Field, R. M. 1968. The preservation of agricultural lands in Puerto Rico. Submitted by Haines, Lundberg & Wachler to PR Planning Board and Agric. Council. June. 205 pp + append. 143 pp.

4. Young, R. N. 1967. A geographic classification of landform types of Puerto Rico. Symposium on the Geography of PR. Quoted (3,p.98).

5. Vicente-Chandler, J. 1978. Concepts, plan, and program for a modern agriculture in Puerto Rico. Commonwealth PR Dept. Agric. Santurce, PR. (in Spanish with English summary pp 498-540).

6. Boccheciamp, R. A. 1977. Soil Survey of the Humacao Area, Eastern Puerto Rico. USDA-SCS in coop. UPR-GAS. Jan. 1977, 103 pp. + soil map.

7. Carter, O. R. 1961. Soil Lajas Valley. Series 1961, No. 623, USDA-SCS in coop. UPR-AES, April 1965, 170 pp. + soil map. (in English and Spanish).

8. Gierbolini, R. E. 1975. Soil Survey of the Mayaguez Area of Western Puerto Rico. USDA-SCS in coop. UPR-AES. Dec. 1975. 296 pp. + soil maps (English and Spanish).

9. Gierbolini, R. E. 1973. Soils of the Sur Conservation District and Their Interpretation for Various Uses. USDA-SCS. Feb. 1973, 45 pp. + maps.

10. Gierbolini, R. E. 1973. Soils of the Caribe Conservation District and Their Interpretations for Various Uses. USDA-SCS April, 1973. 48 pp. + soil maps.

11. Boccheciamp, R. A. 1978. Soil Survey of San Juan Area of Puerto Rico. USDA-SCS in coop. UPR-AES. Nov., 1978. 141 pp. + soil maps.

12. Bonnet, J. A. 1978. Suitability and management of Puerto Rican soils for intensive biomass production. Symposium on alternate uses of sugarcane for development in Puerto Rico. Caribe Hilton Hotel. San Juan, P. R. March 26 and 27.

13. Lugo-López, M. and L. H. Rivera. 1976. Taxonomic Classification of the soils of Puerto Rico, 1975. UPR Exp. Sta. Bull. 245.

14. Lugo-López, M. and L. H. Rivera. 1977. Updated taxonomic classification of the soils of Puerto Rico. UPR-AES Bull. 258.

15. Anon. 1973. Inventario de recursos naturales, culturales y ambientales. P.R. Dept Natural Resources. (Computor printout summary available in library, Institute of Tropical Forestry, Río Piedras, P.R.).

16. Ewel, J. J. and J. L. Whitmore. 1973. Ecological life zones of Puerto Rico and the U.S. Virgin Islands. USDA Forest Service Research Paper ITF-18. Institute of Tropical Forestry, Río Piedras, P.R.

17. Wadsworth, F. H. 1950. Notes on the climax forests of Puerto Rico and their destruction and conservation prior to 1900. Carib. Forest. 11:38-47.

18. Murphy, L. S. 1916. Forests of Puerto Rico, past, present, and future, and their environment. USDA Bull. No. 354. Washington, D. C., 99 pp.

19. Cook, M. T. and H. A. Gleason. 1928. Ecological survey of the flora of Porto Rico. J. Agric. Porto Rico, 12:3-17.

20. Dansereau, P. 1966. Studies on the vegetation of Puerto Rico. I. Description and integration of the plant communities. Special Pub. No. 1, UPR Institute of Caribbean Sci., Mayaguez. 287 pp.

21. Little, E. L. Jr., and F. H. Wadsworth. 1964. Common trees of Puerto Rico and the Virgin Islands. Agricultural Handbook No. 249, USDA Forest Service. Washington, D. C. 548 pp.

22. Williams, L. 1967. Forests of Southeast Asia, Puerto Rico, and Texas. CR 12-67. USDA-ARS, Washington, D. C., 410 pp.

23. Odum, H. T. 1970. A tropical rain forest. Division Technical Information. USAEC, Oak Bidge, Tenn.

24. Koenig, N. 1953. A Comprehensive Agricultural Program for Puerto Rico. USDA in coop. Commonwealth P.R., 299 pp.

25. Hernández-Agrosto, M. A. 1966. La agricultura de Puerto Rico y Posibilidades. Revista de Agricultura P.R. 53(1 + 2) Enero-Dec.

26. Anon. 1977. Timber. Prepared for the Advisory Committee of the Commonwealth Dept. Agriculture by the Institute of Tropical Forestry, USDA Forest Service, Río Piedras.

27. Rivera-Ríos, M. 1977. Statistical Yearbook, Puerto Rico, 1976. Commonwealth of Puerto Rico Planning Board, Santurce, P.R.

28. Alexander, A. G. 1978. Sugar and energy attributes of the genus Saccharum; an overview. Symposium on alternate uses of sugarcane for development in Puerto Rico. Caribe Hilton Hotel, San Juan. March 26 and 27.

