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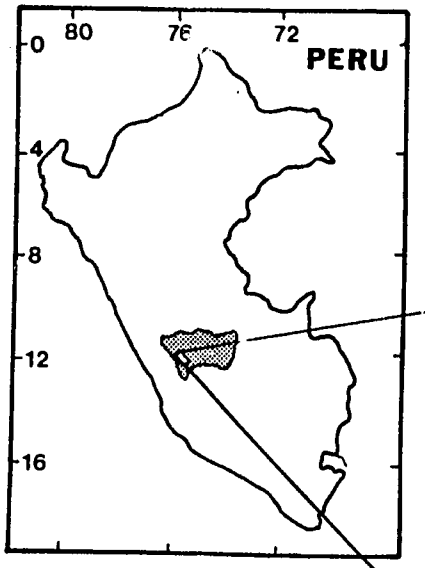
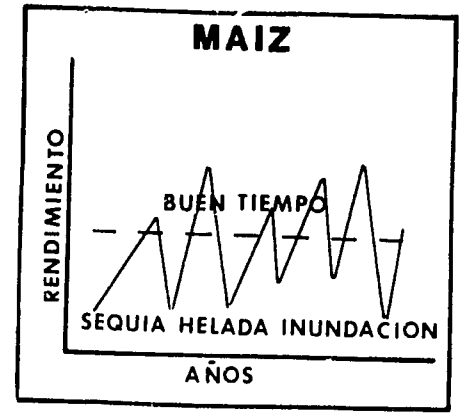
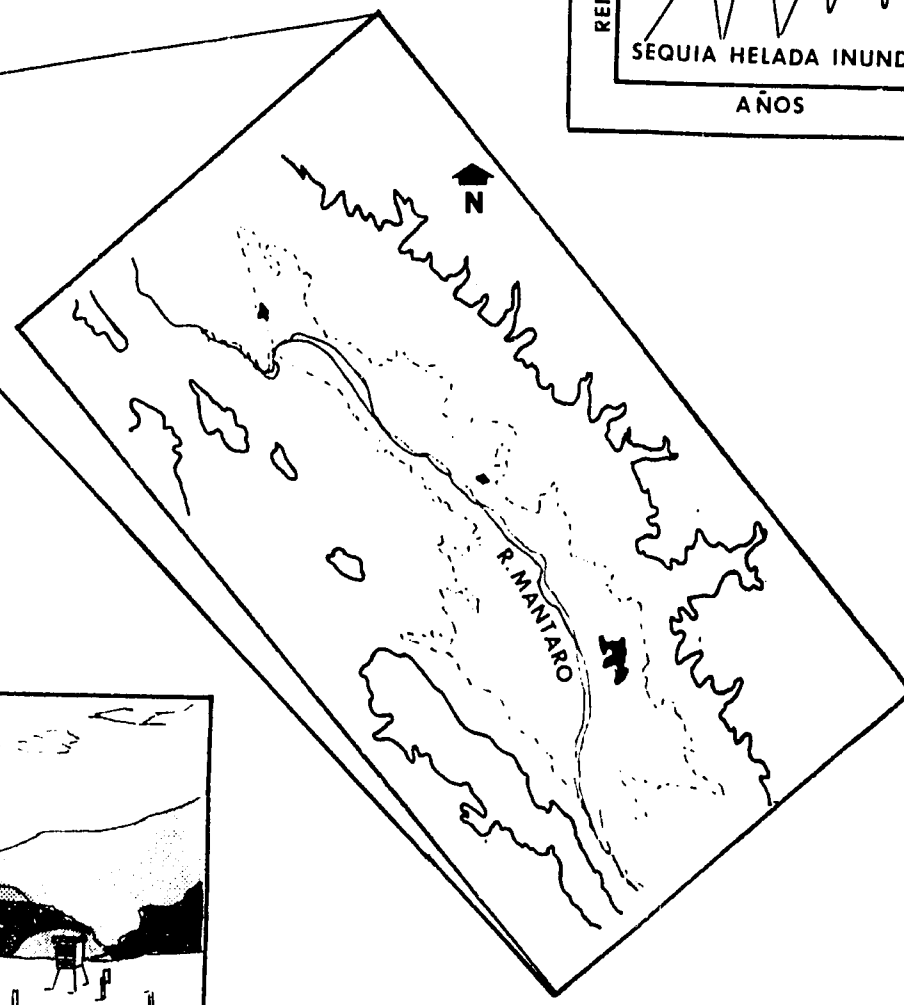
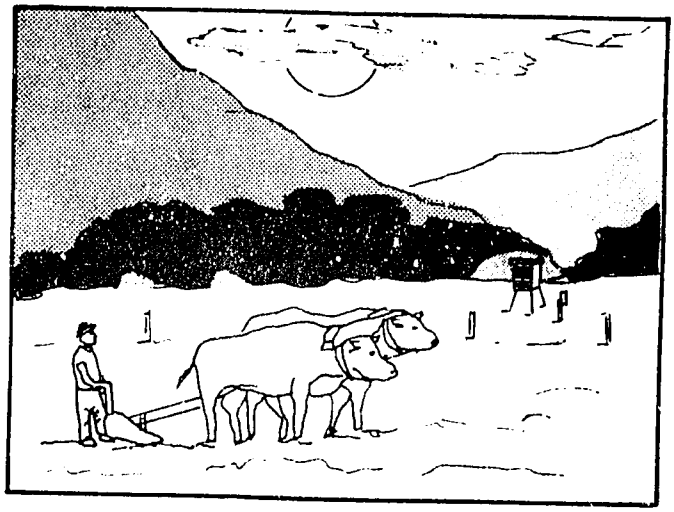
AGROMETEOROLOGICAL ASSESSMENT MODELS FOR ECONOMIC PLANNING AND RURAL DEVELOPMENT IN THE MANTARO VALLEY OF PERU









Walter A. Sánchez

MODELOS AGROMETEOROLOGICOS DE RENDIMIENTO DE CULTIVOS Y SUS APLICACIONES EN LA PLANIFICACION Y DESARROLLO RURAL EN EL VALLE DEL MANTARO, PERU

AGROMETEOROLOGICAL ASSESSMENT MODELS FOR ECONOMIC PLANNING AND RURAL DEVELOPMENT IN THE MANTARO VALLEY OF PERU

Final Report

to

National Agrarian University
Department of Physics
and Meteorology
La Molina
Lima, Peru

and

Ministry of Agriculture
and
National Meteorological and
Hydrologic Service
Lima, Peru

by

Walter A. Sanchez 1/

for

Agency For International Development
Lima, Peru

Agency For International Development 2/
Office of U.S. Foreign Disaster Assistance
Washington, D.C.

U.S National Oceanic and Atmospheric Administration
National Environmental Satellite, Data and Information Service
Center for Environmental Assessment Services
Washington, D.C. and Columbia, Missouri

March, 1982

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2 This project was sponsored by AID/OFDA under NOAA/AID PASA CC/OFDA-001-6-80 and conducted at NOAA/CEAS - Models Branch, Columbia, Missouri.

FORWARD

This report by Dr. Walter A. Sanchez, Agricultural Meteorologist and Associate Professor, Department of Physics and Meteorology, National Agrarian University, La Molina, Lima, Peru, is the result of an intensive six week Orientation Program on Agroclimatic Models and Climatic Impact Assessment Technology. The program was conducted in Columbia, Missouri by the Models Branch of the Center for Environmental Assessment Services (CEAS). As an organization within the U.S. National Oceanic and Atmospheric Administration/ Environmental Satellite-Data and Information Service, CEAS is responsible for using current and historical environmental data to provide timely decision assistance to managers of critical national resources by assessing the impacts of climatic variations on food, transportation, health, energy and the economy.

The agroclimatic assessment models developed by Dr. Sanchez for the agriculturally important Mantaro Valley, Junin Department of Peru can be used as the scientific foundation for planning, organizing and implementing a regional climatic impact assessment program. The data and technical resources for such a program already exist in Peru. However, support is needed to establish the regional project so the economic benefits and value can be demonstrated to decision makers. A successful regional project can lead to a national program in Peru.

This project was sponsored by the Agency for International Development, Office of U.S. Foreign Disaster Assistance, (AID/OFDA), Washington, D.C. It was conducted by CEAS under a NOAA/AID project agreement. The basic goal is to transfer agroclimatic modeling and assessment technology to developing countries and to encourage the development of an in-country program. This technology can improve food security by increasing disaster preparedness and early warning, contributing to land use planning for agricultural and rural development, and mitigating socioeconomic vulnerability to climatic extremes including drought, flooding and frost. The current project focused on Peru and Ecuador. NOAA/AID Projects are also underway for technology transfer to other countries in Latin America and in Southern Asia.

CEAS received assistance through NOAA subcontracts to the Atmospheric Science Department, University of Missouri - Columbia and the Aspen Institute/Food and Climate Forum, Boulder, Colorado. Their contributions are appreciated.

It was a pleasure for us to work with Dr. Sanchez during his visit to CEAS. His professional dedication and long hours of hard work were responsible for the results in this project.

Louis T. Steyaert
Project Leader
NOAA/NESDIS/CEAS

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The author of this report wishes to thank Dr. Clarence Sakamoto, Chief, Models Branch, for all the facilities provided during the Orientation Program. Special thanks are due to Dr. Louis T. Steyaert, Research Meteorologist, CEAS-Models Branch for the effort, enthusiasm and the time he spent sharing with me the techniques of crop yield climate modeling as well as assessment techniques. The author also wishes to thank Ing. Mario Zapata T., Rector of the Universidad Nacional Agraria - La Molina, Lima, Peru for permitting me to attend this Orientation Program in Columbia, Missouri.

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EXECUTIVE SUMMARY

AGROMETEOROLOGICAL ASSESSMENT MODELS FOR ECONOMIC PLANNING AND RURAL DEVELOPMENT IN THE MANTARO VALLEY OF PERU

Walter A. Sanchez

Agriculturally oriented economies are especially vulnerable to climatic extremes, particularly in Peru where 40 percent of the labor force is involved in agriculture. An example is the disastrous 1977-80 drought, the magnitude of which can be seen in the drought index for Cajamarca, Peru presented in Figure 1. Food production in Peru was reduced to the lowest levels in the 1970's. Potato, beef, subsistence food production and sugar for export were particularly affected. This in turn increased rice and wheat imports, influencing the balance of payments and foreign exchange. Frost can also result in significant economic loss; an estimated 2.5 million Soles ($7,812 U.S. 1980 currency rates) were lost in the potato, corn and lima bean crops from the frost of December 20, 1980 in the Mantaro Valley. Some of the climatic events and their economic impact in the Mantaro Valley are shown in the attached table. In addition, the "normal" or mean climatic conditions determine potential land use and therefore the agricultural practices which are necessary to minimize climatic risk.

This report documents agroclimatic models and climatic impact assessment methods which can be used by managers to mitigate potential climatic impact and reduce climatic vulnerability. Historic climatic data, primarily monthly rainfall, were used to develop three types of agroclimatic models for the Mantaro Valley, Junin Department, Peru. These include: 1) statistical climate/crop yield models (attached table) and agroclimatic/crop condition indices to provide crop yield and production forecasts 2) preliminary models for

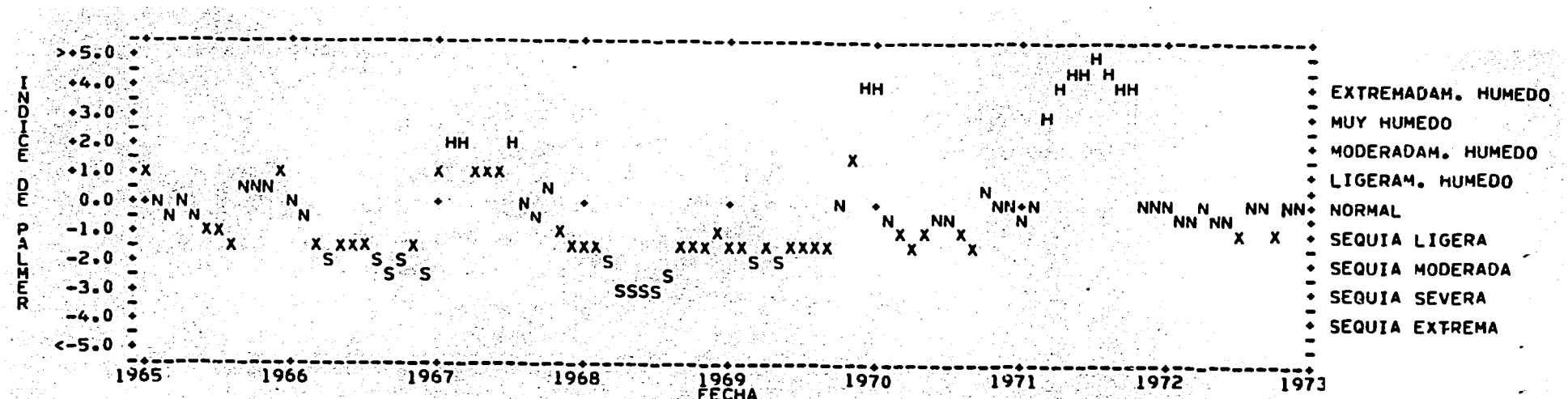
providing early warning crop/frost advisories to farmers so that possible actions can be taken to mitigate disastrous frost damage to crops, and 3) crop water requirement and water balance models plus methods to estimate potential evapotranspiration all of which are necessary tools for land use studies in the Valley and other areas in the Sierra.

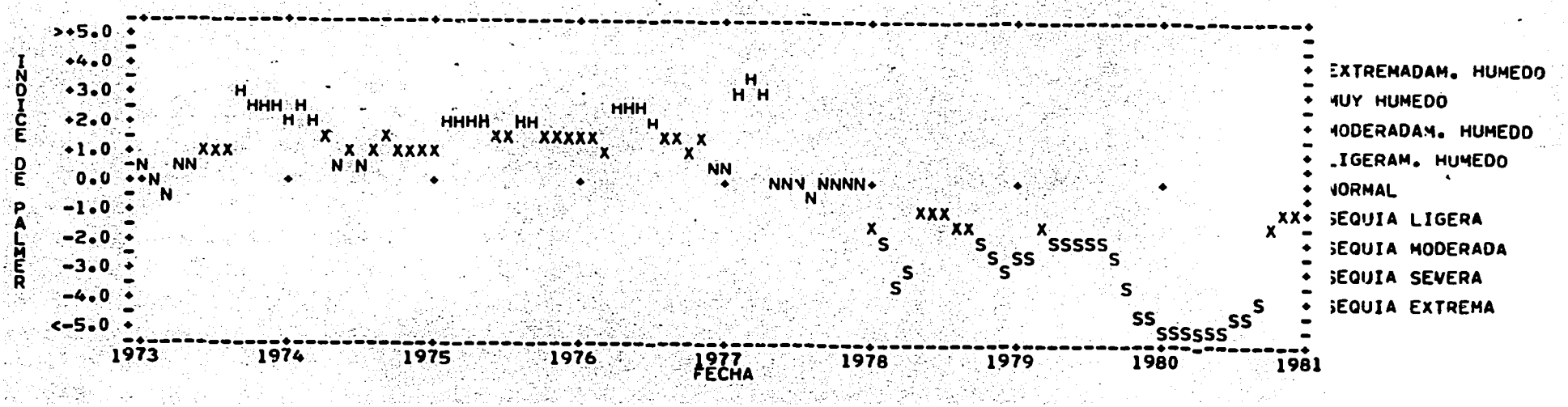
The potential short and long-term economic benefits of climatic impact assessments to decision makers are illustrated. Real-time weather information is used to run the models which convert climatic information into economic terms, e.g., relative crop production loss due to drought. Early warning of drought impact on agricultural production can be provided by at least 30 days prior to the beginning of the crop harvest. This information can contribute to agricultural production forecasts and provide a lead time of one to three months before the actual economic impact of drought occurs. This lead-time permits the adjustment of marketing and pricing policy, importing and exporting plans, or other economic programs. Disaster preparedness plans can be established to mitigate climatic impact on socioeconomic conditions in rural areas. Another important application of real-time weather data for short-term economic benefit is in the crop weather advisory for farmers. In addition to early warning of potential frost, farmers can also be advised on recommended planting date, scheduling of irrigation and application of pesticides. The advisory could also involve extension services. Agroclimatic models can contribute to land use studies by helping determine the regionally appropriate crop, its optimum planting date, and the potential economic returns. This type of model helps to reduce climatic vulnerability and lowers the risk of crop failure.

Agroclimatic models can be used to support the planning, development and implementation of a National Agrometeorological Assessment Project for Peru. The data and technical resources to implement a project already exist. Minimal support is needed for a regional project which can demonstrate the economic benefit and value to decision makers and users. This can lead to a national program which is based on historic climatic data, an under-utilized national resource. It is suggested that agroclimatic models and assessments are essential in formulating long term economic plans for agricultural and rural development, with the ultimate goal of national food self-sufficiency.

PALMER DROUGHT INDEX / INDICE DE SEQUIA DE PALMER

CAJAMARCA, PERU





TABLE

Episodal event data for the Mantaro Valley, Peru
Source: Diario "La Voz de Huancayo"

Weather Event	Date	Place	Affected Crops	Estimated Loss* (Peruvian Soles)
Hail	1/19/79	Mantaro Valley	Potato Corn Lima Beans	
Hail	3/29/79	Concepcion Ocopa	Barley Lima Beans Wheat Quinua	
Drought	12/26/80	Mantaro Valley	Potato Corn	
Hail	11/18/80	Chupaca	Corn Lima Beans	
Hail	11/18/80	Mantaro Valley	Corn Lima Beans	
Frost	12/20/80	Mantaro Valley	Potato Corn Lima Beans	2,500,000.00
Frost	12/27/80	Sicaya Pilcomayo	Potato Corn	
Drought and Frost	12/24/80	San Jose de Quero	Barley Lima Beans Pastures	4,000,000.00
Flood	2/3/81	Chupaca	Potato Barley	
Flood	2/10/81	Huayucachi	Potato Corn Lima Beans	

*1 US$ = 320 soles (July, 1980), 500 soles (Dec., 1981) approximately.

Weather Event	Date	Place	Affected Crops	Estimated Loss* (Peruvian Soles)
Flood	2/27/81	Sincos Mito Muqui Muquiyauyo 3 de Diciembre Huamancaca Chico	Potato Corn Lima Beans Peas	
Flood	3/10/81	Jauja	Potato Corn Lima Beans	
Flood	3/10/81	Matahuasi Yanamuclo Maravilca	Potato Corn Peas Wheat Barley	
Flood	3/13/81	Ataura Huayucachi Chupaca Pilcomayo Ingenio	Corn Wheat Barley Potato Lima Beans	3,000,000.00
Drought	2/3/80	Sais Cahuide	Potato (cows and sheep)	15,000,000.00

PERU

Preliminary Statistical Climate/Crop Yield Forecast Models for the Mantaro Valley, Peru.[1]

Weather Variables

Crop	Crop Variable	Bo	Trend	B1	B2	B3	R^2%	Standard Error of Estimate	Harvest Month	Crop Forecast Month
Barley	XYLD1	1.3240		P2-4 .00098	T2 -.0402		80.0	.0363	Jun	May 1
Barley	XYLD1	.7579		P2-4 .00132	T2 -.0945	T4 .0976	93.2	.0237	Jun	May 1
Wheat	XYLD3	.9051	.0278	LP11-1 .00074			79.6	.0533	Jun	Feb 1
Wheat	XYLD3	.9067	.0357	LP12-1 .00081			76.8	.0568	Jun	Feb 1
Field Corn	XYLD4	1.0488	.0136	P1 .00071			67.8	.0350	May	Feb 1
Sweet Corn	XYLD5	6.5478		P2-4 .0036			66.1	.1418	Mar	May 1
Dry Field Peas	XYLD6	1.6474	.0212	LT10 -.0511			68.0	.0507	Apr	Nov 1
Dry Field Peas	XYLD6	.9793		LP11 .0018			54.4	.0506	Apr	Dec 1
Green Peas	XYLD7	-9.9718	.1578	LT11 1.1127			73.6	.5619	Mar	Dec 1
Dry Lima Beans	XYLD8	2.8108	.0646	LT11 -.1585			86.0	.0850	Apr	Dec 1
Dry Lima Beans	XYLD8	.7174		LP11 .0055			81.9	.0894	Apr	Dec 1
Green Lima Beans	XYLD9	6.9740	.0780	P2-3 -.0097			93.4	.1572	Mar	Apr 1
Green Lima Beans	XYLD9	8.6425	.1662	LT11 -.3643			76.2	.2987	Mar	Dec 1
Traditional Potatoes	XLYD10	1.6873	.4942	P2-4 .0056			99.5	.1000	May	May 1
HYV Potatoes	XYLD11	4.8649		P1-3 .0101			76.4	.3555	Apr	Apr 1

Note[1]: Bo is constant; Trend is "Trend coeff"; B1, B2, B3 are weather variable coefficents, R2 is explained variance; standard error of estimate is in mt/ha.

AGROMETEOROLOGICAL ASSESSMENT MODELS

FOR ECONOMIC PLANNING AND RURAL DEVELOPEMENT

IN THE MANTARO VALLEY OF PERU

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CHAPTER I

INTRODUCTION

Although agriculture in Peru contributes less than 13 percent to the Gross Domestic Product, (US $10.7 billion in 1978), it is the primary source of employment and way of life for about 40 percent of the labor force and their families (Nyrop, 1980). Since the early 1960's per capita production of food has declined and there is the current need to improve the food situation in Peru. Increasing the level of agricultural production and reducing losses due to anomalous climate, particularly drought and frost, can have both economic and social benefit. The economic progress can be maintained and the socio-economic conditions of the rural population can be improved.

The climate, soils, improved technology, economic policies and existing agricultural practices are some of the factors which must be considered in plans for improving agricultural production. Climate determines agricultural production in two ways. First, there are the natural climatic differences between the three major geographic regions in Peru: 1) the arid Costa where irrigation is required, 2) the Sierra where a short growing season, drought and frost are limiting factors, and 3) the Selva where there is great potential for expansion of agriculture into a favorable climatic regime, but the need to implement management practices which preserve soil quality and fertility. Second, climatic variability including severe drought and extreme frost conditions causes agricultural production losses, sometimes throughout Peru such as was the case during the late 1970's.

Peru experienced some of the worst drought conditions on record during the period 1978-1980. Agricultural exports such as sugar cane were reduced. Food production was reduced to the lowest level in the 1970's. Crop yields and the

area planted to some crops, e.g., potatoes, decreased as did production from major subsistence crops. These factors led to increased agricultural imports, a negative contribution to the balance of payments, and reduced foreign exchange. For example, in 1979, rice was imported for the first time since 1976. Although wheat is usually an import crop, drought resulted in a 14 percent increase of imported wheat. As a final example, beef production fell due to drought impact on pastures.

Frost is a major natural climatic hazard which reduces agricultural production. For example, a major frost occurred during the middle of the crop growing season in the Mantaro Valley, Junin Department on December 20, 1980. Severe production losses resulted in the potato, corn and lima bean crops. The estimated economic loss was 2,500,000 Soles or US$7,812 (1980 currency rates). Local food supplies were reduced, farm income was lost and less food was available for marketing in Lima.

The purpose of this research was to develop agroclimatic models from Peruvian data and to demonstrate areas of potential application for economic benefit, agricultural planning, rural development and increased food security in Peru. The Mantaro Valley, Junin Department and one of the most important suppliers of agricultural products to Lima, Peru was selected for this study. For example, 63 percent of Junin's potato production and 11 percent of national potato production comes from the Mantaro Valley.

Three major types of agroclimatic models and the application were investigated. First, agroclimatic techniques for estimating water stress in crops, crop climatic requirements and soil moisture estimates were verified and/or adjusted for use in the Mantaro Valley. These agroclimatic techniques

are fundamental to the development of more sophisticated agroclimatic models. Second, statistical climate/crop yield forecast models were developed for wheat, barley, peas, lima beans, corn and potatoes. Third, the climatology and local weather conditions associated with frost occurrence during the growing season were examined to develop early warning frost advisories for farmers.

A major endeavor in this project was to determine the application of these models for maximum benefit to decision makers in government and on the farm. This requires a process to operate the models, interpret the output of the models and communicate the results to the users. This process is called the CLIMATIC IMPACT ASSESSMENT.

Let us illustrate by example the difference between a "climatic evaluation" and a "climatic impact assessment". A climatic evaluation could be the statement, "The rainfall was only 25 mm during February and was only 50 percent of normal for that month." By using this rainfall data in a reliable agroclimatic model which predicts, for example, corn yield, the following climatic impact assessment would be communicated in early March to decision makers (Ministry of Agriculture, Marketing, Extension and the farmer), "The corn crop to be harvested during April is forecasted at 1.2 metric tons per hectare, or 20 percent below the normally expected yield. This could represent a production of only 10,000 metric tons. This large yield reduction resulted from extremely dry conditions and low soil moisture during February. Rainfall was only 50 percent of normal. The crop experienced moisture stress during the critical grain filling stage."

It is evident from this illustration that an assessment is a statement of the magnitude and effect that climate had (or is expected to have) on some particular area of economic activity. Economic loss or value can be determined.

This type of information can benefit the decision process in the following possible ways:

In the short-term, such early warning information on potential crop failure due to drought or frost can be used to mitigate climate impact.

Export/import plans can be adjusted. Plans for distribution, transportation, and storage of agricultural crops can be modified.

In the case of frost, the farmer can possibly undertake prescribed frost control measures. Other applications could potentially include advisories on planting dates, irrigation scheduling or fertilizer application.

In the long-term, economic benefit can result from models which contribute to land use applications.

This report describes the development of the models, their capabilities and limitations and potential use in Peru.

CHAPTER II

AGROMETEOROLOGICAL BACKGROUND

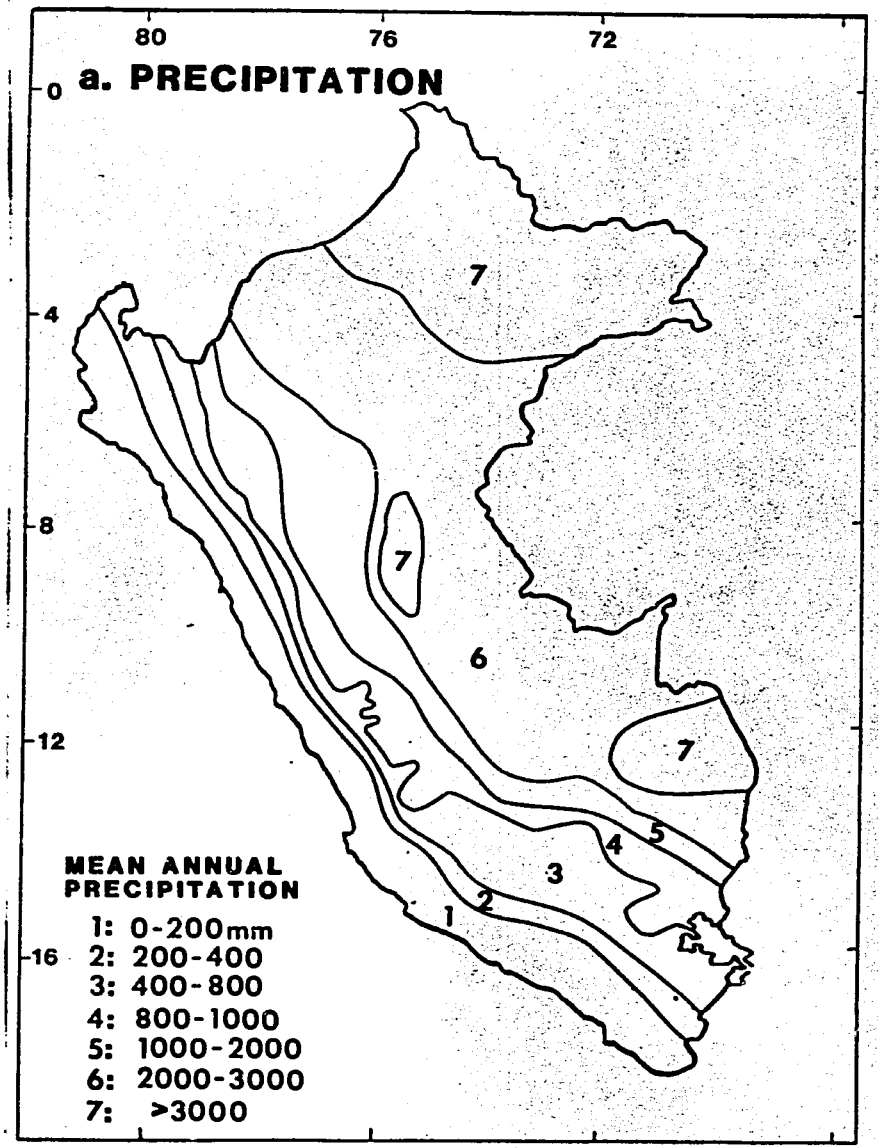
A. Climate And Agriculture In Peru

Agriculture in Peru contributes about 13 percent of the Gross Domestic Product (GDP) and provides employment for approximately 42 percent of the national labor force (Nyrop, 1981). But due to the unique geography of the country, only 28 percent of the total surface area (Figures 2.1 and 2.2) is used for crops. Each geographic region presents serious limitations to agricultural crop production under either rainfed or irrigated conditions.

Because of permanent drought in the coastal region, crops must be grown near irrigation sources, for example along rivers (Figure 2.3). The main cities are also located along rivers; thus, some of the best cropland is being used for houses and industries associated with recent urban growth. Expanded irrigation networks are required to increase cropland.

Seasonal rainfall patterns are more favorable in the Sierra (Fig. 2.4a), but temperature as well as the duration of the frost-free period are also limiting factors (Fig. 2.4b and 2.5a-b). The success of the crop growing season depends upon the beginning of the rainy season and upon the occurrence of sporadic drought and frost conditions. In some areas, irrigation permits planting of some crops earlier than normal conditions. Farmers benefit from better prices associated with an earlier harvest. This type of agriculture is restricted to areas close to rivers, thus cropland extension is limited.

In contrast to the Sierra, temperature and precipitation are not as limiting in the Selva (or Amazon regions), especially at high elevations. The quality of soil and its depth appear to be the factors which make this region less than ideal for the agriculture.



