WATER REQUIRED, WATER USED, AND POTENTIAL WATER SOURCES FOR RICE IRRIGATION, NORTH COAST OF PUERTO RICO

By Angel J. Román-Más

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CONVERSION TABLE

For the convenience of readers who may want to use the International System of units (SI), the inch-pound units used in this report may be converted by using the following factors:

Multiply inch-pound units	by	To obtain SI units
inch (in.)	25.4	millimeter (mm)
	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	4047.	square meter (m^2)
acre-foot (acre-ft)	1233.	cubic meter (m^3)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius (°C)

Specific inch-pound unit combinations

1 Acre-ft = 226.2 gal/min during one day

1 ft^3/s = 448.8 gal/min

1 ft^3/s = 0.65 Mgal/d

WATER REQUIRED, WATER USED, AND POTENTIAL WATER SOURCES FOR RICE IRRIGATION, NORTH COAST OF PUERTO RICO

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ABSTRACT

A 3-year investigation was conducted by the U.S. Geological Survey in cooperation with the Puerto Rico Department of Agriculture to determine the water required and used (both consumed and applied) for irrigation in the rice-growing areas of Vega Baja, Manatí, and Arecibo along the north coast. In addition, the investigation evaluated the water resources of each area with regard to the full development of rice farming areas. Based on experiments conducted at selected test farms, water required ranged from 3.13 to 5.25 acre-feet per acre per crop. The amount of water required varies with the wet and dry seasons. Rainfall was capable of supplying from 31 to 70 percent of the water required for the measured crop cycles. Statistical analyses demonstrated that as much as 95 percent of rainfall is potentially usable for rice irrigation.

The amount of water consumed was found to differ from the quantity required at selected test farms. The difference between the amount of water consumed and that required was due to unaccounted losses or gains, seepage to and from the irrigation and drainage canals, and lateral leakage through levees. Due to poor water-management practices, the amount of water applied to the farms was considerably larger than the sum of the water requirement and the unaccounted losses or gains.

At present, rivers within the rice growing areas constitute the major water supply for rice irrigation. Full development of these areas will require more water than the rivers can supply. Efficient use of rainfall can significantly reduce the water demand from streamflow. The resulting water demand, however, would still be in excess of the amount available from streamflow. Ground-water development in the area is limited because of seawater intrusion in the aquifers underlying the rice-growing areas. Capture of seepage to the aquifers using wells located near streams, artificial recharge, and development of the deep artesian system can provide additional water for rice irrigation.

INTRODUCTION

Commercial scale rice farming began in Puerto Rico in 1980, under the direction of the Rice Corporation of the Puerto Rico Department of Agriculture. Principal rice-growing areas in Puerto Rico are located along the north coast and include 15,000 acres within the valleys of Vega Baja (4,000 acres), Manatí (5,000), and Arecibo (6,000 acres) (fig. 1). Irrigation plays a critical role in rice farming because the plants require large amounts of water during their seeding and vegetative growing stages for maximum yields (Vicente-Chandler and others, 1977, p.30).

In 1983, the U.S. Geological Survey began a cooperative a study with the Puerto Rico Department of Agriculture to investigate the amount of water required and used for irrigation in the rice growing areas of Vega Baja, Manatí, and Arecibo. Water required depends upon the irrigation method used, and the water loss by infiltration and evapotranspiration. The water used (consumed and applied) will almost always be different from that required because of unaccounted losses or gains and water mismanagement. The availability of ground-water and surface-water resources to supply the water demanded by rice irrigation in terms of full development of each rice-growing area was also evaluated during the investigation.

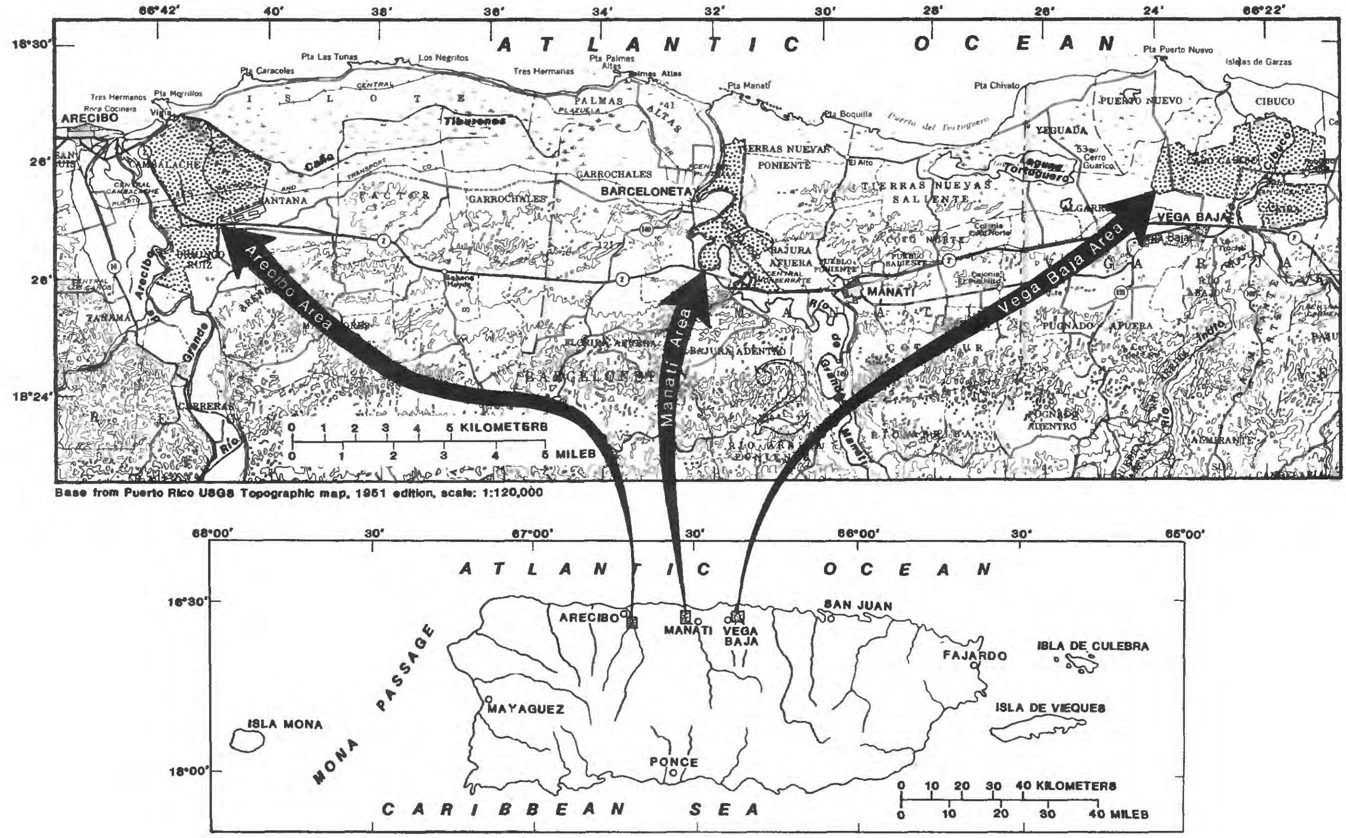


Figure 1.--Location of the rice growing areas along the north coast of Puerto Rico.

INTRODUCTION (Continued)

The investigation included representative farms from the different soil types in each area. Infiltration, evapotranspiration, and inflow and outflow of irrigation water for each test farm were measured. Measurements were conducted over two crop cycles: one during the dry season and one during the wet season. Climatological data (temperature, pan evaporation, wind velocity, and rainfall) were collected daily in each rice-growing area to determine the role of climate on water required for rice irrigation and the amount of rainfall available to augment the existing water supply. Data generated from previous investigations by the U.S. Geological Survey were used to evaluate the water resources of each area.

Terminology

The literature for the hydrologic, agricultural, and soil sciences does not contain uniform scientific terminology. For the purpose of this investigation, definitions have been provided, modified from the "Handbook of Applied Hydrology" (Chow, 1964).

Water required: Quantity of water needed by a crop for its normal growth under field conditions. It includes the water lost by infiltration and evapotranspiration as well as the water required by the irrigation method. (Water Required = Infiltration + Evapotranspiration + Irrigation method).

Irrigation Water Demand: Quantity of Water other than rainfall that has to be supplied to a crop. (Irrigation Water Demand = Water Required - Rainfall).

Water Used: General term that refers to both the amount of water consumed and applied to the fields during a crop cycle.

Water Applied: Quantity of water input to a field during a crop cycle. (Water Applied = Inflow + Rainfall).

Water Consumed: Quantity of water lost (Infiltration + Evapotranspiration + Unaccounted loses or gains) during a crop cycle. (Water Consumed = Water Applied - Outflow).

Unaccounted Losses or Gains: Quantity of water lost or gained in a field: seepage to and from the irrigation and drainage canals, as well as lateral infiltration through leaky levees. (Unaccounted losses (+) or gains (-) = Water Consumed - Water Required).

Field Efficiencies: The capability of each test farm in controlling unaccounted losses or gains.

INTRODUCTION (Continued)

Terminology (Continued)

Water Management Efficiency: The effectiveness of each farmer in applying the right amount of water in addition to rainfall to sustain a rice crop under the prevailing field conditions.

Available Storage Capacity: Available capacity of soils to hold water. Dry soils have maximum water holding capacity, whereas water saturated soils have no water holding capacity.

Acknowledgments

The author gratefully acknowledges the many individuals who provided assistance and cooperation throughout the project. Special mention should be made to: hydrologic technicians Bruce Green, José Merced, and Ana Sánchez for their outstanding work in data collection and processing, José Vicente-Chandler for his technical assistance, and the rice program staff, Marcos Mercado, Héctor Zayas, and Allen Cox for their help in the field operations.

DESCRIPTION OF THE RICE GROWING AREAS

Most of the land in the alluvial valleys of Vega Baja, Manatí, and Arecibo is designated for agricultural use (fig. 2). Sugarcane was the major agricultural enterprise until the early 1970's. Since then, sugarcane was replaced by pasture (for dairy cattle) and rice throughout most of the Vega Baja and Manatí area and in about 45 percent of the Arecibo area (Torres-González and Díaz, 1984, p. 10; Gómez-Gómez, 1984, p. 4; Quiñones-Aponte, 1986, p. 4). The valleys are particularly well suited for rice farming because: (1) the flat topography allows for flooding and the use of heavy machinery, (2) the low permeability soils permit continuous flooding with minimum water loss by infiltration, and (3) water resources are relatively abundant.

The climate in the valleys is characterized as tropical marine, moderated by the trade winds that are almost continuously from the northeast. Climatic data from the study areas (Román-Más, Green, 1987) show that wind velocity ranges from 5 to 150 miles per day (mi/d) with relatively high winds from May to August and low winds from October to January (fig. 3). Air temperatures average 77°F and range from 55°F to 100°F (fig. 4). Potential evaporation ranges from 0.02 to 0.9 inches per day. Relatively high pan-evaporation rates were observed from April to August and low rates from October to February (fig. 5). Normal annual rainfall for the rice growing areas ranges from 55 to 65 inches per year, decreasing to the west from Vega Baja to Arecibo (Calvesbert, 1970). Although copious amounts of rainfall may occur at any time of the year, a relatively dry season occurs from December to March, a spring rainy period in April and May, a short dry period in June and July, and a relatively wet season from August to November. Rainfall during the period of study was above normal (fig. 6).