29. Alexander, A. G. 1979. Sugarcane cultural modifications for maximum biomass. Symposium on alternate uses of sugarcane for development in Puerto Rico. Caribe Hilton Hotel. San Juan, March 26 and 27.

30. Alexander, A. G. 1979. Production of sugarcane and tropical grasses as a renewable energy source. DOE Contract No. ET-78-S-05-5912. Annual Report, 1979.

31. Whitmore, J. L. and A. G. Alexander. 1979. Intensive production of tropical forests as a renewable energy source. Research project proposal USDOE, Fuels from Biomass Branch, Washington, D. C.

32. Inman, R. E. 1977. Silviculture biomass farms. Vol. 1. Mitre Corp., MacLean, Va.

33. Samuels, G. 1979. Sugarcane in food and energy crop rotations in Puerto Rico. Symposium on alternate uses of sugarcane for development in Puerto Rico. Caribe Hilton Hotel. San Juan, March 26-27

34. Alexander, A. G. 1979. Biomass as a source of boiler fuel and molasses for Puerto Rico. Technical congress for the investigation and conservation of energy sources. El San Juan Hotel, San Juan, Nov. 7-9, 1979.

TABLE 1. LAND AREA 1/ BY PERCENT OF SLOPE 2/

Percent of slope	Area in Acres	Percent of total
0-5	393,116	19.2
6-15	173,312	18.4
16-35	333,838	16.3
36-45	372,372	18.1
46-59	172,244	8.4
60+	608,372	29.6
Total	2,053,254	100.0

1/ This excludes approximately 82,550 acres in urban or non-productive use as well as the land area of the islands of Culebra, Vieques, and Mona.

2/ After Field (3).

TABLE 2. A BRIEF DESCRIPTION OF THE NINE ORDERS OF PUERTO RICAN SOILS ACCORDING TO THE NEW TAXONOMIC SYSTEM 1/

Order	Horizon	Features
Entisols	not developed	affected by floods and high water tables
Inceptisols	incipient development	on sloping lands
Alfisols	clayey (argillic)	moist having high base status and low in percolation
Mollisols	dark	high base status
Vertisols		cracking and clayey
Spodsols 2/	illuvial with silicate clays	accumulation of Al and organic matter in second horizon
Histosols		organic soil
Oxisols	reddish brown no illuvial horizon of silicate clays	acid with low base exchange capacity; advanced stage of weathering; mixture of hydrated oxides of Al or Fe, or both, with variable amounts of kaolinitic clay and insoluble quartz sand; good drainage
Ultisols	clayey subhorizon more acid than surface	acid with low base exchange status and capacity in regions of high rainfall; where leaching exceeds base liberation; low permeability

1/ Derived from (12)

2/ Very rare in Puerto Rico

TABLE 3. ACREAGE AND PERCENTAGE DISTRIBUTION OF SOILS BY ORDER IN THE SIX SOIL SURVEY AREAS OF PUERTO RICO 1/

Order	Acreages and percent distribution for Area					
	Lajas	Mayaguez	Humacao	Arecibo	San Juan	Ponce
Entisol	11,492 (11.2) 2/	22,121 (4.8)	35,736 (4.8)	20,119 (5.0)	5,367 (1.2)	3,970 (1.3)
Inceptisol	28,525 (27.8)	125,813 (47.0)	220,997 (47.0)	62,772 (15.6)	227,218 (50.8)	171,636 (56.2)
Alfisol	5,131 (5.0)	14,286 (3.1)	26,332 (5.6)	30,582 (7.6)	14,313 (3.2)	0
Mollisol	8,209 (8.0)	30,877 (6.7)	17,398 (3.7)	66,796 (16.6)	12,524 (2.8)	69,937 (22.9)
Vertisol	25,344 (24.7)	1,383 (0.3)	9,404 (2.0)	0	0	16,186 (5.3)
Spodosol	0	0	0	2,414 (0.6)	0	0
Histosol	0	0	0	4,829 (1.2)	0	0
Oxisol	0	21,199 (4.6)	0	24,143 (6.0)	1,789 (0.4)	0
Ultisol	4,310 (4.2)	147,473 (32.2)	77,114 (16.4)	115,887 (28.8)	128,369 (28.7)	35,121 (11.5)
Others	19,598 (19.1)	97,240 (21.1)	83,697 (17.8)	74,843 (18.6)	57,699 (12.9)	8,857 (2.9)
Totals	102,609 (100)	460,853 (100)	470,202 (100)	402,384 (100)	447,279 (100)	305,402 (100)

1/ Derived from Bonnet (12, Table 7).

2/ Numbers in parenthesis refer to percentages for Area.