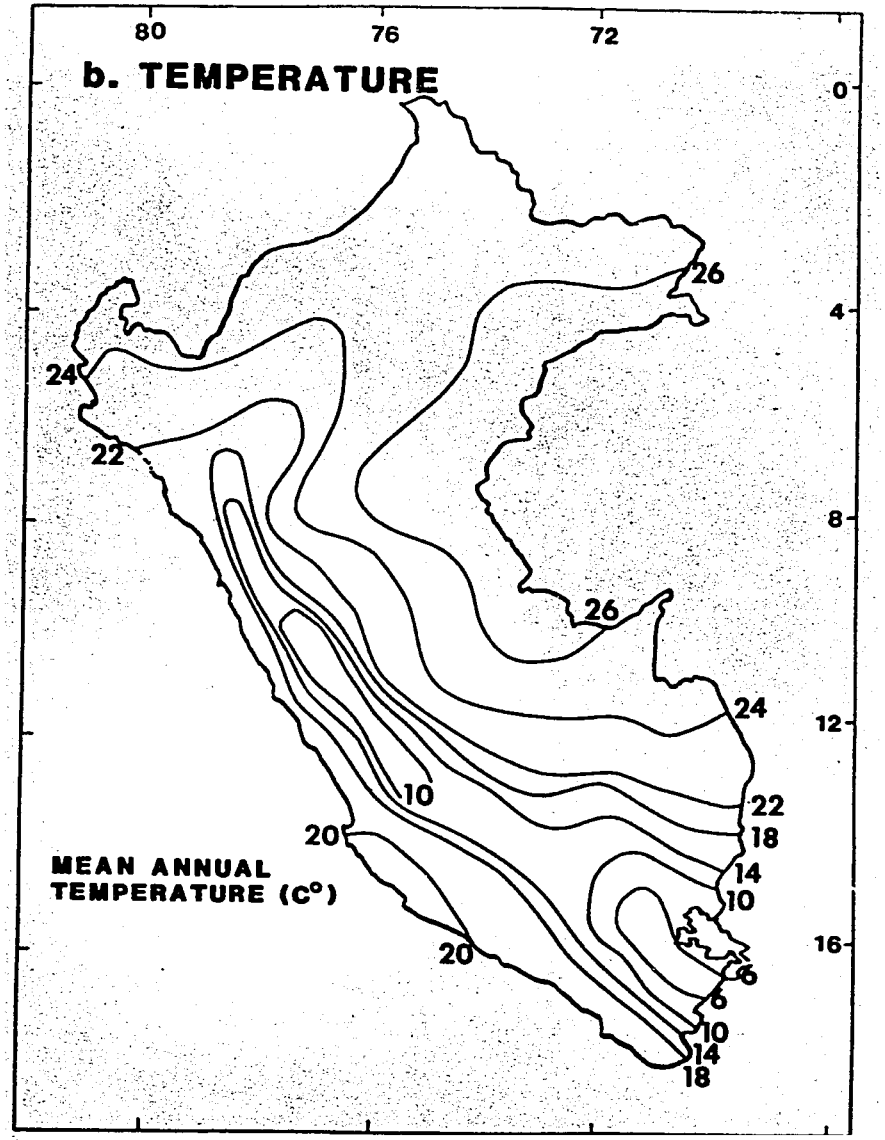


Figure 2.4a-b. Mean Annual Precipitation Amount (mm) and Mean Annual Temperature (°C) in Peru

Precipitacion Anual Promedio (mm) y Temperatura Anual Promedio (°C) en Peru

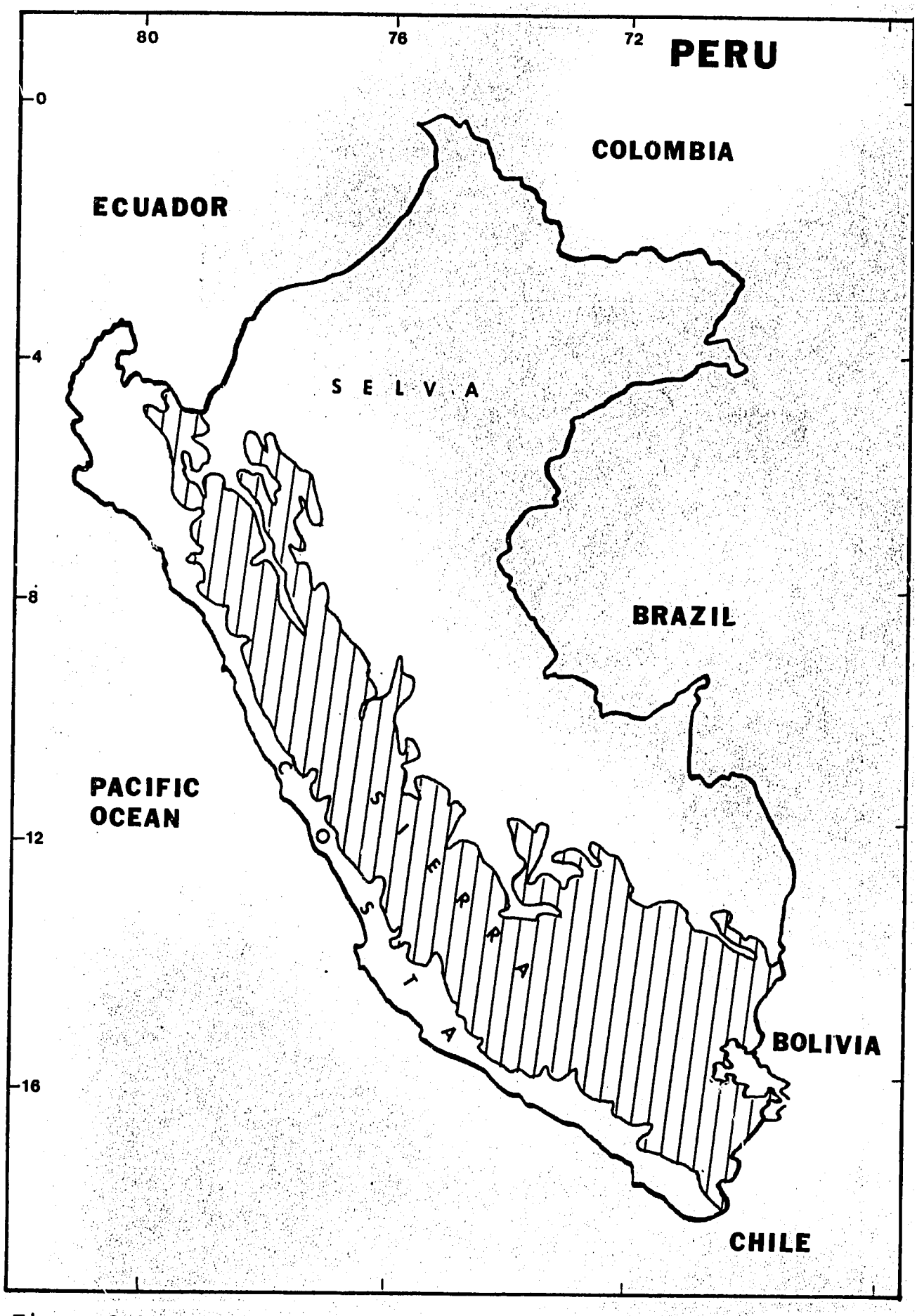


Figure 2.2. Major Georgraphic Regions in Peru
Principales Regiones Geograficas del Peru

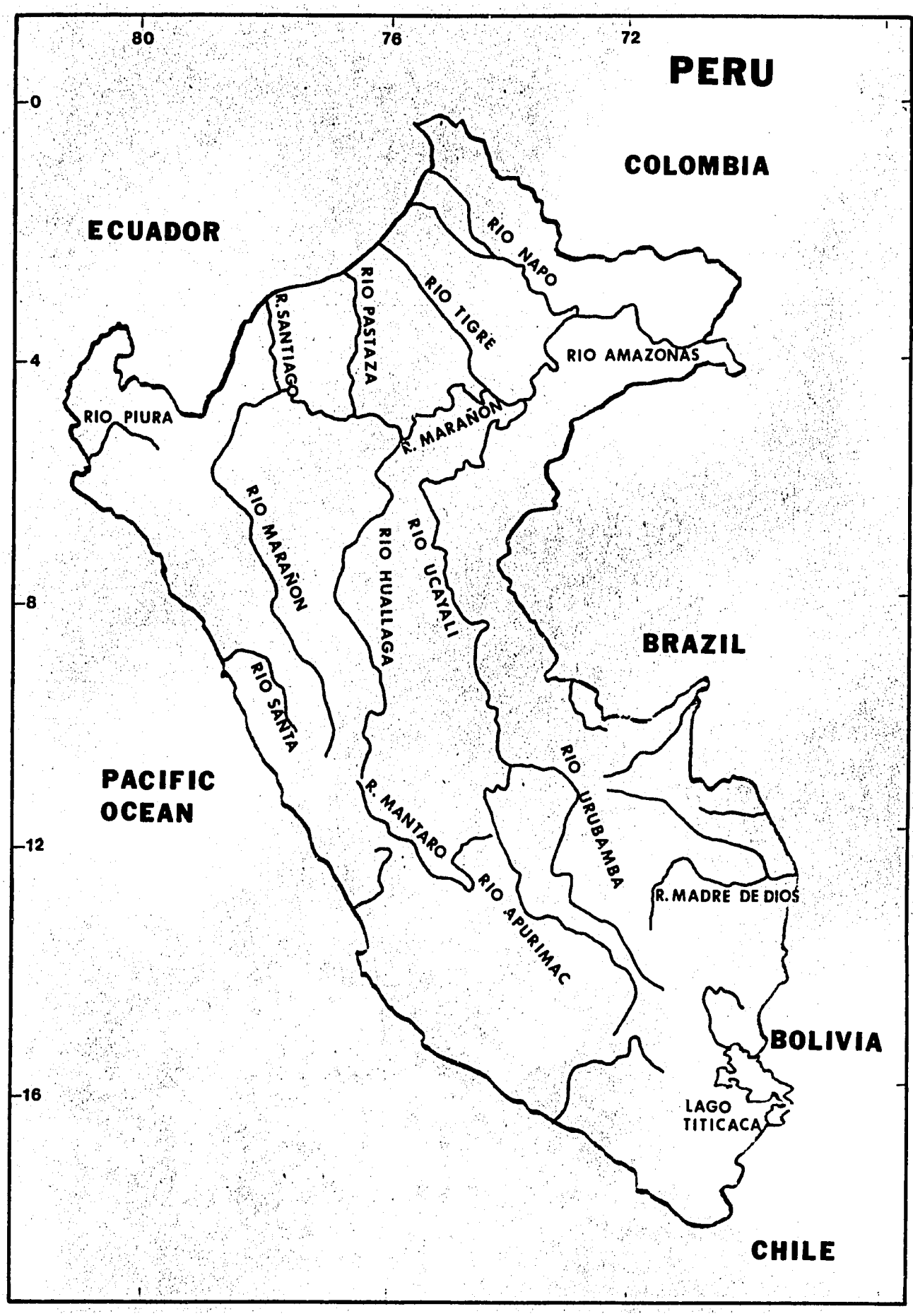


Figure 2.3. Major Rivers in Peru
Principales Rios en Peru

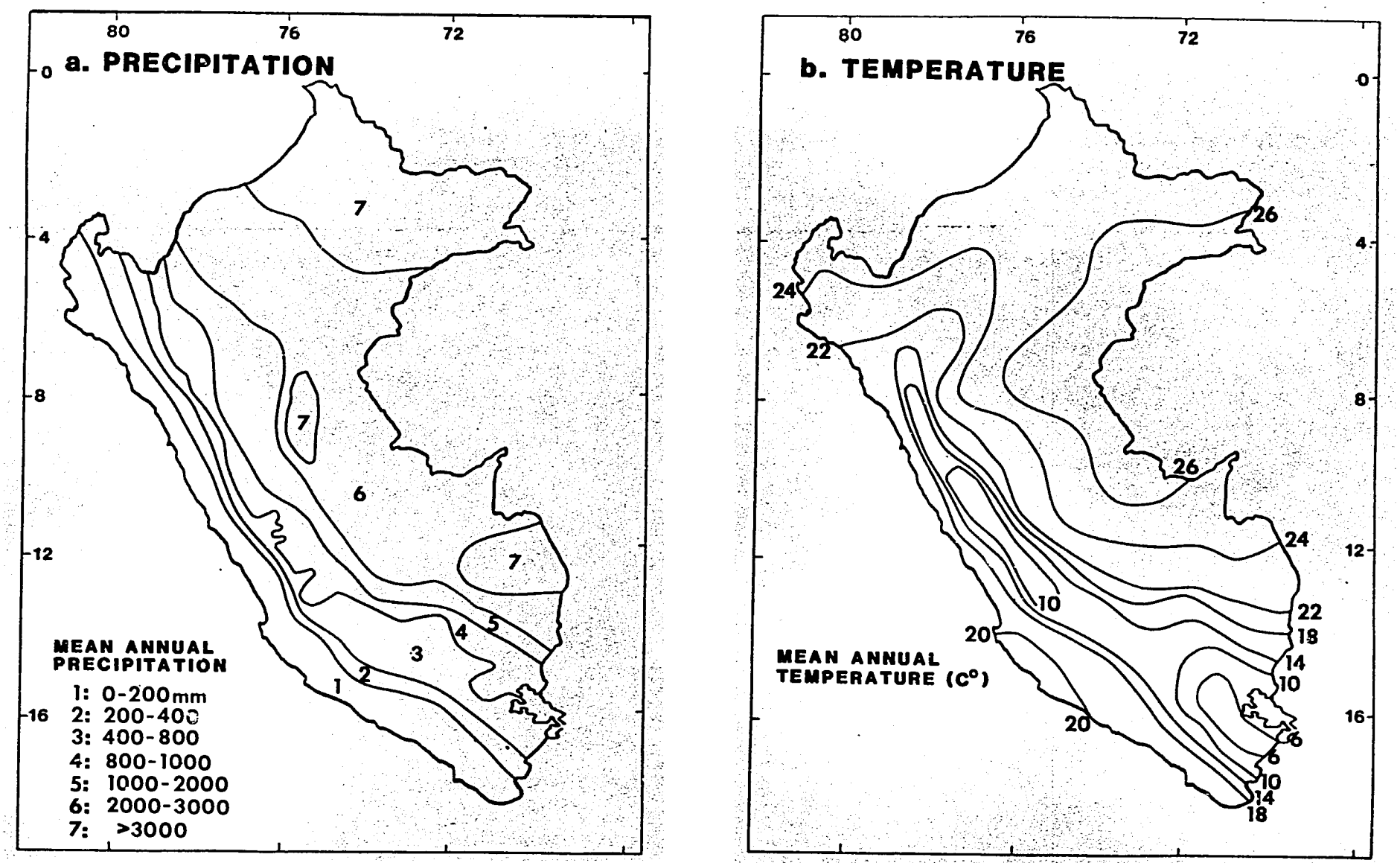
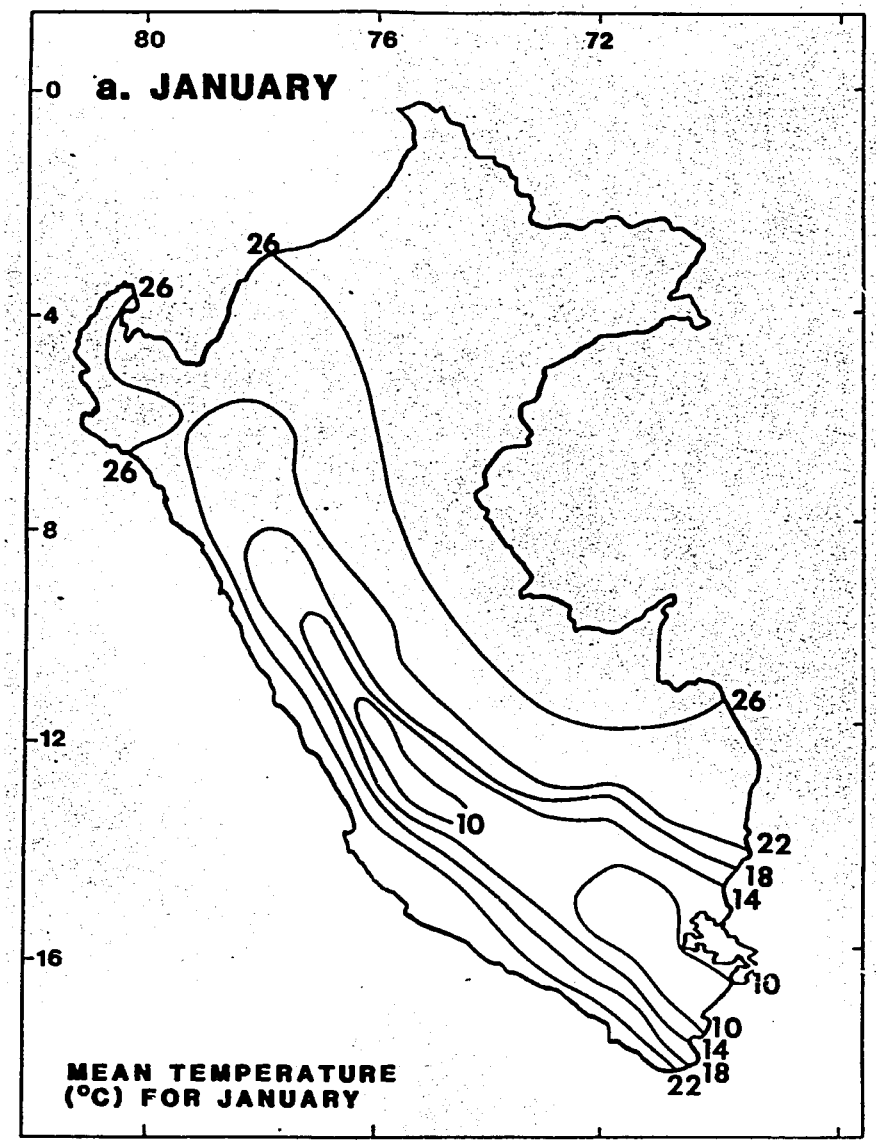


Figure 2.4a-b. Mean Annual Precipitation Amount (mm) and Mean Annual Temperature (^{o}C) in Peru

Precipitacion Anual Promedio (mm) y Temperatura Anual Promedio (^{o}C) en Peru



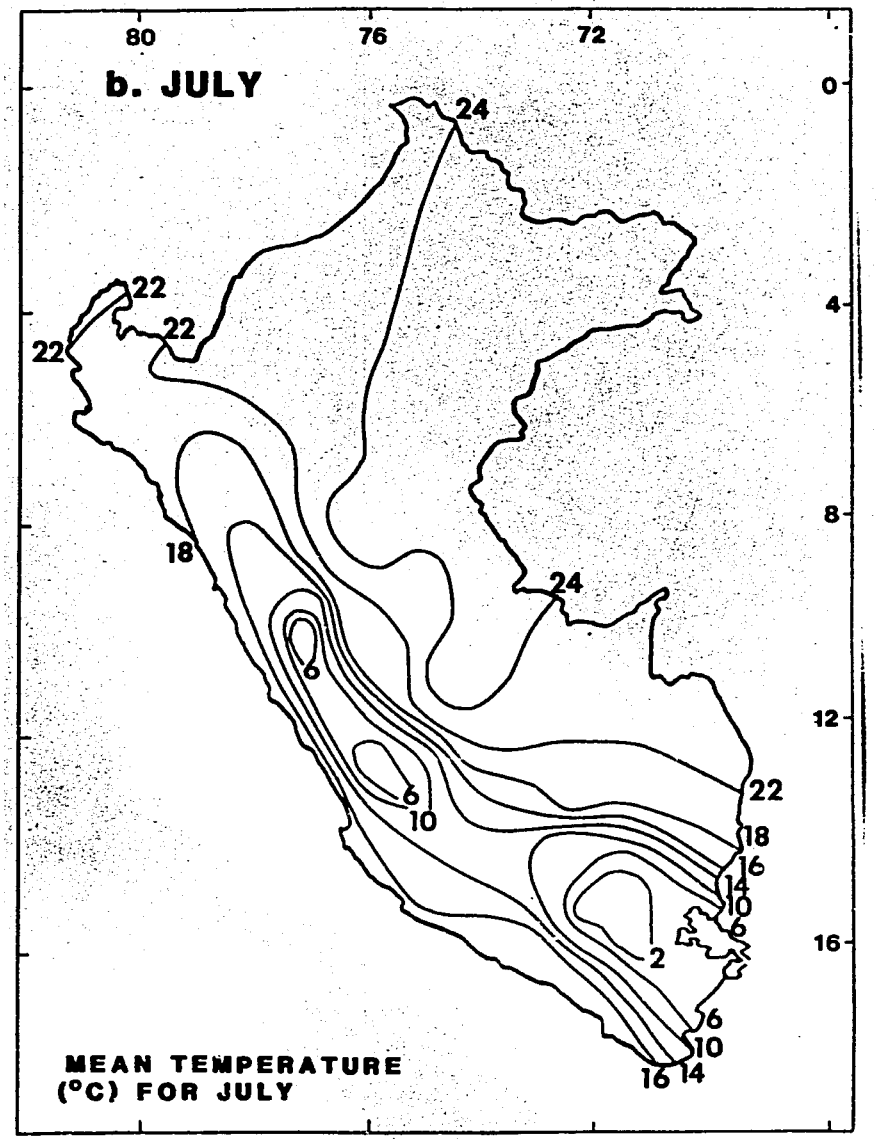


Figure 2.5a-b. Mean January and July Temperature (°C) in Peru

Distribucion espacial de la Temperatura promedio en los meses de Enero y Julio, Peru

This problem is compounded in regions where the soil erosion is excessive as a consequence of the uncontrolled deforestation associated with expansion into new croplands. The lower elevations of the Selva represent a large potential for forestry and some tropical crops, if appropriate agricultural practices can be applied.

Thus, Peru has quite different macro-, meso-, and microclimatic conditions. Figure 2.6 provides a rather simplified natural vegetation distribution which shows the response of plants to the existing and limiting conditions as well as the potential regions where crops or new varieties may be introduced.

1. Land Use

Only 28 percent of the total land area (128,521,560 hectares), is used for crops and pastures. The mean regional distribution of land according to agricultural area, agricultural production and total land area expressed as a percent of National Totals (1976-79) are shown in Table 2.1. Agricultural area and production are not proportional to the size of each region because of natural limiting factors in each region and the level of the agricultural technology being used. If sufficient water can be supplied through irrigation, the coastal oases are favorable for important commerical crops such as cotton, sugar cane, rice, corn and fruits. It is very important to preserve soil quality through proper soil management in order to prevent high salinity.

More than 50 percent of the national cropland is located above the 2000 m level in the Sierra. Total production is not proportionate to the total cropland because yields are low due to soil quality, low technology level and the limiting action of the temperature and rainfall regimes.

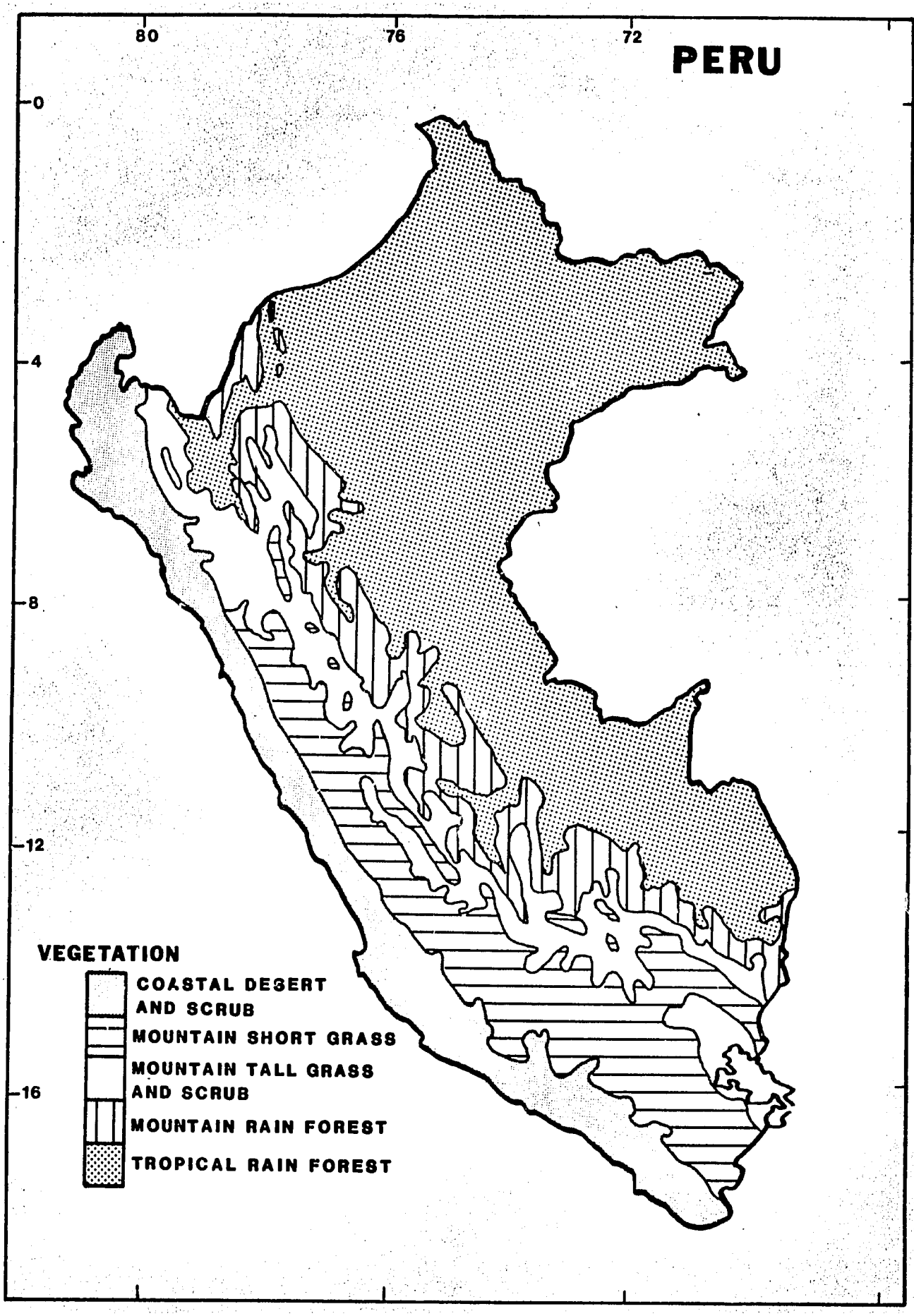


Figure 2.6. Natural Vegetation Zones in Peru
Zonas con Vegetacion Natural en Peru

Although the Selva is the largest region, the area devoted to agriculture and the contribution to the national production are small, relative to other regions. In addition to the natural limitations in the region, agricultural activity is strongly dependent on the transportation system to the main cities in the Sierra and Costa, especially to Lima.

2. Rainfed Agriculture

More than 54 percent of the national cropland is rainfed (Figure 2.2). If we consider the source of water for the agriculture in the Costa, we may conclude that 69 percent of the crop growing area (Sierra and Costa) is rainfed and therefore very much dependent on the climatic and weather conditions prevailing on the highlands of Peru. Similarly, one may point out that not only 22 percent but 70 percent of the national production is attributed to the rainfed agriculture. Thus, for example, we may note that the recent drought of 1978-80 which occurred on the Sierra and higher Selva affected not only the agriculture in these regions but also on the northern areas of the Costa. So we see that the agricultural activity in Peru may be vulnerable to weather and climatic anomalies which occur locally or in remote regions of the whole country.

The main types of crops grown in Peru are shown in Table 2.3. Annual crops contribute more than 75 percent of the national production. It is recognized that improved access to the Selva coupled with an appropriate land use will significantly increase the contribution of forests to the national production. The area devoted to pastures and agricultural production could be increased if the farmers, especially in the Sierra, receive technical assistance and advice.

The regional crop growing area for annual crops is Costa 33 percent, Sierra 57 percent, and Selva 10 percent of the total crop growing area. The irrigated, annual crops in the Costa contribute about 52 percent of the national production.

TABLE

PERU

Mean agricultural area, agricultural production and total land area expressed as a percent of national totals for major geographic regions in Peru (1976-79). Values are in Percent.

REGION	AGRICULTURAL AREA	AGRICULTURAL PRODUCTION	TOTAL AREA
Costa	31	48	10.6
Sierra	52	37	30.6
	17	15	58.8

TABLE 2.2

PERU

Rainfed agricultural area and production by major geographic regions of Peru expressed as a percent of the national values (1976-79).

REGION	MEAN AGRICULTURAL AREA	AGRICULTURAL PRODUCTION
Costa	0.09	0.02
Sierra	38.53	22.65
Selva	15.66	13.24

Table 2.3

PERU

Mean agricultural area and production by type of crops, expressed as a percent of the national values (1976-79).

TYPE OF CROP	AGRICULTURAL AREA	AGRICULTURAL PRODUCTION
Forests	1.1	-
Pastures	12.5	11.2
Perennial crops	9.7	13.5
Annual crops	76.7	75.3

Similarly, the Sierra and Selva contribute about 38 and 10 percent, respectively, to production values. The main annual crops according to the crop growing area are as follows:

Field Corn	Sugar Cane
Potatoes	Beans
Barley	Cassava
Wheat	Sorghum
Rice	Sweet Potatoes
Cotton	Tobacco

The area and distribution of the first four crops are presented in Figures 2.7 through 2.10. These crop maps indicate to some extent the agroclimatic conditions which are favorable for the crop. In the case of corn and potatoes, there are crop varieties which can be grown under relatively warm conditions of the Costa. Other varieties with a shorter growing season or increased tolerance to drought conditions and low temperatures are also available.

B. Junin Department

1. Geographic Characteristics

The Junin Department is located in the Sierra and central regions of the Selva (Fig. 2.1), between 10°41' and 12°41'S and 73°16' and 76°30'W. The elevation varies from 450 m on the eastern side to 5000 m on the west. About 40 percent of the Department is at elevations greater than 2000 m. The distance to the capital of Peru, Lima, is about 310 km. The area of the Department is 4,338,442 hectares, which corresponds to 3.38 percent of the national land area. Junin is divided in provinces including: Junin, Tarma, Jauja, Yauli, Concepcion, Huancayo (Capitol), Satipo and Chanchamayo.

The estimated population in 1980 was 897,300 (Nyrop, 1981), i.e., 5.1 percent of the national population. Three-quarters of the Departmental population is located in rural areas and the remainder in towns or cities of about 20,000 inhabitants.

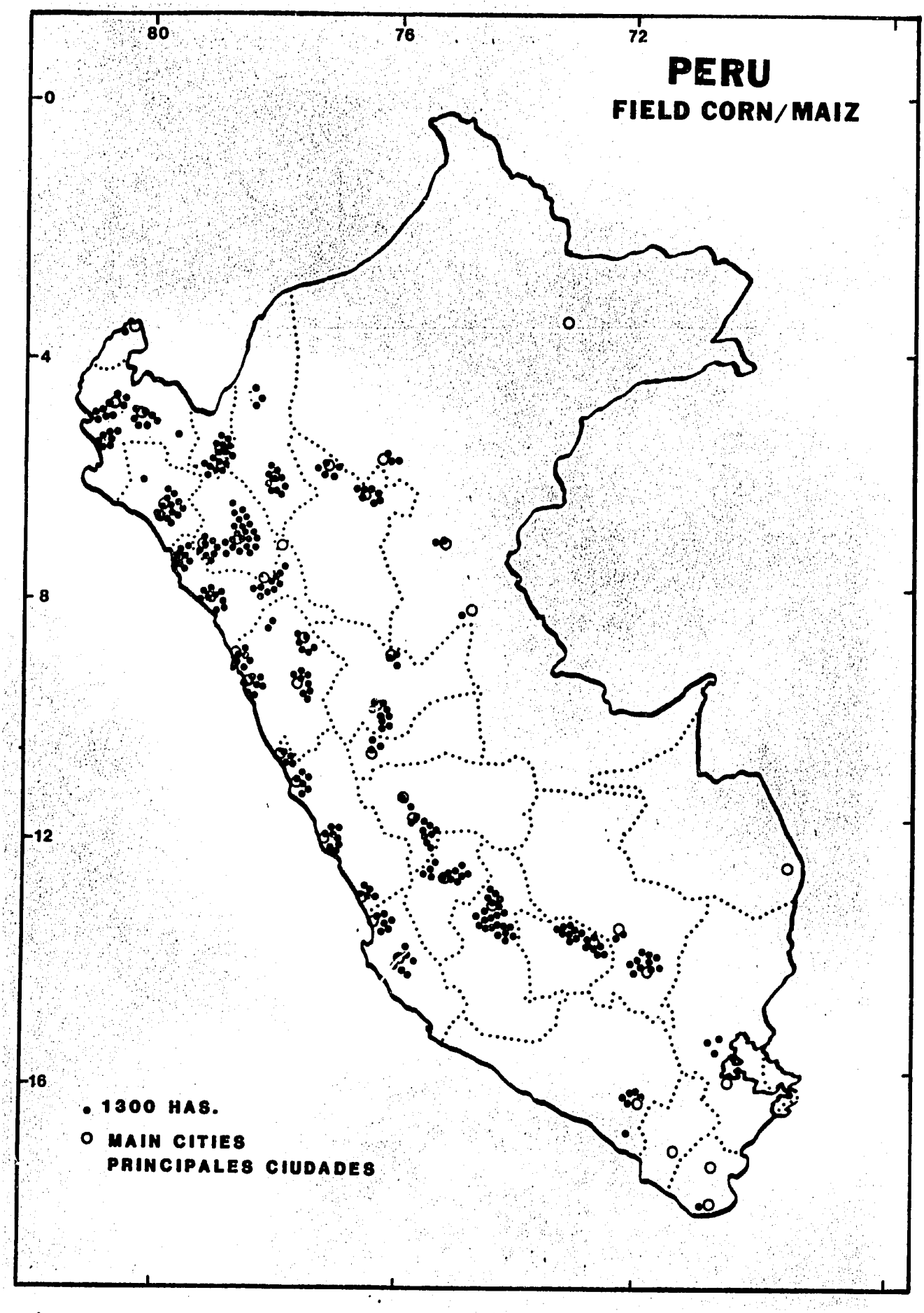


Figure 2.7. Major Field Corn Growing Areas in Peru
Principales Areas de Cultivo de Maiz en Peru

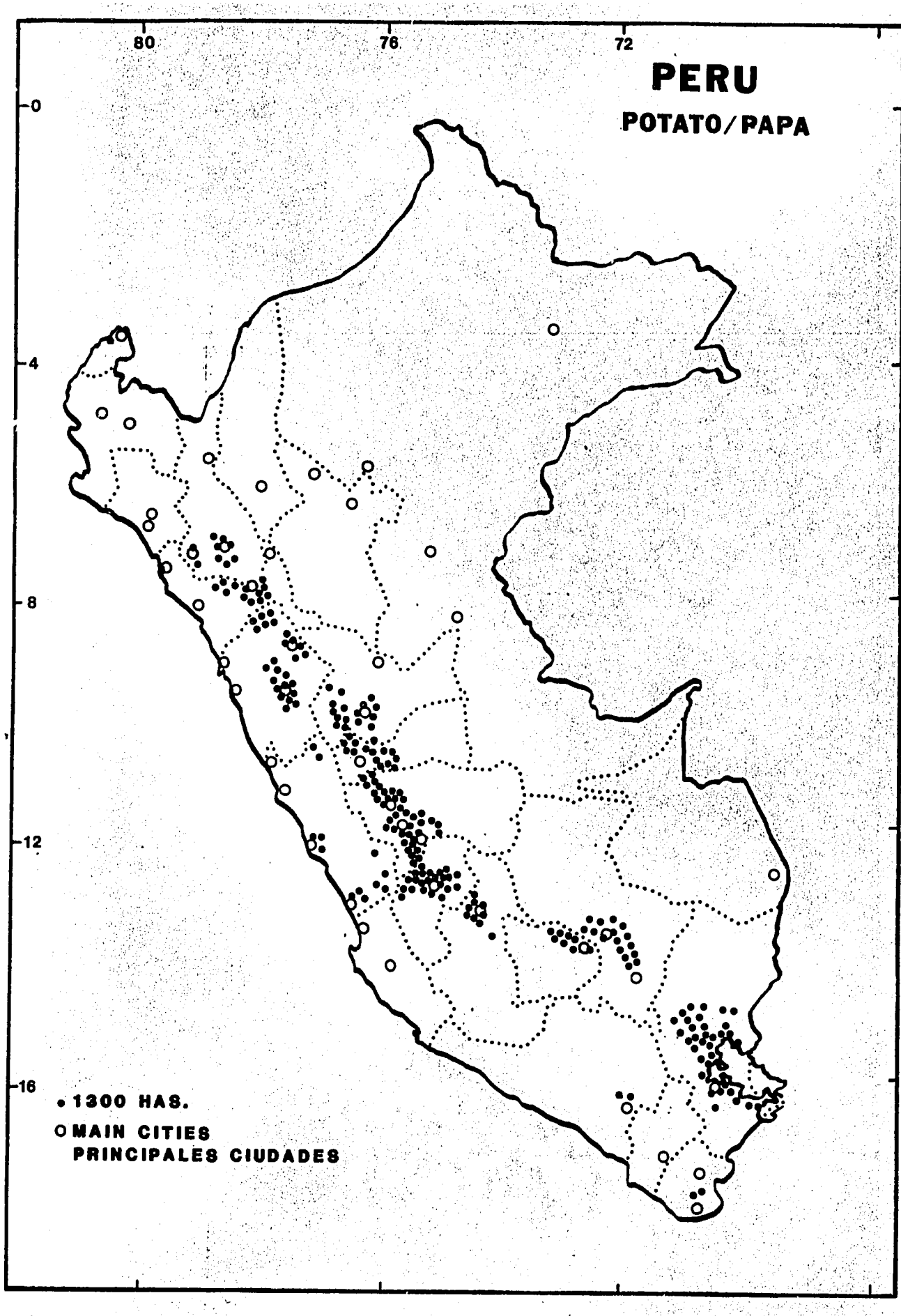


Figure 2.8. Major Potato Growing Areas in Peru
Principales Areas de Cultivo de Papa en Peru