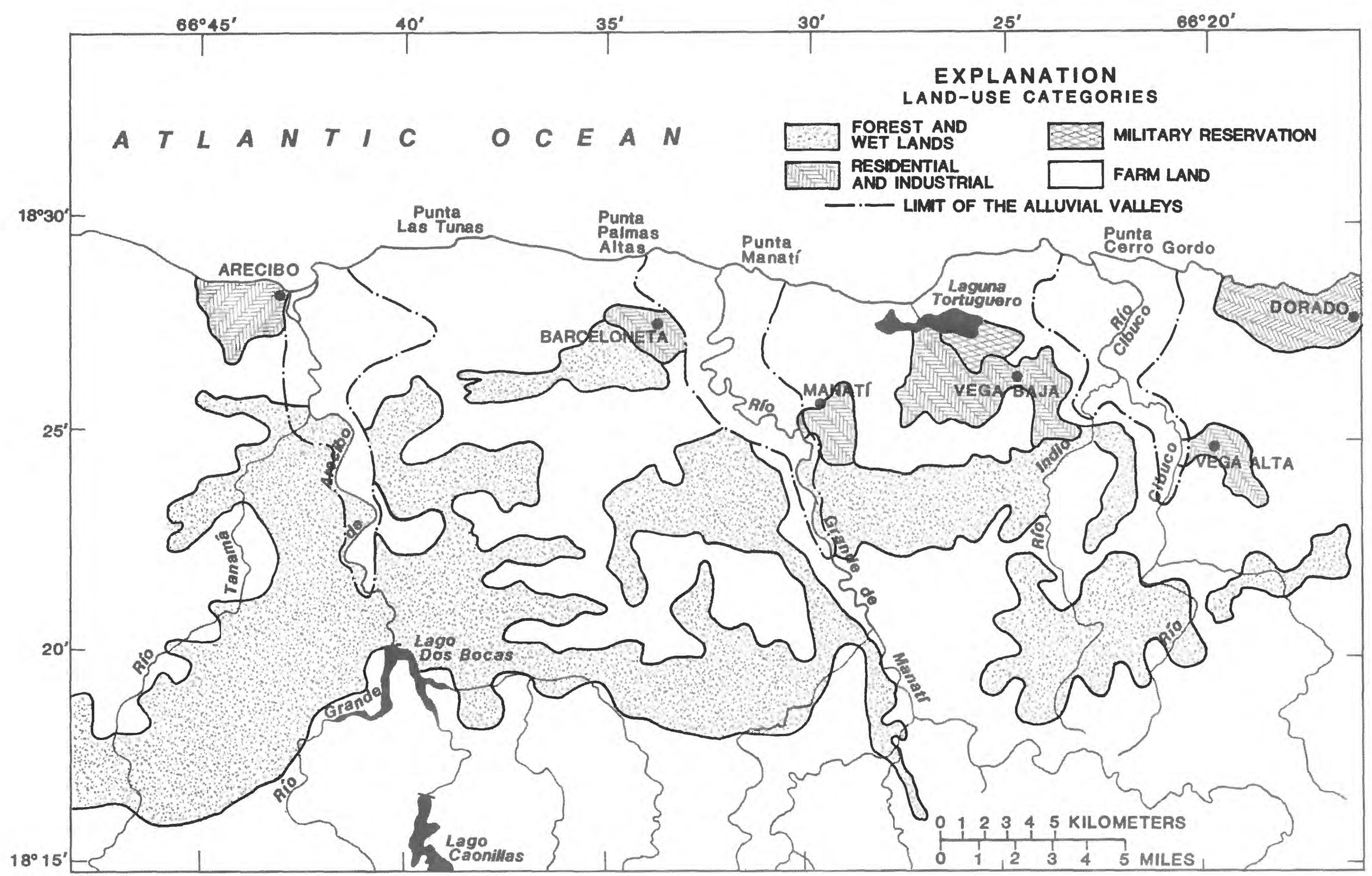


Figure 2.--General land use in the valleys of Vega Baja, Manatí, and Arecibo. (Base map adapted from Natural, Cultural, and Environmental Map of the Puerto Rico Department of Natural Resources.)

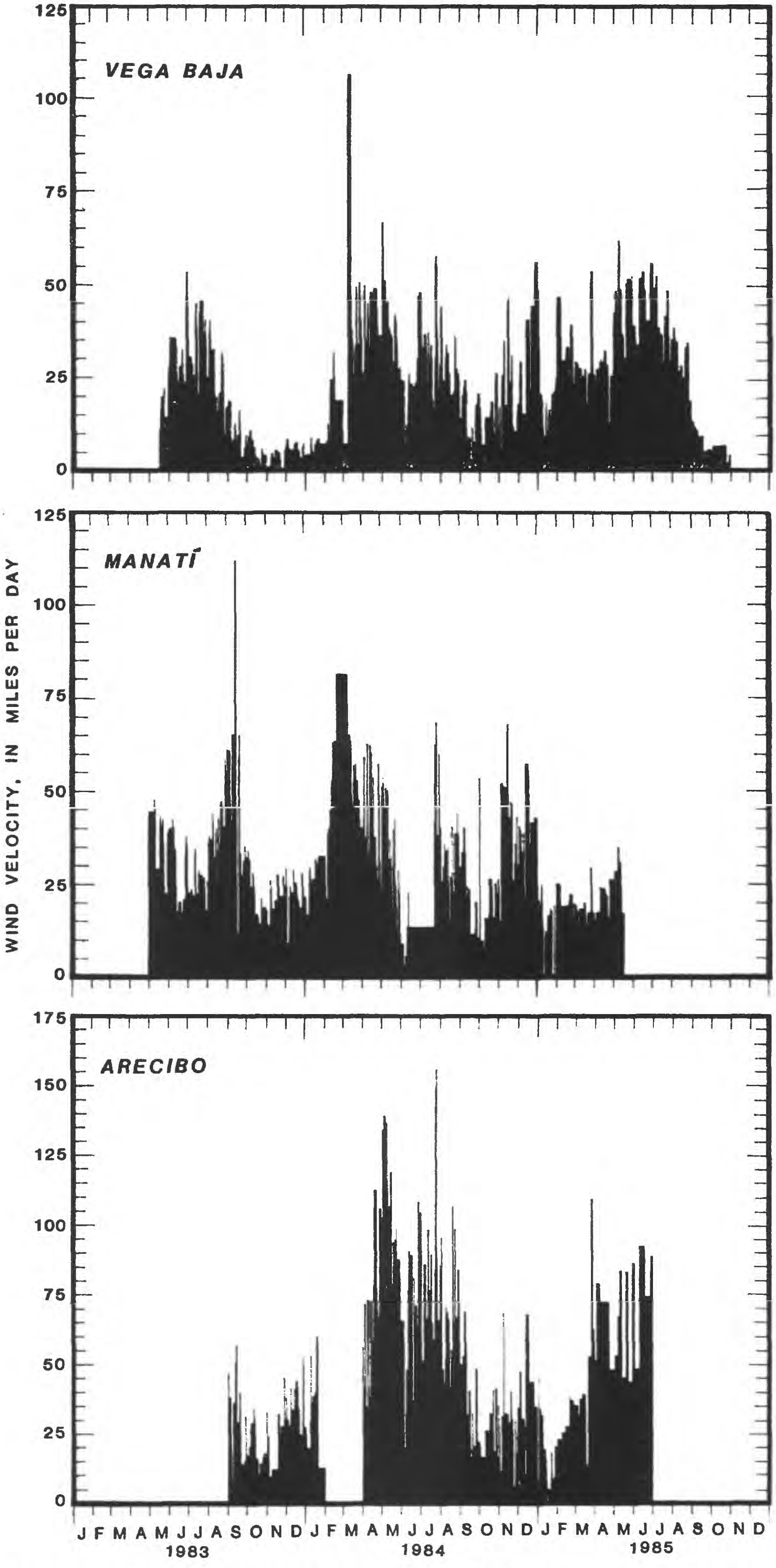


Figure 3.--Daily wind velocity at the Vega Baja, Manatí, and Arecibo weather stations. (Adapted from Román-Más, A. and Green, B. 1986.)

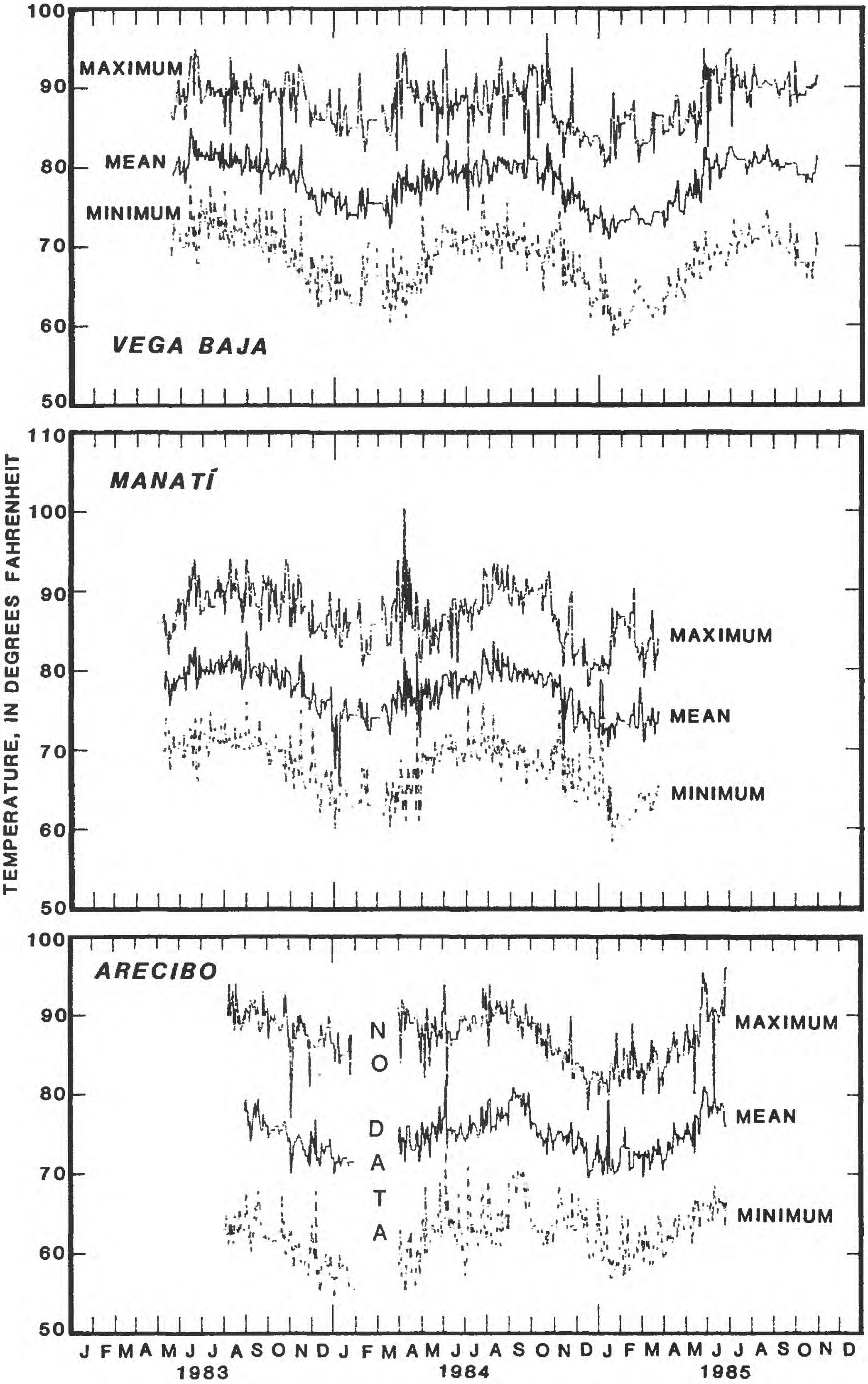


Figure 4.--Daily maximum, minimum, and mean temperatures at the Vega Baja, Manatí, and Arecibo weather stations. (Adapted from Román-Más, A. and Green, B. 1986.)