TABLE 4. SOIL RESOURCES OF PUERTO RICO GROUPED IN ACCORDANCE WITH THEIR AGRICULTURAL POTENTIAL

	Total acres	Acres available 1/
I. Soils of the humid coastal region		
A. Deep, alluvial soils (sugarcane, rice, starchy vegetables) New crops	129,408	103,326
B. Deep, red soils (pineapples, pigeonpeas, starchy vegetables, dairying)	118,112	94,490
II. Soils of the humid midlands		
C. Soils of rolling topography (plantains, citrus, dairying)	134,592	107,674
III. Soils of the humid mountain region		
D. Deep soils with 50% slopes (coffee, plantains, bananas, citrus, dairying, beef cattle)	606,640	485,312
E. Medium deep soils with 50% slopes (commercial forests)	350,578	280,462
F. Shallow soils or soils 50% slopes (natural woodlands, wildlife, recreation)	283,106	227,585
B. Shallow calcareous soils (natural woodlands, wildlife, recreation)	101,760	81,408
IV. Soils of the semi-arid region		
H. Deep, level, heavy, irrigable soils (sugarcane, hay, beans, new crops)	58,940	47,152
I. Deep, level, friable, irrigable soils (vegetables, beans)	30,272	24,218
J. Gently rolling soils, (some-adapted to drip irrigation) (mangos, avocados and other fruits)	49,152	39,322
K. Steep shallow soils (natural woodlands, wildlife and recreastion)	230,016	230,016
V. Soils of the coastal lowlands		
L. Saline, organic, marshy or sandy (aquaculture, ecological reserves)	96,450	96,450
	2,189,026	1,817,415

1/ 20% discounted for urban, industrial, roads and other uses except in groups K and L.

TABLE 5. ACREAGES AND PERCENT DISTRIBUTION, BY ORDER, OF MECHANIZED AND NON-MECHANIZED SOILS OF PUERTO RICO 1/.

Order	Mechanized		Non-mechanized		Total	
Entisol	61,284	(2.8) 2/	37,208	(1.7)	98,492	(4.5)
Inceptisol	118,190	(5.4)	726,652	(33.2)	844,842	(38.6)
Alfisol	45,963	(2.1)	45,963	(2.1)	91,926	(4.2)
Mollisol	96,303	(4.4)	120,379	(5.5)	216,682	(9.9)
Vertisol	52,529	(2.4)	0		52,529	(2.4)
Spodosol	2,189	(0.1)	0		2,189	(0.1)
Histosol	4,377	(0.2)	0		4,377	(0.2)
Oxisol	41,586	(1.9)	4,327	(0.2)	45,913	(2.1)
Ultisol	111,624	(5.1)	396,157	(18.1)	507,781	(23.2)
Totals	534,045	(24.4)	1,330,736	(60.8)	1,864,781	(85.2)

1/ Derived from Bonnet (12, Table 11).

2/ Numbers in parentheses refer to percentage distribution by Order.

TABLE 6. AVAILABLE WATER BALANCE FOR THE SEMIARID REGION OF PUERTO RICO (EXOLUDING THE LAJAS VALLEY) IN MILLIONS OF GALLONS OF WATER DAILY 1/

Municipality	WATER					
	Available 2/	Demand				Balance
		Agriculture	Industrial Domestic	Lost	Total Effective	
Guánica	23.2	13.3	3.9	1.3	18.5	4.7
Yauco	8.7	4.2	2.8	1.4	8.4	-0.3
Guayanilla	13.6	11.1	4.5	-	15.6	-0.2
Peñuelas	19.1	6.2	11.9	1.4	19.5	5.7
Ponce	48.4	43.0	20.0	5.6	68.6	-20.2
Juana Díaz	36.3	27.0	2.5	2.0	31.5	4.8
Santa Isabel	56.2	48.2	1.1	4.1	53.4	2.8
Salinas	39.8	29.9	6.0	2.5	38.4	1.4
Gurayama	36.2	27.0	6.5	4.0	37.5	-1.3
Arroyo	10.4	7.7	.8	1.9	10.4	0
Patillas	11.4	8.7	1.1	2.2	12.0	-0.6
Coamo	4.5	2.1	1.5	.9	4.5	0
Villalba	1.7	.3	1.1	.4	1.8	-0.1
Maunabo	2.2	1.5	.7	.1	2.3	-0.1
TOTALS	317.3	230.2	64.4	27.8	322.4	-5.1

1/ Derived from (5, table 42).

2/ Includes wells, dams, and surface water.

TABLE 7. CHANGES IN LAND USE BY SOIL GROUPS FROM 1976 TO 1988

Agricultural enterprise	Mechanizable land (270,000 acres)		Deep, moderately steep soils (600,000 acres)		Steep but deep soils (280,000 acres)	
Sugarcane	110,000	70,000	10,000	-	-	-
Rice	-	50,000	-	-	-	-
Vegetable crops 1/	1,000	15,000	2,000	-	600	-
Pineapple	4,500	12,000	-	-	-	-
Pigeonpeas	1,000	8,000	5,000	-	6,500	-
Starchy vegetables	500	7,500	6,000	-	8,500	-
Beans	-	13,500	-	-	-	-
Hay	2,000	5,000	-	-	-	-
Pastures	149,250	79,200				
Coffee	-	-	50,000	243,300	10,000	13,500
Citrus	-	-	20,000	30,000	50,000 2/	-
Tobacco	-	-	1,000	7,000	7,000	-
Plantains	1,000	2,000	3,000	-	1,000	-
Bananas	-	-	10,000 2/	13,000	4,000	-
Fuuits	-	-	3,000 2/	8,000	5,000	-
Poultry	300	500	200	5,500	-	-
Pigs	200	300	100	1,500	-	-
Ornamentals	200	500	100	700	-	-
Wood (commercial)	-	-	100	1,500	-	-
Aquaculture	50	6,000	-		-	-
Abandoned or native pastures	-	-		-	-	150,000
	-	-	489,500	220,000	187,400	116,500