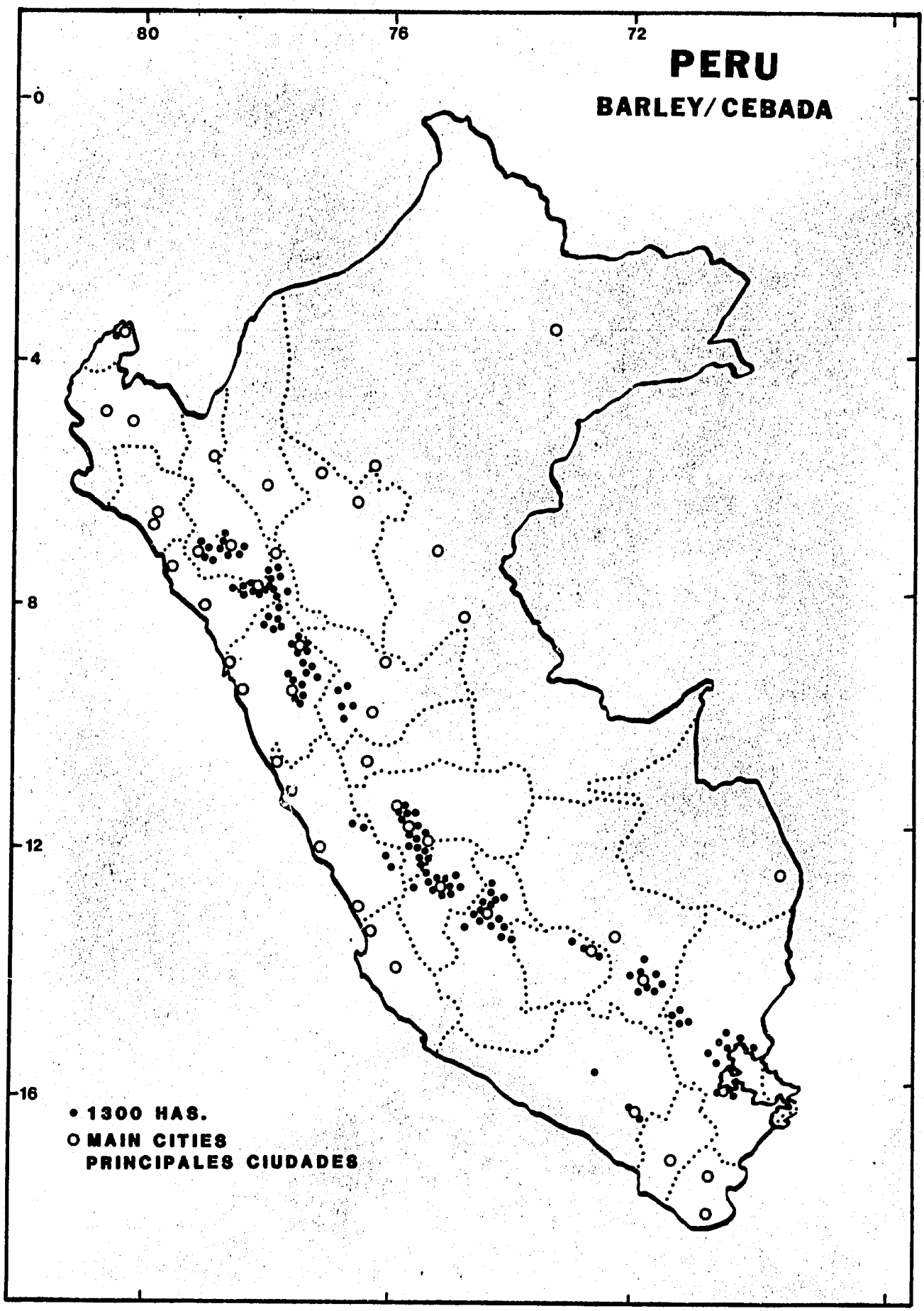


Figure 2.9. Major Barley Growing Areas in Peru
Principales Areas de Cultivo de Cebada en Peru

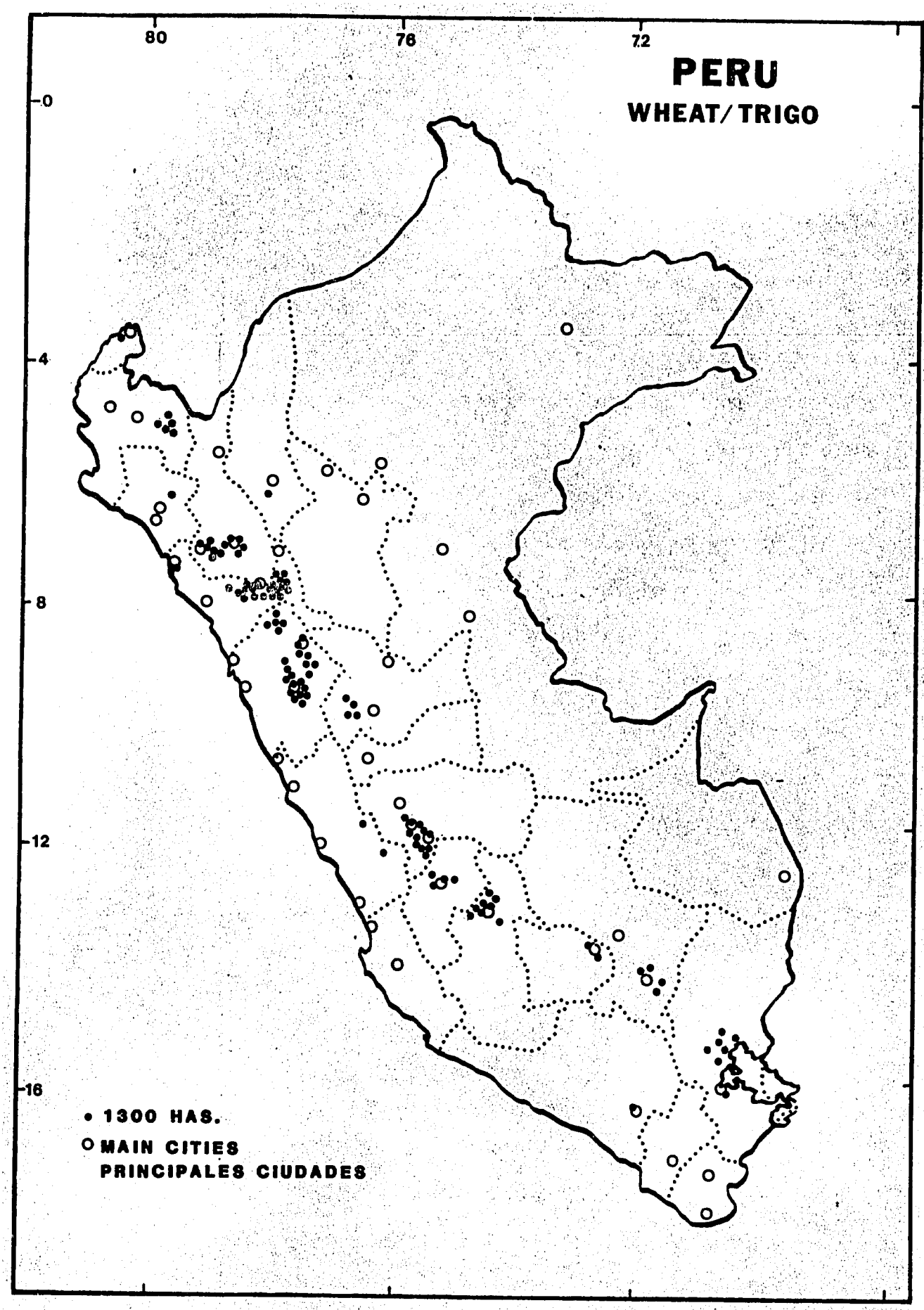


Figure 2.10. Major Wheat Growing Areas in Peru
Principales Areas de Cultivo de Trigo en Peru

Because of the Andes, there are different geographic configurations within the Department, i.e., plateaus, valleys, and peaks. The Mantaro Valley, one of the most extensive areas, has a relatively dense population and is an important agricultural region.

The temperature and precipitation regimes are influenced and controlled by the elevation and exposure to the mesoscale wind circulation as well as by the local wind circulation. Seasonal precipitation comes as rain associated with convective showers in the lower elevations or as snow at higher elevations where the frost-free period may be zero.

2. Agriculture in Junin

Agriculture represents one of the primary areas of economic activity in Junin. Mining and commerce represent other major economic activities. The primary land use is small farms where subsistence-type agriculture is practiced. Mechanization is either limited or in many cases nonexistent because of topography, the size of the farms or economic capability of the average farmer.

The total cropland of the Department is about 166,500 hectares with about 1 percent under irrigation, especially in the Mantaro Valley and the Province of Tarma. Rainfed agriculture was 77 percent of total Departmental production in the years 1977-79. Cropland is mainly used for the growing of the following crops:

Barley	Lima Beans (dry)
Field Corn	Lima Beans (green)
Wheat	Peas (dry)
Sweet Corn	Peas (green)
Potatoes	Pastures

According to the Sistema Nacional de Planificacion (1981) the potential cropland area in Junin could be as much as 340,000 hectares with the potential area for pasture lands exceeding 7,000,000 hectares. These levels can be

realized in part with increased fertilizer applications and good management. This would significantly increase animal production. In the eastern regions of the Selva there are 7,300,000 hectares for potential forestry-production.

C. Mantaro Valley

The Mantaro Valley is named after the major river in the Junin Department. The Rio Mantaro crosses Junin from the Northwest to the Southeast. The population in the Valley as well as neighboring towns is about 230,000. Most of this population is concentrated in Hauncayo, the Capitol of the Department. The Mantaro Valley is the major agricultural production region in the Junin Department and one of the important food sources for Lima. For example, Lima experienced shortages of agriculture products and price increases during the summer of 1980 because the access roads to Junin were closed due to the excessive rainfall-induced mudslides.

When viewed on a map of Peru, the Mantaro Valley looks quite small. However, this can be misleading with respect to the Valley's importance to agriculture. For example, the Valley produces 68 percent of Junin wheat and 8 percent of national production. Similarly, 80 percent of Junin's barley is produced in the Valley, representing 14 percent of national barley production. About 63 percent of Junin's potato production comes from the Valley which produces 11 percent of national potato production. Although the Valley produces 71 percent of Junin's corn, this only represents two percent of national production.

1. Physical Description

The Valley is located between 11°40' and 12°13'S latitude and 75°08' and 75°40'W longitude within Junin Department (Fig. 2.11). There are three provinces: Jauja in the north, Concepcion in the center and Huancayo in the

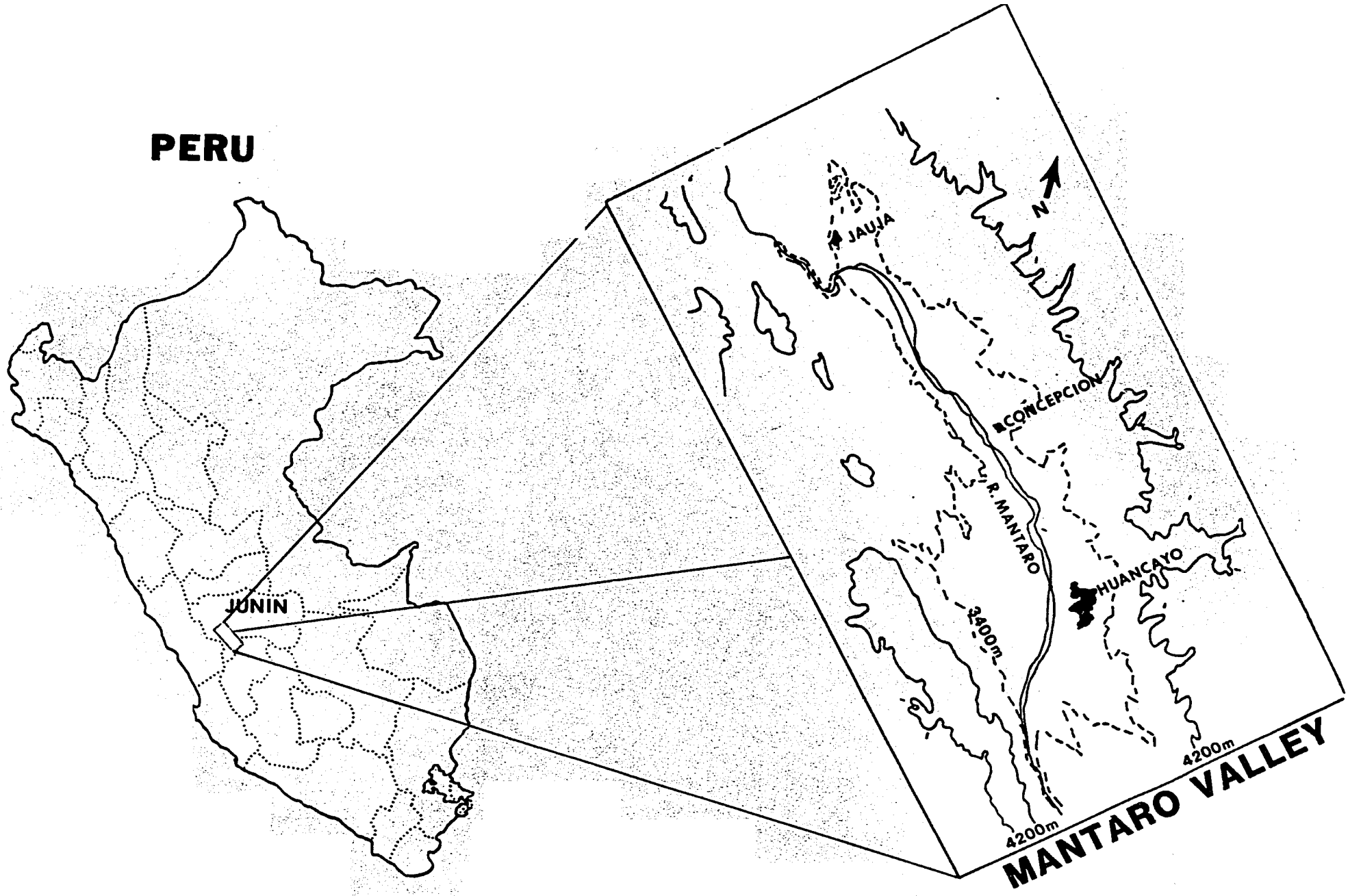


Figure 2.11. Geographic Location of the Mantaro Valley in Junin Department - Peru
Ubicacion del Valle del Mantaro en el Departmento de Junin - Peru

south. The length of the Valley is approximately 70 km. The natural boundaries of the Valley are defined by the steep slopes of the Andes Mountains, Figure 2.12. As indicated by Figure 2.13, most agricultural production is located between the river valley and 3,400 m elevations.

2. Agriculture in the Mantaro Valley

With the exception of the relatively small proportion of the Valley which is irrigated, the types of crops as well as the agricultural practices are primarily determined by both the temperature and precipitation regimes. Carrion (1975) found that the date of occurrence of the last frost ($\leq$0°C) in the spring (August and September) varies within the Valley from August 8 to about September 2. The frost-free period ranges from 230 to 286 days. Thus, this climatological result provides some indication of the time of the year favorable for the growing of crops. In another study of the Valley, Bernui (1978) estimated a mean annual rainfall of 754 mm with 95 percent occurring during the mean growing season in the Valley (September-May). The "normal" planting of crops begins during September as the temperature increases and with the normal beginning of the rainy season. Farmers in the Valley know that they can begin planting as soon as the soil contains enough moisture and the soil temperature is high enough to permit germination. If the rainy season is delayed, the farmer must also delay the planting. However, he must plant before the end of December to ensure sufficient rains to permit successful growth and maturity of the crop. The climatological or mean date for the last frost can be misleading because frosts can also occur anytime during the growing season, particularly during November, December or even January. The precipitation pattern is sometimes characterized by a secondary minimum during November (Sanchez, 1981). These

CROSS SECTION-MANTARO VALLEY

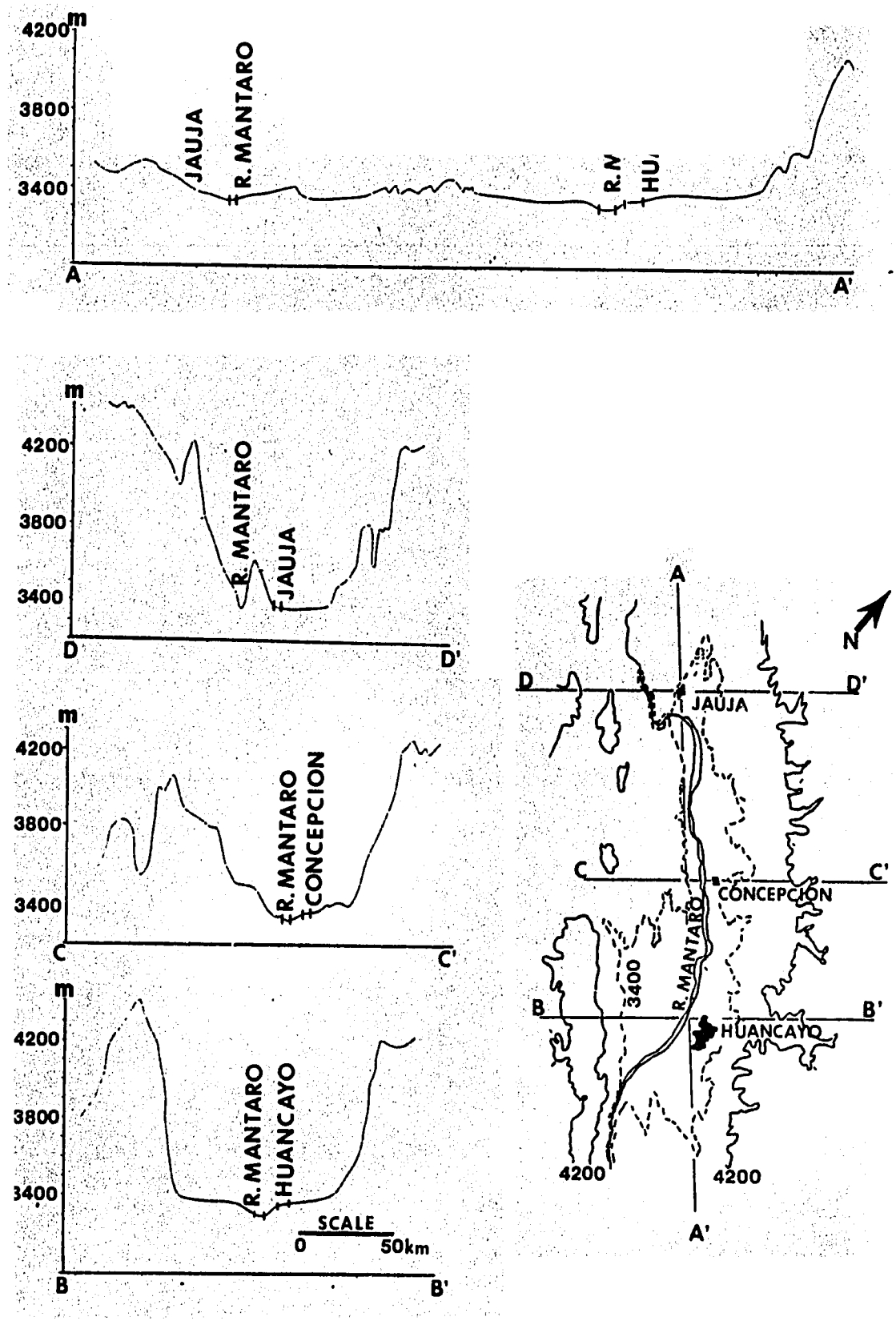


Figure 2.12. Selected Cross Sections through the Mantaro Valley

Cortes Transversales a Traves del Valle del Mantaro

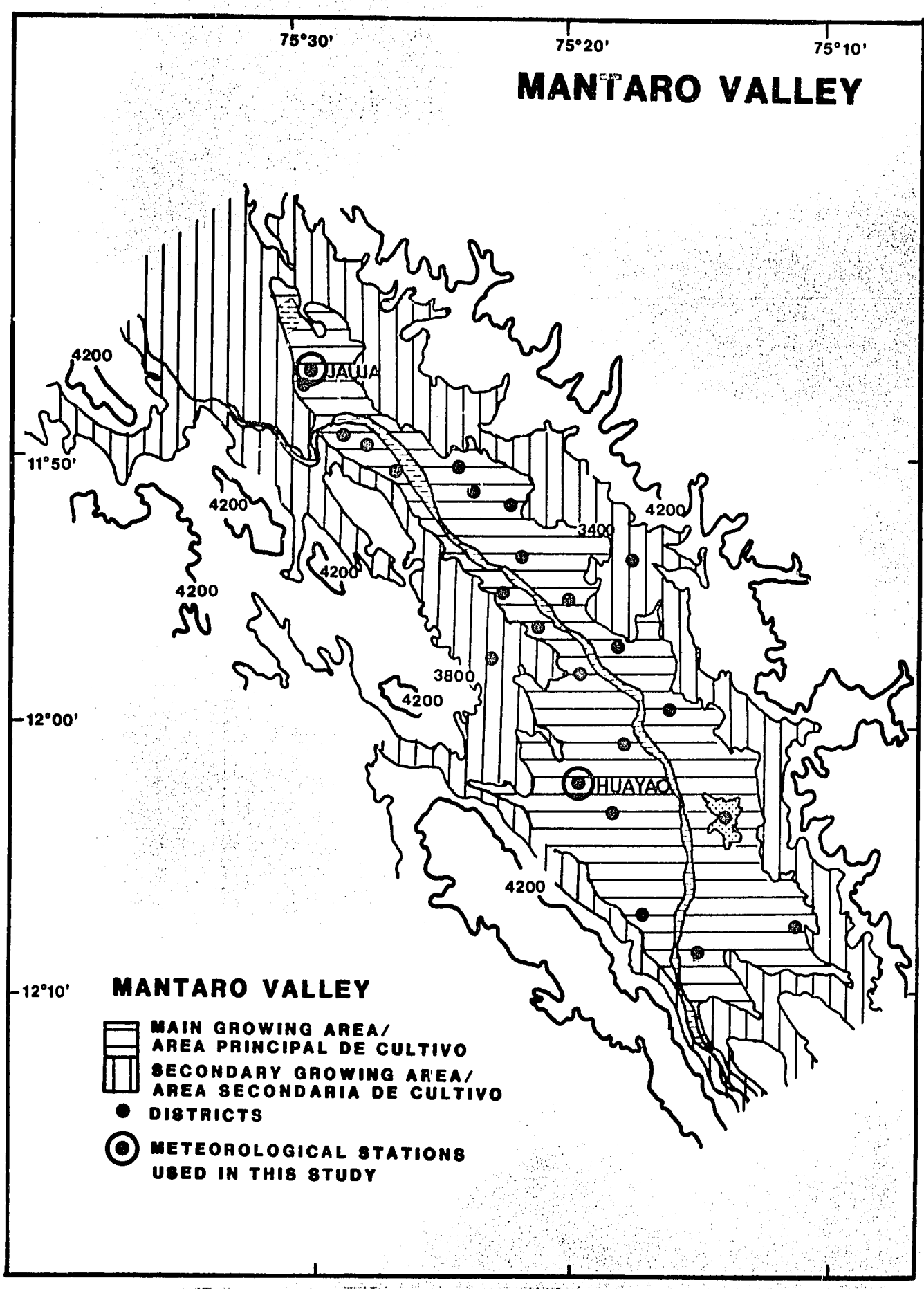


Figure 2.13. Primary and Secondary Crop Growing Areas in the Mantaro Valley

Area de Cultivo Principal y Secundaria en el Valle del Mantaro

temperature and precipitation anomalies which sometimes occur during the early vegetative stage of the crops cause serious damage, consequently reduced yields.

Crops are distributed in the Valley according to mesoclimatic conditions and soil quality. In the lower regions of the Valley there are deeper soils and temperature is not as limiting as in the hills of the Valley. Barley, wheat and pasture for livestock are grown on these slopes. A list of crops, some of which are mainly for the farmer's consumption, is provided in Table 2.4. The planting and harvest dates, i.e. crop calendar, for the most important crops are indicated in Table 2.5.

Therefore, the success of a particular growing season depends on the timely beginning of the rainy season, the distribution of rainfall during the growing season so that the water requirements of the crops in their different phenological stages are fulfilled, and the frequency and intensity of the agronomic frosts.

TABLE 2.4

PERU

Primary Crops and Pastures Grown in the Mantaro Valley of Peru

CROP		RAINFED	IRRIGATED
Pastures:	Lucenic		X
	Barley-forage	X	
	Oats-forage	X	
Annual: crops	Potato	X	X
	Wheat	X	
	Field Corn	X	
	Sweet Corn	X	X
	Peas (dry)	X	
	Peas (green)	X	
	Lima Beans (dry)	X	
	Lima Beans (green)	X	
	Barley (grain)	X	
	Malt	X	
	Onions		X
	'Quinua' (*)	X	
	'Mashua' (*)	X	
	Vegetables		X

TABLE 2.5

PERU

Planting and Harvest Months of Rainfed Crops in the Mantaro Valley of Peru

CROP	PLANTING	HARVEST
Field Corn	Sep/Oct	May
Sweet Corn	Sep/Oct	Mar/Apr
Potato	Sep/Oct	May
Potato (V. Renacimiento)	Sep/Oct	Feb/Mar
Wheat	Nov/Dec	Jun
Barley	Nov/Dec	Jun
Malt	Nov/Dec	May
Lima Beans (dry)	Sep/Oct	Apr/May
Lima Beans (green)	Sep/Oct	Mar
Peas (dry)	Sep/Oct	May
Peas (green)	Sep/Oct	Mar

CHAPTER III

METHODOLOGY AND ANALYTIC RESULTS

A. Data

1. Meteorological Data

Meteorological data used in this study consist of: 1) monthly mean temperature and total precipitation at Huayao/Huancayo (12°02'S, 75°19'W, 3370 m) and Jauja (11°45'S 75°30'W, 3410 m) as shown in Figure 2.13, and 2) daily values of all meteorological elements (pressures, temperatures, humidity, vapor pressure, cloud cover, sunshine hours, radiation, wind and precipitation), observed at Huayao/Huancayo for the period 1960-1980. Although there is a relatively longer series of monthly data for both Jauja and Huayao, the base data for this study corresponds to the years 1960-1980.

2. Agricultural Data

As noted in Chapter II, there are a large number of crops grown in the Mantaro Valley. Eleven crops (Table 2.4) were treated in the climate/crop yield modeling. Data used were for rain-fed crops which are most extensively grown. The agricultural data (acreage, production and yield) correspond to the period 1971-1980. These data were taken from the yearly report provided by the crop reporting districts within the Valley. An annual mean yield for the Valley was computed for each year. This required aggregation of approximately 37, 15, and 35 districts each year in Huancayo, Conception and Jauja Provinces, respectively.

3. Capabilities and Limitation of Data

Production and acreage data were not available in some districts for some years. Because only acreage information was reported in 1977, it was not used for the crop modeling.

The daily meteorological data for Huayao is of high quality. All meteorological elements which are required for estimating potential evapotranspiration (PET) as well as for crop modeling are available. The monthly temperature data have some missing values, which were filled in with the long-term mean. Missing precipitation data at Jauja were estimated by ratioing methods using long-term monthly means at Jauja and Huayao and actual data at Huayao. This procedure is reasonable because of the short distance between the two stations. Quality control of the daily meteorological data to delete erroneous cases was completed by comparisons of daily, decadal and monthly values with appropriate "normals". Meteorological elements were also examined by correlation analysis and scatter diagrams. Questionable values were deleted. In computing monthly values from daily observations, at least 28 daily observations were required.

B. Analytic Methods

1. Climatological Analysis

The daily minimum temperature was classified according to:

Low:	Minimum temperature $\leq 2°C$
Medium:	$2°C <$ minimum temperature $\leq 6°C$
High:	Minimum temperature $>6°C$

The "low" class is considered to represent frost conditions on the ground. This assumes that a temperature inversion is present within the atmospheric layer near the ground. The "medium" class was treated to represent conditions associated with agronomic frost for threshold temperature values of +2 and +6°C. At minimum temperatures greater than +6°C, the temperature may not be a limiting factor unless the crop is very susceptible to low temperature. All meteorological elements were analyzed according to each minimum temperature stratification. These daily associations were analyzed in terms of concurrent

and antecedent conditions (previous 1 and 2 days) to develop a preliminary model for frost advisories to farmers. Decadal and monthly relationships were also investigated. Decadal "normals" as well as monthly "normals" were computed.

By analyzing the daily data at Huayao from the beginning to the end of the "hydrological" year (August through July), the dates of the last spring and first fall frost for each year were determined. The threshold values used to define frosts was: -4°C, -2°C, 0°C, +2°C and +4°C which correspond to meteorological frosts (T min $\leq$0°C) and agronomic frosts. Table 3.1 provides the mean date of frost occurrence as well as the mean duration of the frost-free periods. The empirical probabilities for frost occurrence were computed for each decade of the year (Figure 3.1 and Table 3.2).

Monthly and decadal normals for precipitation were determined for Huayao and Jauja (Figures 3.2a-b, 3.3a-b and 3.4). The comparison of precipitation-potential evapotranspiration normals is illustrated in Figure 3.5.

The occurrence of drought was examined at both Huayao and Jauja by using the Palmer Drought Index (PDI) according to Palmer (1965). The potential evapotranspiration (PET) needed for computing the PDI was obtained by the Penman Method.

Linear correlations were used to establish dependence between meteorological elements and to investigate time-trends.

2. Potential Evapotranspiration

The quantity of water transpired by a crop is a measure of the physiological activity of the plants and their interaction with the energy and water balances in the lower atmosphere-crop-soil system. Because it is rather difficult to

Table 3.1

Mean Dates of last spring-frost, early fall-frost and duration of frost-free period for indicated threshold temperatures at Huayao, Peru, 1960-1980.