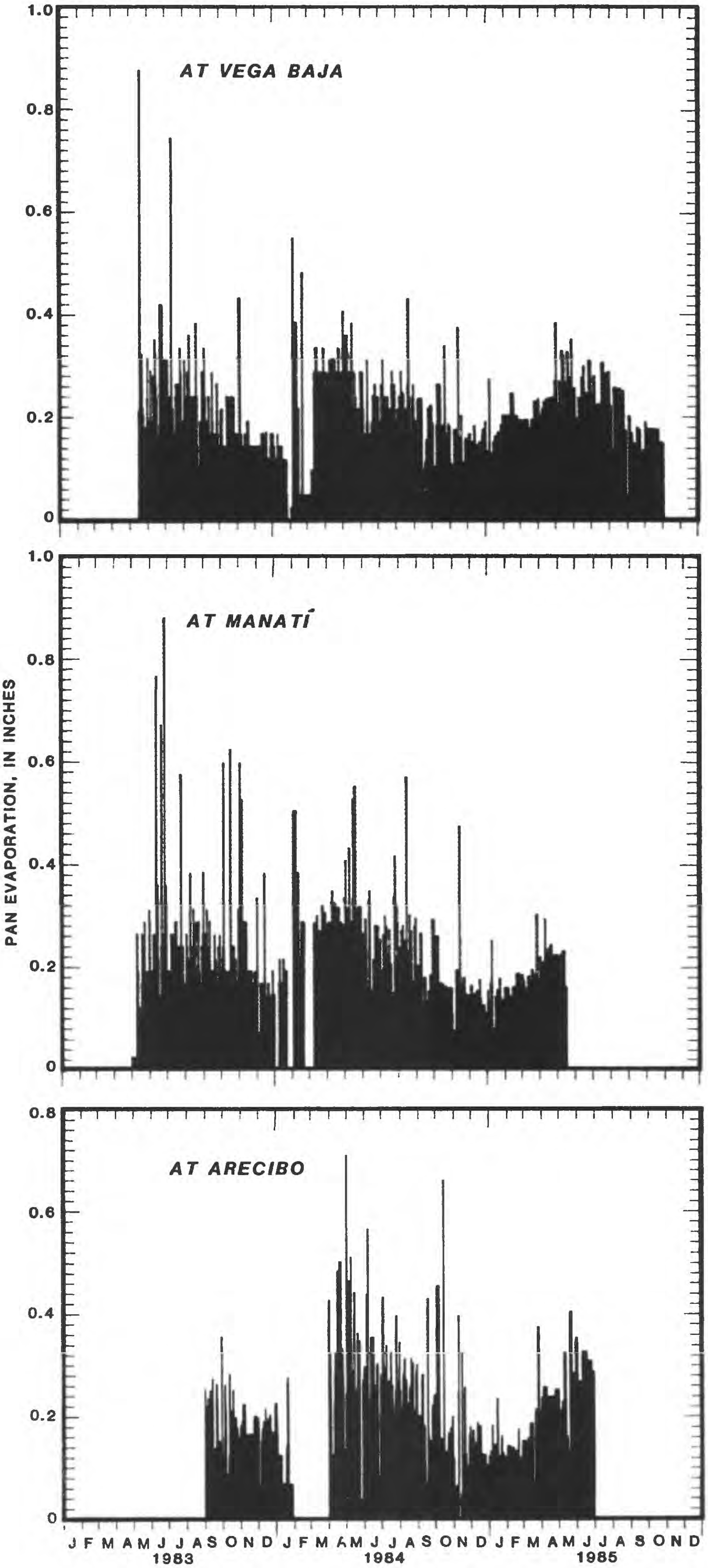


Figure 5.--Daily pan evaporation at the Vega Baja, Manatí, and Arecibo weather stations. (Adapted from Román-Más, A. and Green, B., 1986.)

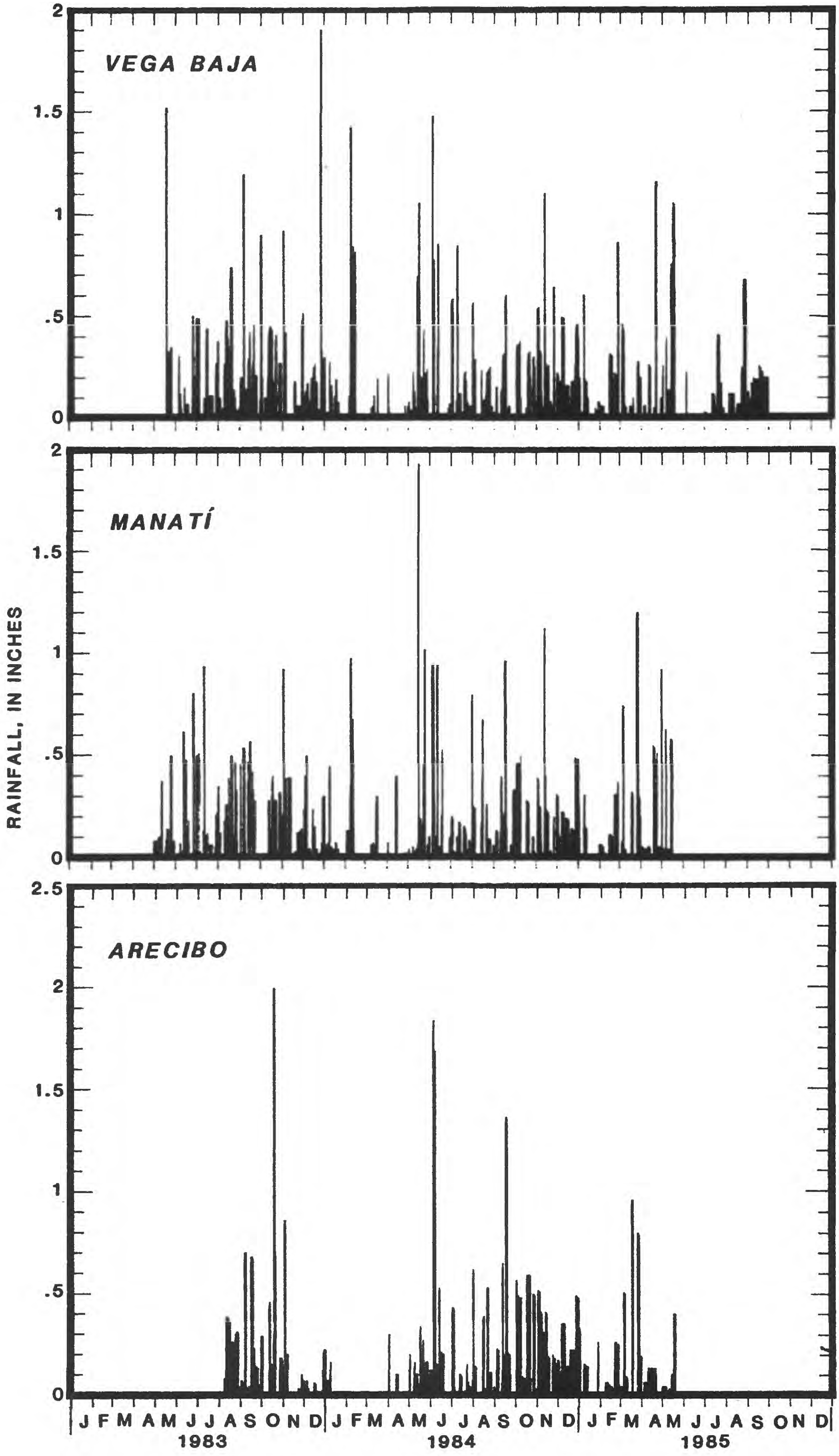


Figure 6.--Daily rainfall at the Vega Baja, Manatí, and Arecibo weather stations. (Adapted from Román-Más, A. and Green, B., 1986.)

DESCRIPTION OF THE RICE GROWING AREAS (Continued)

Río Cibuco, Río Grande de Manatí, and Río Grande de Arecibo presently provide most of the irrigation water for the rice fields in the areas of Vega Baja, Manatí, and Arecibo respectively. Average discharges for these rivers are as follows:

River	Years of Record	Average discharge (cubic feet per second)
Río Cibuco at Vega Baja USGS Station 50039500	5	85
Río Grande de Manatí at Highway 2 near Manatí USGS Station 50038100	10	368
Río Grande de Arecibo at Central Cambalache USGS Station 50029000	11	496

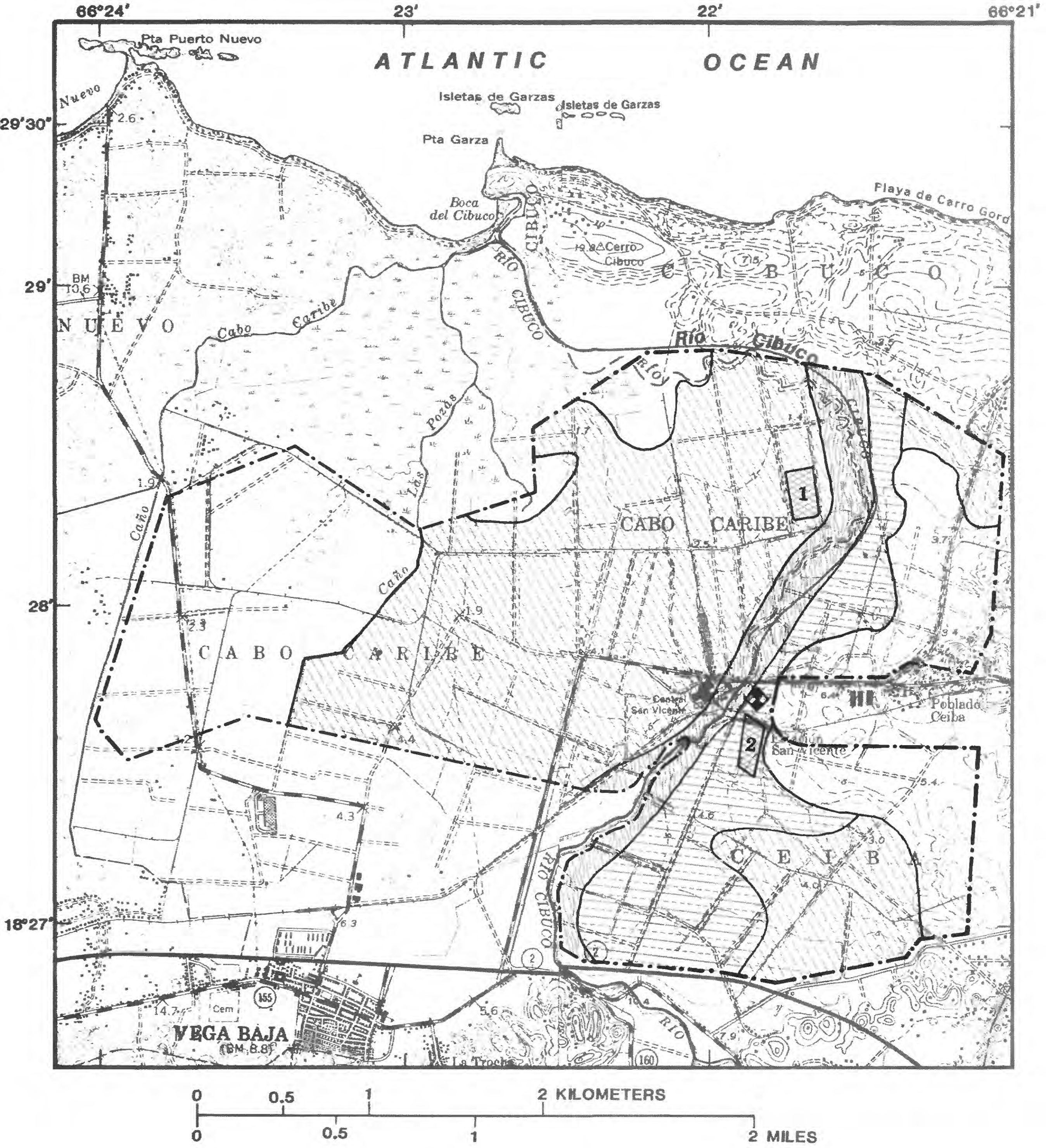
Two productive aquifer systems occur along the north coast of Puerto Rico: (1) a deep artesian system occurs within the Lares Limestone and the Montebello Limestone Member of the Cibao Formation and (2) a water-table system occurs within the alluvial deposits in the valleys and within the adjacent and underlying Aymamón and Aguada limestones (Giusti, E.V., 1978, p. 22-31). In general, water from these aquifers is suitable for public supply as well as industrial and agricultural uses. Water that contains elevated concentrations of chloride, however, may be found within the water-table aquifers due to seawater intrusion.

METHOD OF STUDY

Test Farms Selection

Test farms were selected according to the infiltration characteristics of the different soils in the rice-growing areas. The Toa-Coloso-Bajura Soil association occurs throughout most of these areas (figures 7 to 9). The soils occurring in this association are described below (Acevedo, 1979):

TOA - This soil is deep, nearly level, and well drained. It makes up 37 percent of the association. Typically, the surface and subsurface layers are dark brown silty clay loam with a combined thickness of 16 inches. The subsoil is mottled, brown silty clay loam 15 inches thick. The substratum is mottled, dark yellowish-brown and dark brown silty-clay loam to a depth of 60 inches or more. The permeability is moderate (0.6 to 2.0 inches per hour), the available storage capacity is high (0.15 to 0.20 inches per inch), and the runoff is slow. It is well suited for most cultivated crops.



EXPLANATION

BAJURA

COLOSO

TOA

SOIL ASSOCIATIONS OTHER THAN BAJURA-COLOSO-TOA

TEST FARM AND NUMBER

WEATHER STATION

LIMIT OF RICE GROWING AREA

Figure 7.--Test farms, weather station, and distribution of major soil types in the rice-growing area of Vega Baja.