1/ One crop yearly in 1977 - 2 crops yearly in 1988

2/ Intercropped with coffee

3/ In the year 2,000

TABLE 8. AREA, PRODUCTION, FARM VALUE, AND EMPLOYMENT OF THE MODERN AGRICULTURE IN 1988 AND COSTS TO THE GOVERNMENT OF DEVELOPING IT OVER A 12-YEAR PERIOD (5, p. 537).

Agricultural enterprise	Acres	Production	Farm value ($ million)	Employment 1/	Cost to government ($ millions)
Sugarcane	70,000	200,000 tons	60.0	6,000	40.0
Rice	50,000 3/	5 million cwt. of rough rice	55.0	1,500	25.4
Vegetables	15,000 3/	-	36.3	4,000	12.0
Pineapples	12,000	128,000 tons	12.8	1,600	0
Pigeonpeas	8,500	153,000 cwt.	4.6	600	3.6
Starchy vegetables	7,500 3/	1.4 million cwt.	18.7	1,500	2.4
Beans	13,500 3/	534,000 cwt.	10.7	500	2.9
Hay	5,000	60,000 tons.	4.8	200	0
Milk	250,000	431 million lts.	138.0	5,000	35.0
Beef	150,000	68.3 million lbs.	47.8	3,000	25.4
Coffee	30,000	450,000 cwt.	63.0	6,000	32.0
Citrus	7,000	440 million fruits + 9 million lbs citrus	23.5	1,600	7.0
Bananas	8,000	800 millions	11.9	1,400	2.4
Plantains	15,000	450 millions	36.0	2,500	0
Fruits	5,500	-	23.0	800	5.5
Poultry	1,000	58.7 millions lbs.	35.2	600	6.0
Eggs	1,000	42.5 thousands of doz.	31.9	900	6.0
Pork	1,000	62.1 millions lbs.	50.9	1,400	12.0
Commercial forest	220,000	(in the year 2,000)	83.0	4,000	16.9
Aquaculture	6,000	8.4 millions lbs.	5.9	600	2.4
Ornamentals	2,000	-	-	4,000	0
Permanent improvements on mechanizable lands 1/		-	-	-	24.0
Human resources		-	-	-	12.0
Application of technology		-	-	-	12.0
Marketing		-	-	-	45.0
Totals	878,000		$793.0	47,700	329.9

1/ Includes laborers, farmers, farm operators and, in some enterprises, processing e.g. sugar, and rice mills, canning of pigeonpeas, packing of fresh vegetables

2/ Does not include operation costs of the agricultural agencies or subsidies to traditional agriculture.

3/ Planted 2 times a year

4/ + 100,000 acres in semi-arid region

5/ In addition to $25 million included for such improvement in the rice industry and $20 million in the sugarcane industry.

TABLE 9. NUMBER OF FARMS AND ACREAGE BY FARM SIZE, 1974 1/

Size Acres	Number of farms		Acreage of farms	
	Actual	% of total	Acres	% of total
Less than 3	2,781	9.4	4,061	0.3
3-9	11,537	38.9	59,418	4.9
10-18	6,083	20.5	8,117	6.6
19-48	5,293	17.9	153,347	12.5
49-96	1,785	6.0	118,142	9.7
97-169	885	3.0	111,274	9.1
170-252	414	1.4	85,607	7.0
253+	872	2.9	610,618	49.9
TOTAL	29,650	100	1,223,631	100

1/ Derived from (5, Table 45b).

TABLE 10. PROJECTED BIOMASS PRODUCTION ON THE SOILS OF PUERTO RICO

Crop	Soils	Acreage 1/	Dry biomass (tons/A)	Totals: Dry biomass (tons)	Totals: BTU's 5/ x 1012
	Humid				
Sugarcane	Deep, level alluvial	129,000	17 2/	2,193,000	32,895
	Deep red	118,000	13 2/	1,534,000	23,010
	Rolling & deep, 20% slope	186,000	11 2/	2,046,000	30,690
	Semiarid				
	Deep level, heavy, irrigated	59,000	26 1/	1,534,000	23,010
	Deep level, fiable, irrigated	30,000	26	780,000	11,700
	Total	522,000		8,087,000	121,305
Tropical grasses: Napier	Humid, deep 20-50% slopes	554,000	16 3/	8,864,000	132,960
Sordan 70A	Semiarid, gentle rolling hills	49,000			
	Total	603,000		9,158,000	137,370
Silviculture	Humid, medium deep soils 50% slope	351,000	8 4/	2,808,000	42,120
	Shallow or 50% slopes	283,000	8	2,264,000	33,960
	Shallow calcareous	102,000	8	816,000	12,240
	Total	736,000			
Gran total		1,861,000		23,133,000	346,995

1/ From table 4, total acres rounded off to thousands.