Threshold Temperature (°C)	Spring-frost	Fall-frost	Frost-free period (days)
-4	Aug 10	Jun 13	308
-2	Aug 24	May 26	275
0	Sep 22	May 1	221
+2	Nov 30	Mar 5	95
+4	Dec 21	Jan 25	35

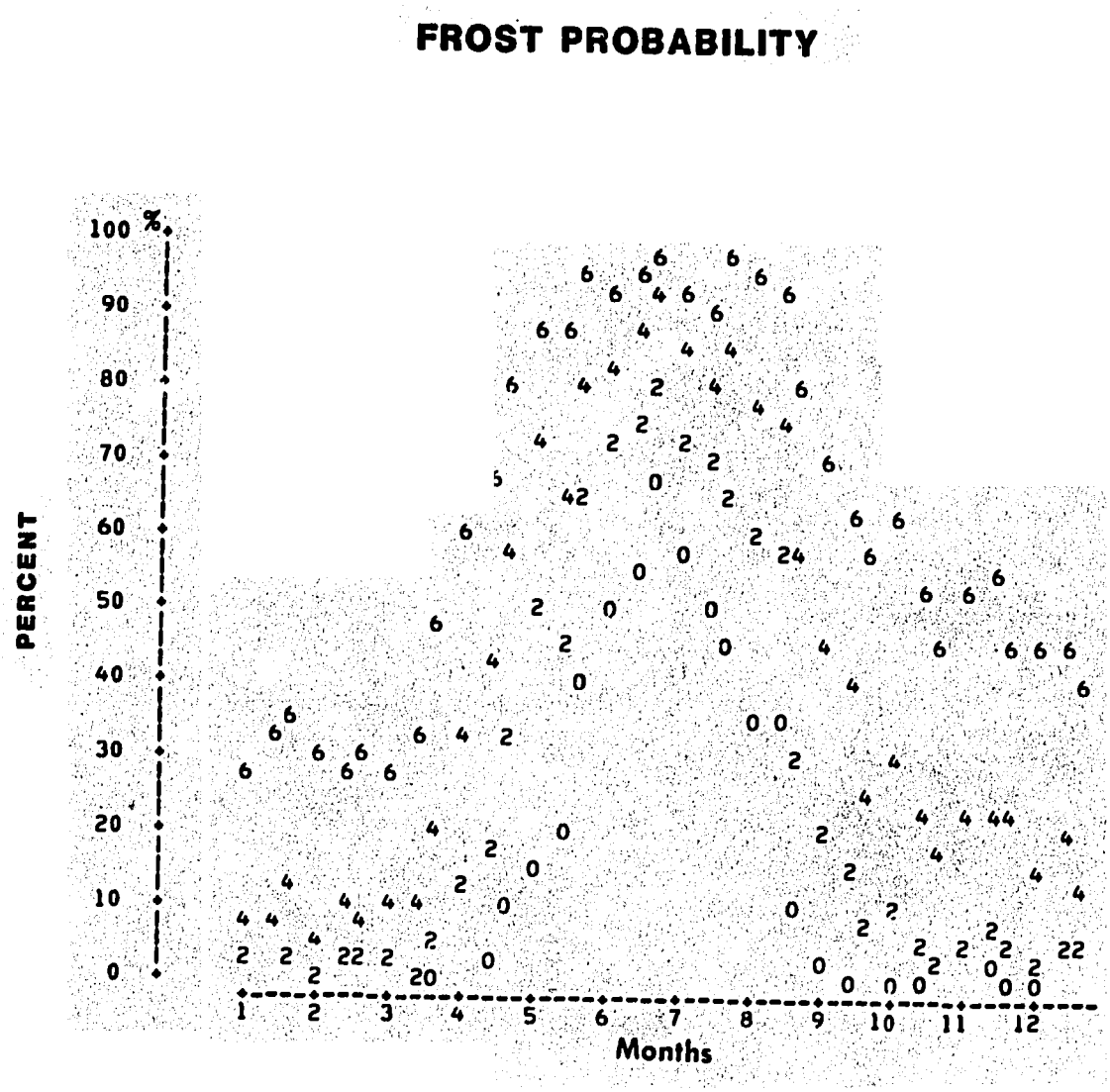


Figure 3.1. Probability of Meteorological and Agronomic Frosts by Decades for Huayao, Peru

Probabilidad de Ocurrencia de Heladas Meteorologicas y Agronomicas por Decadas para Huayao, Peru

OBS	MODEC	PHEL	PHELP2	PHELP4	PHELP6
1	1.00	.	1.7341	8.6705	28.3237
2	1.33	.	.	8.1395	32.5581
3	1.67	.	3.0769	11.7949	34.3590
4	2.00	.	0.5000	4.0000	29.5000
5	2.33	.	2.5126	10.0503	27.6382
6	2.67	.	1.8182	7.2727	29.0909
7	3.00	.	2.5000	10.5000	28.5000
8	3.33	.	1.0526	11.0526	31.5789
9	3.67	0.9302	4.1860	20.4651	46.5116
10	4.00	.	11.3744	33.1754	60.1896
11	4.33	2.8846	16.3462	43.2692	67.3077
12	4.67	10.5263	32.5359	57.8947	79.9043
13	5.00	15.4589	50.2415	72.9469	86.9565
14	5.33	21.1055	44.2211	63.8191	87.9397
15	5.67	41.0959	63.9269	79.4521	94.0639
16	6.00	49.0000	71.5000	83.5000	93.0000
17	6.33	55.0000	76.0000	86.5000	95.0000
18	6.67	67.5000	81.0000	91.5000	96.5000
19	7.00	56.6138	72.4868	84.1270	93.1217
20	7.33	49.7354	69.8413	80.4233	91.0053
21	7.67	44.1748	65.0485	84.4660	96.6019
22	8.00	34.7594	60.4278	76.4706	94.1176
23	8.33	34.0314	57.0681	73.8220	92.6702
24	8.67	11.0092	31.1927	57.7982	79.8165
25	9.00	3.6649	20.9424	44.5026	71.2042
26	9.33	0.5319	13.8298	39.3617	62.7660
27	9.67	.	6.3492	25.3968	57.1429
28	10.00	0.5000	10.0000	29.5000	63.0000
29	10.33	1.0000	5.0000	22.5000	51.5000
30	10.67	.	1.3761	17.4312	45.4128
31	11.00	.	4.1237	23.7113	51.5464
32	11.33	1.5306	7.1429	23.4694	56.1224
33	11.67	0.5051	4.0404	22.2222	44.4444
34	12.00	1.0753	2.1505	13.9785	45.6989
35	12.33	.	4.8649	18.9189	45.4054
36	12.67	.	4.4554	13.3663	41.0891

Table 3.2. Empirical Probabilities of Occurrence of Meteorological and Agronomic Frosts for Huayao/Huancayo, Peru, 1960-1980

Probabilidad de Ocurrencia de Heladas Meteorologicas y Agronomicas para Huayao/Huancayo, Peru, 1960-1980

(MODEC=decade, PHEL: T=0°C, PHELP2: T=2°C, PHELP4: T=4°C and PHELP6: T=6°C)

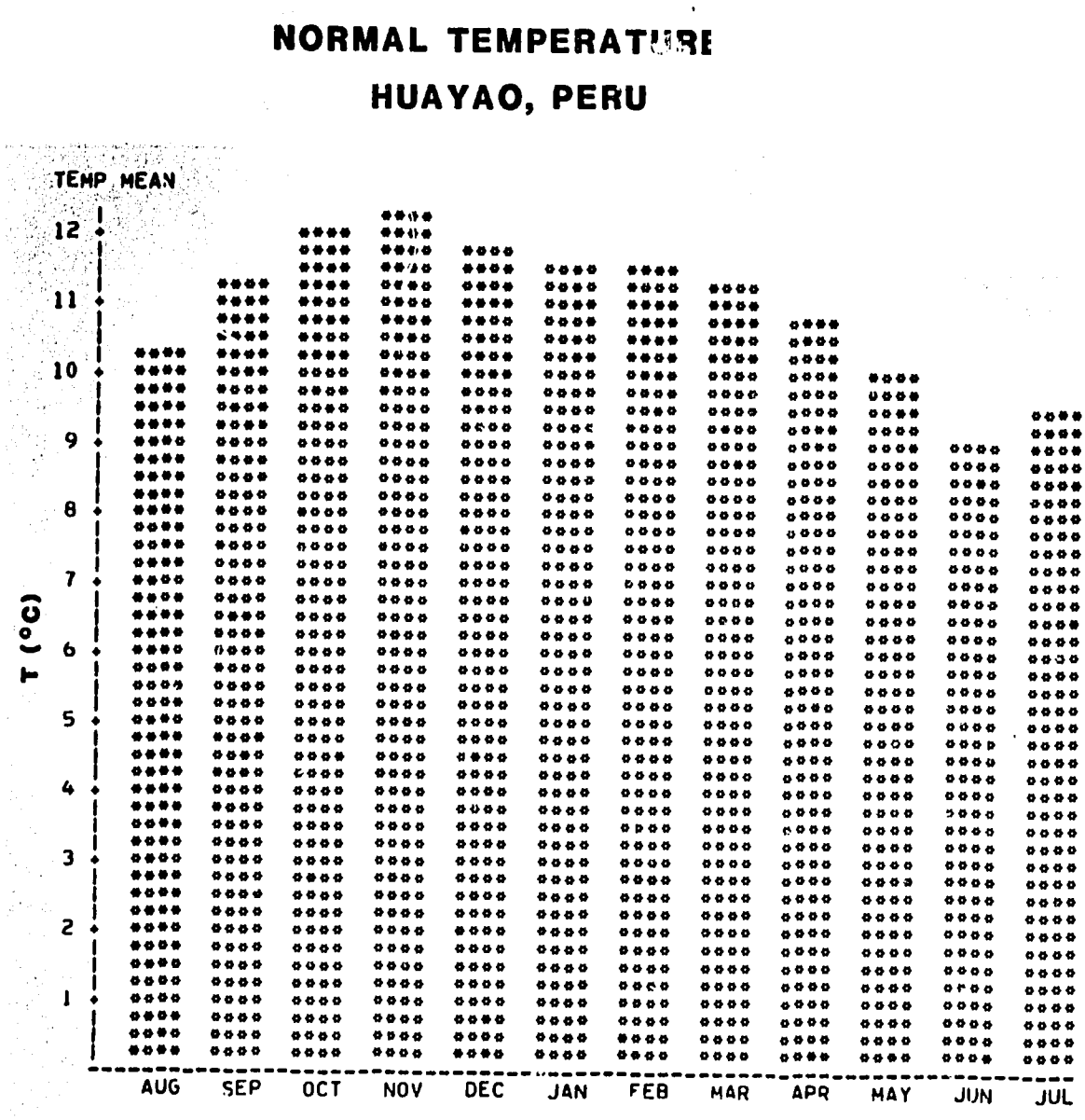


Figure 3.2a. Monthly Normals for Temperature (°C) for Huayao, Peru

Normales Mensuales de Temperatura (°C) para Huayao, Peru

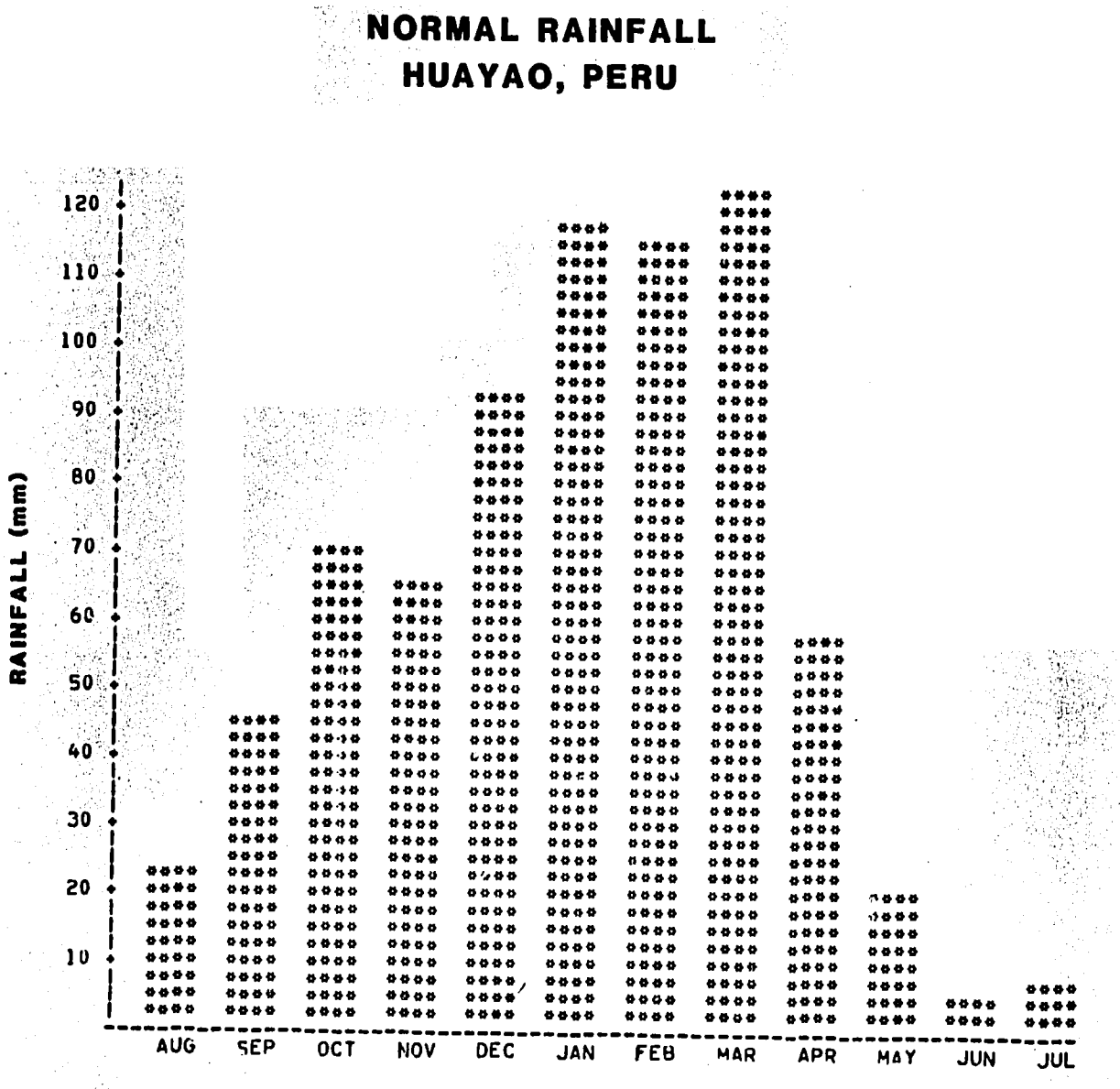


Figure 3.2b. Monthly Normals for Precipitation (mm) for Huayao, Peru

Normales Mensuales de Precipitacion (mm) para Huayao, Peru

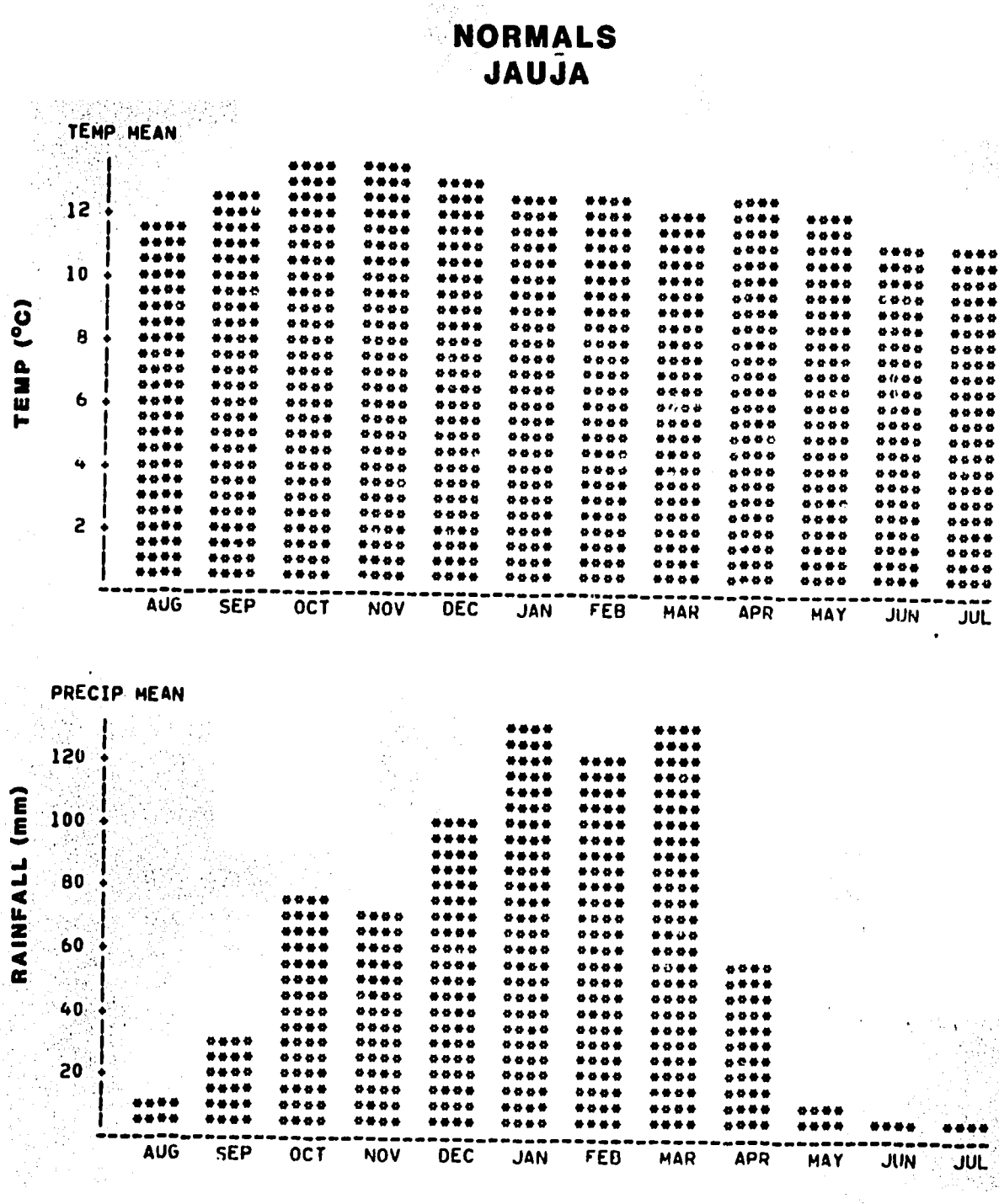


Figure 3.3a-b. Monthly Normals for Temperature (°C) and Precipitation (mm) for Jaúja, Peru

Normales Mensuales de Temperatura (°C) y Precipitacion (mm) para Jauja, Peru

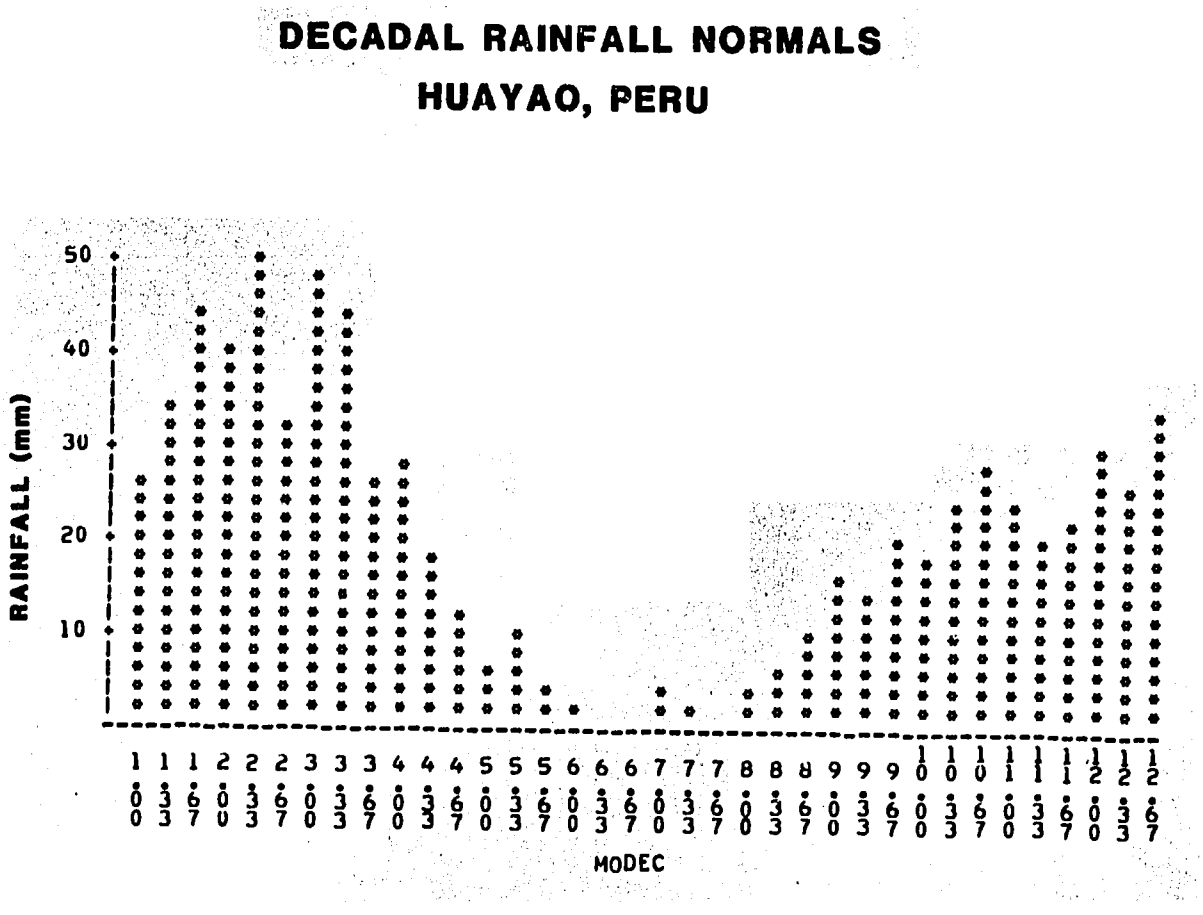


Figure 3.4. Decadal Normals for Precipitation (mm) for Huayao/Huancayo, Peru, 1960-1980

Normales Decadarios de Precipitacion (mm) para Huayao/Huancayo, Peru, 1960-1980

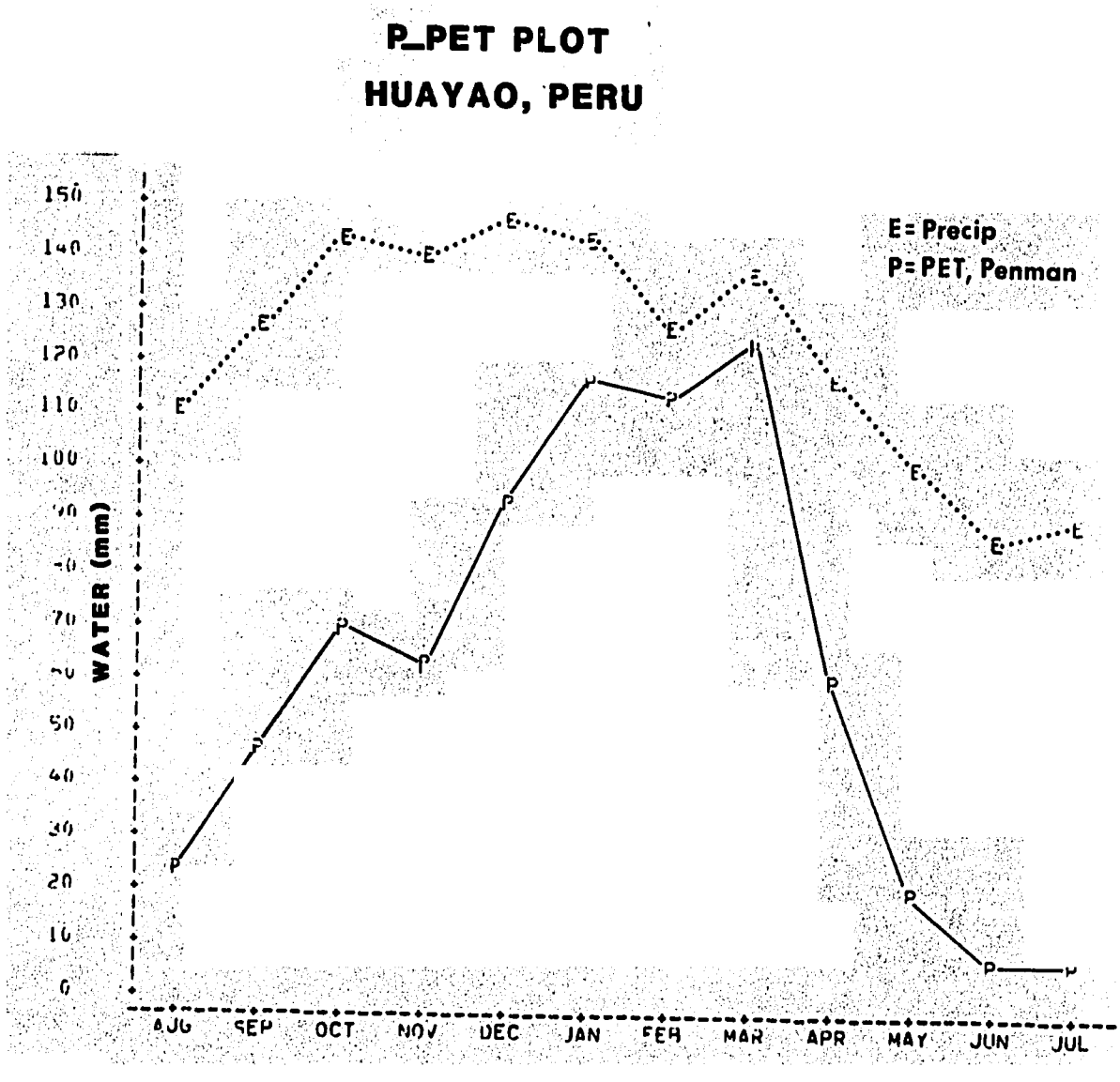


Figure 3.5. Monthly Normals of Potential Evapotranspiration (mm) and Precipitation for Huayao/Huancayo, Peru

Normales Mensuales de Evapotranspiracion Potencial (mm) y Precipitacion (mm) para Huayao/Huancayo, Peru

quantify this water vapor flux in open fields, special conditions such as unlimited soil moisture supply and complete ground cover by short green plants must be considered in order to estimate the maximum water flux, which is called potential evapotranspiration (PET) for a reference crop.

There have been many attempts to develop a methodology for estimating PET (WMO, 1969). Some of these are described below.

Penman Method

A simplified version of Penman equation (1948) is presented by Rosenberg (1974) in the following form:

$$PET = \frac{aRn + bc\,(e_s - e_a)(1 + U_2 \times 10^{-2})}{a + b} \text{ [mm/day]}$$

where:

a = slope of the saturation vapor pressure curve for pure water at mean temperature (mmHg °F^{-1}),

R_n = net solar radiation (mm/day),

b = constant in the hygrometric equation (0.27 mmHg °F^{-1}).

c = constant (0.35),

e_s = saturation vapor pressure (mmHg),

e_a = actual vapor pressure (mmHg), and

U_2 = mean wind speed at 2 m (km/day).

This method has the advantage that it considers both the energy (solar radiation) and vapor fluxes within the crop canopy's evapotranspiring surface and the lower atmosphere. It does not account for advective fluxes such as sensible and latent energy. However, an operational disadvantage of the method is that the required meteorological elements (solar radiation or sunshine

used to estimate solar radiaton) are not observed at very many weather stations in the country. The Penman method can be used for daily, decadal and monthly time scales.

Thornthwaite Method

This method is based only on mean monthly air temperature and was expressed by Thornthwaite (1948) as follows:

$$PET = 1.6 \left(\frac{10T}{I}\right)^{a} \qquad [cm/month]$$

where:

T = monthly mean air temperature (°C)

I = annual heat index which is function of T

a = polynomial function of I.

An adjustment for latitude is required for locations with day lengths different than 12 hours. This method has the great advantage of using only one meteorological element and the local latitude as input. This is the main reason it has been used worldwide. But we should be aware that mean temperatures do not necessarily correspond to the surface energy balance which is closely related to the evapotranspiration process. If temperature determines PET, then this method can probably be used.

Hargreaves' Method

Hargreaves (1975) developed an equation for computing PET based on solar radiation (or sunshine hours) and temperature:

$$PET = 0.0075\ (RSM)TF \qquad [mm/month]$$

where;

RSM = solar radiation (mm/day)

TF = monthly mean temperature (°F),

The method requires solar radiation data that is not always available. If only temperature and sunshine information are available, it is possible to estimate solar radiation. Hargreaves has developed several empirical formulas to estimate solar radiation from a variety of commonly observed meteorological elements.

Pan Evaporation

If we desire to consider all meteorological elements which are involved in the processes of evaporation and transpiration, then Pan Evaporation information is useful. But as Doorenbos and Pruitt (1977) have noted, there are some limitations to Pan Evaporation data. Net radiation over water is quite different from that over crops because of differing reflectivities. The daily temperature of the water mass differs from the active surface of a plant canopy and according to the location of the pan relative to the crops and wind circulation. Thus, the water losses may be different. There are potentially serious disadvantages to this type of measurement if there are water-level changes in the pan due to non-meteorological factors or if corrections are not made for precipitation.

Crop coefficients

The amount of water that any crop can lose by evapotranspiration under unlimited soil moisture conditions as well as free from other limiting factors is not the same as that from a reference crop PET. Thus, a coefficient is needed to explain the water requirements of a specific crop during its different stages of growth and development. Doorenbos and Pruitt (1977) define this crop coefficient (KC) as:

$$KC = \frac{PET_{crop}}{PET_{ref}}$$

This explains why two different crops have a different response given the same water supply (by rainfall or irrigation) or why the same crop responds differently in two stages given the same water supply. For example, the crop coefficients for rice are larger than those for maize and those for maize are larger than crop coefficients for yuca. The rice water requirement is quite large while water rquirement for yuca is much smaller, i.e., yuca is more drought resistant. Crop coefficients for a given crop are usually largest for the flowering/reproductive stage relative to other stages, for example, planting and early vegetative stages. Crop water demand is equal to the product of the specific crop coefficient and reference PET (e.g., calculated by Penman).

Crop coefficients should be tested for the location to be applied especially if the climatic characteristics differ substantially from those where the coefficients were obtained. The advantage of using crop coefficients is that one is able to evaluate more exactly if the soil moisture (precipitation) meets the crop water requirement during each of its stages.

Therefore, reference PET can be adjusted by crop coefficients to estimate the crop's water requirement for each crop stage and the entire crop season at a specific location. The probability of this requirement being satisified can be estimated from historical data. This is a major land use tool. Crop coefficients have also been used by Steyaert, Ravelo and Achutuni (1979) to develop historical agroclimatic/crop condition indices for use in the Caribbean Basin. Because crop coefficients represent the relative water requirement between crop stages, an improved cumulative rainfall index based on weighted rainfall data can be developed.

3. Soil Moisture Budgets

The growth and development of a crop depends on the water available to it in the root system. Soil moisture is difficult to measure directly in the field. Estimates of soil moisture can be determined from agroclimatic techniques; however, one should only view these estimates as an index of soil moisture conditions. Simple water balance equations based on gains and losses can provide useful information if capabilities and limitations are carefully considered.

Thornthwaite proposed the one-layer water balance model:

$$Si = Si-1 + P - PET\ (Si-1)/FC$$

where:

Si is the soil moisture estimate,

Si-1 is the soil moisture for the previous period,

P is precipitation,

PET is potential evapotranspiration, and

FC is the field capacity of the soil.

In contrast to this one-layer model, Palmer (1965) discusses a two-layer model in which the second layer is termed the "plough" layer. The Palmer two-layer model has been extensively used throughout the world. Although Palmer and Thornthwaite recommend estimating PET by the Thornthwaite Method, other methods can be used, e.g., the Penman Method. In many subtropical regions the year-to-year variability of PET is quite small compared to rainfall variability. Thus, in some cases it is reasonable to use "normal" PET in the soil moisture budgeting process.

The Palmer Drought Index (PDI), also described by Palmer (1965), is an important application of the Palmer two-layer soil moisture model. The PDI is

an index which provides relative information on moisture conditions ranging from extreme drought to very wet conditions. The PDI acts as an integrator of climatic conditions. It is based on the Z-index which measures the moisture anomally according to the locally appropriate climatic conditions (i.e., long-term means). Sakamoto (1978) used the Z-index as the primary climatic predictor variable in statistical climate/wheat yield models for Australia. Steyaert, Ravelo and Sakamoto (1980) discuss application of the PDI as an important indicator of crop failure/food shortages due to drought and hurricanes.

R-Index

An estimate of the actual evapotranspiration (ET) of the crop is obtained in the soil moisture budgeting process. Yao (1969) has defined the R-Index to be the ratio of ET (a measure of moisture supply to the crop) to PET (moisture demand on the crop). The index ranges from 0.0 to 1.0, or extreme stress to no stress condition, respectively.

The R-Index has been used in two types of applications: as a predictor in statistical climate/crop yield models and also in land use studies. For example, the R-Index for the flowering/reproductive stage is sometimes highly correlated with crop yield. Yao (1973) used the R-Index as a land use tool to demonstrate that climatic conditions in regions of Tanzania would not permit groundnut production without irrigation. This classic analysis demonstrated that millions of dollars could have been saved by the investors if very inexpensive agroclimatological analysis had been used as part of the planning process.

The R-Index and crop coefficients has also been used to estimate optimum crop calendars (Ravelo and Steyaert, 1981).

FAO Index

Frere and Popov (1977) have developed an agroclimatic/crop condition index for use in subtropical regions. The index uses a simplified water balance which is based on crop coefficients to obtain the crop water requirement.

C. Analytic Results

1. Frost

Low temperature may be a limiting factor which causes actual yield to be well below potential yield. Depending on the physiological stage of the crop, the nocturnal temperature may cause partial or total damage to the plant components if they are exposed to intensive radiational cooling. Each growth stage of a plant requires that the temperature should be higher than the corresponding threshold temperature for growth without restraints. If the temperature drops below this threshold value, then the plant suffers some physiological damage. Normally the effects of low temperatures are not detected immediately, but are reflected in final yields. Reduced yields or low quality of the productive parts of the plant may be the consequence of low temperature.

The damage is more serious if the temperature falls below the freezing point of water (°C) because the effect on the plant is not reversible. It is important to know if the reproductive parts were damaged which could mean that the economic losses are at a maximum. This last type of frost is of major concern in the Mantaro Valley. Frosts which occur during December and January are the most dangerous for maize, potatoes and lima beans. If frost occurs during these months, replanting is usually not feasible because the remaining growing season is too short for a normal growth and development of the crop.

Frequency of Occurrence and Empirical Probabilities

The long-term, decadal mean minimum temperature (Figure 3.6) for Huayao ranges from +7°C in the summer months to frost conditions in June and July. During some decades in October, November and December the mean minimum temperature drops instead of increasing with time as would be expected. This represents periods of potential frost during the early growth stages of most crops in the Valley. Agronomic frosts with threshold values of +6 and +4°C may occur until December (Figures 3.7a-b).