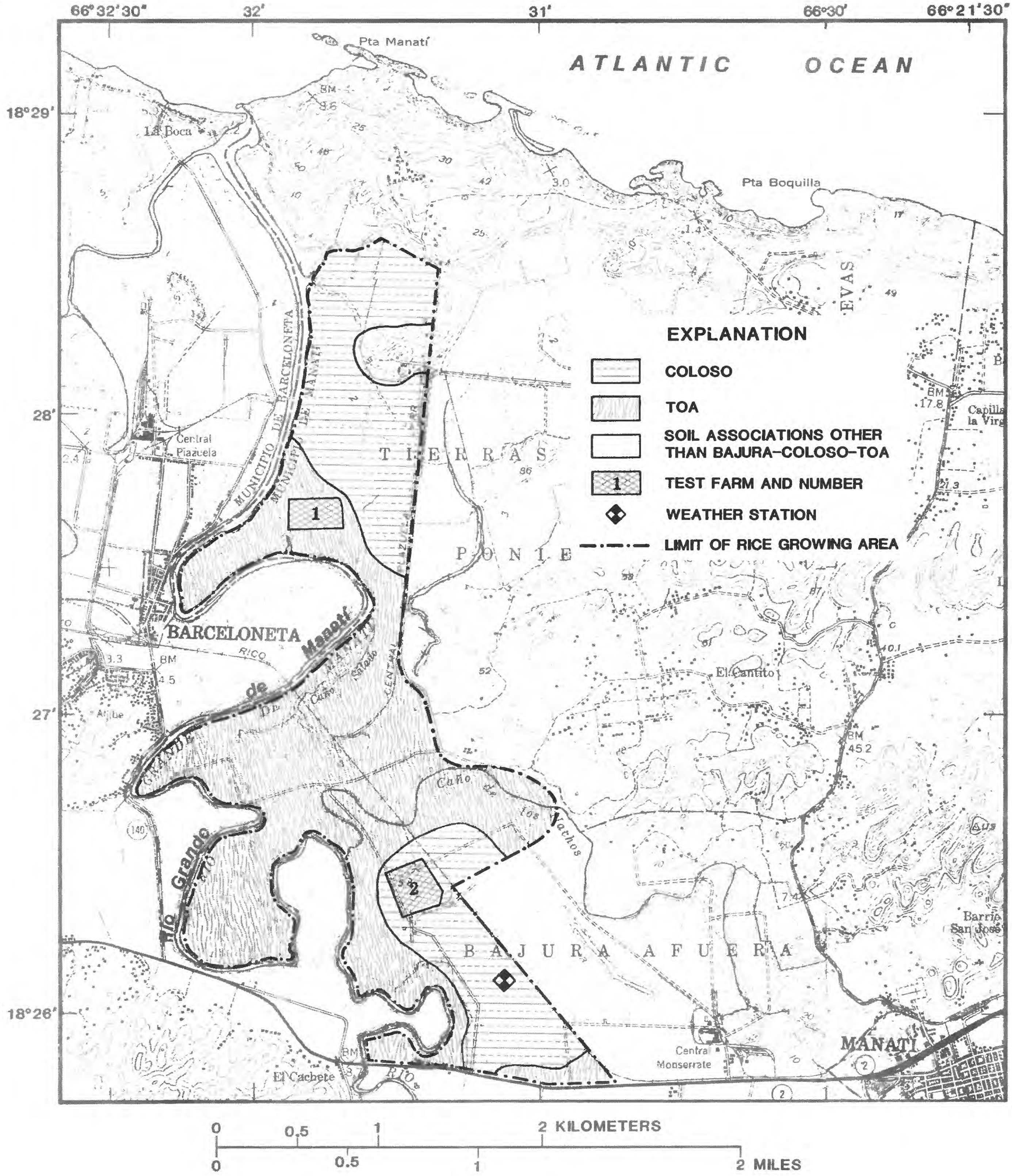


Figure 8.--Test farms, weather station, and distribution of major soil types in the rice-growing area of Manatí.

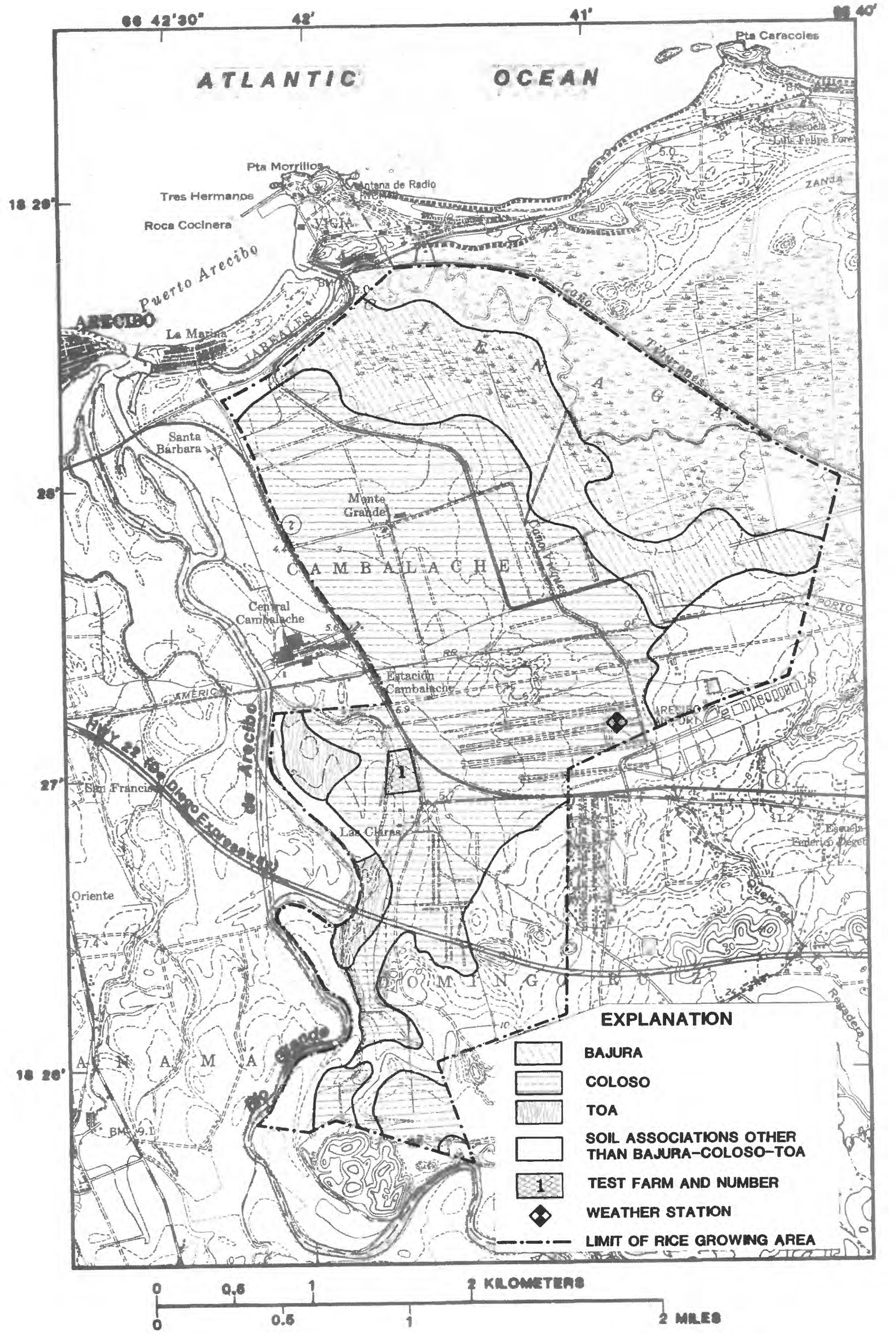


Figure 9.--Test farms, weather station, and distribution of major soil types in the rice-growing area of Arecibo.

METHOD OF STUDY (Continued)

Test Farms Selection (Continued)

COLOSO - This soil is deep, nearly level and somewhat poorly drained. It makes up 34 percent of the association. Typically, the surface layer is brown, silty clay about 7 inches thick. The subsoil is brown, firm, mottled clay 8-inches thick. The substratum extends to a depth of 60 inches or more. It is brown and gray, firm clay mottled with dark yellowish brown. The permeability is low (0.06 to 0.6 inches per hour), the available storage capacity is high (0.12 to 0.18 inches per inch), and the runoff is slow. Drained areas of this soil are well suited for cultivated crops. Undrained areas are well suited for rice.

BAJURA - This soil is deep, nearly level and poorly drained. It makes up 19 percent of the association. Typically, the surface layer is very dark grayish brown, very firm clay about 7 inches thick. The subsoil is mottled, black, very firm clay, 8-inches thick. The substratum is gray and yellowish brown, firm clay to a depth of 60 inches or more. The permeability is low (0.06 to 0.2 inches per hour), the available storage capacity is high (0.15 to 0.20 inches per inch), and the runoff is slow. Undrained areas are well suited for rice.

Reilly and Viví soils makeup the remaining 10 percent of the Toa-Coloso-Bajura association. Both soils are nearly level and well drained. Permeability ranges from 2 to more than 20 inches per hour and the available storage capacity ranges from less than 0.05 to 0.18 inches per inch.

Two test farms in the Vega Baja area were located in Bajura and Coloso soils, which are the dominant soil types within the area (fig. 7). Two test farms were selected in the Manatí area, one for each of the dominant soils, Toa, and Coloso (fig. 8). One test farm was selected in the Arecibo area, where Coloso is the dominant soil (fig. 9). To facilitate the data collection, the following nomenclature was used to name the test farms: first the rice-growing area where they were located (Vega Baja, Manatí, and Arecibo); second the farm number for the area, and because measurements were conducted over two crop cycles, the cycle number, for example:

area name	farm number	cycle number
Vega Baja	1	1

The test farms selected were relatively new commercial rice farms and many operational and logistical difficulties arose during the investigation. Measurements were conducted in four of the five farms selected (Arecibo 1, Manatí 1, Vega Baja 1, and Vega Baja 2). Measurements for two crop cycles were conducted only in the two test farms located at the Vega Baja area.

METHOD OF STUDY (Continued)

Instrumentation

Water loss by infiltration and evapotranspiration at the selected test farms was determined by the cylinder method of the U.S. Department of Agriculture Salinity Laboratory (U.S. Salinity Laboratory Staff, 1954). Three open metal cylinders, 12 inches in diameter and 28 inches high, penetrate the soil to a depth of 18 inches (fig. 10). Water levels inside the cylinders are measured and compared under a different set of field conditions. Cylinder one is open to the atmosphere and maintained free of rice plants. Water lost by evaporation and infiltration is measured inside the cylinder. Cylinder two is closed to the atmosphere, and water lost by infiltration alone is measured. Cylinder three is open to the atmosphere and rice plants are permitted to grow inside of it. Water lost by evapotranspiration and infiltration is measured. Water levels inside the cylinders are measured with a micrometer hook gage and the difference in water level from one measurement time to the next indicates the amount of water lost in each cylinder during an equivalent length of time. Rainfall affects the amount of water in cylinder 1 and 3. By subtracting results of cylinder 2 from those of cylinder 3 evapotranspiration was determined. Two sets of cylinders were installed at each test farm to avoid any local condition that might affect the measurements. The second set are referred to as cylinders 4, 5, and 6.

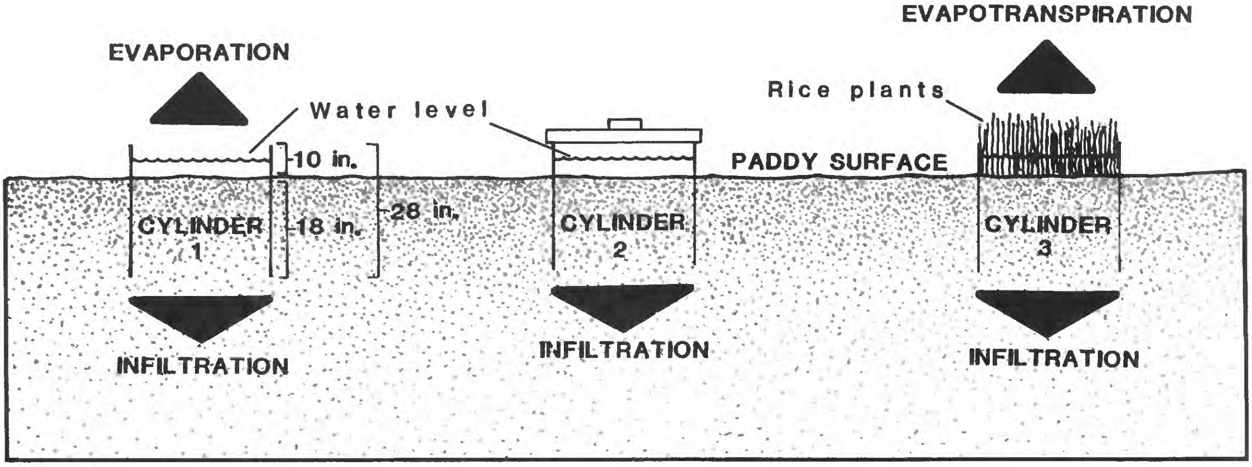


Figure 10.--Cylinder method for measuring infiltration and evapotranspiration of the U.S. Department of Agriculture Salinity Laboratory (1954).