2/ Base 30 dry tons/A x 0.85 factor allowing for roadways, ditches, etc. The deep, level alluvial soils: 17 tons/A projected from 26 x 0.67 factor for rainfall only. The deep red soils: 13 tons/A projected from 17 x 0.75 factor rainfall only and soil location. The rolling topography: 11 tons/A projected from 17 x 0.67 factor for rainfall only and soil location.

3/ After Alexander (31) with two 6-month Napier crops/year: 29 tons/A x 0.85 factor for roads, ditches, etc. x 0.67 factor for no irrigation. Sordan 70A three 4-month crops/yr: 10 tons/A x 0.85 x 0.67 (factors).

4/ From Inman (33): 11 tons/A x factor 0.75 roads and soil location.

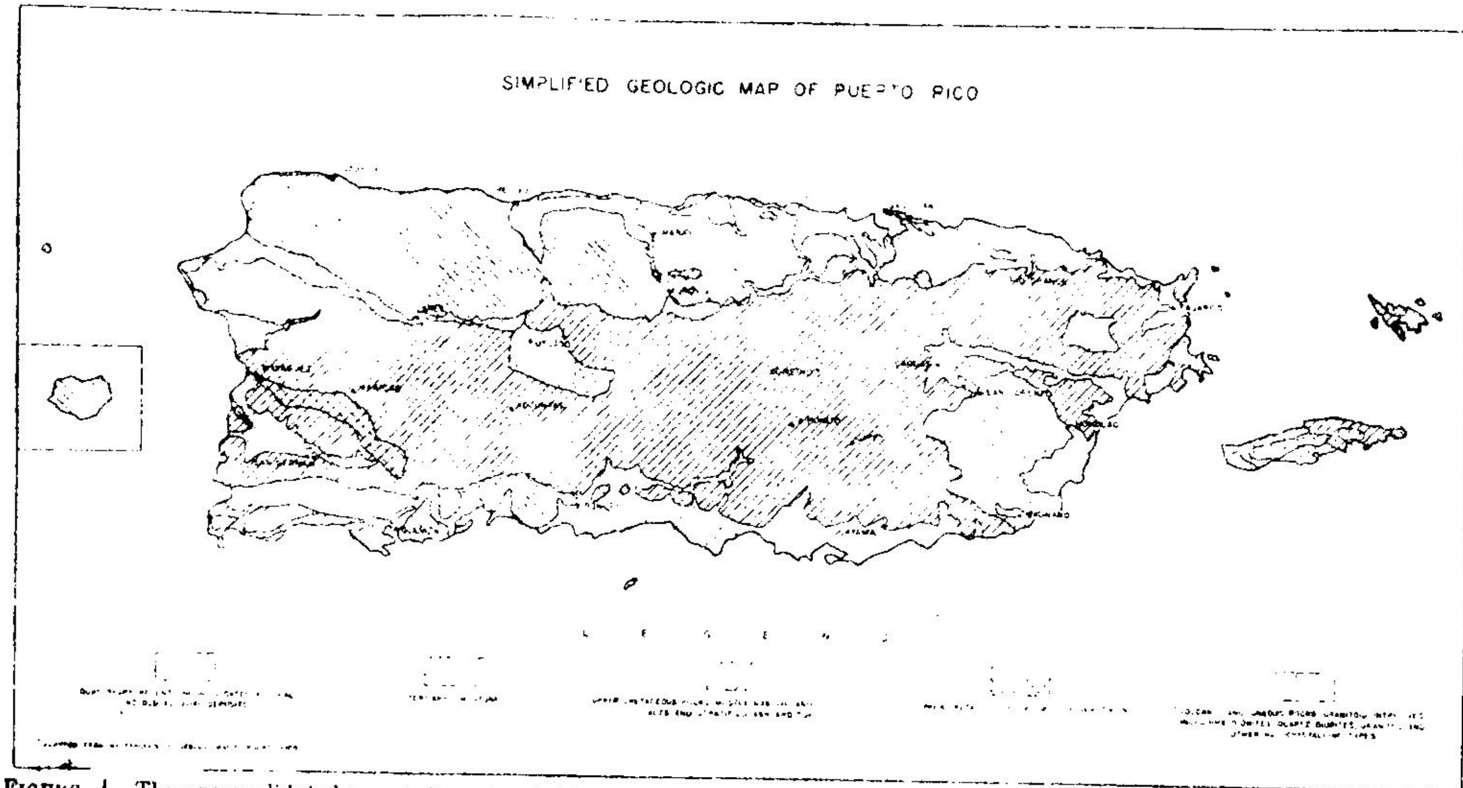

Figure 1 The unconsolidated recent alluvial and old alluvial deposits largely comprise the playa plains. The areas occupied by Tertiary limestone comprise the northern and part of the southern coastal plains. The remainder of the island consists of complex mountain ranges and dissected plateaus of various rock types indicated in the legend.