A minimum temperature of 2°C at the weather shelter (1.6m) may be an indicator of frosts at the soil surface or on the plant canopy. Thus, Figure 3.8a shows that these frosts may occur even in December. According to the monthly means, meteorological frost ($T \leq 0$°C) only occurs until September, the start of the growing season in the Valley, and then reoccurs in April, when most of the crops have reached the late maturity stages (Figure 3.8b). This can be very misleading as a land use guide. The mean date for the last spring frost occurs on September 22 (Table 3.1). The first fall frost occurs in the mean on May 1. The mean frost-free period is 221 days. The corresponding frost-free period for agronomic frosts of +2 and +4°C are naturally shorter, 95 and 35 days, respectively. This means that the introduction of new crops or varieties with high threshold values will not be successful unless the growing season of the crop is very short. The empirical probability of frost occurrence is shown in Figure 3.1 where 0, 2, 4 and 6 represents the probabilities for frosts with threshold values of 0, 2, 6 and 6°C, respectively. As expected, the probability drops (increases) from Winter (Summer) to Summer (Winter) months. However, an increase of the probability is noticeable even in October, November, December

DECADAL NORMAL MINIMUM TEMPERTURE

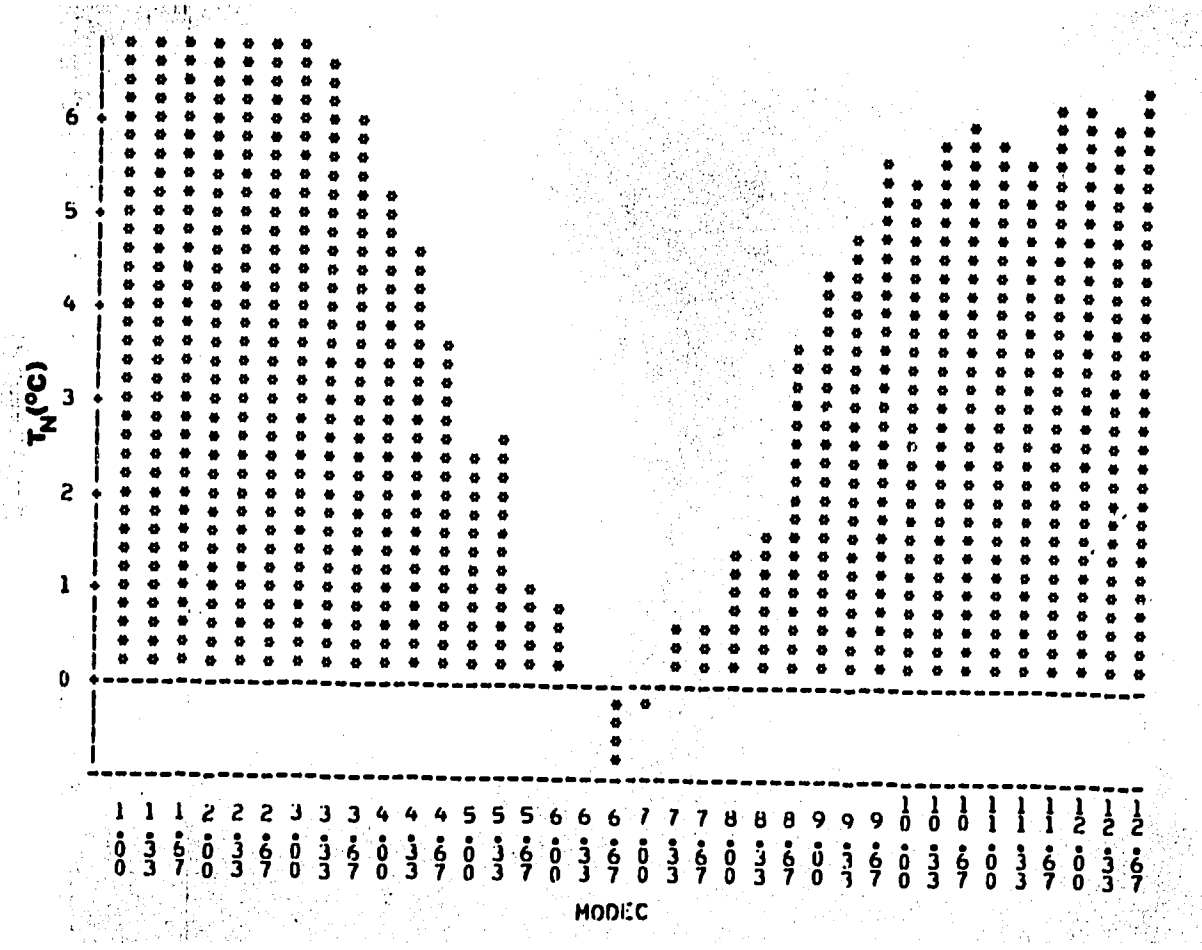


Figure 3.6. Decadal Normals of Minimum Temperature (°C) for Huayao/Huancayo, Peru, 1960-1980

Normales Decadarios de Temperatura Minima (°C) para Huayao/Huancayo, 1960-1980

FROST STUDY HUAYAO, PERU

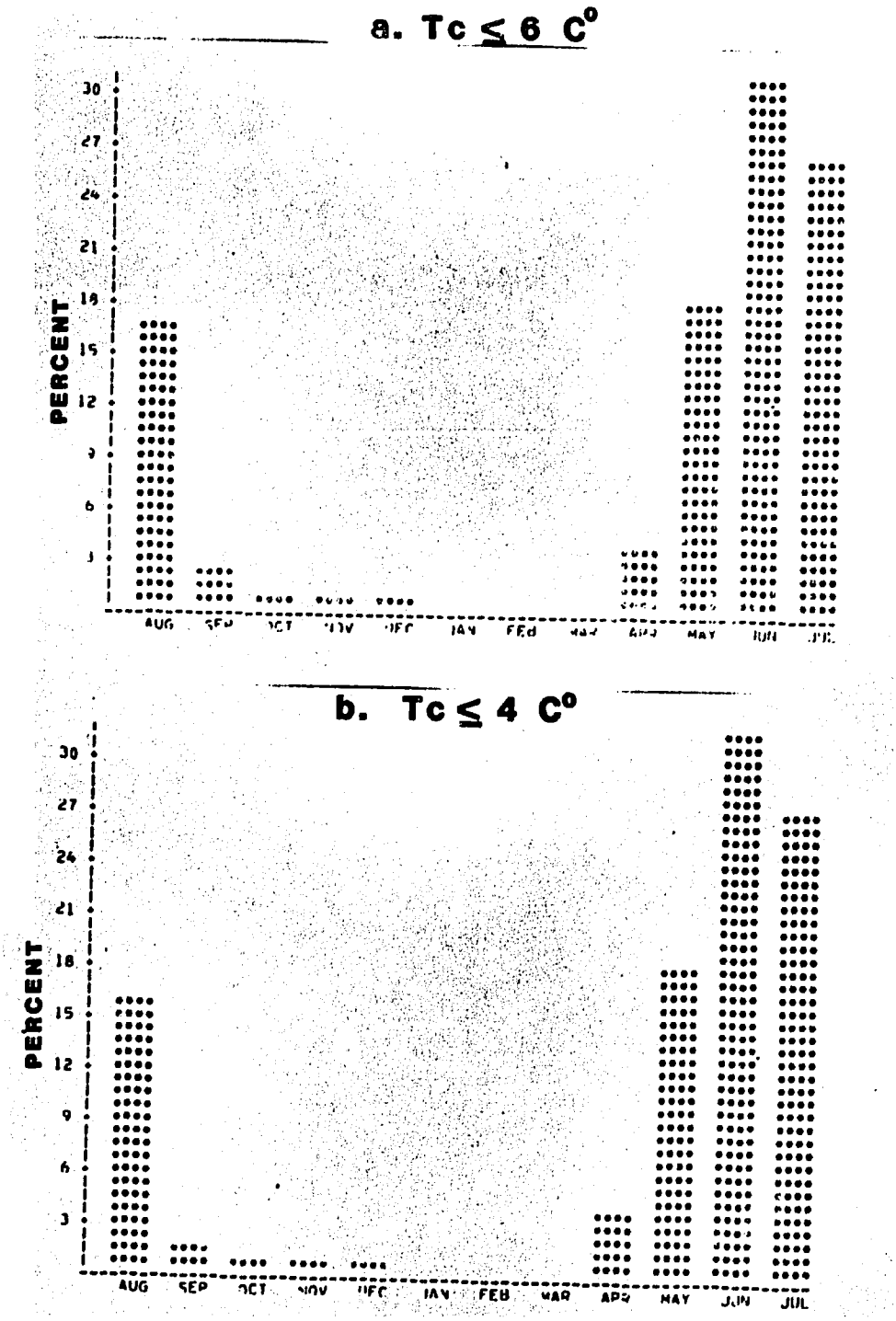


Figure 3.7a-b. Number of Agronomic Frosts, Expressed as a Percent of the Total Number of Frosts During the Period 1960-1980

Numero de Heladas Agronomicas, Expresado en % del Total de Casos Ocurridos en el Periodo 1960-1980

FROST STUDY HUAYAO, PERU

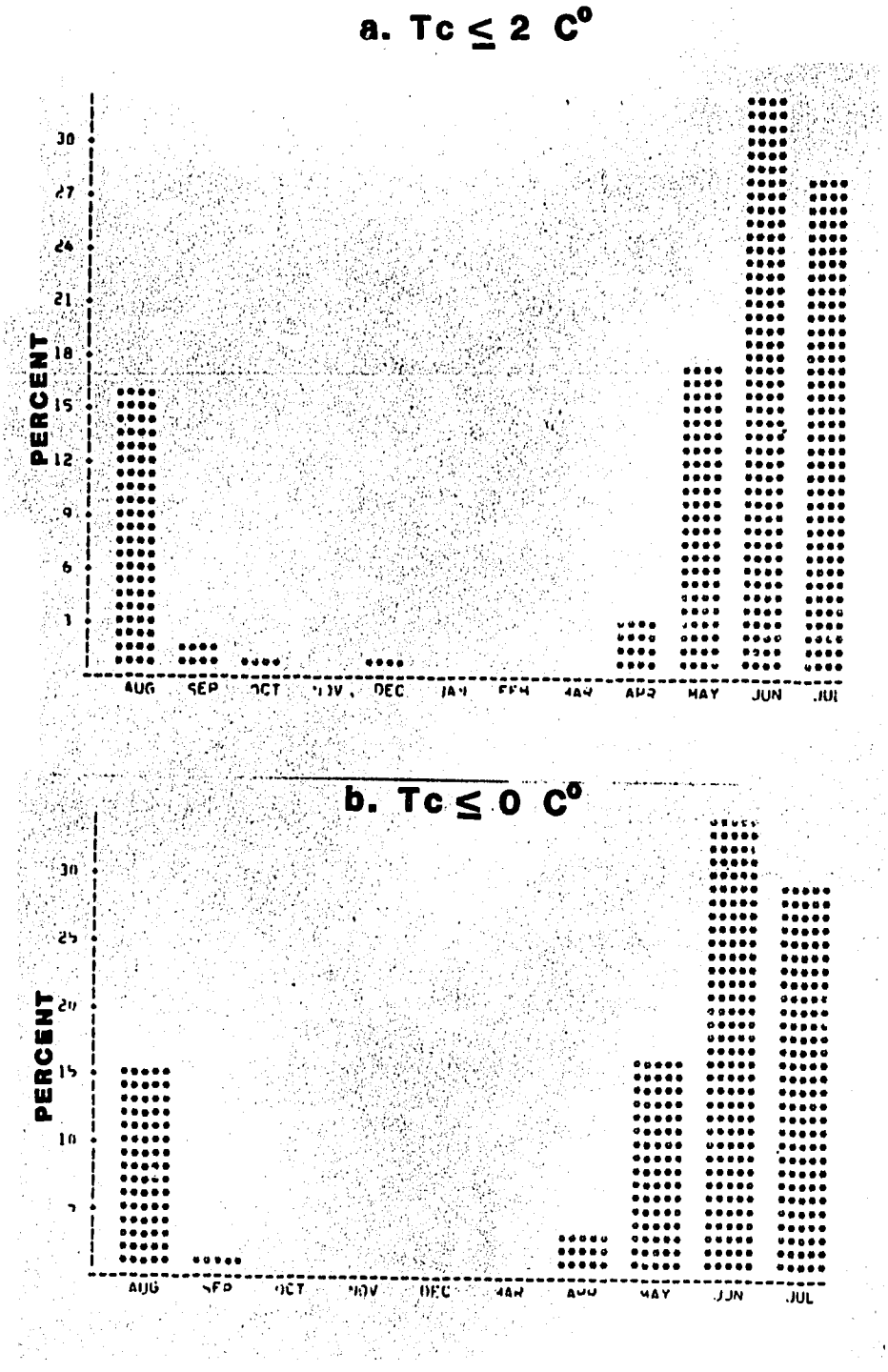


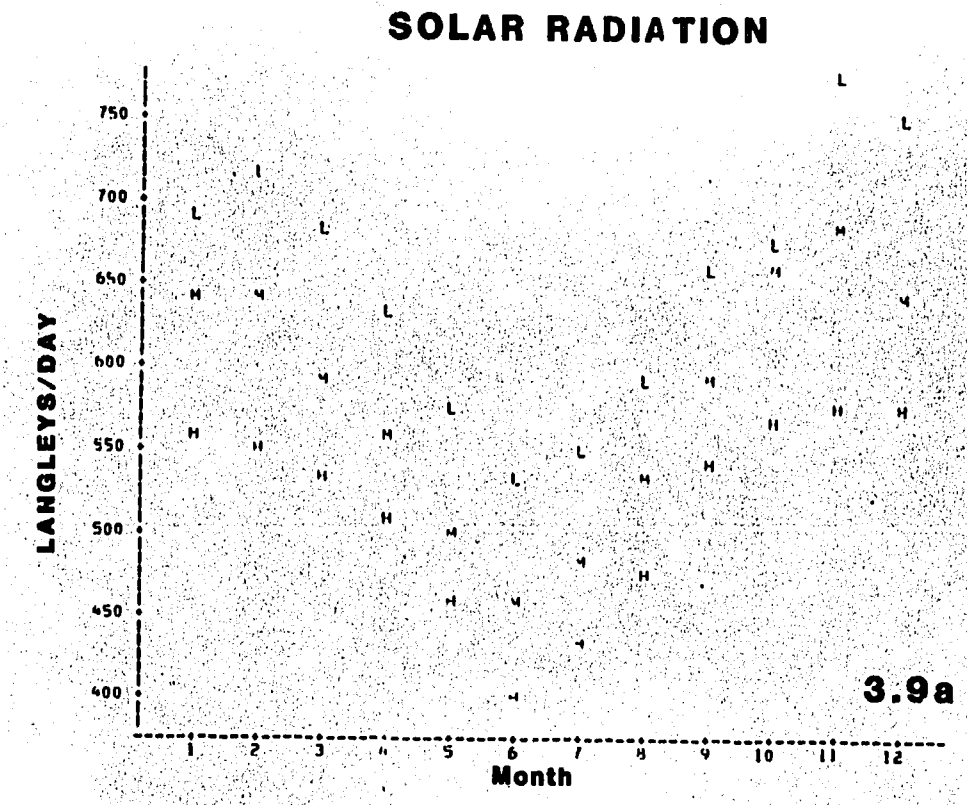
Figure 3.8a-b. Number of Agronomic and Meteorological Frosts, Expressed as a Percent of the Total Number of Frosts During the Period 1960-1980

Numero de Heladas Meteorologicas, Expresado en % del Total de Casos Ocurridos en el Periodo 1960-1980, Huayao/Huancayo, Peru

and January, indicating that there must be atmospheric circulation conditions which favor unusual, excessive radiational cooling. An examination of synoptic weather maps for South America suggested that southerly/southeasterly winds, possibly associated with synoptic low pressure systems located near Bolivia and Argentina, tend to be related to frost potential. Minimum temperatures greater than 6°C are associated with the more moist northeasterly flow regimes.

Figures 3.9a through 3.9e show meteorological elements stratified according to the previously defined "low", "medium" and "high" minimum temperature classes. These plots correspond to conditions on the same day of the occurrence of the minimum temperature class. Thus, Figures 3.9a and 3.9b show that "low" temperatures are followed by both lower cloudiness and higher solar radiation. If the minimum temperature is "high" then there is more cloud cover and less solar radiation. Therefore, we might expect that on the frost days the maximum temperatures must be much higher than are non-frost days (Figure 3.9c). Low temperatures are associated with small water vapor content in the atmosphere, here expressed as dew point (Figure 3.9d). There is a tendency for lower atmospheric pressures after the frost occurrence, but this is true only during the months of October through February. During the rest of the year there are pressure differences for the temperature classes. It also appears that static energy during the day after frost occurrence is much lower than on relatively warm nights (Figure 3.9e).

The same stratification on minimum temperature was performed on the meteorological elements observed on <u>the day before</u> the occurrence of the minimum temperatures (Figures 3.10a through 3.10f). The minimum temperature of the previous day is lowest for the frost-cases, suggesting some persistence of frost



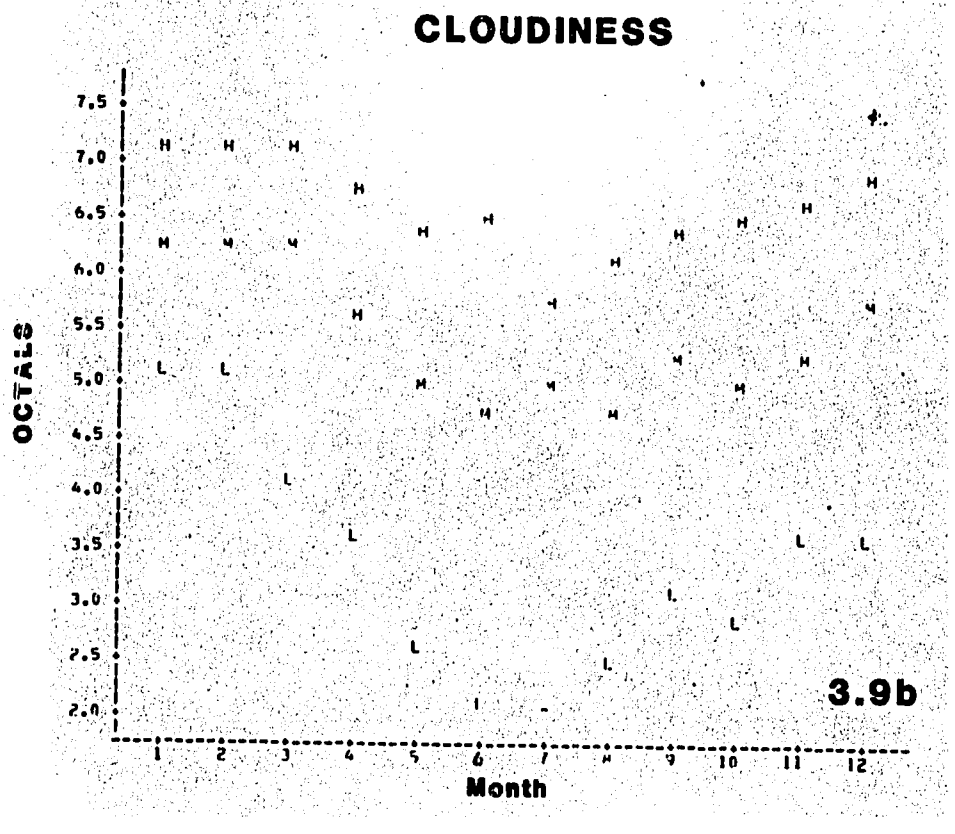
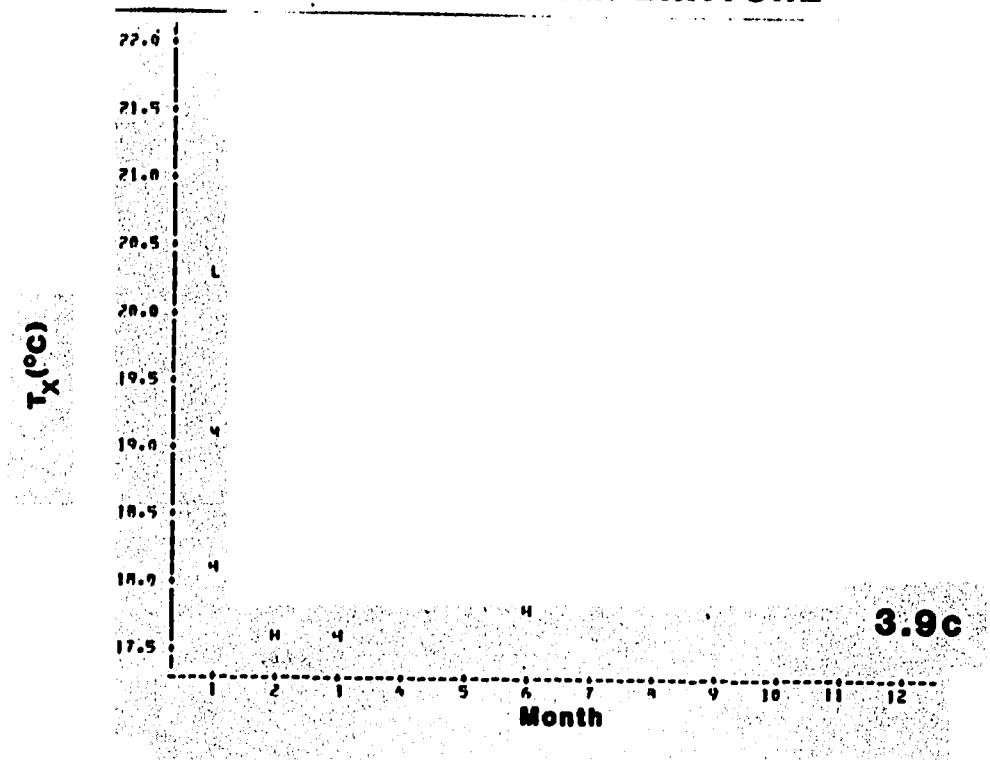


Figure 3.9a-e. Average of Indicated Meteorological Elements Stratified According to "Low", "Medium" and "High" Minimum Temperature Classes

Promedio de Elementios Meteorologicos Stratificados de Acuerdo a la Clase de Temperatura Minima: "Baja", "Media" y "Alta"

MAXIMUM TEMPERATURE



MEAN DEW POINT

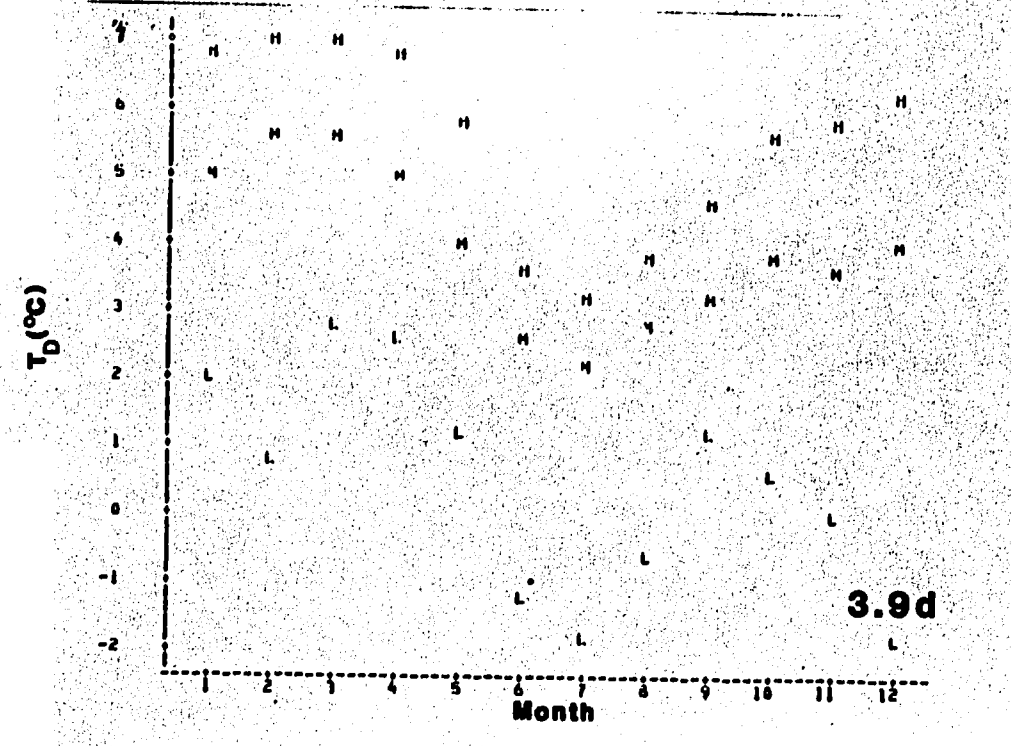


Figure 3.9a-e. Average of Indicated Meteorological Elements Stratified According to "Low", "Medium" and "High" Minimum Temperature Classes

Promedio de Elementios Meteorologicos Stratificados de Acuerdo a la Clase de Temperatura Minima: "Baja", "Media" y "Alta"

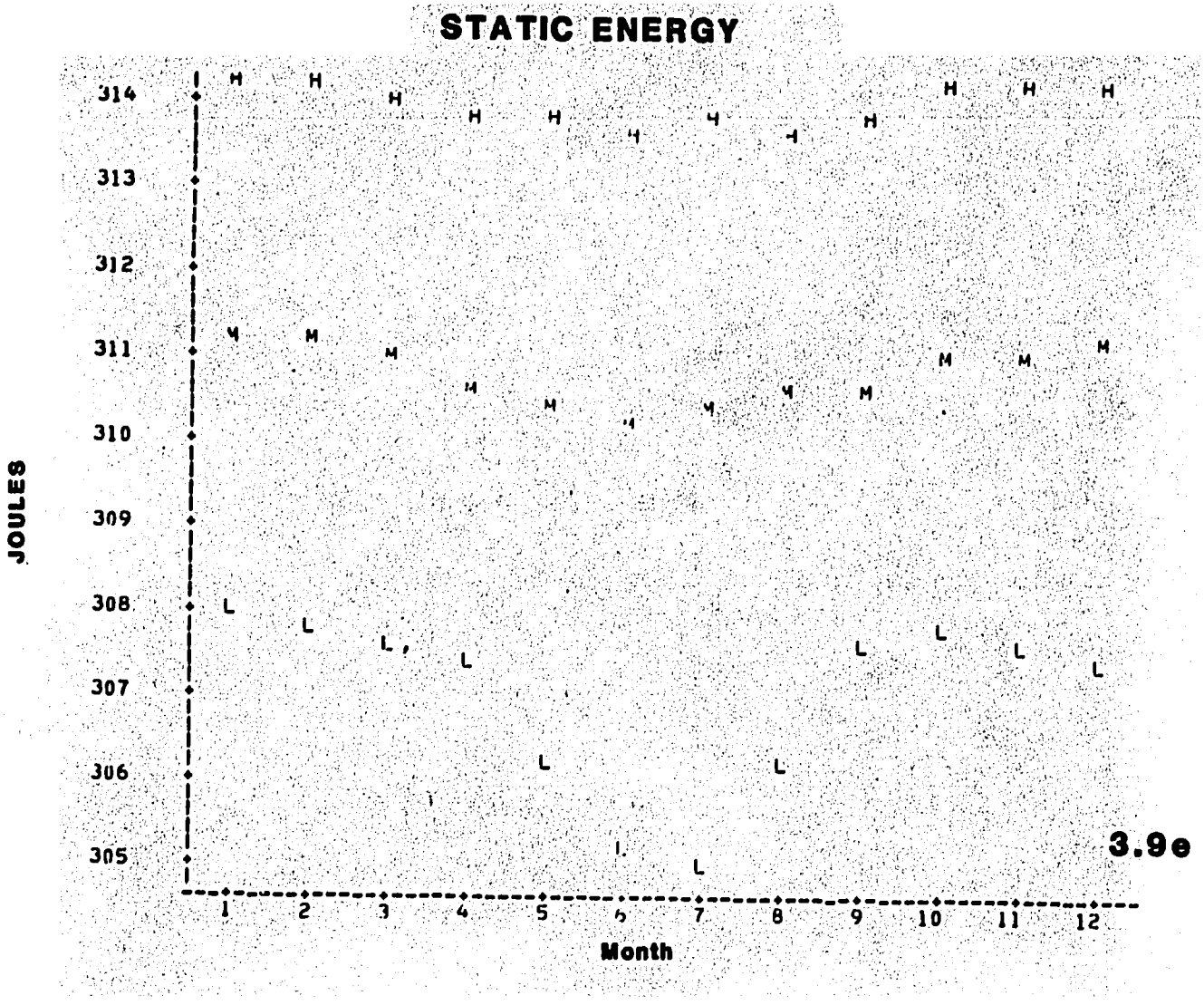
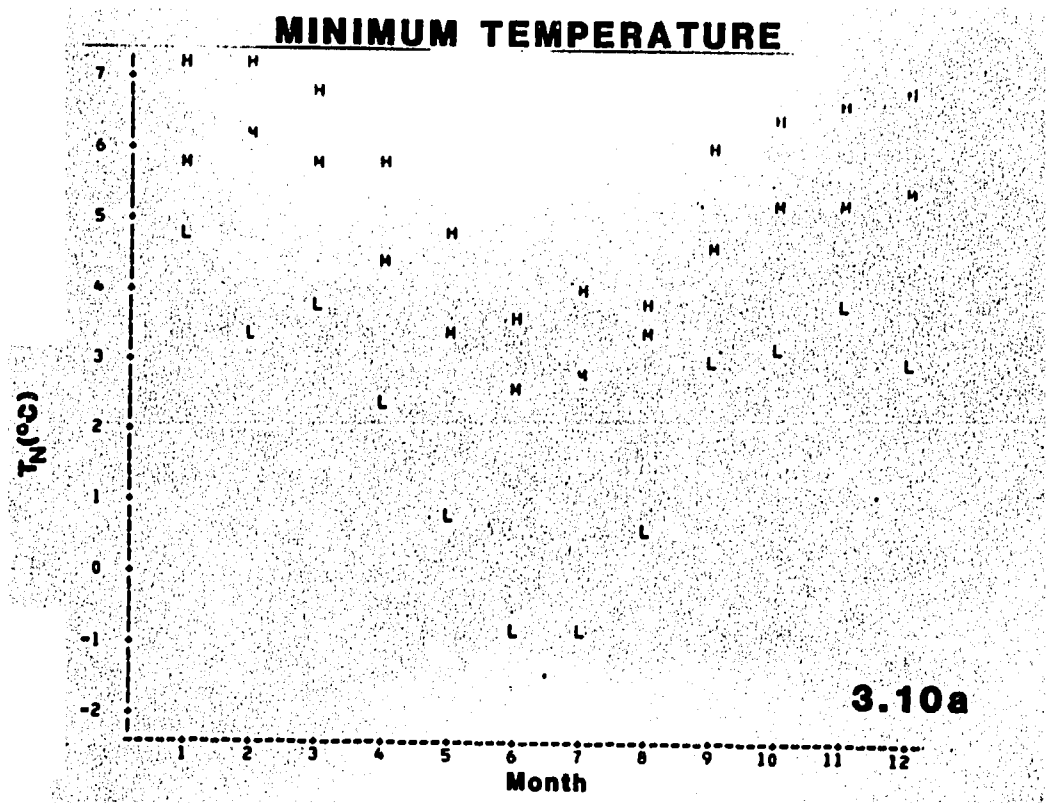


Figure 3.9a-e. Average of Indicated Meteorological Elements Stratified According to "Low", "Medium" and "High" Minimum Temperature Classes

Promedio de Elementios Meteorologicos Stratificados de Acuerdo a la Clase de Temperatura Minima: "Baja", "Media" y "Alta"



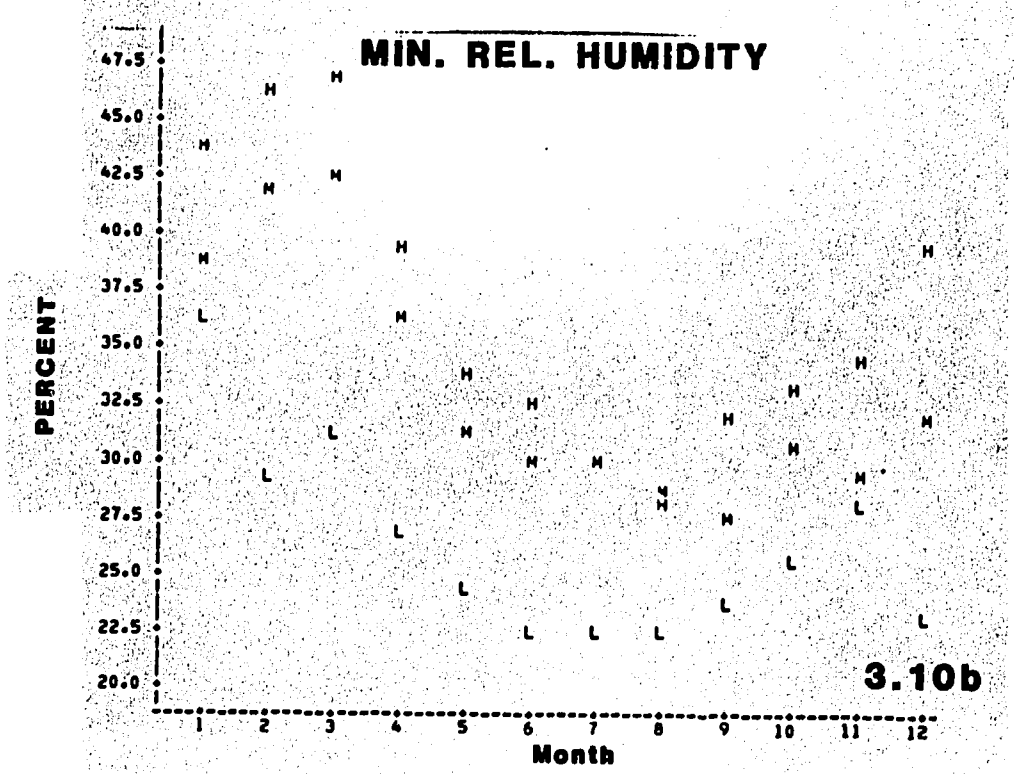
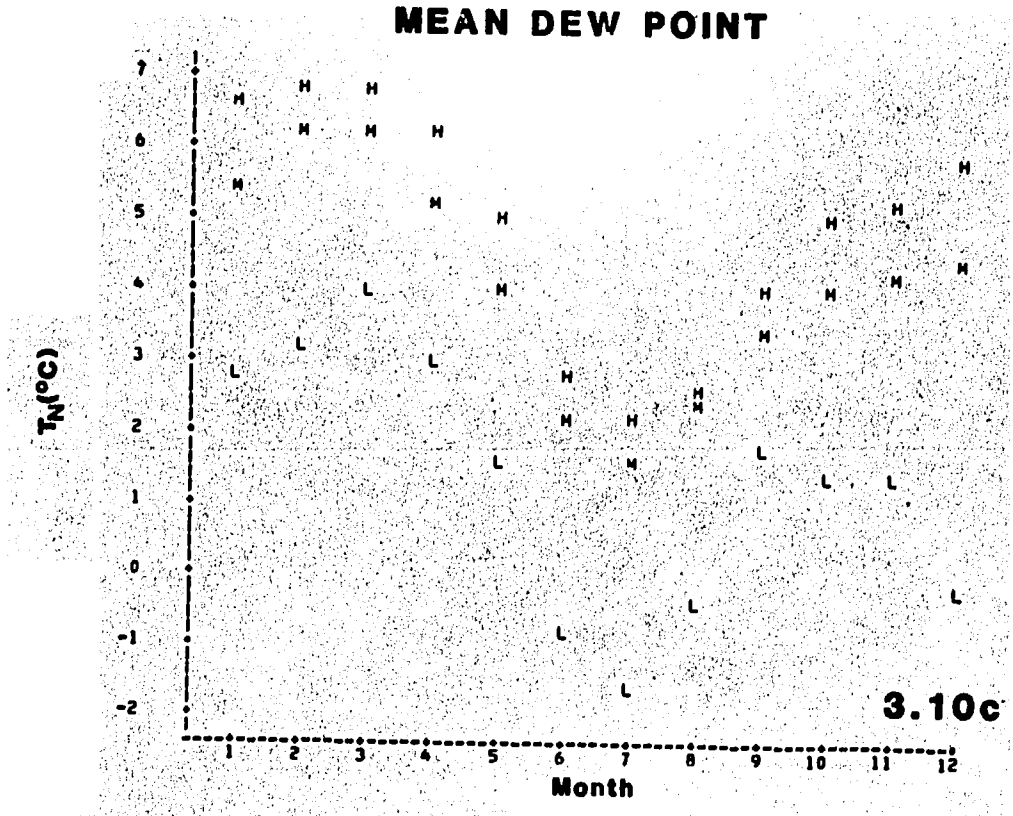


Figure 3.10a-f. Average of Indicated Meteorological Elements of the Previous Day Stratified According to "Low", "Medium" and "High" Minimum Temperature

Promedio de los Elementos Meteorologicos del dia Anterios ala Ocurrencia de Temperaturas Mimimas "Bajas", "Medias" y "Altas"