Instrumentation (Continued)

An evapotranspiration box was used to corroborate the evapotranspiration values obtained by the cylinder method. A fiberglass box having a volume of 3 cubic feet was buried in the soil at each test farm; rice was planted in the box and cultivated as in the actual field (fig. 11). The box has a well that allows for measurements of water level. Water lost by evapotranspiration was determined by the changes in water level after correcting for rainfall.

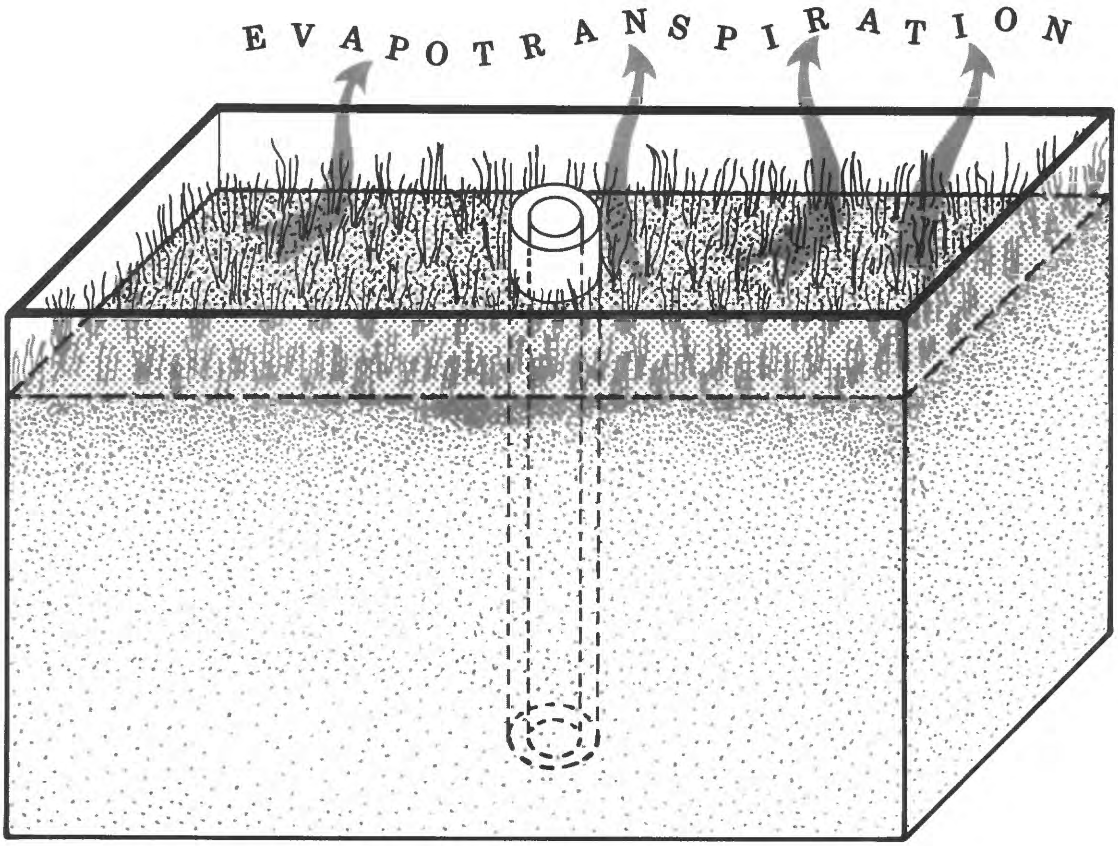


Figure 11.--Evapotranspiration box for measuring evapotranspiration.

Cipolletti weirs outfitted with an automatic digital recorder (ADR), were installed to measure the inflow and outflow of irrigation water for each test farm (fig. 12). A calibration curve relating water stage to flow was prepared for each weir. The ADR provided a water-stage record with a resolution of 0.01 inch at 15-minute intervals. The amount of irrigation water entering and leaving each test farm was calculated based on the rating curve and the water-stage record.

METHOD OF STUDY (Continued)

Figure 12.--Cipolletti weir outfitted with an automatic digital recorder for measuring inflow and outflow of irrigation water.

Weather Stations

A weather station was installed in each rice-growing area to monitor changes in the water required, used, and supplied with changes in climatic conditions (figures 7 to 9). Each station was equipped with a rain gage, a maximum-minimum thermometer, an evaporation pan, an anemometer, and a wind-speed indicator. Equipment installation and operation was in accordance with the standard National Oceanographic and Atmospheric Administration (NOAA) criteria (U.S. Department of Commerce, 1970).

WATER REQUIRED FOR IRRIGATION

Irrigation Technique

Water required to sustain a rice crop includes the water losses by evapotranspiration and infiltration plus the amount of water required by the irrigation method used (continuous flooding). The quantity of water lost by infiltration and evapotranspiration increases proportionally to the quantity of water applied to the fields. Therefore, the calculated quantity of water required to irrigate a rice crop is influenced, to a small degree, by excess water applied to the field.

Irrigation Technique (Continued)

Where sufficient water is available and the soils have low permeability, the continuous flooding method is preferred over other less water-intensive methods. Continuous flooding assures that sufficient water is always available as required by the plant, and helps in controlling pests and weeds. Satisfactory rice harvests have been obtained by using this irrigation method in the rice growing areas along the north coast of Puerto Rico. Water is supplied to the field continuously in order to maintain a water level from 2 to 6 inches above the land surface from 2 weeks after planting to 2 or 3 weeks before harvesting. Approximately 0.33 acre-ft/acre (acre-feet per acre) are required when irrigating continuously. This amount of water must be supplied to the fields in addition to that water necessary to cover the losses by infiltration and evapotranspiration. The 0.33 acre-ft/acre of water can be recovered at the end of the crop cycle if the operation is fully efficient.

Infiltration

In general, infiltration consists of a three-step sequence: (1) surface entry, (2) transmission through the soil, permeability, and (3) depletion of storage capacity in the soil (Chow, 1964, p. 12-2). However, when the continuous flooding method is used for rice irrigation the surface entry is not a factor in the infiltration process. The soils are fully saturated and water above and below the soil surface is hydraulically connected. The available storage capacity of the soil is also not a factor for fully saturated soils. The rate of infiltration is at a maximum when the soil is dry; as the soil becomes saturated and the soil pore spaces are filled with water the available storage capacity of the soil decreases. At saturation with continuous flooding, the available storage capacity is fully depleted. Transmission of water through the soil is the only applicable step in the infiltration process when the continuous flooding method is used. Transmission is determined by the soil permeability, which is the capability of the soil to transmit water downward through the soil profile. Soil permeability is measured by the number of inches per day that water moves downward through the saturated soil. It is influenced by the bulk density, pore size distribution, particle size distribution, and aggregate stability of the soil. Changes in the permeability of the soil can be affected by the irrigation method used, the crop type, and other agricultural practices.

Results showed that total water lost during a complete crop cycle due to infiltration ranged from 0.276 to 0.808 acre-ft/acre with daily mean values ranging from 0.026 to 0.075 inches (table 1). Rates of water loss by infiltration were observed to be higher at the beginning of the crop cycle than at the end. With time, the rate of infiltration decreased because soil aggregates disintegrate and the growth of algae and other microorganisms as well as the development of rice roots tend to seal the pore space of the soil (fig. 13). In general, infiltration values obtained agree with those reported by Silva and Vicente-Chandler (1982, p. 185) from the U.S. Department of Agriculture experimental farm (table 1).

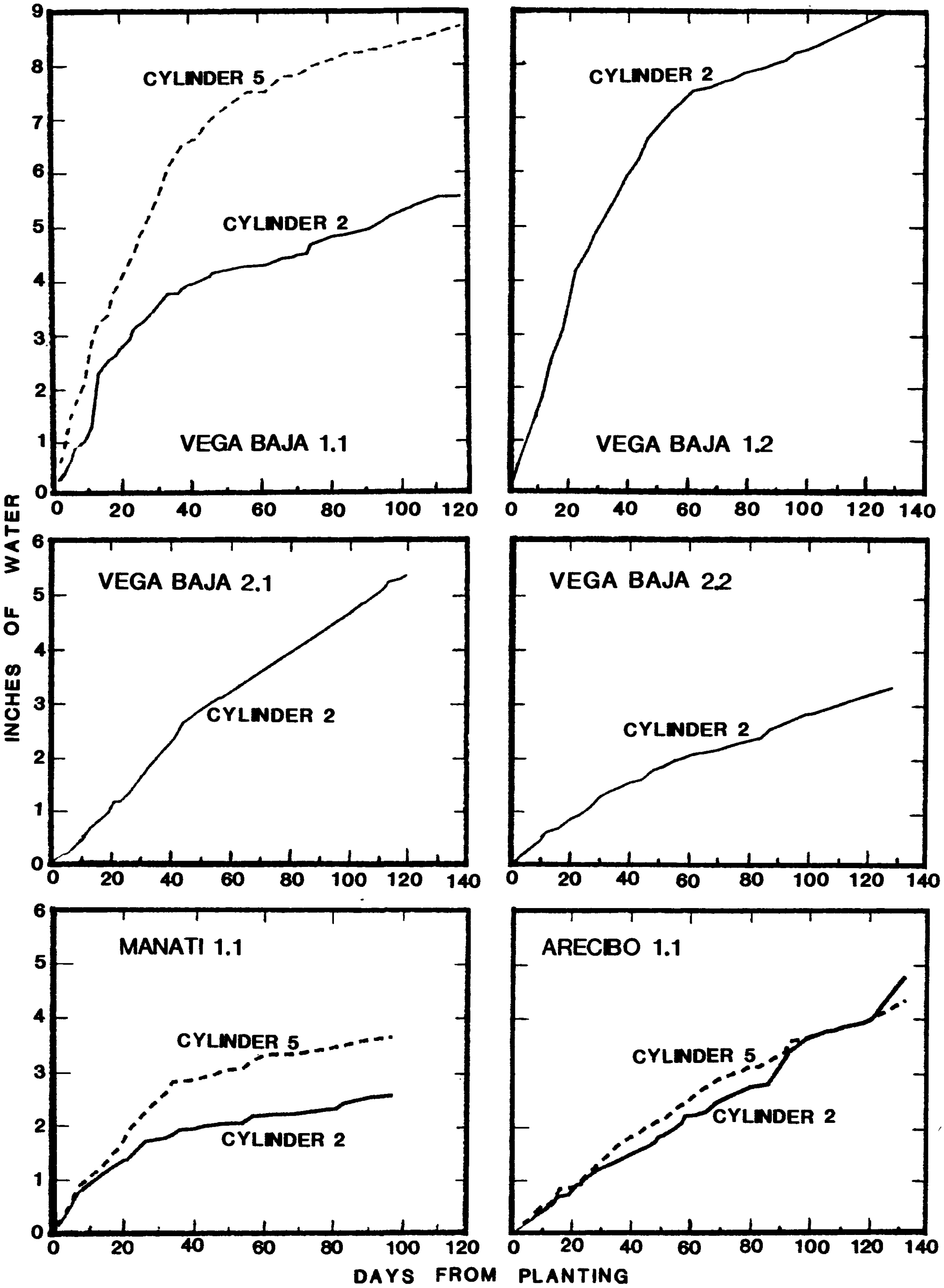


Figure 13.--Accumulative water lost due to infiltration at selected test farms.