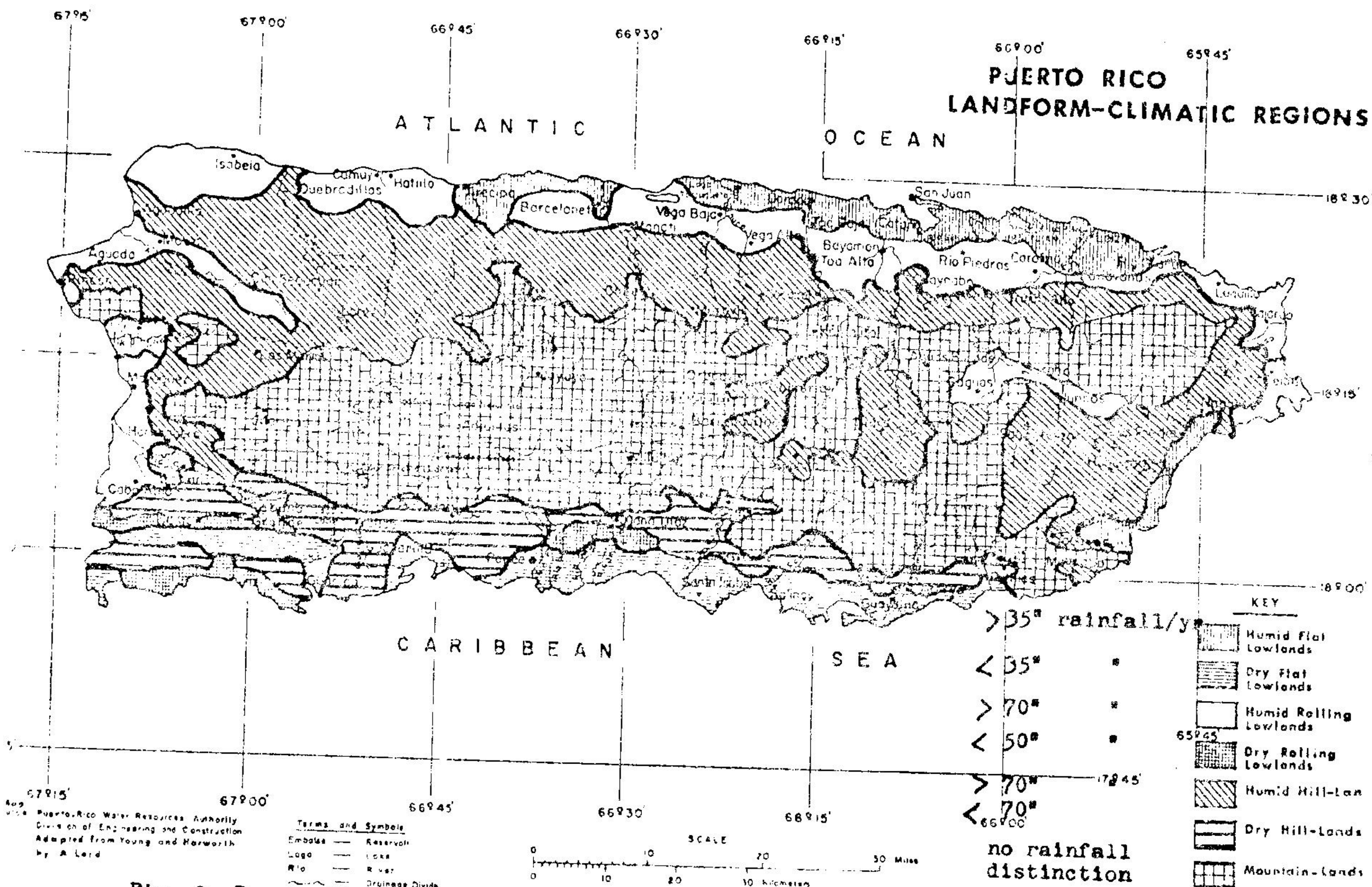

Fig. 2. Puerto Rico Landform-Climatic Regions (3).