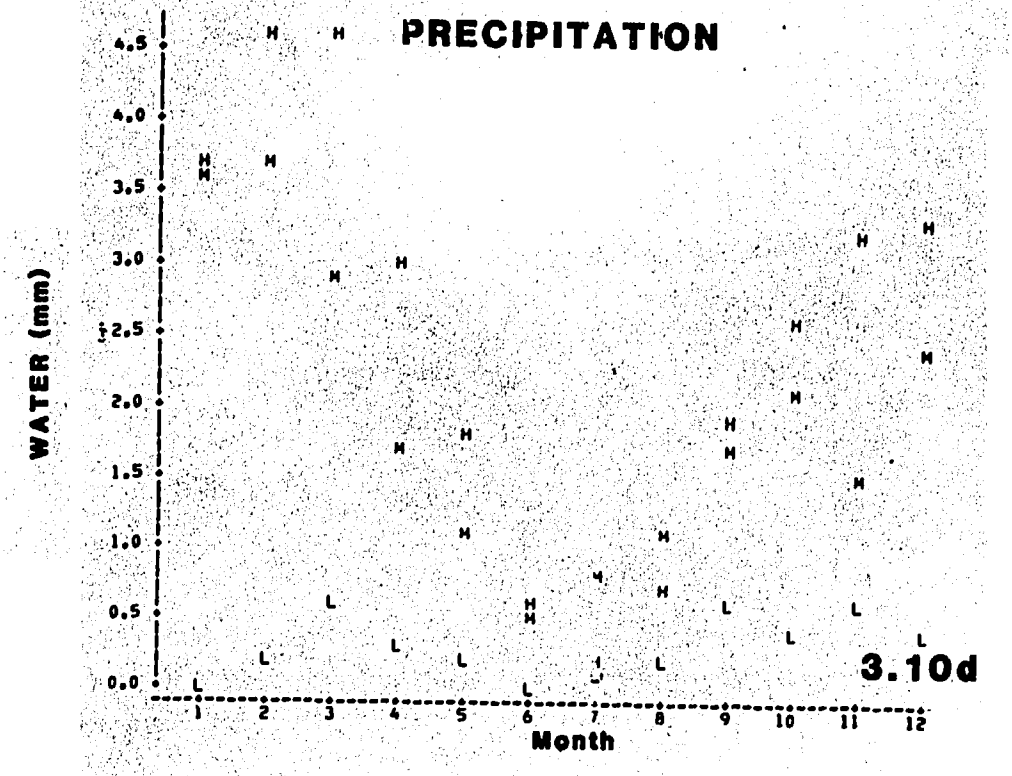
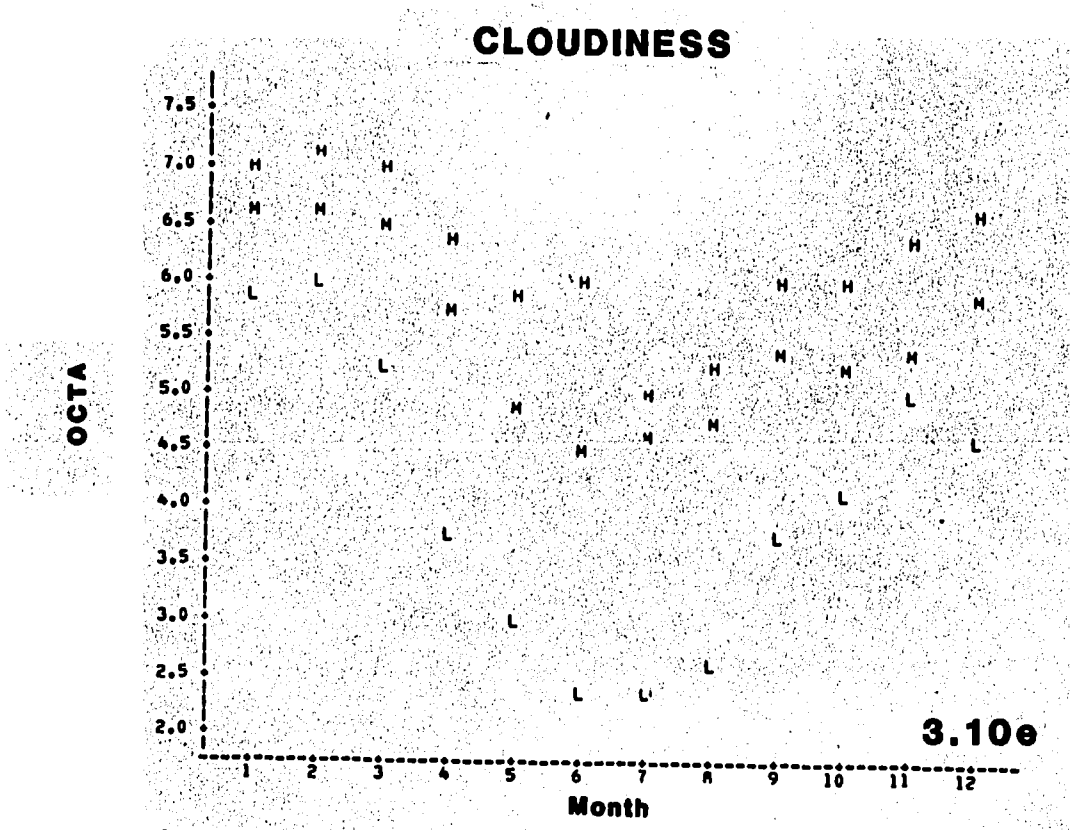


Figure 3.10a-f. Average of Indicated Meteorological Elements of the Previous Day Stratified According to "Low", "Medium" and "High" Minimum Temperature

Promedios de los Elementos Meteorologicos del dia Anterios ala Ocurrencia de Temperaturas Minimas "Bajas", "Medias" y "Altas"



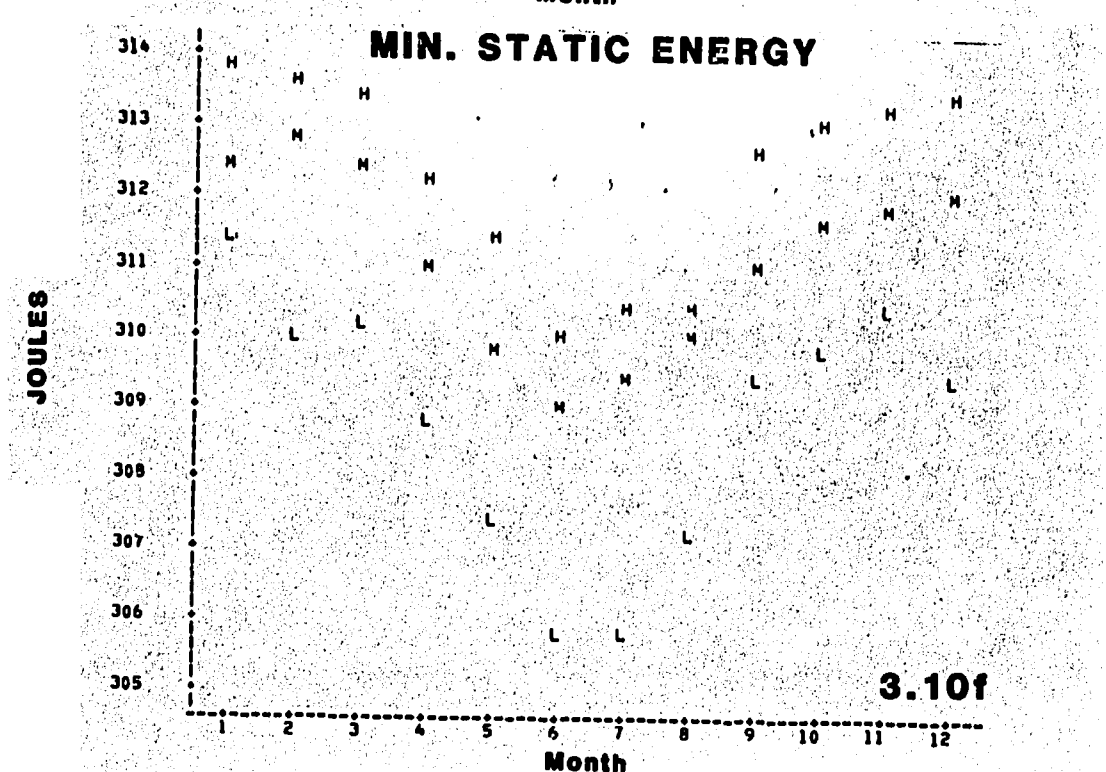


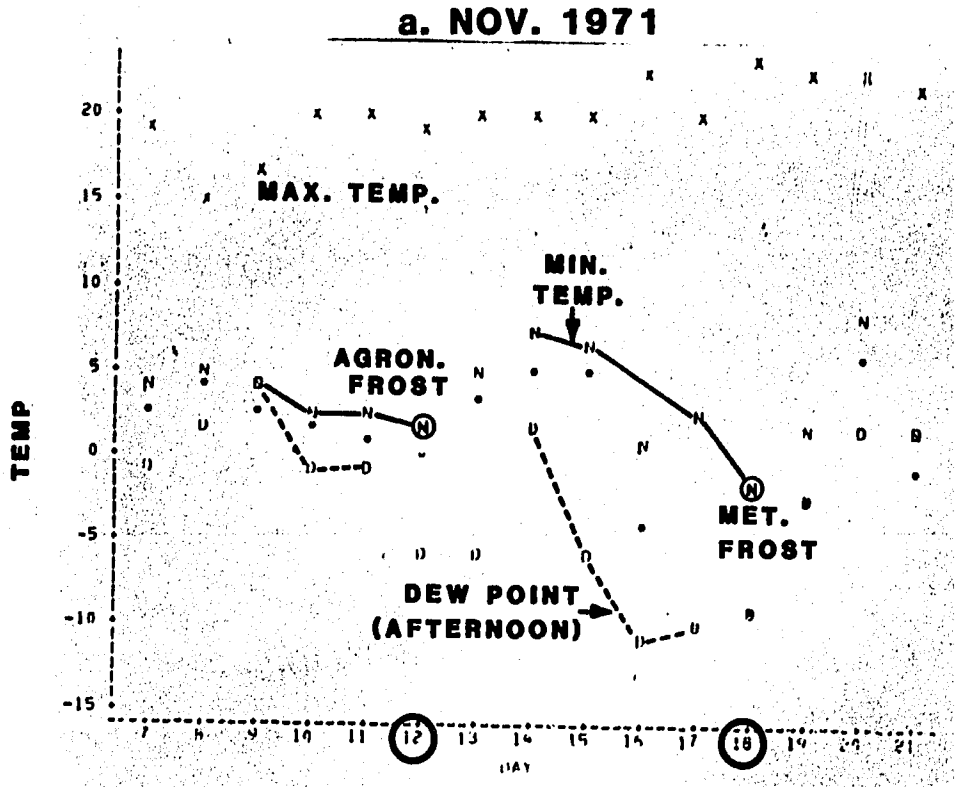
Figure 3.10a-f. Average of Indicated Meteorological Elements of the Previous Day Stratified According to "Low", "Medium" and "High" Minimum Temperature

Promedios de los Elementos Meteorologicos del dia Anterios ala Ocurrencia de Temperaturas Minimas "Bajas", "Medias" y "Altas"

conditions. The maximum temperature does not show any stratification, especially for the months we are interested in. This suggests that if the maximum temperature is high, it does not indicate anything about the minimum temperature on the next day. The relative humidity during the afternoon of the day before frost conditions is much lower than those preceding non-frost conditions (Figure 3.7b). The dew point of course, shows a similar relation (Figure 3.10c). If there is rain the day before, then it is not favorable for nocturnal cooling, not only because the soil surface is moist but because there are usually more clouds (Figures 3.10d and 3.10e). Again, the static energy on the day before frost is much less than static energy for the other minimum temperatures classes. This variable might be a good frost predictor because it considers three types of energy: Sensible, Latent and Potential.

Case studies of single frost days were analyzed to relate the daily weather conditions of the days which precede the frost occurrence. Figures 3.11a and 3.11b show an example of a meteorological frost (Nov. 18, 1971), agronomic frosts (Nov. 12, 1971 and Nov. 23, 1980) and non-frost conditions. The dew point in the afternoon (point D) drops a few days before the frost. Thus given clear skies and calm winds, conditions are favorable for IR cooling during the night. The air temperature can approach the dew point which is at or below 0°C, hence frost.

Correlations between minimum temperature for frost cases and meteorological elements on the preceding day given the requirement for calm, clear and low humidity conditions were not significant. This is not surpizing because daily data (mean wind, cloud cover, etc.) are not adequate for the analysis. We are interested in those conditions during the late afternoon of the day preceding frost occurrence.



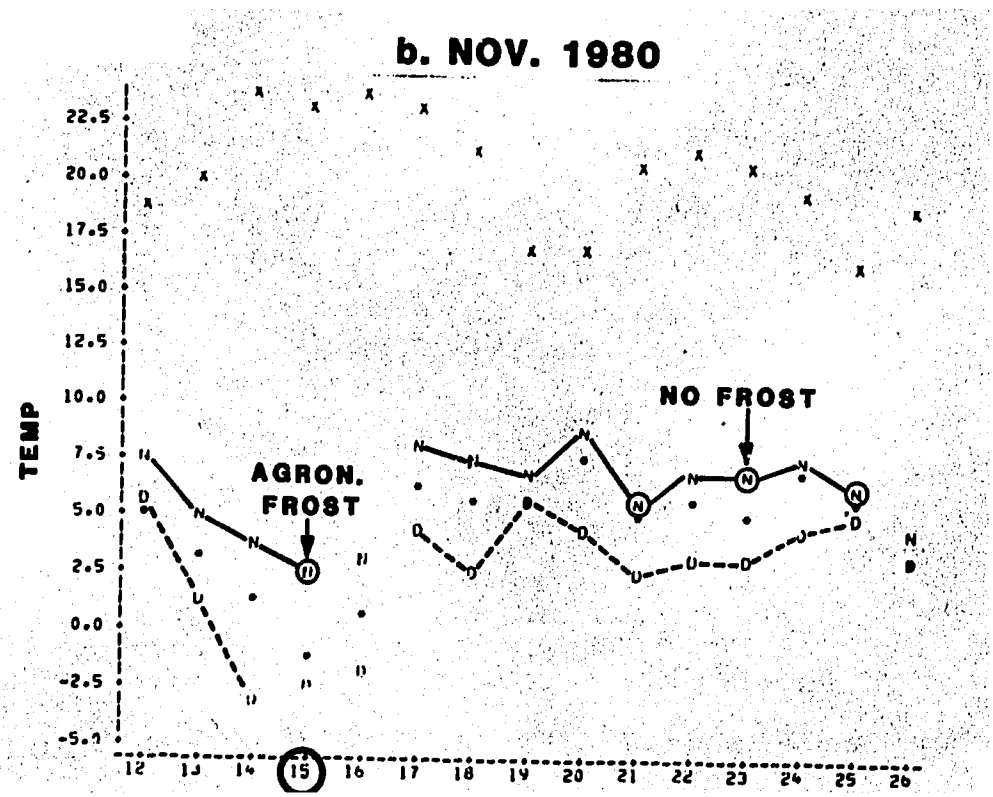


Figure 3.11a-b. Daily Changes of Minimum Temperature (N), Maximum Temperature (X), Dewpoint-Afternoon (D) and Dewpoint-Morning (*)

Comporamiento Temporal de Temperatura Minima (N), Temperatura Maxima (X), Punto de Rocio-Tarde (D) y Punto de Rocio-Manana (*)

The preliminary model for frost prediction and the steps to verify and expand on this model are as follows:

- o Hourly meteorological data should be examined to determine if calm clear, low dewpoint conditions during the later afternoon of the day before frost occurrence are consistently associated with frost later during the night. If a predictive model is specified, then the number of times it leads to a false forecast must also be determined, i.e., the probabilities of being "correct" or "wrong".

- o Hourly data must also be examined to determine if low level advection or changes in cloud conditions during the night can lead to increased or decreased potential for frost. For example, low level advection of warm, moist air from the east/northeast could reduce frost potential. Frost potential could also be reduced by upper level winds which lead to cirrus clouds. In contrast, low-level advection of cool dry air could increase the potential for frost.

- o As previously noted and related to the above analysis, synoptic weather maps should be examined to determine if south/southeasterly flow conditions lead to frost.

- o Soil moisture conditions should also be investigated.
- o The frost prediction model may require analysis of local meteorological conditions plus analysis of synoptic conditions.

Frost Advisories

The results of this frost study suggest two types of frost advisories which can be of economic benefit to the farmers and the local economy. First, long-term economic benefits can result by using this frost climatology as an integral

component of the land use decisions associated with the introduction of new or improved varieties. Vulnerability to frost can be reduced by matching the crop's tolerance for the low temperatures with existing conditions in the Mantaro Valley, particularly to maximze potential yield under the subtle agronomic frost conditions. Secondly, short-term economic benefit can result from a frost prediction model to alert farmers of potential frost. They can take actions to mitigate or reduce frost damage to crop.

The climatology of frost should be considered in the planning of crop calendars and selection of new varieties. The frost potential may be avoided if planting is done after the "normal" date of the last spring frost. After this date frosts may occur but with lower probabilities. The occurrence of the first fall frost in the Valley is not as serious because the crops are less susceptible to low temperatures in the late phenological stages. The crop type as well as the variety selected for the Valley have been done mainly through many years of experience. The farmer knows which crop and when to plant under "normal" climatic conditions, except if he wishes to introduce new varieties. But the probability of frost occurrence in the Valley is from the agronomic point of view still significant even after the mean date of last frost.

What the farmer needs to know is not the exact prediction of the minimum temperature of the next morning but rather to know if conditions are favorable for a potential frost. He can then be well prepared to make some decision on frost-control. In that situation, a timely and quick advisory of the potential for frost occurrence is needed as soon as the institution obtains the meteorological data and is able to make an agrometeorological forecast of frost. The advisory could be done through the local radios as well as on the TV station.

According to the characteristics of the potential frost an advisory on "what to do" and "how to do it" is also needed. Advisories must consider the technology and tools actually available to the farmers. Frost control equipment and material should not be expensive or hard to obtain. On the other hand, if we consider the great losses due to frosts and express them in terms of financial loss to farmers, we will realize that it is worth putting some effort toward implementation of the frost forecast model, the frost advisory as well as frost control measures. All these efforts will reduce or control completely the effects of frosts, thus the farmer's economic conditions and annual income will be improved. Consequently, production goals will be achieved and the food supply to the regional cities as well as to Lima will be more secure.

2. Derived Indices

We have seen that one of inputs in the soil moisture budget is the potential evapotranspiration. Daily data from Huayao/Huancayo permitted us to estimate the PET by three different methods: Penman, Thornthwaite and Hargreaves, which were compared to the evaporation measured with a US Class A pan.

All the estimated PET values are always less than the pan evaporation (Fig.3.12). Pan evaporation reaches 5 mm/day in the first half of the year and ranges from 6.5 to 7 mm in the months of August-November. The yearly regime of pan evaporation does not have a winter/summer type of variability, instead the extreme values occur in the transition seasons of fall and spring.

The Penman estimates have a noticeable yearly oscillation with a maximum in the month of November-December when the solar radiation reaches its maximum value. In the summer months both the Penman estimates and the pan evaporation are good indicators of PET in the Mantaro Valley. During these months the oasis effect of the pan would be minimum because the surface is covered by crops in full development. In the winter months the Penman estimates reach their minimum of approximately 85-90 mm/month (Figure 3.13), while the pan evaporation varies from 150 to 200 mm.

The PET estimates by Hargreaves' method are almost the same as those estimated by Penman, providing lower values only in the summer months. This difference may be due to the fact that Penman considers the atmospheric water vapor content which has a maximum value in the summer months. This would imply that the net radiation increases and thus the PET.

The estimated values by Thornthwaite's method oscillate very little during the year: 40 mm in winter to 55 mm in summer. These values are much below the other estimates because the sensible heat, which the temperature represents, is

POTENTIAL EVAPOTRANSPIRATION
COMPARISON OF METHODS
HUAYAO, PERU

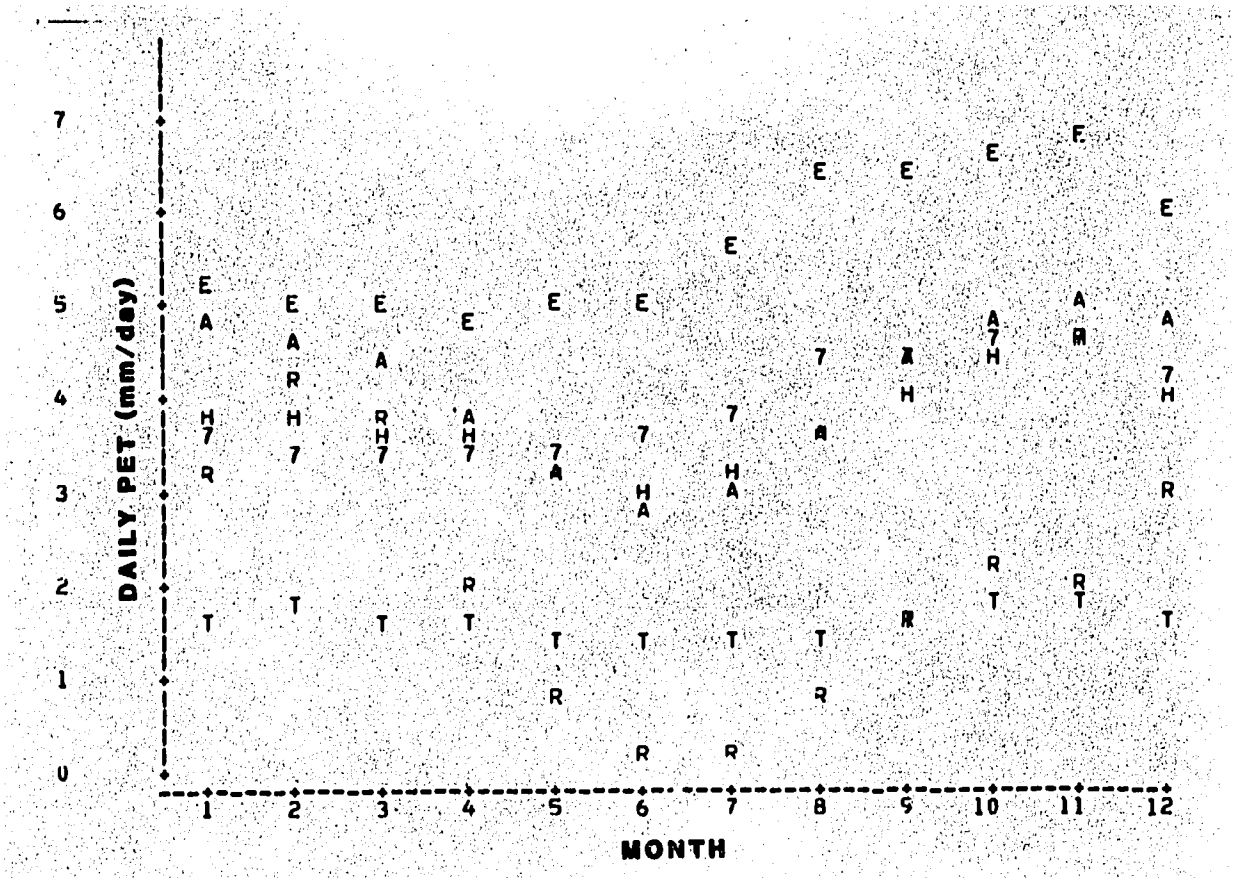


Figure 3.12. Comparisons of Mean Monthly Potential Evaporatranspiration made by Penman (A), Thornthwaite (T), Hargreaves (H) as well as Pan Evaporation (E), 70 Percent Pan Evaporation (7) and Monthly Rainfall (R) at Huayao, Peru (1960-1977). Values are in mm/day.

Promedios Mensuales de Evapotranspiracion Potencial Estimada por Penman (A), Thornthwaite (T), Hargreaves (H), Evaporacion en Tanque (E), 70 Porciento de Evaporacion en Tanque (7) y Precipitacion Mensual (R), Huayao, Peru (1960-1977). Valores estan expresados en mm/dia

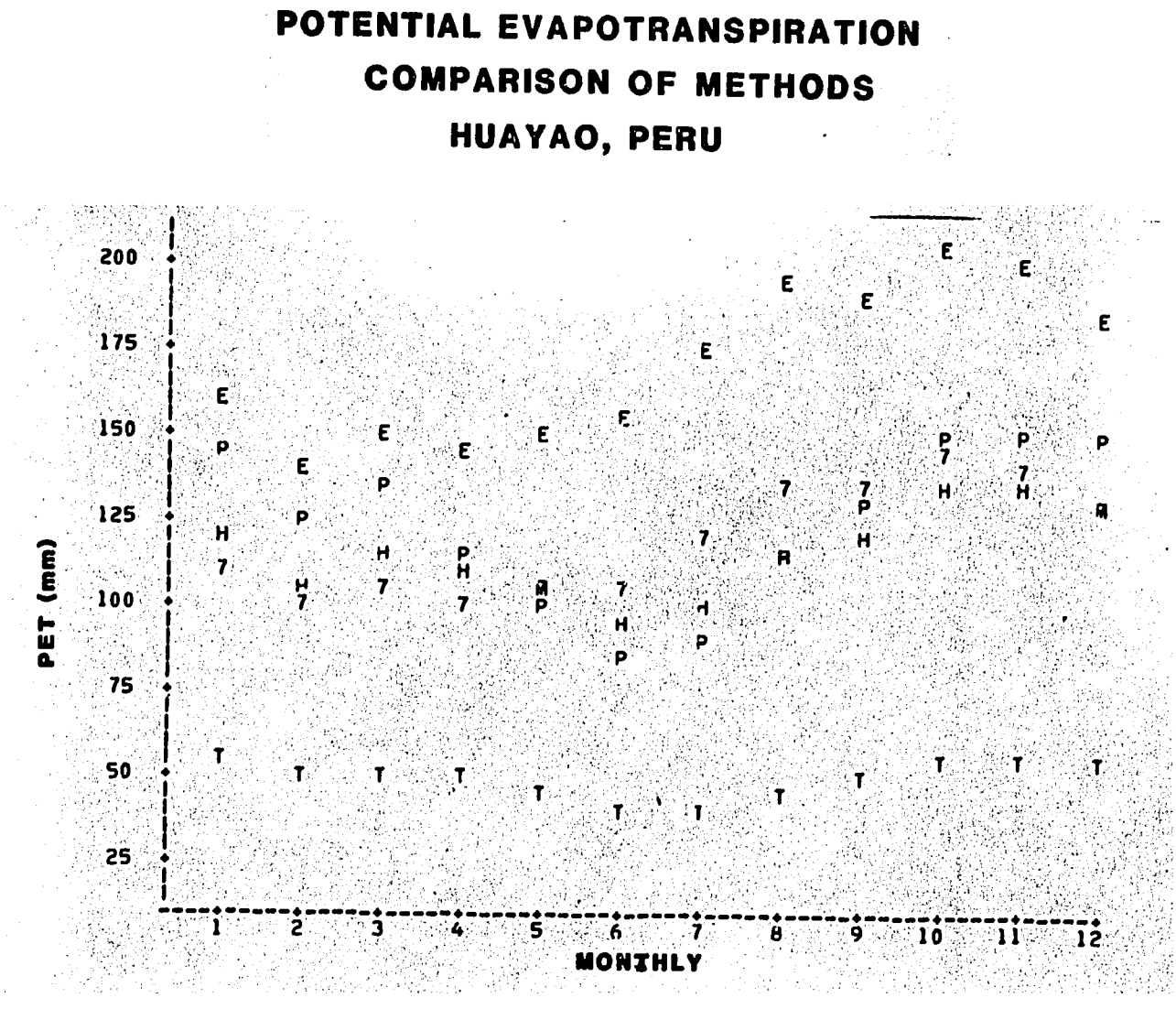


Figure 3.13. Comparison of Monthly Mean Potential Evapotranspiration Estimates (mm/month) for Penman (A), Thornthwaite (T), Hargreaves (H), as well as Pan Evaporation (E) and 70 Percent Pan Evaporation (7), at Huayao, Peru (1960-1977)

Promedios Mensuales de Evapotranspiracion Potencial Estimada (mm/mes) por Penman (P), Thornthwaite (T), Hargreaves (H), Evaporacion en Tanque (E) y 70 Porciento de Evaporacion en Tanque, Huayao, Peru (1960-1977)

very small due to the low density of the atmosphere in the Mantaro Valley. One characteristic of the climate of the Valley is the great difference between the temperature of the surfaces exposed to direct solar radiation and the air temperature. Thus at the evaporating surface (e.g., crop canopy) there is more available energy for evapotranspiration processes than what the air temperature at the weather shelter level would indirectly imply/indicate. The small variability of Thornthwaite PET during the year is due to the small annual temperature range which for the lower part of the Mantaro Valley is 2.5 K (Figure 3.2a).

Figure 3.14 shows the variation of all estimated values by decades. Here one notices that Thornthwaite's method indicates lower variability during a month; Hargreaves' estimates also show this characteristic. It seems that Penman's method is more sensitive to short period changes of PET because it considers more meteorological elements.

If we compare the estimated PET with the rainfall (Figure 3.12), we notice that only Thornthwaite's method shows a positive rainfall-PET balance from October through April, which coincides more or less with the growing season of the Valley. Considering the other methods, the precipitation in the Valley balances the water demands only in January and February.

Decadal means and standard deviations of the estimated PET are presented in Figures 3.15 through 3.18. The Hargreaves PET has the lowest variability for all decades of the year. The greatest deviations correspond to Thornthwaites' estimates. Penman PET shows more variability in the summer months when the daily change of net radiation is greater than in winter. The pan evaporation has a similar variability, that is, greater in summer than in winter. But the absolute deviations are greater than those corresponding to the estimates by Penman and Hargreaves.

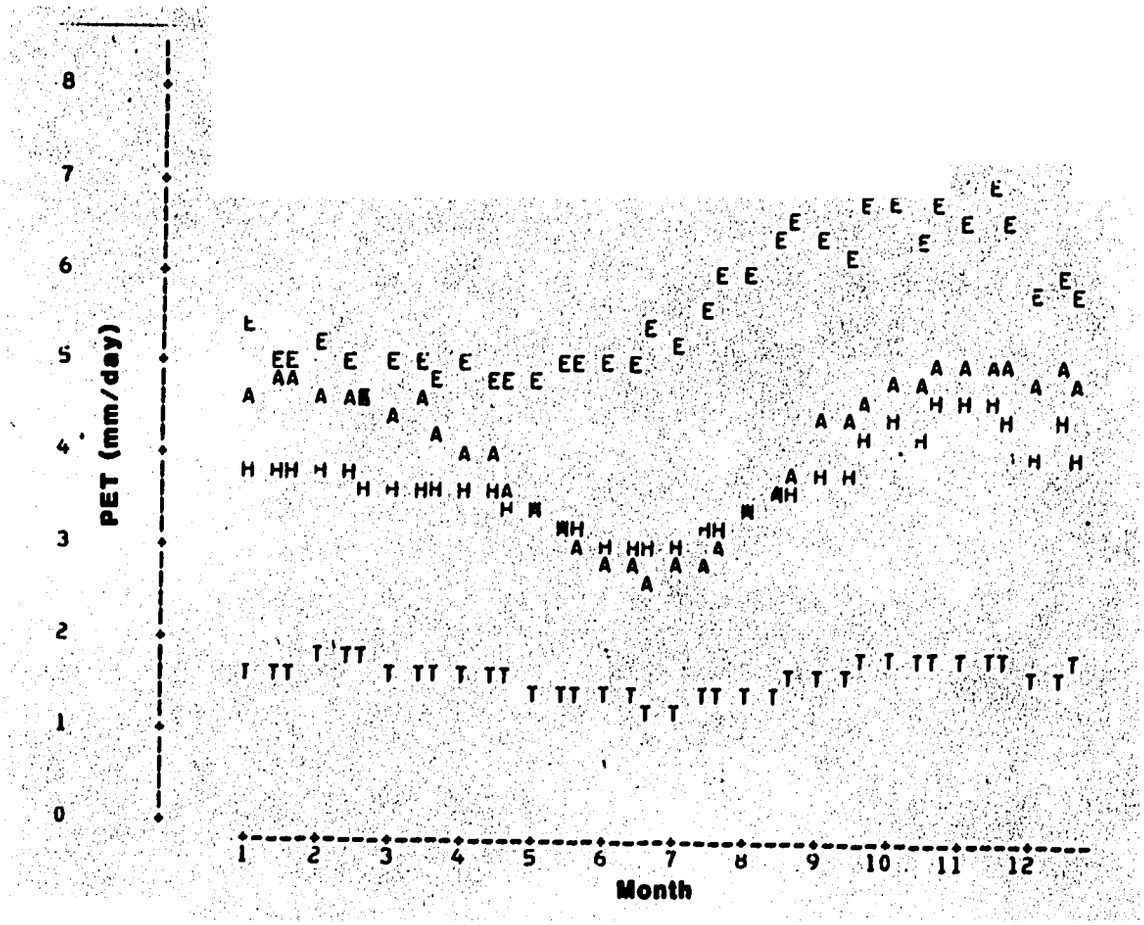


Figure 3.14. Comparison of Mean Decadal Potential Evapotranspiration Estimates made by the Penman (A), Hargreaves (H), Thornthwaite (T) as well as Pan Evaporation (E) at Huayao, Peru (1960-1977). Values are daily rate in mm.

Promedios Decadarios de Evapotranspiracion Potencial por Penman (A), Hargreaves (H), Thornthwaite (T) y Evaporacion de Tanque (E) para Huayao, Peru (1960-1977), expresados en mm/dia.