WATER REQUIRED FOR IRRIGATION (Continued)

Infiltration (Continued)

Table 1. Water lost due to infiltration at selected test farms

Test Farm	Soil Type	Cycle Date	Water Lost (inches per day)			Water Lost (acre-feet per acre)
			Mean	Maximum	Minimum	Accumulative
Vega Baja 1.1	Bajura	From: 10/27/84 To: 03/15/85	0.061	0.510	0.001	0.595
Vega Baja 1.2	Bajura	From: 05/24/85 To: 10/15/85	0.075	0.269	0.011	0.808
Vega Baja 2.1	Coloso	From: 02/14/85 To: 06/12/85	0.045	0.176	0.002	0.445
Vega Baja 2.2	Coloso	From: 06/27/85 To: 11/01/85	0.026	0.062	0.005	0.276
Manati 1.1	Toa	From: 02/01/85 To: 04/26/85	0.032	0.123	0.001	0.258
Arecibo 1.1	Coloso	From: 11/01/84 To: 04/01/85	0.035	0.135	0.005	0.376
USDA	Toa	---	0.020	0.096	0.008	0.200

Evapotranspiration

Evapotranspiration is the amount of water lost due to a combination of evaporation and transpiration. Poor correlation between pan evaporation and evapotranspiration was observed. Because rice fields are continuously flooded, evaporation is treated as a free water surface. The effects of temperature and wind on evaporation are attenuated by the presence of rice plants in such a way that the evaporation from rice fields is somewhat lower than that of free surface. However, it appears that the magnitude of the attenuated evaporation was small as compared to transpiration. Daily evapotranspiration was consistantly higher than the pan evaporation (fig. 14).

Results showed that evapotranspiration during a crop cycle ranged from 2.541 acre-ft/acre to 4.395 acre-ft/acre of water. Daily values range from 0.280 to 0.443 inches per day (table 2). Evapotranspiration measured by using the cylinder and the box were very similar (fig. 15). Correlations between temperature-evapotranspiration and wind velocity-evapotranspiration were very poor. However, water lost by evapotranspiration was greater for those crop cycles measured during the dry season, when higher winds and higher temperatures occur, than those measured during the wet season.

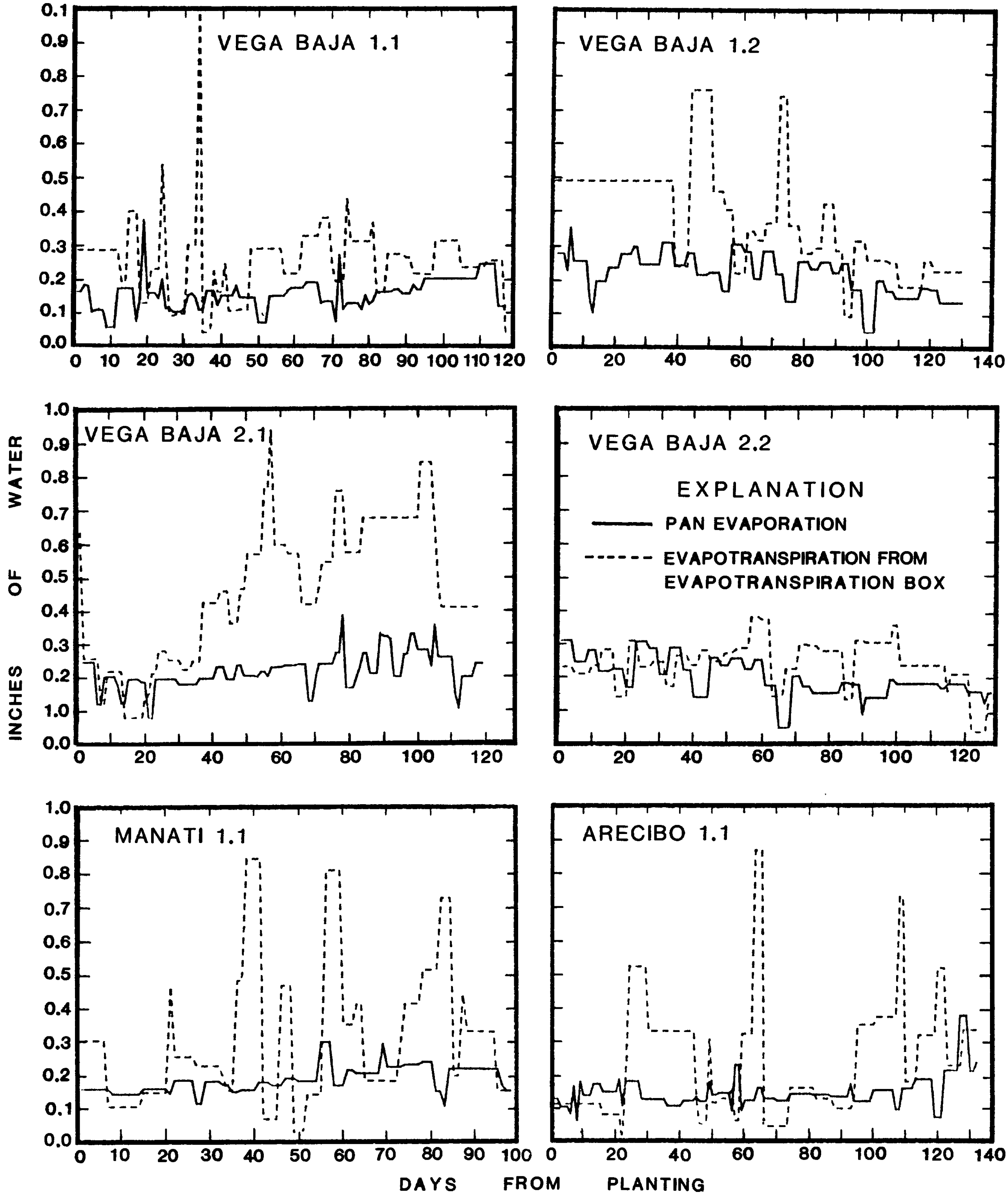


Figure 14.--Pan evaporation and evapotranspiration at selected test farms.

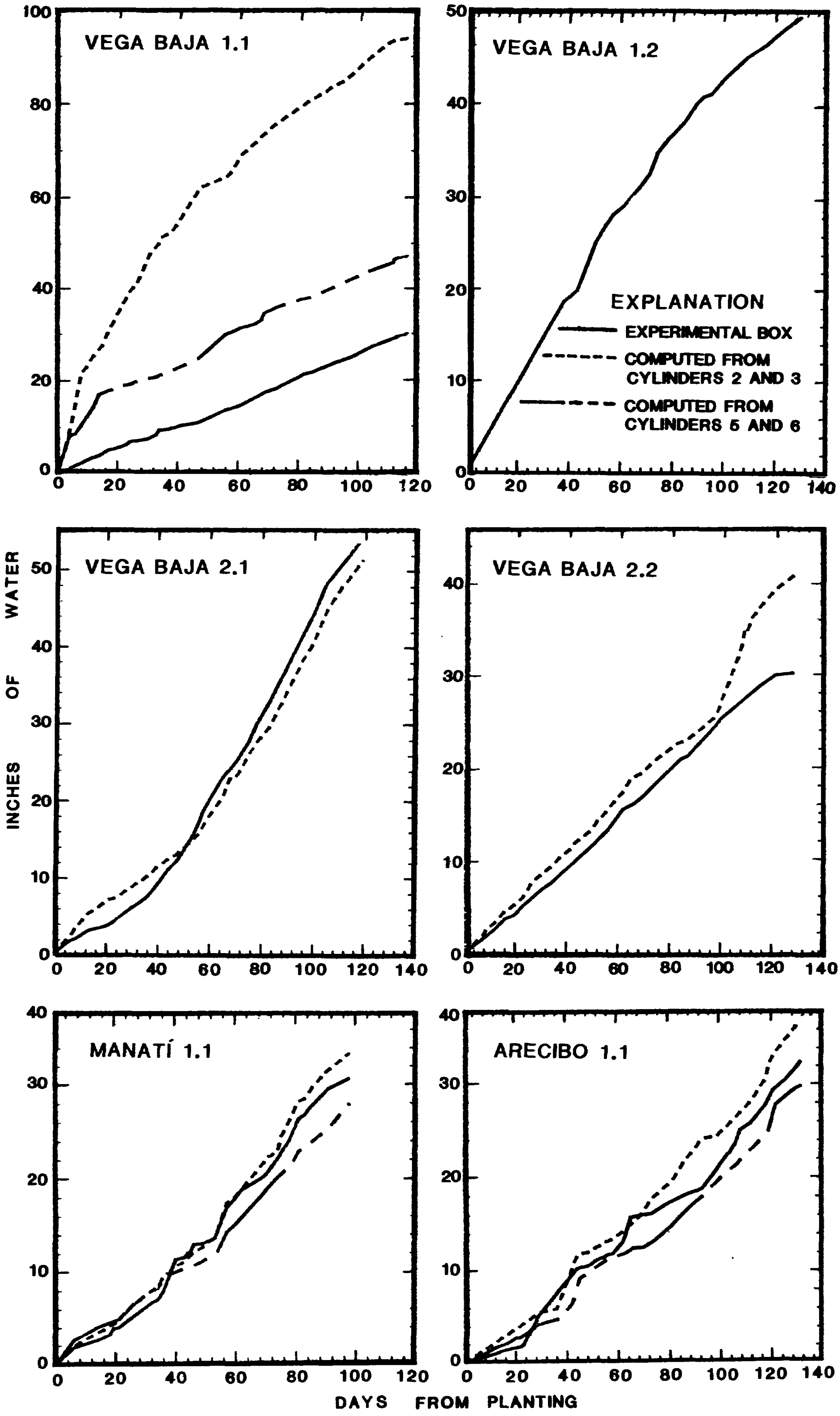


Figure 15.--Accumulative water lost due to evapotranspiration at selected test farms.

WATER REQUIRED FOR IRRIGATION (Continued)

Water Required

Results showed that water required at the test farms ranges from 3.129 to 5.254 acre-feet per acre for a complete crop cycle (table 3). In general, water required was larger for those crop cycles during the dry season. Average water required was 4.118 acre-ft/acre per crop cycle; the rate of water required decreased as the cycle advanced:

	Average water required, in acre-ft
First month of the crop year	1.827
Second month of the crop year	1.026
Third month of the crop year	0.938
Fourth month of the crop year	0.171

The average water-required values support the estimates of Vicente-Chandler (1977, p. 33 and 34) and Allen Cox (Consultant Hydrologist for the Puerto Rico Rice Corporation, oral commun., Nov. 1984) that approximately 4 acre-ft/acre of water per crop cycle will be necessary for rice irrigation on the north coast.

Table 2. Water lost due to evapotranspiration at selected test farms

Test Farm	Cycle Date	Soil Type	Water Lost (inches per day)			Water Lost (acre-feet per acre)
			Mean	Maximum	Minimum	Accumulative
Vega Baja 1.I	From: 10/27/84 To: 03/15/85	wet	0.330	1.426	0.029	3.210
Vega Baja 1.2	From: 05/24/85 To: 10/15/85	Dry	0.380	0.760	0.091	4.116
Vega Baja 2.1	From: 02/14/85 To: 06/12/85	Dry	0.443	0.938	0.010	4.395
Vega Baja 2.2	From: 06/27/85 To: 11/01/85	Wet	0.280	0.787	0.031	2.981
Manatí 1.1	From: 02/01/85 To: 04/26/85	Dry	0.311	0.811	0.029	2.541
Arecibo 1.1	From: 11/01/84 To: 04/01/85	Wet	0.248	0.929	0.045	2.729
USDA	---	---	0.244	0.336	0.124	2.440

Table 3. Water required at selected test farms

Test Farms (1)	Season	Water lost by Evapotranspiration and Infiltration (2)	Continuous flooding technique (3)	Water required (2+3=4)
Vega Baja 1.1	wet	3.805	0.33	4.135
Vega Baja 1.2	dry	4.924	0.33	5.254
Vega Baja 2.1	dry	4.840	0.33	5.170
Vega Baja 2.2	wet	3.257	0.33	3.587
Manatí 1.1	dry	2.799	0.33	3.129
Arecibo 1.1	wet	3.105	0.33	3.435

NOTE: All units in acre-ft/acre.

IRRIGATION WATER DEMAND

Irrigation water demand was considerably lower than the water required for those crop cycles measured. Rainfall data collected at the rice-growing areas during the investigation showed that rainfall can supply from 48 to 70 percent of the water required for the crop cycles during the wet season and from 31 to 39 percent of the water required for the crop cycles during the dry season (table 4). The contribution of rainfall must be considered as an alternative to irrigation water because the streams that presently provide most of the irrigation water are not capable of supplying the total water required. Although rainfall would not be capable of supplying the amount of water needed for the initial flooding of the rice field (approximately 5 inches in 48 hours) it seems feasible that rainfall can provide a portion of the water lost daily by infiltration and evapotranspiration (0.4 inches per day).

The rainfall patterns need to be well defined and the intensity of the rainfall events needs to be relatively low if rainfall is going to represent a major water source for rice irrigation. A larger percent of rainfall can be used for rice irrigation if the sequence and the intensity of the rainfall events do not produce unacceptable water levels in the rice fields. Farmers must exercise good water-management practices in order to effectively use a large percent of the rainfall.