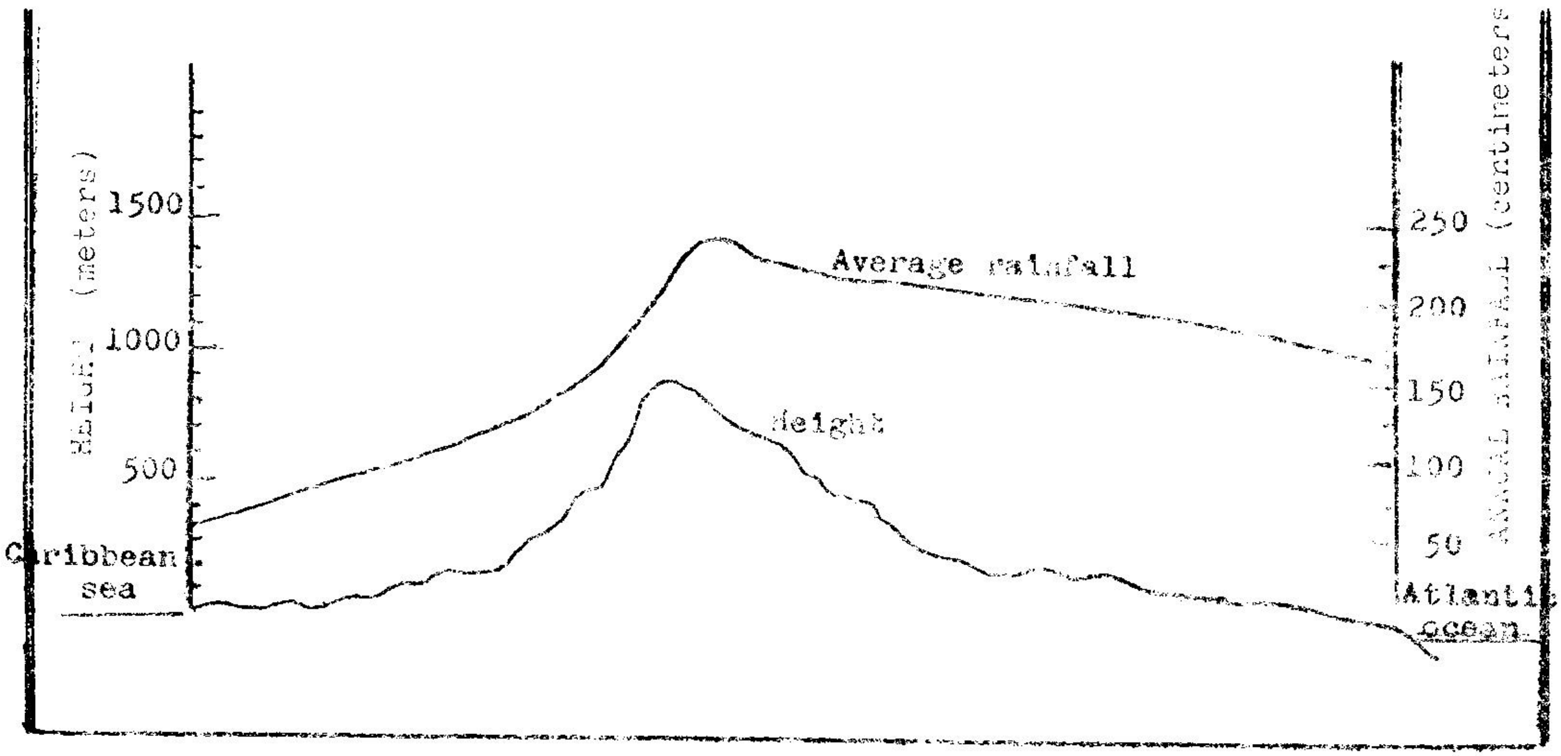

Fig. 3. Relation between elevation and rainfall in Puerto Rico (5,p.66).