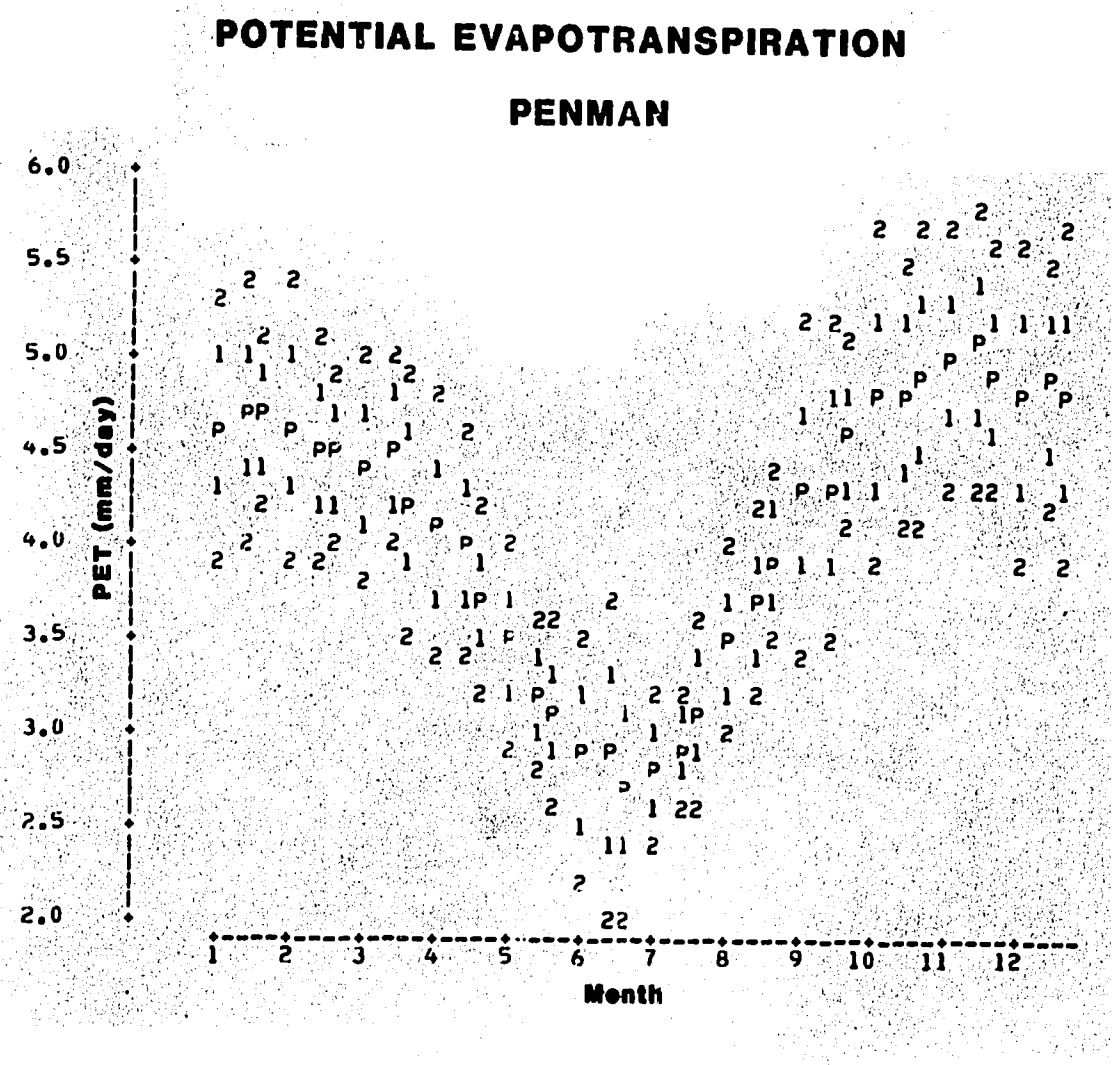


Figure 3.15. Mean Decadal Potential Evapotranspiration by Penman Method and the First and Second Standard Deviations about the Mean for Data at Huayao, Peru (1960-1977). Values are daily rate in mm.

Promedios Decadarios de Evapotranspiracion Potencial Estimados por el Metodo Penman + 1 y 2 Desviaciones Standard, Huayao, Peru (1960-1977). Valores estan expresados en mm/dia

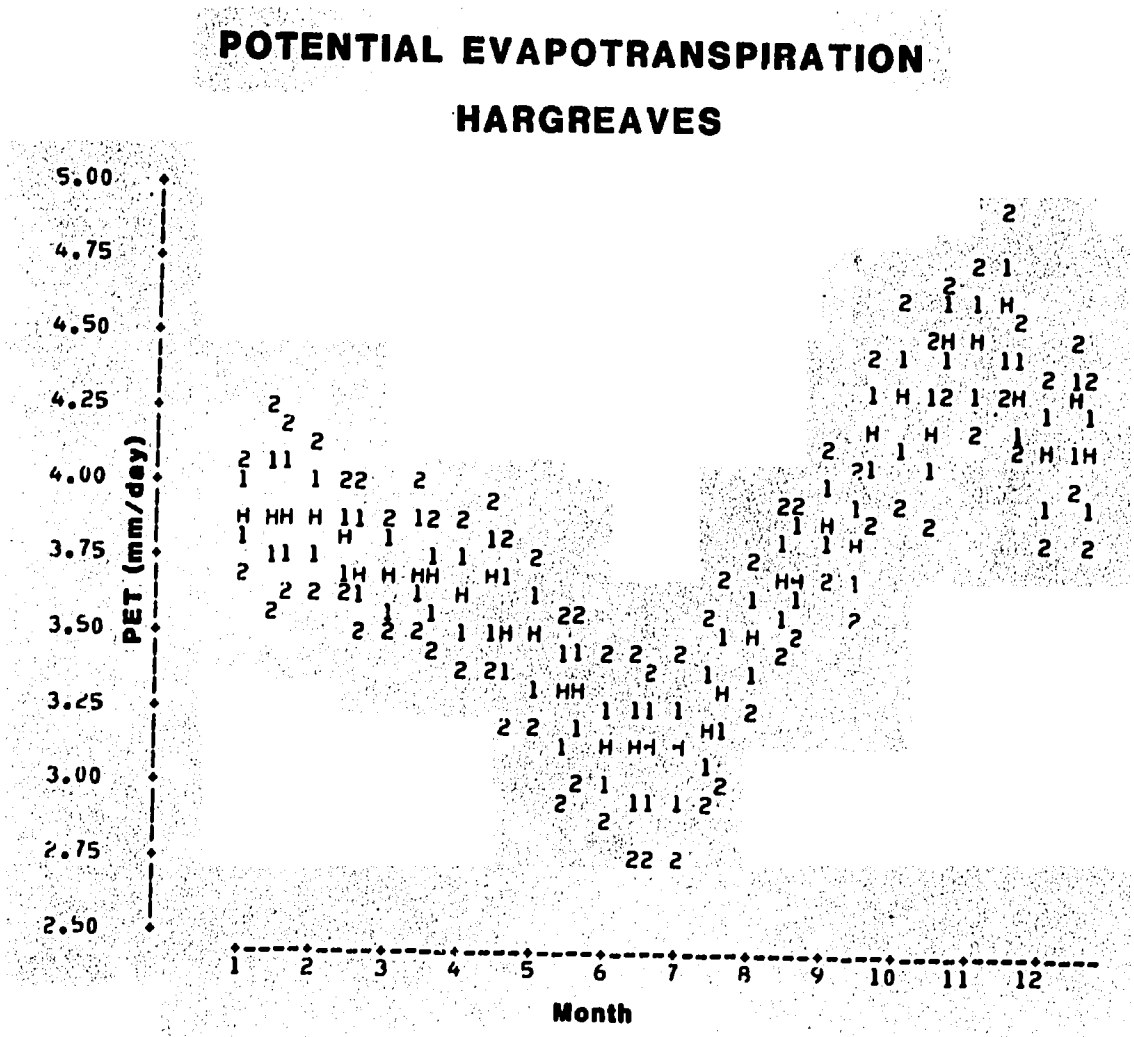


Figure 3.16. Mean Decadal Potential Evapotranspiration by Hargreaves Method and the First and Second Standard Deviations about the Mean for Data at Huayao, Peru (1960-1977). Values are daily rate in mm.

Promedios Decadarios de Evapotranspiracion Potencial Estimados por el Metodo Hargreaves ± 1 y 2 Desviaciones Standard Huayao, Peru (1960-1977). Valores estan expresadeos en mm/dia

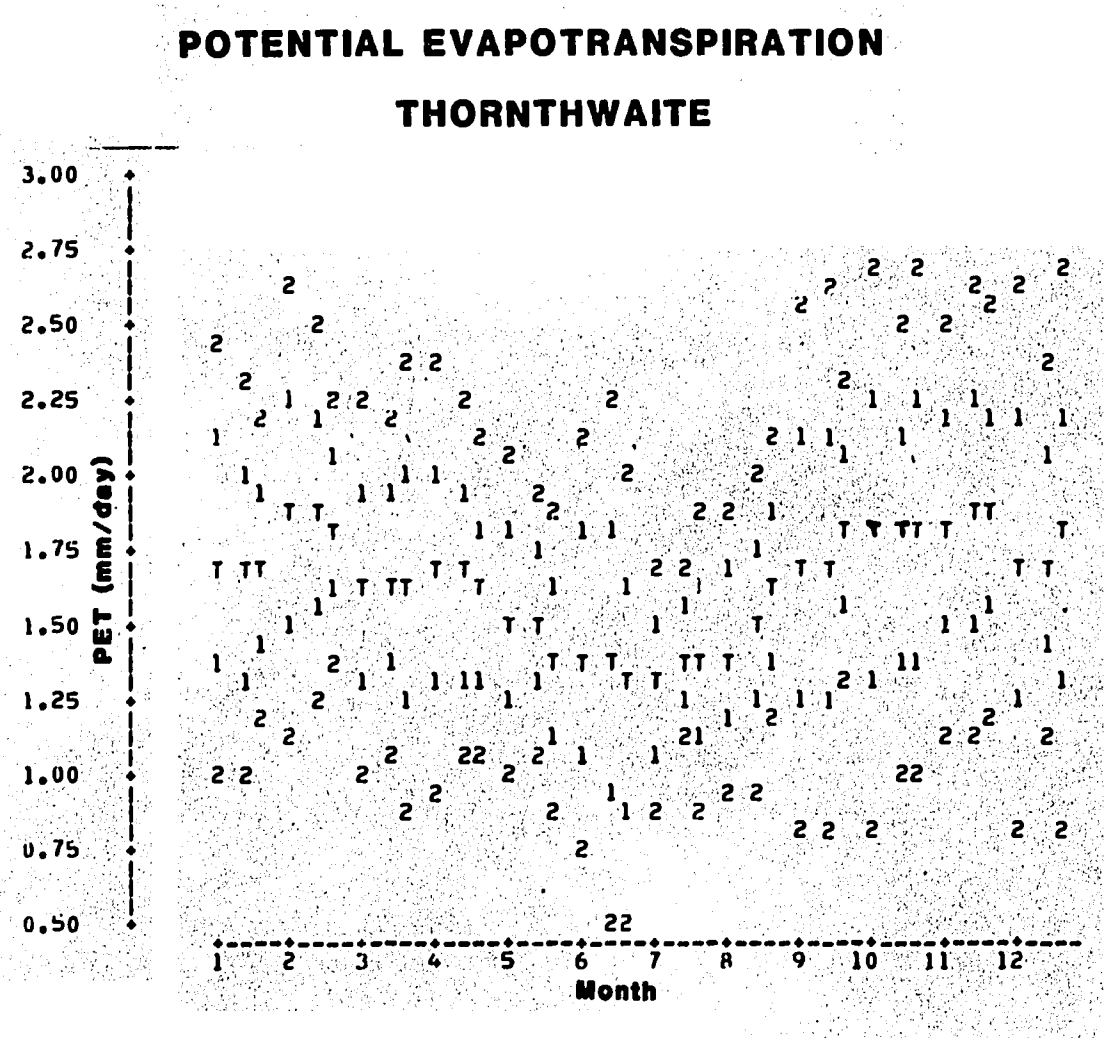


Figure 3.17. Mean Decadal Potential Evapotranspiration by Thornthwaite Method and the First and Second Standard Deviations about the Mean for Data at Huayao, Peru (1960-1977). Values are daily rate in mm.

Promedios Decadarios de Evapotranspiracion Potencial por el Metodo Thornthwaite ± 1 y 2 Desviaciones Standard, Huayao Peru (1960-1977). Valores estan expresados en mm/dia

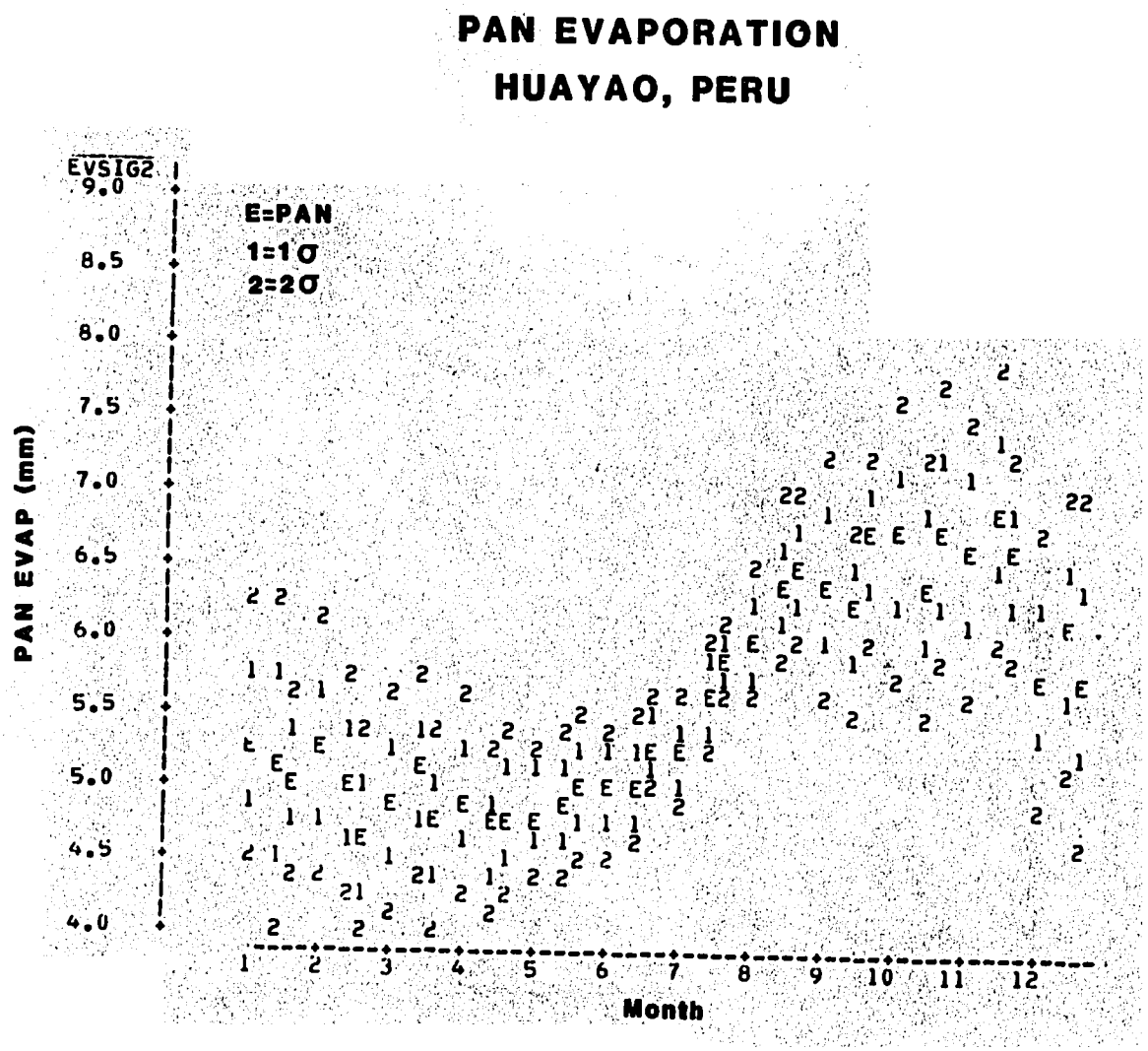


Figure 3.18. Mean Decadal Pan Evaporation and the First and Second Standard Deviations about the Mean for Data at Huayao, Peru (1960-1977). Values are in daily rate in mm.

Promedios decadarios de Evaporacion de Tanque $\pm$ 1 y 2 Desviaciones Standard Huayao, Peru (1960-1977). Valores estan expresados en mm/dia

Table 3.3 contains the means of the estimated PET and pan evaporation computed by decades.

If we compare the ratios of the estimated PET to the corresponding pan evaporation values, we see that Penman's estimates account for 0.80 to 0.96 of pan evaporation in summer and 0.52 to 0.58 of pan evaporation in winter (Figure 3.19). These ratios are presented in Table 3.4, where RPEN-EV stands for the ratio between Penman PET to pan evaporation or RHAR-EV7 indicates the ratio between Hargreaves PET and 70% of pan evaporation. Hargreaves estimates are 0.73 to 0.83 and 0.52 to 0.58 of pan evaporation in summer and winter, respectively. The lowest ratios correspond to Thronthwaites estimates; thus the ratio varies from 0.23 in August to only 0.39 in February.

Monthly means of Penman estimates (see SPEN in Table 3.5) were computed from the daily values. In the case of both Hargreaves and Thornthwaite estimates, the monthly means were obtained from daily values (see STHOR or SHAR) as well as computed having monthly means of solar radiation and temperature as input data (see THORTM or HARGRM). There is not much difference between these means, which implies that monthly estimates of PET may be well obtained from monthly means of meteorological data.

Comparisons of monthly estimates of PET among different methods as well as with pan evaporation were made in order to find a useful relationship to estimate PET giving only reduced meteorological data, such as temperature (Table 3.6). Thornthwaite estimates account only for 36-40% of what the Penman method estimates (see RTH-PEN in Table 3.6) and for 33-37% of pan evaporation (RTHR-EV) in the summer months. The same kind of comparisons for Hargreaves estimates indicate

Table 3.3. Decadal Means of Potential Evapotranspiration (mm/da

Promedios Decadarios de Evapotranspiracion Potencial (mm/dia)

OBS	MODEC	PENMAN	PENMANA	THORT	HARGRS	EV	EV_PT7
1	1.00	4.6	4.7	1.7	3.9	5.3	3.74
2	1.33	4.7	4.8	1.7	3.9	5.1	3.58
3	1.67	4.7	4.8	1.7	3.9	5.0	3.52
4	2.00	4.6	4.8	1.9	3.9	5.2	3.67
5	2.33	4.5	4.6	1.9	3.8	5.0	3.49
6	2.67	4.5	4.6	1.8	3.7	4.6	3.25
7	3.00	4.4	4.6	1.6	3.7	4.9	3.40
8	3.33	4.5	4.6	1.6	3.7	5.1	3.56
9	3.67	4.2	4.4	1.6	3.7	4.7	3.28
10	4.00	4.1	4.2	1.7	3.6	4.9	3.45
11	4.33	4.0	4.1	1.7	3.7	4.7	3.27
12	4.67	3.7	3.8	1.6	3.5	4.8	3.39
13	5.00	3.5	3.5	1.5	3.5	4.8	3.39
14	5.33	3.2	3.3	1.5	3.3	4.9	3.43
15	5.67	3.1	3.2	1.4	3.3	5.0	3.51
16	6.00	2.9	2.9	1.4	3.1	5.0	3.47
17	6.33	2.9	2.9	1.4	3.1	5.0	3.53
18	6.67	2.7	2.8	1.3	3.1	5.3	3.70
19	7.00	2.8	2.8	1.3	3.1	5.2	3.66
20	7.33	2.9	3.0	1.4	3.2	5.6	3.95
21	7.67	3.1	3.1	1.4	3.3	5.9	4.11
22	8.00	3.5	3.5	1.4	3.5	6.0	4.22
23	8.33	3.7	3.7	1.5	3.7	6.4	4.47
24	8.67	3.9	4.0	1.6	3.7	6.5	4.53
25	9.00	4.3	4.4	1.7	3.9	6.4	4.50
26	9.33	4.3	4.4	1.7	3.8	6.2	4.31
27	9.67	4.6	4.7	1.8	4.2	6.7	4.66
28	10.00	4.8	4.9	1.8	4.3	6.7	4.69
29	10.33	4.8	4.9	1.8	4.2	6.4	4.48
30	10.67	4.9	5.0	1.8	4.5	6.8	4.75
31	11.00	5.0	5.1	1.8	4.5	6.6	4.62
32	11.33	5.1	5.2	1.9	4.6	6.9	4.85
33	11.67	4.9	5.0	1.9	4.3	6.6	4.60
34	12.00	4.8	4.9	1.7	4.1	5.8	4.05
35	12.33	4.9	5.0	1.7	4.3	6.1	4.25
36	12.67	4.8	4.9	1.8	4.1	5.8	4.07

Table 3.4. Decadal Means of Ratios Between Estimates of Potential Evapotranspiration

Promedios Decadarios de las Relaciones entre Valores Estimados de Evapotranspiracion Potencial. (PEN=Penman, PEND=Adjusted Pen, THOR=Thornthwaite, HAR=Hargreaves, EV=Pan Evapo., EV7= 70% EV).

HUAYAO/HUANCAYO P E R U 1960-77

OBS	RPEN_EV	RPENA_EV	RTHOR_EV	RHAR_EV	RPEN_EV7	RTHR_EV7	RHAR_EV7	RTHR_PEN
1	0.86	0.89	0.32	0.73	1.24	0.46	1.04	0.37
2	0.92	0.94	0.33	0.76	1.31	0.47	1.09	0.35
3	0.92	0.95	0.33	0.78	1.32	0.48	1.11	0.36
4	0.89	0.91	0.36	0.74	1.27	0.51	1.06	0.40
5	0.90	0.92	0.37	0.76	1.28	0.53	1.09	0.42
6	0.96	0.99	0.39	0.80	1.37	0.56	1.15	0.41
7	0.91	0.94	0.34	0.76	1.30	0.48	1.08	0.37
8	0.88	0.91	0.32	0.74	1.26	0.46	1.05	0.37
9	0.90	0.93	0.35	0.78	1.29	0.50	1.12	0.38
10	0.83	0.85	0.34	0.73	1.18	0.48	1.05	0.41
11	0.85	0.87	0.35	0.78	1.21	0.51	1.12	0.42
12	0.77	0.78	0.33	0.72	1.09	0.47	1.04	0.43
13	0.71	0.73	0.31	0.72	1.02	0.45	1.03	0.44
14	0.66	0.67	0.31	0.66	0.94	0.44	0.95	0.47
15	0.62	0.63	0.27	0.66	0.89	0.39	0.94	0.44
16	0.58	0.58	0.29	0.63	0.82	0.42	0.90	0.50
17	0.57	0.57	0.27	0.61	0.81	0.39	0.88	0.48
18	0.52	0.52	0.24	0.58	0.74	0.34	0.83	0.46
19	0.54	0.54	0.25	0.59	0.77	0.35	0.85	0.46
20	0.52	0.53	0.25	0.57	0.75	0.36	0.82	0.48
21	0.53	0.53	0.23	0.57	0.76	0.33	0.81	0.44
22	0.58	0.59	0.24	0.58	0.83	0.34	0.83	0.41
23	0.58	0.58	0.23	0.58	0.82	0.33	0.83	0.40
24	0.61	0.62	0.25	0.58	0.87	0.36	0.82	0.42
25	0.67	0.68	0.26	0.61	0.95	0.37	0.87	0.39
26	0.70	0.72	0.28	0.62	1.01	0.40	0.89	0.39
27	0.69	0.70	0.27	0.63	0.98	0.39	0.89	0.39
28	0.71	0.73	0.26	0.64	1.02	0.38	0.91	0.37
29	0.75	0.76	0.28	0.65	1.07	0.39	0.93	0.37
30	0.72	0.74	0.27	0.66	1.03	0.39	0.95	0.37
31	0.76	0.77	0.28	0.68	1.08	0.40	0.97	0.37
32	0.73	0.74	0.27	0.67	1.04	0.39	0.95	0.37
33	0.75	0.76	0.28	0.66	1.07	0.41	0.94	0.38
34	0.82	0.84	0.30	0.71	1.18	0.42	1.01	0.36
35	0.80	0.82	0.29	0.70	1.15	0.41	1.00	0.36
36	0.82	0.84	0.30	0.70	1.17	0.43	1.01	0.37

PET RATIOS

HUAYAO, PERU

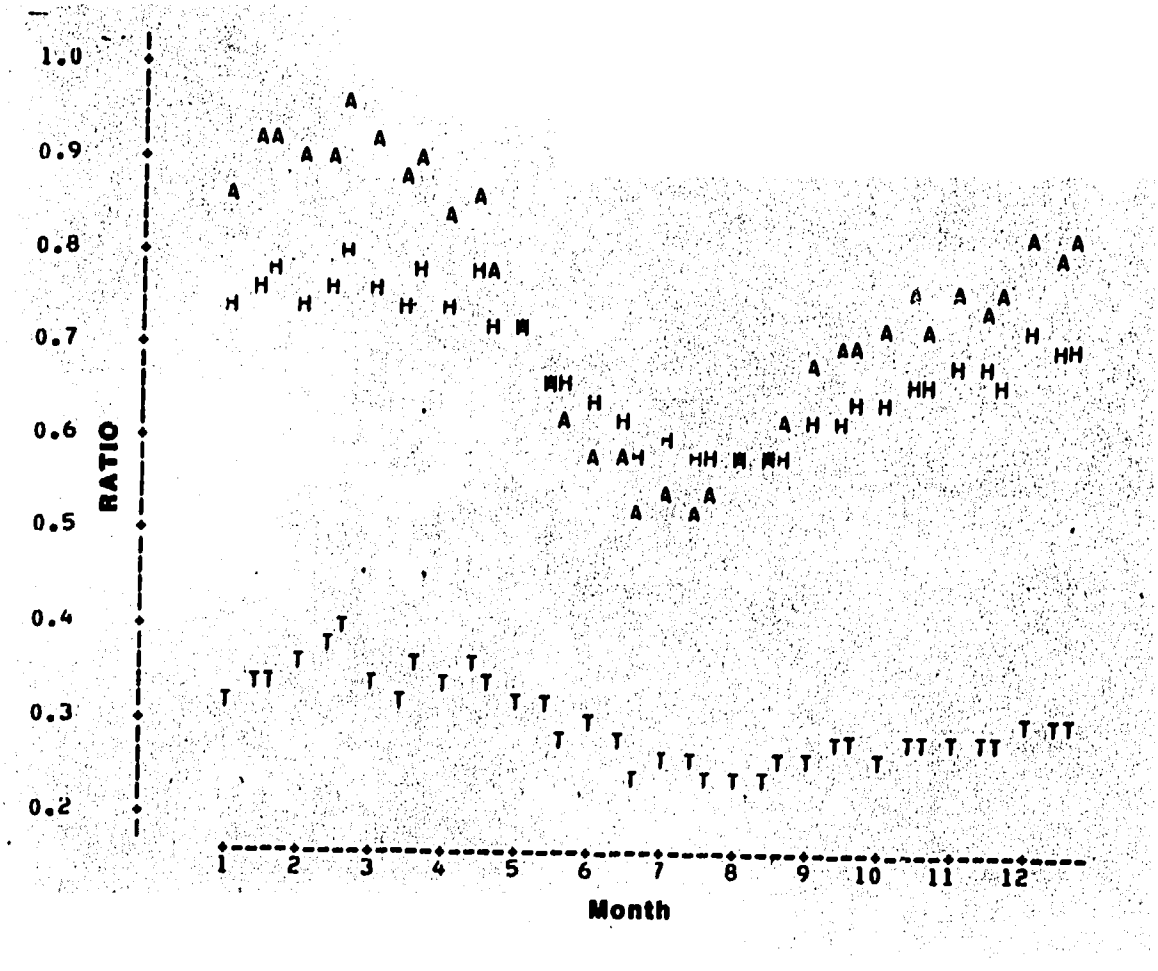


Figure 3.19. Comparison of various Mean Decadal Potential Evapotranspiration Estimates expressed as a ratio of Pan Evaporation at Huayao, Peru (1960-1977).

Relaciones entre valores estimados de evapotranspiracion potencial y evaporacion de tanque para Huayao, Peru (1960-1977).

Table 3.5. Monthly Means of Estimates of Potential Evapotranspiration (mm) Pan Evaporation, 70% of Pan Evaporation and Associated Standard Deviation

Promedios Mensuales de Evapotranspiracion Potencial Estimada, Evaporacio de Tanque, 70% de Evaporacion de Tanque y sus Respectivas Desviaciones Standard

HUAYAO/HUANCAYO P E R U 1960-77

OBS	MO	SPEN	STHOR	THORTM	SHAR	HARGRM	SEV	SEV7	STDPEN	STDTHOR	STDTHORM	STDHAR	STDHARGM	STDEV	STDEV7
1	1	144.5	52.5	52.5	120.2	120.2	159.8	111.8	8.0	3.7	3.7	10.9	10.8	22.1	15.5
2	2	127.0	52.0	51.9	106.4	106.0	139.3	97.5	5.1	3.1	2.9	7.9	7.6	15.7	11.0
3	3	136.2	50.6	50.7	114.5	114.3	151.3	105.9	7.1	2.9	2.8	8.2	8.3	13.6	9.5
4	4	117.4	49.1	49.0	107.8	107.7	144.0	100.8	6.7	3.7	3.4	6.7	6.9	13.2	9.2
5	5	101.1	45.1	45.4	103.8	103.8	152.3	106.6	5.6	3.6	3.7	4.9	5.0	19.6	13.7
6	6	84.6	40.9	40.7	92.6	93.1	152.6	106.8	10.3	3.3	3.2	5.4	4.9	16.6	11.7
7	7	91.7	42.1	42.1	100.3	100.3	172.7	120.9	5.7	4.0	3.5	4.6	4.8	16.5	11.6
8	8	114.9	47.4	47.0	112.9	112.8	195.7	137.0	6.8	2.6	2.4	5.7	5.5	18.3	12.8
9	9	131.8	51.6	51.8	118.8	118.7	192.2	134.5	9.3	2.6	2.5	6.3	6.5	14.5	10.2
10	10	149.4	55.2	55.4	134.1	133.7	205.6	143.9	9.0	3.0	3.1	9.6	9.4	13.6	9.5
11	11	150.0	56.3	55.9	134.4	133.8	201.2	140.8	7.9	3.7	3.3	8.9	9.5	17.6	12.4
12	12	149.0	54.1	53.8	128.5	128.1	182.7	127.9	10.0	3.4	3.6	12.4	12.2	22.8	16.0

Table 3.6. Monthly Means of Rations Between Estimates of Potential Evapotranspiration and Associated Standard Deviations

Promedios Mensuales de las Relaciones Entre Valores Estimados de Evapotranspiracion Potencial y sus Respectivas Desviaciones Standard

(RTHR-PEN=Ratio THOR to PEN, STDRTHPN=Standard Deviation of Ratio THOR to PEN)

HUAYAO/HUANCAYO P E R U 1960-77

OBS	MO	RTHR PEN	STDRTHPN	RHAR PEN	STDRHPN	REV PEN	STDREVPN	RTHR EV	STDRTHEV	RPEN EV	STDRPNEV	RHAR EV	STDRHEV
1	1	0.364	0.022	0.831	0.038	1.105	0.132	0.332	0.030	0.916	0.102	0.758	0.063
2	2	0.408	0.020	0.834	0.038	1.096	0.110	0.376	0.035	0.921	0.089	0.766	0.053
3	3	0.373	0.023	0.839	0.040	1.112	0.099	0.337	0.030	0.906	0.082	0.758	0.054
4	4	0.418	0.035	0.917	0.024	1.228	0.096	0.342	0.033	0.819	0.065	0.751	0.050
5	5	0.449	0.039	1.028	0.058	1.510	0.211	0.302	0.037	0.675	0.097	0.689	0.069
6	6	0.486	0.059	1.112	0.102	1.821	0.232	0.268	0.026	0.559	0.085	0.615	0.050
7	7	0.461	0.043	1.096	0.050	1.882	0.100	0.245	0.023	0.533	0.028	0.584	0.037
8	8	0.410	0.024	0.983	0.039	1.703	0.116	0.242	0.022	0.590	0.042	0.579	0.043
9	9	0.395	0.032	0.902	0.035	1.463	0.128	0.271	0.021	0.688	0.060	0.619	0.037
10	10	0.372	0.032	0.895	0.039	1.379	0.094	0.270	0.015	0.729	0.052	0.651	0.037
11	11	0.374	0.031	0.892	0.029	1.342	0.100	0.279	0.024	0.749	0.058	0.667	0.040
12	12	0.362	0.026	0.859	0.050	1.225	0.118	0.297	0.029	0.823	0.080	0.704	0.042

TABLE 3.7

PERU

Crop coefficients for Major Crops of the Mantaro Valley

Crop	Month								
	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Field Corn	0.45	0.53	0.75	0.92	1.08	1.10	0.86	0.60	-
Potato	-	0.65	0.73	0.85	1.00	1.10	1.03	0.73	-
Barley/wheat	-	-	0.45	0.57	0.72	1.02	1.10	0.80	0.23

83% of Penman PET (RHAR-PEN) and 76% of pan evaporation (RHAR-EV) also in the summer months. Should only pan evaporation be available, then Penman PET may be obtained by using the ratio RPEN-EV. This ratio varies from month to month, thus the ratios for each month as well as their standard deviations should be taken into account.

It is suggested that the Penman estimate, especially the monthly means for the period 1960-1977, may be used as reference values for the Mantaro Valley. This method does consider the main meteorological elements which define the climatic conditions of the Valley and explain better the process of evapotranspiration for a reference crop (PET).

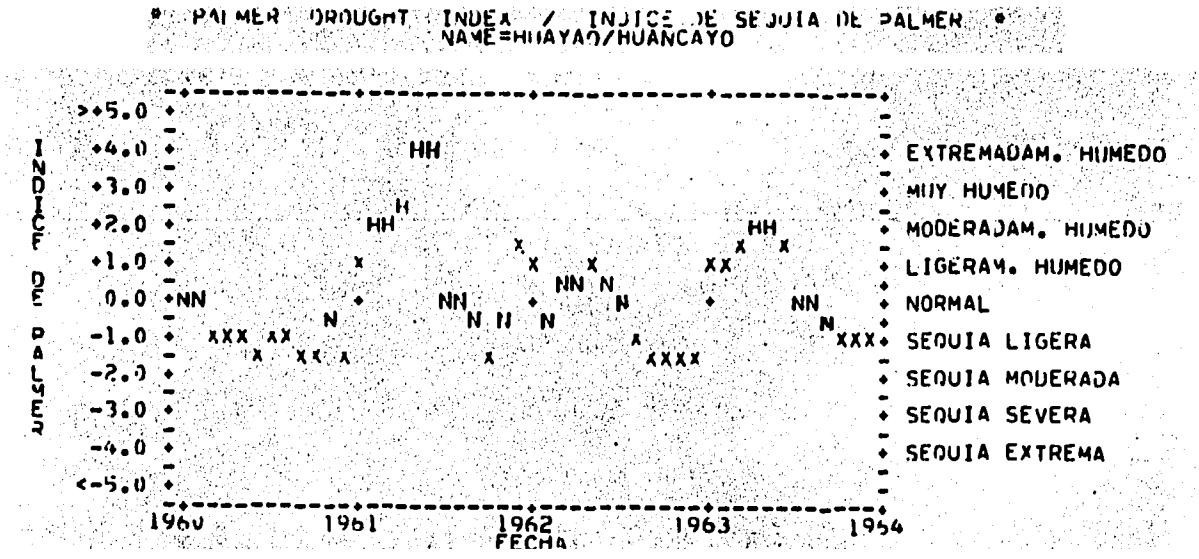
3. Agricultural Drought

A simple climatic diagram like the one shown in Figure 3.5 indicates that the water demands of a reference crop are normally met by precipitation in the Mantaro Valley only in the months of January and February. Thus these are the months appropriate for phenological stages of crops which have the highest water requirements. In fact most of the crops in the Mantaro Valley reach the flowering stage in this time of the year. In this case, the crop coefficient shows the highest values. The crop coefficient of corn (Table 3.7) reaches 1.0-1.1. Potatoes have the highest water requirement in the months January-March. These coefficients also show that the crops grown in the Mantaro Valley are well adapted to the local climatic conditions. This means that the local farmers under "normal" or expected climatic conditions also know the expected yields and therefore production. One way of monitoring for agricultural drought, that is, a deficit of water in the root-system (water available to crops) compared to the crop water requirements at a particular

phenological stage, is by assessing moisture stress with an index. Some of the traditional indices include the R-Index by Yao (1969) and the Palmer Drought Index (PDI) by Palmer (1965). Other indices are discussed in Chapter IV.