A statistical model was prepared to define what percent of rainfall would be usable for rice irrigation in the rice-growing areas along the north coast of Puerto Rico. Daily accumulative water levels in a rice field were calculated from daily rainfall from NOAA historical files as the water input to the rice fields. The mean daily water lost by infiltration and evapotranspiration (0.4 in/day) was modeled as the water output from the rice field. The resulting water-level values were arrayed in a monthly water-level probability table (tables 5, 6, and 7). The table presents the percent of occurrence that at any day during a particular month the water level will be equal to or less than the value shown in the table. The model considered that the initial water level is 2 inches, and that water levels in the rice field could range from 2 to 6 inches above land surface. Accordingly, the water level could be raised to 4 inches and 100 percent of that rainfall would still be usable. Any computed water level higher than 4 inches implies that some accumu-lated rainfall must be drained out, diminishing the percent of the rainfall usable to irrigate rice. Negative water levels imply a water deficit (water levels less than two inches above the land surface) and that irrigation water needs to be supplied to the rice field.

Results of the statistical models show that as much as 95 percent of rainfall is usable for rice irrigation at any of the rice-growing areas. In addition, the analyses indicate that the probability of having to supply irrigation water to the fields ranges from 60 to 90 percent (tables 5, 6, and 7). The results obtained from these analyses, the monthly normal rainfall, and the mean monthly stream discharge provide the information required to determine when to schedule the crop cycles. It was determined that for the areas of Arecibo and Manatí, the first crop cycle could be scheduled to start in May and end in August, whereas the second cycle could start in October and end in January. For the Vega Baja area, the first cycle remains the same, however, the second cycle could start in November and end in February.

Table 4. Irrigation required for selected test farms

Test Farm	Date	Season	Water required (1)	Rainfall* (2)	Percent of water required, provided by rainfall (2) - (1)X100 = (3)	Irrigation required (1) - (2) = (4)
Vega Baja 1.1	From: 10/27/84 To: 03/15/85	wet	4.14	2.00	48	2.14
Vega Baja 1.2	From: 05/24/85 To: 10/15/85	dry	5.25	2.05	39	3.20
Vega Baja 2.1	From: 02/14/85 To: 06/12/85	dry	5.17	1.62	31	3.55
Vega Baja 2.2	From: 06/27/85 To: 11/01/85	wet	3.59	2.51	70	1.08
Manatí 1.1	From: 02/01/85 To: 04/26/85	dry	3.13	1.12	36	2.01
Arecibo 1.1	From: 11/01/84 To: 04/01/85	wet	3.44	2.07	60	1.37

NOTE: All units in acre-ft/acre, except for percents (3).
* Adapted from Román-Más, A., and Green, B., 1987.

Table 5. Monthly water-level probability analysis of daily computed water levels at a rice field in the area of Vega Baja, using rainfall as the only water input to the field

Percent of proba-bility	Water Level, in inches											
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
5	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
10	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
15	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
20	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
25	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
30	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
35	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.35	-0.36	-0.40	-0.40	-0.35	-0.35
45	-0.40	-0.40	-0.40	-0.40	-0.37	-0.40	-0.30	-0.32	-0.37	-0.40	-0.30	-0.31
50	-0.36	-0.40	-0.40	-0.40	-0.32	-0.38	-0.25	-0.28	-0.32	-0.37	-0.23	-0.28
55	-0.32	-0.40	-0.40	-0.38	-0.25	-0.33	-0.18	-0.22	-0.28	-0.32	-0.17	-0.20
60	-0.30	-0.37	-0.40	-0.32	-0.16	-0.27	-0.10	-0.15	-0.22	-0.28	-0.08	-0.12
65	-0.24	-0.33	-0.40	-0.26	-0.02	-0.20	-0.00	-0.07	-0.17	-0.21	-0.03	-0.02
70	-0.18	-0.30	-0.39	-0.18	0.14	-0.09	0.10	0.03	-0.07	-0.15	0.20	0.08
75	-0.10	-0.24	-0.35	-0.04	0.33	0.05	0.22	0.16	0.05	-0.06	0.36	0.28
80	0.00	-0.17	-0.30	0.13	0.55	0.25	0.40	0.30	0.20	0.10	0.58	0.53
85	0.15	-0.07	-0.23	0.38	0.87	0.50	0.58	0.47	0.42	0.30	1.00	0.85
90	0.32	0.10	-0.15	0.76	1.25	0.86	0.83	0.72	0.80	0.60	1.53	1.35
95	0.73	0.60	0.01	1.30	1.94	1.54	1.15	1.08	1.37	1.00	2.51	2.38
100	8.44	4.80	4.38	19.20	10.73	6.49	4.75	4.71	5.80	7.67	8.63	11.23
a/	4.82	3.17	2.98	5.02	6.16	5.24	6.77	7.36	5.51	5.50	6.98	7.14
b/	4,982	3,278	3,342	4,821	5,106	4,167	3,937	2,976	3,383	4,859	5,774	3,752

a/ Monthly normal rainfall, in inches, adapted from the U.S. Department of Commerce, 1983.
b/ Mean monthly stream discharge in acre-ft adapted from Quiñones, F., Colón-Dieppa, E., and Juarbe, M., 1984, p. 33.

Table 6. Monthly water-level probability analysis of daily computed water levels at a rice field in the area of Manatí, using rainfall as the only water input to the field

Percent of proba-bility	Water Level, in inches											
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
5	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
10	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
15	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
20	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
25	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
30	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
35	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.39	-0.40	-0.36	-0.40
45	-0.40	-0.40	-0.40	-0.40	-0.35	-0.40	-0.38	-0.38	-0.35	-0.39	-0.31	-0.36
50	-0.37	-0.40	-0.40	-0.40	-0.30	-0.40	-0.35	-0.35	-0.32	-0.36	-0.25	-0.32
55	-0.35	-0.39	-0.40	-0.39	-0.21	-0.39	-0.31	-0.31	-0.27	-0.33	-0.17	-0.28
60	-0.30	-0.36	-0.40	-0.35	-0.07	-0.35	-0.26	-0.27	-0.20	-0.29	-0.07	-0.20
65	-0.25	-0.32	-0.38	-0.29	0.07	-0.30	-0.20	-0.20	-0.10	-0.23	0.07	-0.13
70	-0.19	-0.28	-0.35	-0.20	0.32	-0.22	-0.12	-0.11	0.04	-0.15	0.24	-0.05
75	-0.10	-0.20	-0.31	-0.05	0.62	-0.14	-0.01	-0.03	0.20	-0.02	0.47	-0.15
80	0.02	-0.05	-0.26	0.26	0.99	0.00	0.08	0.10	0.41	0.09	0.71	0.34
85	0.24	0.12	-0.18	0.71	1.44	0.18	0.25	0.[illegible]	0.69	0.27	1.11	0.70
90	0.52	0.52	-0.02	1.50	2.10	0.44	0.51	0.[illegible]	1.13	0.52	1.75	1.14
95	1.10	1.60	0.25	2.47	3.23	0.87	0.92	0.71	1.96	0.88	2.82	1.90
100	6.15	6.73	7.76	17.41	10.43	2.85	6.10	5.23	4.23	10.38	7.53	19.35
a/	4.89	3.59	3.63	4.79	6.40	4.24	5.24	5.53	5.87	5.59	7.30	6.45
b/	12,373	9,167	8,735	10,596	13,040	8,512	7,812	7,620	14,271	19,806	17,918	15,993

a/ Written communication Calvesbert, B., National Oceanic and Atmospheric Administration (NOAA), January 25, 1986.
b/ Adapted from Quiñones, F., Colón-Dieppa, E., and Juarbe, M., 1984, p. 30.

Table 7. Monthly water-level probability analysis of daily computed water levels at a rice field in the area of Arecibo, using rainfall as the only water input to the field

Percent of proba-bility	Water Level, in inches											
	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
5	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
10	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
15	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
20	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
25	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
30	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
35	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
45	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40	-0.40
50	-0.40	-0.40	-0.40	-0.40	-0.35	-0.40	-0.40	-0.40	-0.40	-0.39	-0.31	-0.40
55	-0.40	-0.40	-0.40	-0.40	-0.30	-0.38	-0.40	-0.35	-0.34	-0.31	-0.25	-0.32
60	-0.38	-0.40	-0.40	-0.34	-0.24	-0.30	-0.40	-0.32	-0.29	-0.24	-0.16	-0.27
65	-0.34	-0.38	-0.40	-0.29	-0.14	-0.25	-0.35	-0.29	-0.24	-0.16	-0.07	-0.20
70	-0.29	-0.33	-0.40	-0.17	0.02	-0.15	-0.30	-0.23	-0.15	-0.05	0.13	-0.10
75	-0.20	-0.25	-0.40	-0.04	0.15	+0.02	-0.25	-0.18	-0.08	0.10	0.42	0.08
80	-0.10	-0.15	-0.34	0.21	0.38	0.24	-0.17	-0.06	0.11	0.29	0.75	0.27
85	0.05	0.02	-0.28	0.49	0.64	0.47	-0.07	0.11	0.31	0.55	1.17	0.60
90	0.24	0.28	-0.19	1.05	1.12	0.84	0.12	0.30	0.61	0.91	1.95	1.35
95	0.77	0.83	0.04	1.81	2.00	1.50	0.38	0.65	1.26	1.46	3.47	2.81
100	4.15	5.60	8.56	7.74	7.03	3.62	2.70	3.85	8.60	5.43	9.78	7.77
a/	4.34	2.79	2.48	4.77	4.84	4.33	3.59	4.18	4.83	5.29	6.09	6.11
b/	17,408	14,556	16,670	17,025	26,635	21,132	19,499	19,168	29,526	39,060	33,097	23,682

a/ Monthly normal rainfall, in inches, adapted from the U.S. Department of Commerce, 1983.
b/ Mean monthly stream discharge in acre-ft adapted from Quiñones, F., Colón-Dieppa, E., and Juarbe, M., 1984, p. 22.

WATER CONSUMED AND APPLIED

Water consumption at each test farm was calculated by subtracting the outflow from the water applied (inflow + rainfall). Results indicated that water consumed was considerably more than that required (evapotranspiration + infiltration + continuous flooding) at Vega Baja 1.1, 1.2, 2.1, 2.2, and Manatí 1.1, whereas, at Arecibo 1.1 the consumption was lower (table 8). It was concluded from field observations that the differences between the amount of water required and that consumed were due to unaccounted losses or gains: seepage in and out of the irrigation and drainage canals as well as leakage through levees. The field efficiency was calculated as follows:

$$\left(1 - \left(\frac{\text{unaccounted losses or gains}}{\text{Water Required}}\right)\right) \text{X } 100 = \text{Field Efficiency}$$

Computed field efficiencies range from 53.7 to 86.6 percent (table 8).

Table 8. Water used, field efficiencies, and water management efficiencies at selected test farms

Test farm	Water required (1)	Water applied: Inflow (2)	Water applied: Rainfall (3) a/	Outflow (4)	Water Consumed (2)+(3)-(4)=(5)	Unaccounted losses (+) or gains (-) (5)-(1)=(6)	Field efficiency (percent) c/	Water management efficiency (percent) d/
Vega Baja 1.1	4.14	88.70	11.00	71.40	5.15 b/	+1.01	75.6	88.8
Vega Baja 1.2	5.25	167.77	11.28	140.29	7.05 b/	+1.80	65.7	72.5
Vega Baja 2.1	5.17	12.07	1.62	7.59	6.10	+0.93	82.0	4.3
Vega Baja 2.2	3.59	6.62	2.51	6.45	2.68	-0.91	74.7	5.1
Manati 1.1	3.13	7.76	1.12	0.94	7.94	+4.81	53.7	35.1
Arecibo 1.1	3.44	11.42	2.07	10.51	2.98	-0.46	86.6	0.3

NOTE: All units in acre-ft/acre, except inflow, rainfall, and outflow at Vega Baja 1.1 and Vega Baja 1.2 which are in acre/feet.

a/ Adapted from Román-Más, A., and Green, B., 1986.

b/ Water used = (inflow + rainfall - outflow) - 5.5

c/ $\left(1 - \left(\frac{\text{Unaccounted losses or gains}}{\text{Water Required}}\right)\right)$ X 100 = Field Efficiency.

d/ For Vega Baja 1.1 and 1.2; $\left(\begin{array}{l}\text{Estimated water required} \\ \text{for contiguous field} \\ \text{(water required at Vega Baja} \\ \text{1 X area of adjacent field} \\ \text{(28.93 acres))}\end{array} \div \begin{array}{l}\text{Inflow to Contiguous field} \\ \text{Vega Baja 1 outflow + rain} \\ \text{+ unaccounted losses at Vega} \\ \text{Baja 1.}\end{array}\right)$ X 100 = Water Management Efficiency.