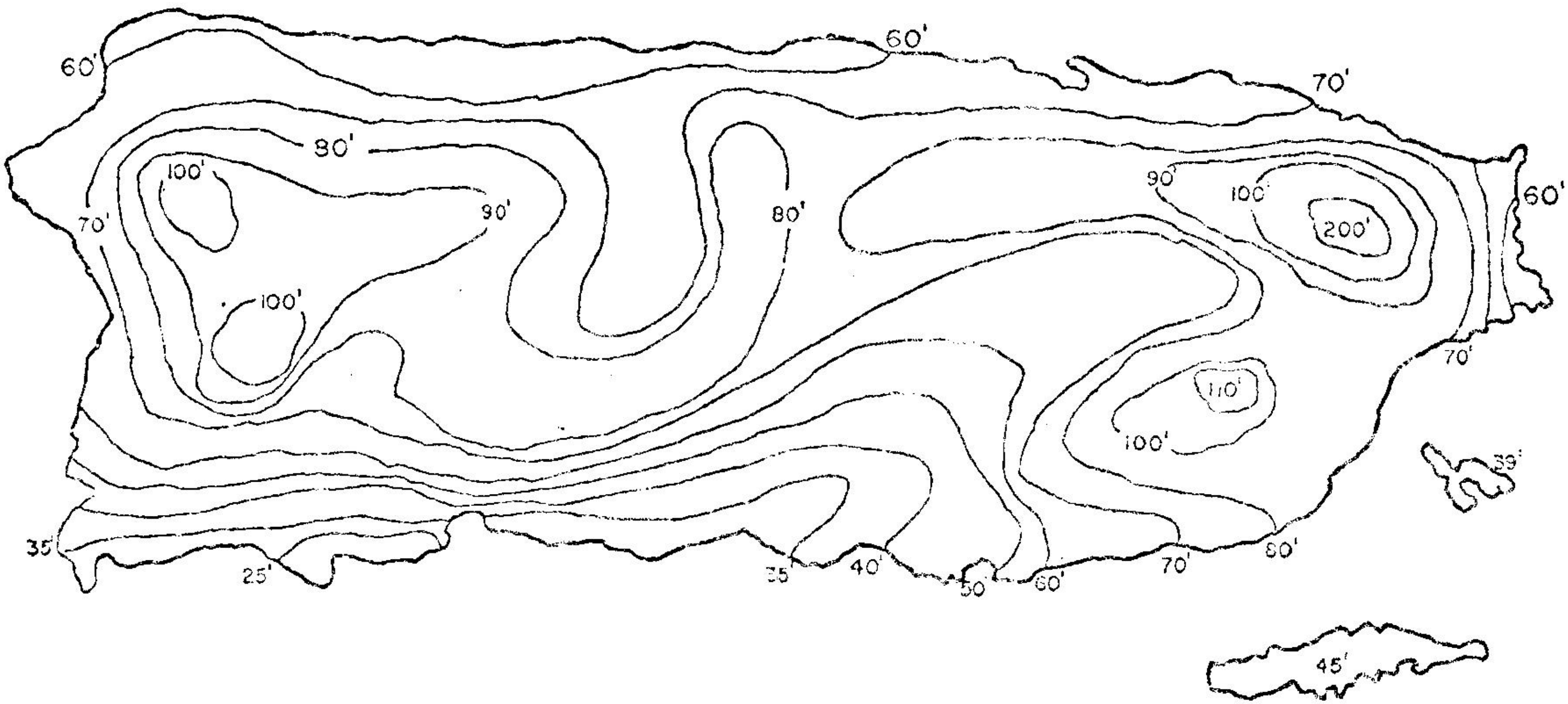

Fig. 4. Average rainfall for Puerto Rico (inches/year) (5,p.65)

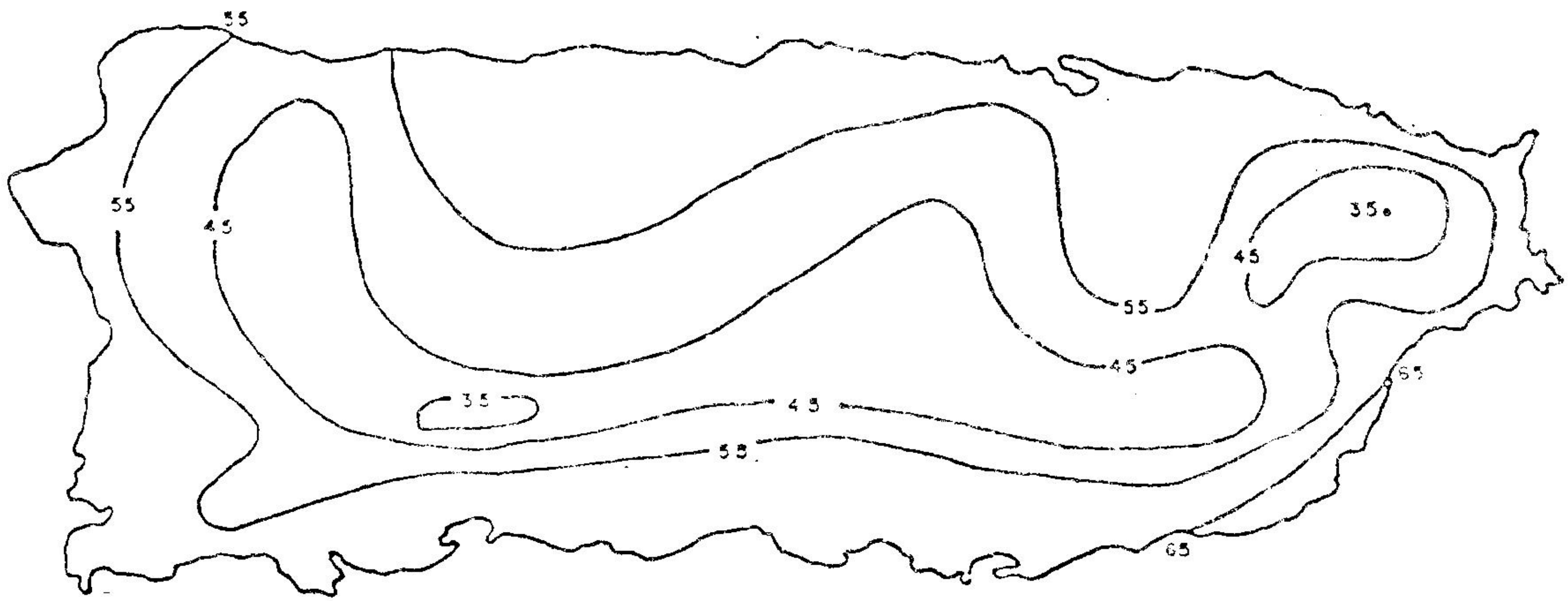

Fig. 5. Average evapotranspiration potential in Puerto Rico (inches/year) (5, p. 68)