For the other test farms; $\left(\begin{array}{l}\text{Amount of water demanded} \\ \text{by the continuous} \\ \text{flooding technique (0.33} \\ \text{acre-ft/acre)}\end{array} \div \text{outflow}\right)$ X 100 = Water Management Efficiency.

WATER CONSUMED AND APPLIED (Continued)

The amount of water applied to the fields will be different from that required because of unaccounted water losses or gains. However, due to poor water-management practices, the amount of water applied (inflow + rainfall) to each test farm was considerably more than the sum of the water required and the unaccounted water losses or gains. Water-management efficiency compares the outflow in terms of the water demanded by the continuous flooding technique calculated as follows:

$$\left(\begin{array}{l}\text{Amount of water demanded}\\ \text{by the continuous}\\ \text{flooding technique}\\ \text{(0.33 acre-ft/acre)}\end{array} \div \text{outflow}\right) \times 100 = \begin{array}{l}\text{Water management}\\ \text{Efficiency}\end{array}$$

Water-management efficiency is not dependent on the field efficiency. A water-management efficiency of 100 percent implies that the amount of water applied to the farm equals the sum of the water required and the unaccounted water losses or gains. Therefore, as water applied is partly consumed during a crop cycle, the water-management efficiency can only be 100 percent when the outflow equals the water required by the continuous flooding method.

Test farm Vega Baja 1 consists of several fields in series which means that the field outflow is the inflow for the adjacent field. Water management efficiencies for the two crop cycles measured at this test farm were calculated as follows:

$$\left(\begin{array}{l}\text{Estimated water required}\\ \text{for adjacent field}\\ \text{[Water required at Vega Baja 1}\\ \text{X area of adjacent field}\\ \text{(28.93 acres)]}\end{array} \div \begin{array}{l}\text{Inflow to adjacent field}\\ \text{(Vega Baja 1 outflow + rain +}\\ \text{unaccounted losses at Vega Baja}\\ \text{1)}\end{array}\right) \times 100 = \text{Water Management Efficiency}$$

The unaccounted water losses from Vega Baja 1 were included as part of the inflow to the adjacent field, as from field observations nearly 100 percent of these losses occurred through the levee that divided one field from the other.

Table 8 shows the resulting water-management efficiencies. The highest efficiency was 88.8 percent at Vega Baja 1.1, whereas the lowest was 0.3 percent at Arecibo 1.1.

POTENTIAL WATER RESOURCES FOR RICE IRRIGATION

Ground-water use for irrigation is limited to the Vega Baja and Arecibo areas where wells provide 11,000 and 600 acre-ft/acre per crop respectively (Torres-Sierra, U.S. Geological Survey, written commun., January 25, 1986; and Quiñones-Aponte, U.S. Geological Survey, written commun., January 28, 1986). Although the full potential for development of ground-water resources in these areas has not been determined, saltwater intrusion problems limit the expansion of ground-water withdrawals in the rice-growing areas. Capture of seepage from streams to the alluvial aquifers using wells located near streams, artificial recharge, and the development of a deep artesian system may provide substantial additional sources of water. These methodologies have not been fully explored.

At present, Río Cibuco, Río Grande de Manatí, and Río Grande de Arecibo are the major sources of water for rice irrigation. Because of the wide variation in the measured amount of water consumed or applied to the test farms, it is difficult to estimate the amount of surface water development required for rice irrigation. However, a total demand, based on 4 acre-ft/acre, was made and an analysis was conducted for each area to see if the mean stream discharge could provide the amount of water demanded. Actual ground-water withdrawals and rainfall (tables 9, 10, and 11) were used in the analysis. Although rainfall may reduce the water demand from streamflow significantly, the resulting water demanded is in excess of that available from streamflow.

Table 9. Water demand from Río Cibuco for rice irrigation in the Vega Baja area

Month	Mean monthly stream Discharge a/ (acre-ft) (1)	Water required b/ (acre-ft) (2)	Present ground-water supply c/ (acre-ft) (3)	Water required from streamflow for rice irrigation (acre-ft) (2)-(3)=(4)	Percent of streamflow [(4)-(1)]X100=(5)	Rainfall d/ (acre-ft) (6)	Water required from stream-flow for rice irrigation (acre-ft) (4)-(6)=(7)	Percent of streamflow for rice irrigation [(7)-(1)]X100=(8)
JAN	4,982	3,752	275	3,477	70	1,607	1,870	38
FEB	3,278	684	275	409	12	1,057	no irrigation required	0
MAR	3,342	-	275	-	-	933	-	-
APR	4,821	-	275	-	-	1,673	-	-
MAY	5,106	7,308	275	7,033	138	2,053	4,980	98
JUNE	4,167	4,104	275	3,829	92	1,747	2,082	50
JULY	3,937	3,752	275	3,477	88	2,257	1,220	31
AUG	2,976	684	275	409	14	2,577	no irrigation required	0
SEPT	3,383	-	275	-	-	1,837	-	-
OCT	4,859	-	275	-	-	1,833	-	-
NOV	5,774	7,308	275	7,033	122	2,327	4,706	82
DEC	3,752	4,104	275	3,829	102	2,380	1,449	39

a/ Adapted from Quiñones, F., Colón-Dieppa, E., and Juarbe, M., 1984, p. 33.
b/ Water required for: first month of the cycle = 1.827 acre-ft/acre X 4,000 acres.
second do. = 1.026 Do.
third do. = 0.938 Do.
fourth do. = 0.171 Do.
c/ Written communication - Torres, H., U.S. Geological survey, January 25, 1986.
d/ Adapted from U.S. Department of Commerce, 1983.

NOTE: Crop cycle - 1 - May, June, July, and August.
Crop cycle - 2 - November, December, January, and February.

Table 10. Water demand from Río Grande de Manatí for rice irrigation in the Manatí area

Month	Mean monthly stream Discharge a/ (acre-ft) (1)	Water required b/ (acre-ft) (2)	Present ground-water supply (acre-ft) (3)	Water required from streamflow for rice irrigation (acre-ft) (2)-(3)=(4)	Percent of streamflow [(4)-(1)]X100=(5)	Rainfall (acre-ft) c/ (6)	Water required from stream-flow for rice irrigation (acre-ft) (4)-(6)=(7)	Percent of streamflow for rice irrigation [(7)-(1)]X100=(8)
JAN	12,373	855	0	855	7	2,038	no irrigation required	0
FEB	9,167	-	0	-	-	1,496	-	-
MAR	8,735	-	0	-	-	1,513	-	-
APR	10,596	-	0	-	-	1,996	-	-
MAY	13,040	9,135	0	9,135	70	2,667	6,468	50
JUNE	8,512	5,130	0	5,130	60	1,767	3,363	43
JULY	7,812	4,690	0	4,690	60	2,183	2,507	32
AUG	7,620	855	0	855	11	2,304	no irrigation required	0
SEPT	14,271	-	0	-	-	2,446	-	-
OCT	19,806	9,135	0	9,135	46	2,329	6,806	34
NOV	17,918	5,130	0	5,130	29	3,042	2,088	12
DEC	15,993	4,690	0	4,690	29	2,688	2,002	13

a/ Adapted from Quiñones, F., Colón-Dieppa, E., and Juarbe, M., 1984, p. 30.
b/ Water required for: first month of the cycle = 1.827 acre-ft/acre X 4,000 acres.
second do. = 1.026 Do. .
third do. = 0.938 Do. .
fourth do. = 0.171 Do. .
c/ Written communication Calvesbert, B., National Oceanic and Atmospheric Administration (NOAA), January 25, 1986.

NOTE: Crop cycle - 1 - May, June, July, and August.
Crop cycle - 2 - October, November, December, and January.

Table 11. Water demand from Río Grande de Arecibo for rice irrigation in the Arecibo area

Month	Mean monthly stream Discharge a/ (acre-ft) (1)	Water required b/ (acre-ft) (2)	Present ground-water supply c/ (acre-ft) (3)	Water required from streamflow for rice irrigation (acre-ft) (2)-(3)=(4)	Percent of streamflow [(4)-(1)]X100=(5)	Rainfall d/ (acre-ft) (6)	Water required from stream-flow for rice irrigation (acre-ft) (4)-((6)=(7)	Percent of streamflow for rice irrigation [(7)-(1)]X100=(8)
JAN	17,408	1,026	150	876	5	2,170	no irrigation required	0
FEB	14,556	-	150	-	-	1,395	-	-
MAR	16,670	-	150	-	-	1,240	-	-
APR	17,025	-	150	-	-	2,385	-	-
MAY	26,635	10,962	150	10,812	41	2,420	8,392	32
JUNE	21,132	6,156	150	6,006	28	2,165	3,841	18
JULY	19,499	5,628	150	5,478	28	1,795	3,683	19
AUG	19,168	1,026	150	876	5	2,090	no irrigation required	0
SEPT	29,526	-	150	-	-	2,415	-	-
OCT	39,060	10,962	150	10,812	28	2,645	8,167	21
NOV	33,097	6,156	150	6,006	18	3,045	2,961	9
DEC	23,682	5,628	150	5,478	23	3,055	2,427	10

a/ Adapted from Quiñones, F., Colón-Dieppa, E., and Juarbe, M., 1984, p. 22.
b/ Water required for: first month of the cycle = 1.827 acre-ft/acre X 4,000 acres.
second do. = 1.026 Do. .
third do. = 0.938 Do. .
fourth do. = 0.171 Do. .
c/ Written communication Quiñones-Aponte, V., U.S. Geological Survey, January 28, 1986.
d/ Adapted from the U.S. Department of Commerce, 1983.

NOTE: Crop cycle - 1 - May, June, July, and August.
Crop cycle - 2 - October, November, December, and January.

SUMMARY

Water required for normal growth of a rice crop includes the amount of water required by the irrigation method used and the water losses by infiltration and evapotranspiration. The continuous flooding method used in the rice-growing areas along the north coast of Puerto Rico required 0.33 acre-ft/acre per crop. Based on experiments conducted at the test farms selected on the basis of different soil types, average water lost by infiltration ranges from 0.276 to 0.808 acre-ft/acre per crop, whereas average water lost by evapotranspiration ranges from 2.541 to 4.395 acre-ft/acre per crop. Differences in values of evapotranspiration result from wet and dry season variations. Water required ranges from 3.13 to 5.25 acre-feet per acre for a complete crop cycle. Differences in the amount of water required also result from seasonal variations. The rate of water required was observed to decrease as the cycle advanced.

Rainfall is capable of supplying from 31 to 70 percent of the water required for the crop cycles measured. A statistical model demonstrated that as much as 95 percent of the rainfall is usable for rice irrigation at all rice-growing areas. The models also indicated that the probability that irrigation water would be needed ranged from 60 to 90 percent. Finally, to optimize the use of rainfall for rice irrigation, a first crop cycle could be scheduled from May to August. A second cycle could be scheduled from October to January, however, for the area of Vega Baja it could be scheduled from November to February.

The amount of water consumed ranged from 18 to 154 percent more than that required at the test farms Vega Baja 1.1, 1.2, 2.1, and Manatí 1.1. Water consumed at test farms Vega Baja 2.2 and Arecibo 1.1 was 25 and 13 percent less than that required, respectively. It can be concluded that excess water consumed was due to unaccounted water losses or gains such as seepage to and from the irrigation and drainage canals, as well as lateral leakage through levees. Field efficiencies ranged from 53.7 to 86.6 percent. The unaccounted water losses or gains imply that the amount of water applied to the fields is different from that required. However, due to poor water-management practices, the amount of water applied to the farms was considerably more than the sum of the water required and the unaccounted losses or gains. Water-management efficiencies ranged from 0.3 to 88 percent.

At present, major rivers within the rice growing areas are the main sources of water for rice irrigation. Full development of the rice growing areas will require more water than the rivers can supply. Efficient use of rainfall may significantly reduce the water demand from streamflow, however the resulting water demands appear greater than can be supplied by the streams. Ground-water development within the areas is limited because of seawater intrusion problems that affect the aquifers underlying the valleys. Capture of stream seepage to the aquifers by using wells located near streams, artificial recharge, and development of the deep artesian system may provide additional sources of water.

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