The Palmer Drought Index was computed for Huayao/Huancayo and Jauja using Penman PET estimates, Figures 3.20 and 3.21, respectively, for years 1960-1980. The PDI is based on the Z-Index (see Sakamoto, 1978) and is scaled to potentially indicate various categories ranging from anomalously wet to extreme drought conditions. Mild drought has occurred at the beginning of the season, for example for Huayao in the years 1963, 1969, 1975 and 1980. Jauja was affected by moderate and severe drought during the growing seasons of 1964, 1965, 1966, 1968, 1969, 1975 and 1977. We may say that the years with severe drought for the Mantaro Valley were 1966, 1969 and 1980.

These drought conditions do limit and alter the normal agricultural practices in the Valley. If they tend to persist for extended periods, the farmer is forced to reduce the growing area or crop failure may occur, consequently production will be down. Thus, there is the need to quantify drought occurrences. The Palmer Drought Index is an important indicator of crop failure (good crops) depending on the rainfall distribution relative to the distribution and amount normally expected. Most of the crops in the Valley have low potential yields compared to those under more favorable climatic conditions. However, the farmer expects a low potential yield under the local conditions. An anomaly in the soil moisture budget for one or more months will affect the crop with an intensity proportional to the anomaly relative to the water requirements of the crop in that same period of time. The PDI must be tested and evaluated for potential use as an operational index to monitor general agricultural conditions.



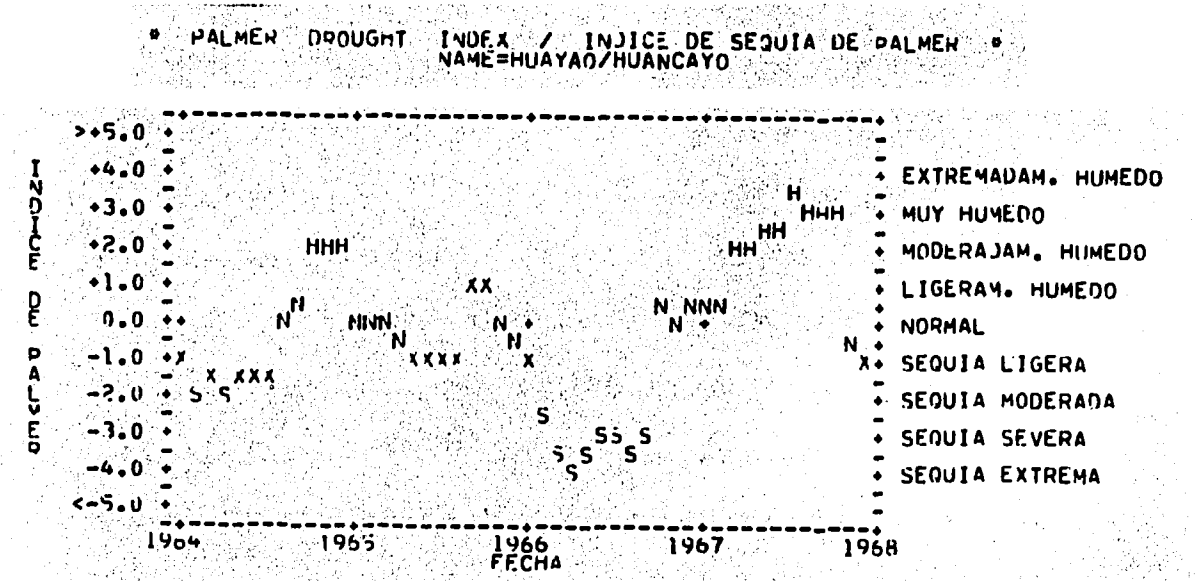
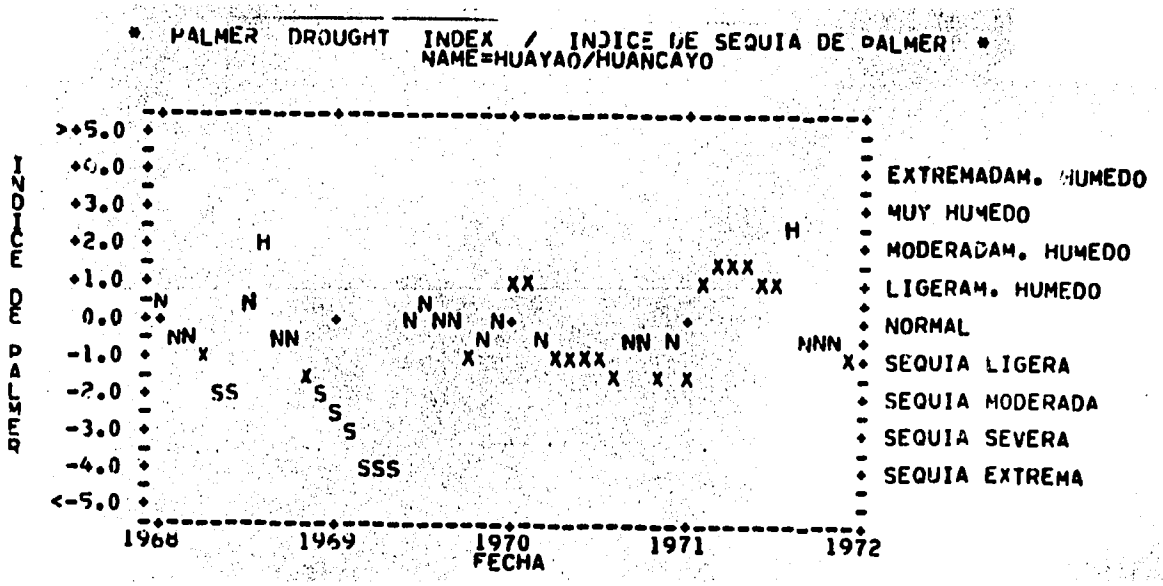


Figure 3.20. Drought Palmer Index

Indice de Sequia de Palmer para Huayao/Huancayo, Peru



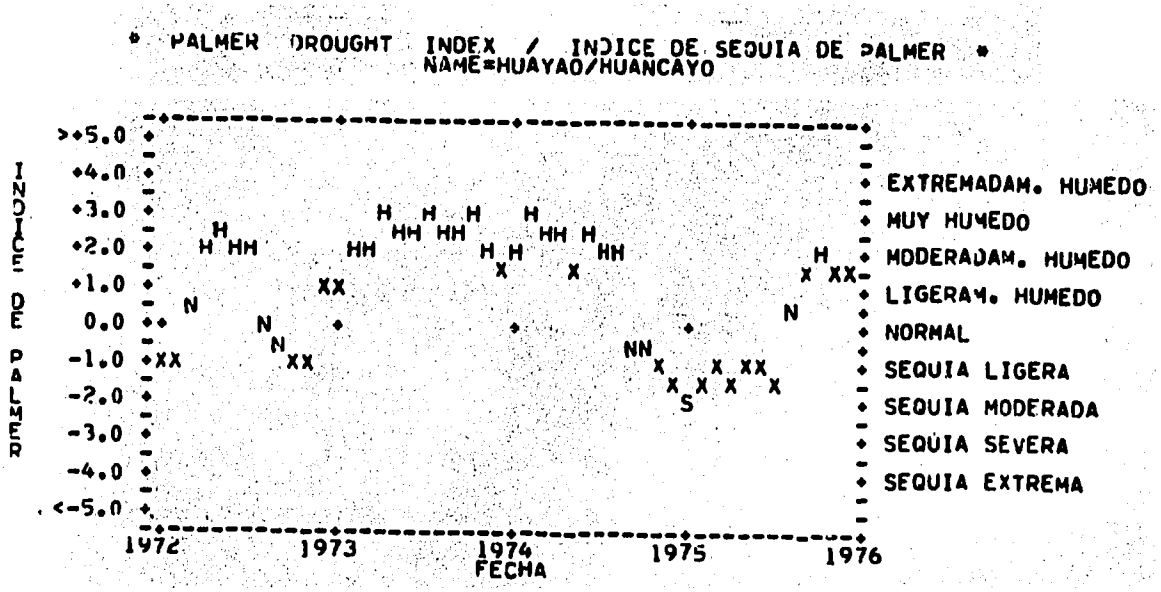
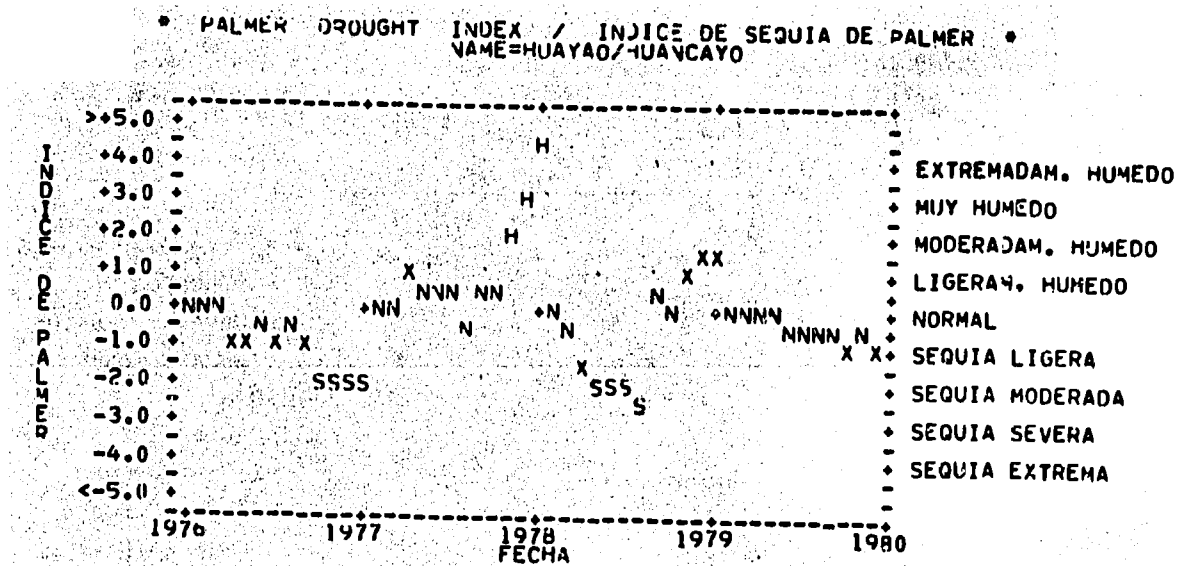


Figure 3.20. Drought Palmer Index

Indice de Sequia de Palmer para Huayao/Huancayo, Peru



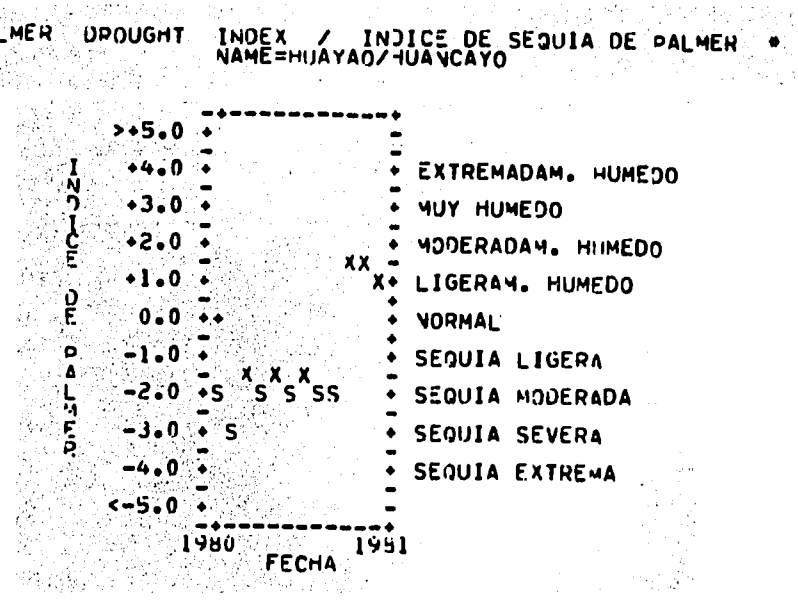
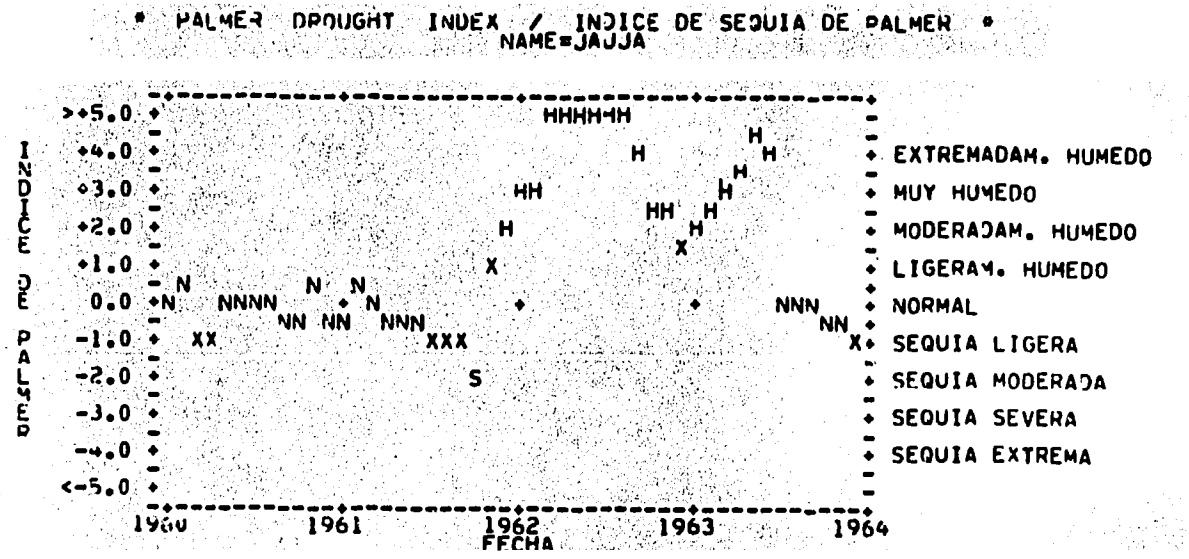


Figure 3.20. Drought Palmer Index

Indice de Sequia de Palmer para Huayao/Huancayo, Peru



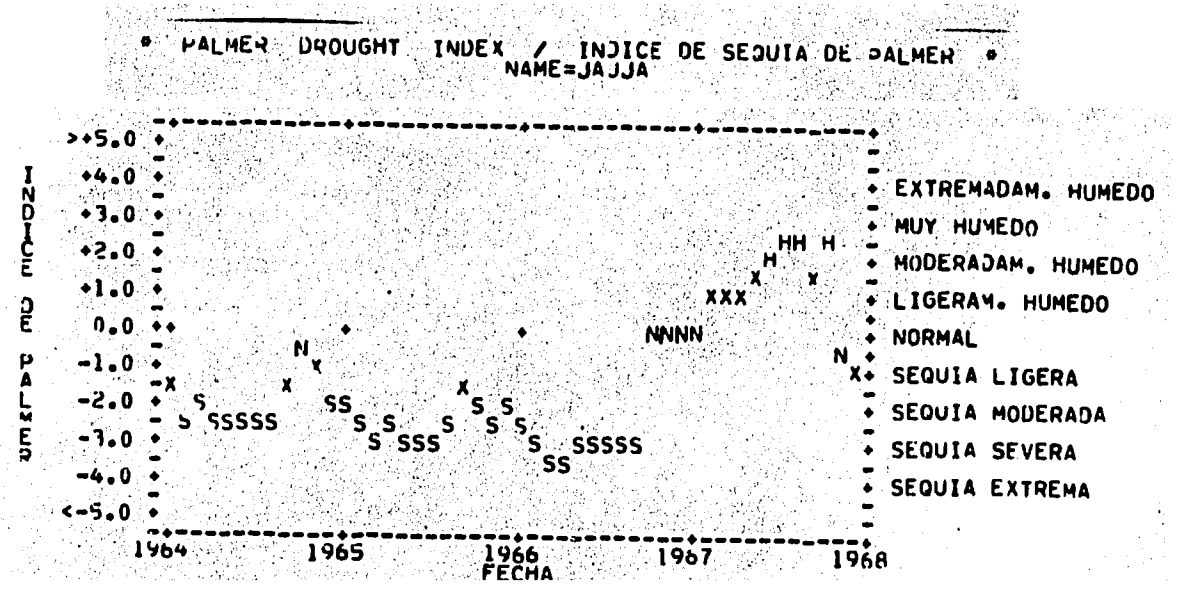
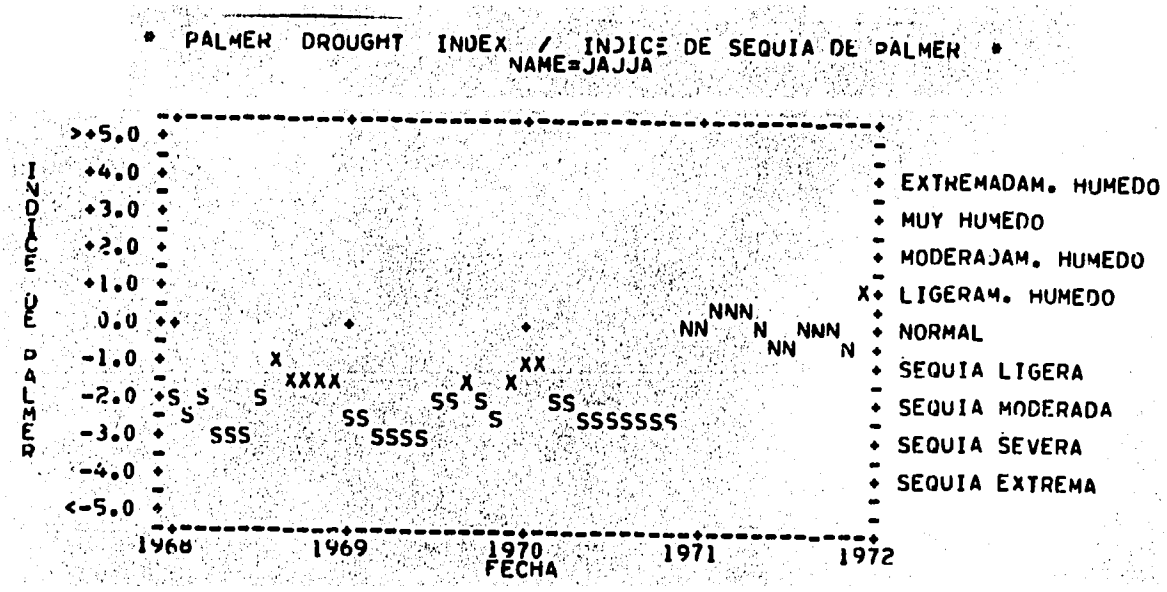


Figure 3.21. Drought Palmer Index

Indice de Sequia de Palmer para Jauja, Peru



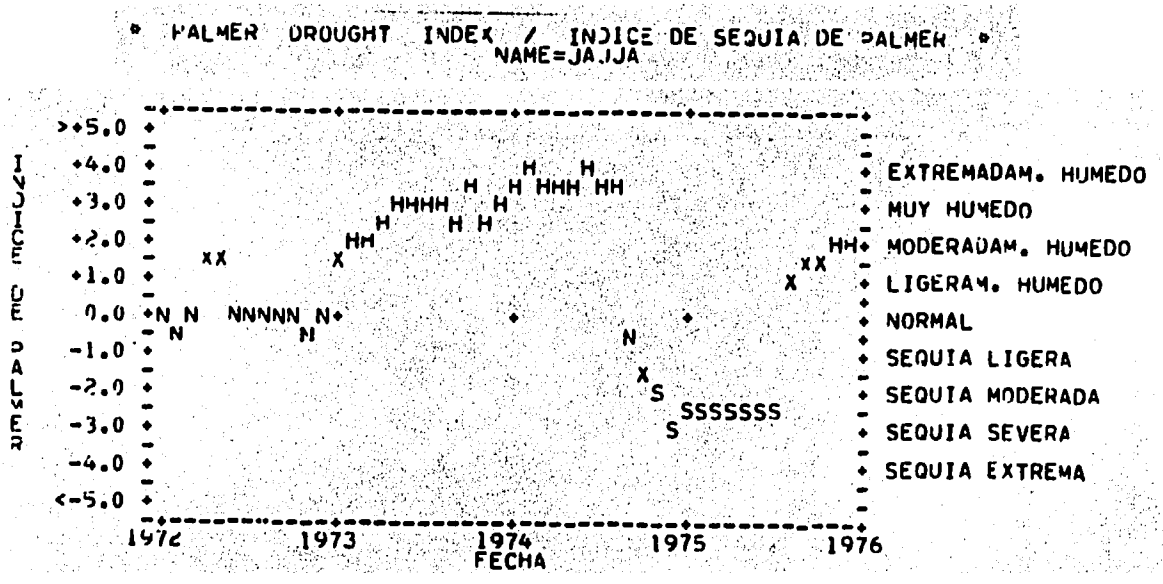
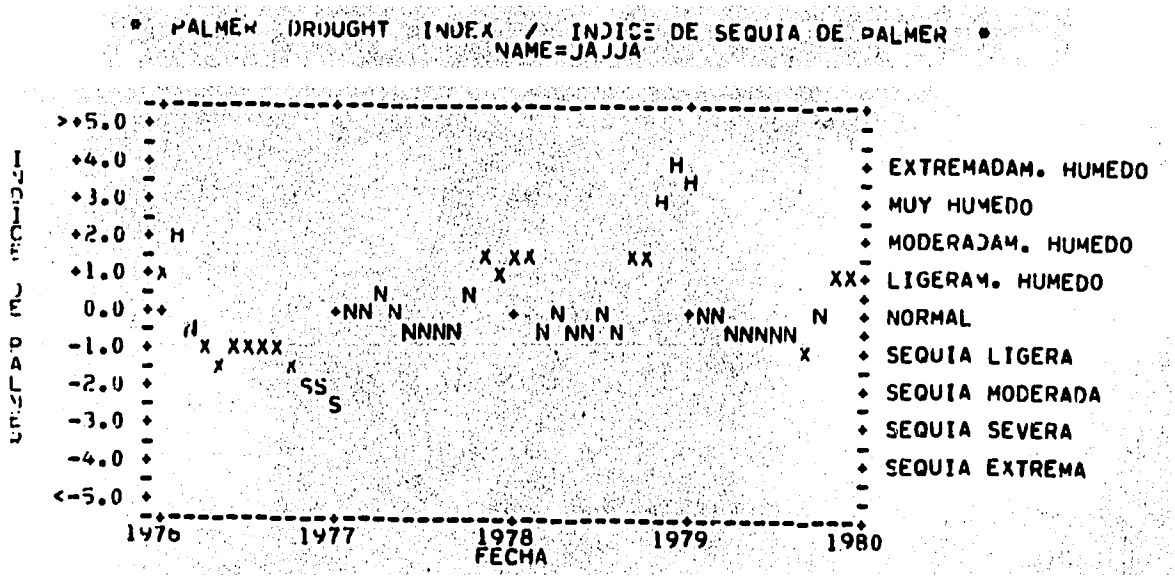


Figure 3.21. Drought Palmer Index

Indice de Sequia de Palmer para Jauja, Peru



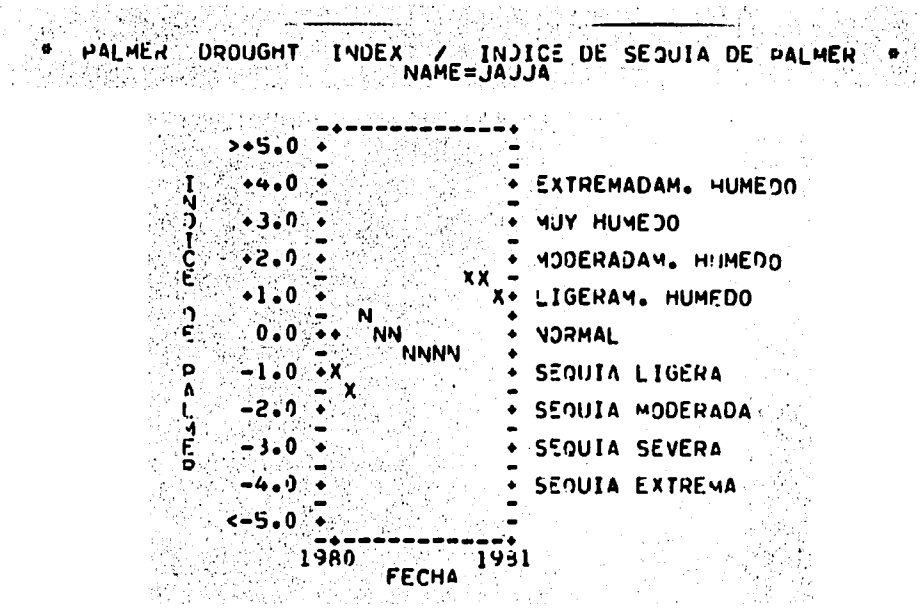


Figure 3.21. Drought Palmer Index

Indice de Sequia de Palmer para Jauja, Peru

CHAPTER IV

CROP YIELD MODELING RESULTS

Statistical climate/crop yield forecast models were developed for major grain and food crops grown in the Mantaro Valley. Models for barley, wheat, field corn, sweet corn, green and dry peas, green and dry lima beans and potatoes are based on some very significant relationships between climatic variables and year-to-year yield variations. These relationships reflect the biological or agronomic response of the crop to moisture and temperature anomalies during the growing season, particularly during the critical flowering/reproductive crop stages. Although the models require full test and evaluation, they provide a solid foundation for crop yield and production forecasts by at least 30 days before the harvest of the crop. The models also suggest some of the critical periods during the crop growing season when the agroclimatic requirements of the crops must be satisfied. This identification of key agroclimatic requirements can contribute to improved land use. Farm management practices can be developed to increase food production by reducing climatic vulnerability.

In addition to discussions on the crop yield modeling results, this chapter also includes information on the history of crop yield modeling, analytic steps for model development, agroclimatic/crop condition indices for the Mantaro Valley and suggestions for test and evaluation of the models.

A. Background

During the decade of the 1970's, significant advances were made in the development and application of climatic/crop yield forecast models. The success of this applied modeling is associated with the increased availability of computers which permitted scientists to develop the models plus the critical need for climate impact information. Decision makers, planners and economists have come to

recognize that this approach can provide timely, reliable and yet inexpensive information concerning the impact of climate on crop yields and agricultural production. The role of these models as providing information to supplement and complement other information sources has become recognized, e.g., crop information sources including farm and marketing reports, probability surveys involving area frame analysis, census, demand side economic analysis and others. Statistical models have been developed or at least attempted for many geographic regions in the world, particularly major grain producing areas. Some of the crops modeled include wheat, corn, barley, soybeans, sorghum/millet, rice, cotton, sunflower, flax, groundnuts, sesame, sugar cane, oil palm and others.

Climate/crop yield models are also being used to provide early warning of potentially disastrous food shortages resulting from severe drought. For example, the United Nations, Food and Agricultural Organization and the U.S. National Oceanic and Atmospheric Administration, Center for Environmental Assessment Services (NOAA/CEAS) are two organizations involved in this type of effort. The NOAA/CEAS program provides support to the Office of U.S. Foreign Disaster Assistance of AID (Steyaert et al, 1981).

Types of Models

There are essentially three types of crop yield models: statistical climate/crop yield models, agroclimatic/crop condition indices and the phenologic or "process" models.

The most widely used approach is the statistical model based on multiple linear regression analysis using historic climatic data and crop yield. These models provide absolute yield forecasts.

The second type of model is the agroclimatic/crop condition index. This approach can be used if yield data are not available for regression analysis. Relative crop yield information is obtained from the index. The index is based on an agroclimatic variable (cumulative precipitation, PET, ET/PET, FAO index, soil moisture index, Z-Index and others) which is directly associated with the year-to-year variations in crop yield. The index provides a measure of climatic impact on the crop.

The agroclimatic variable on which the index is based could be viewed as that predictor variable which would produce a statistically significant regression model - if yield data were available. The choice of the proper agroclimatic variable can be determined by: 1) knowledge of those climatic conditions which determine yield, particularly true for marginal, semi-arid production regions where crops are rainfed, 2) information on the appropriate variables determined by regression analysis for similar regions and 3) qualitative information, termed episodic data, on the historical causes (both weather and non-weather factors) of crop failure or bumper crops. For example, published reports, newspaper articles, discussions with farmers and other sources of information can be used to assemble these qualitative accounts for many different years. Episodic data can also be used to interpret or "calibrate" the indices for a particular region. For example, the index can be computed from 20-30 years of historic climatic data and plotted as a time-series. The values of the index are entirely relative and can be expressed in raw numbers, percent of normal, percent of some base year, percentiles, standard deviations, etc. Episodic reports on the failure of crops due to drought may suggest for example, that "historically crop failure is associated with index values which are below the 20th percentile or equivalently 60 percent of normal."

The third type of model is the phenologic or "process" model which is based on plant processes such as photosynthesis. These models are still in the research and development stage. They were designed primarily to simulate the growth and development of a plant, for example, cotton, corn and sorghum. The models in some cases have been used as a farm management tool, for example, to examine various strategies for production. The models are being tested for potential application to provide yields for a large area such as a department or state. The models work best in the regions where they were developed, but are redefined for application in other areas.

Applications

The statistical crop models and the agroclimatic/crop condition indices are primarily drought impact models. Excessive moisture or flooding conditions are usually quite difficult to model. However, a skilled analyst can use the models to provide very useful crop yield information. The capabilities (when the model works) and limitations (when the model does not work) of the model must be used as guidelines for interpreting the output of the model.

Statistical climate/crop yield models can be used for other applications. For example, long-term records of climatic data can be used to simulate yield well beyond the period of record for observed yield data. Yield is an integrator of climate and the model converts climate data into simulated yield. Simulated yields can be used to determine the risk of crop failure, estimate probabilities of crop failure (2 consecutive or 3 consecutive years, etc.), estimate various probabilities for simultaneous crop failure in two or more regions and in the analysis of climatic trend. For example, an often overlooked

fact is that trends in yield or production can also be associated with long-term trends in rainfall. Sometimes trend in yield due to climate trend can also be associated with trend in yield due to improved technology or decreased soil fertility.

Steyaert, Ravelo and Achutuni (1979) used a statistical crop yield model to investigate the vulnerability of corn to drought in Haiti due to soil erosion. They found that soil erosion (associated with deforestation) and the reduced water holding capacity of the soil resulted in increased vulnerability of corn to drought, i.e., shallow soils cannot store much water to carry the crop through dry spells.

Crop yield models can be important tools for land use studies or analysis of climatic change (What happens to yield if rainfall decreases by 50 percent?). The models can increase awareness and knowledge about those climatic conditions which affect yield. Finally, the models can in some cases be used as a basis for farmer's advisories, e.g., recommended planting date, irrigation scheduling, and fertilizer applications (see Steyaert et al, 1981).

B. Analytic Steps to Model Development

Year-to-year changes in crop yield can be caused by weather events (frost, flooding, winds, etc.), climate (drought, anomalously "wet" years, low solar radiation, etc.), management decisions (planting date, weed and pest control, water control, tillage practices, etc.), and/or technology (variety, fertilizer and pesticide applications, irrigation, etc.). These factors plus soil determine the potential yield. Trends in yield can be associated with either changes in technology (e.g., increased technology impact each year), trend in climate or both.

The above factors suggest the need for several different types of data bases: meteorological, crop statistics (area, yield and production), technology data and episodic data as previously described. Detailed information on crop calendars and agricultural practices are also necessary.

The first requirement is to assemble the available data and thoroughly perform quality control checks. The reliability and adequacy of meteorological and yield data must be determined. Too much emphasis cannot be placed on this step.

The modeler must become very familiar with agricultural practices and the factors which cause yield variability. The candidate predictor variables, role of technology, and significance of decadal, monthly or seasonal predictor variables must be determined.

In the traditional statistical climate/crop yield models, the basic predictor variables are monthly precipitation, temperatures or derived indices such as the R-Index. If technology has caused a time trend in yield, a time or year term has traditionally been used as a surrogate variable for technology. The time trend variable is included as a predictor variable in the model development.

Scatter diagrams and linear correlations are used to select preliminary predictor variables which must be statistically related to yield as well as biologically related to the crop. Linear regression analysis is used to develop the model. The final models must be tested and evaluated.

Some of the advantages and disadvantages of statistical climate/crop yield models include:

Disadvantages

1) They use a fixed crop calendar, i.e., it is assumed that the planting and vegetative growth stages, etc., occur at the same time each year. Therefore, if a delay in planting occurs, the model may not be able to respond.

2) Monthly data are used. Crops are also responsive to more frequent changes in the weather or climate.

3) Shorter period weather phenomena, especially episodes such as extreme temperatures, high winds, freeze, or flooding cannot be modeled very well.

4) Episodes usually do not occur frequently enough to do a quantitative analysis.

5) Regression models tend to predict "close to the mean yield" and do not predict extremes very well. The models should not be used to predict independently outside of the range data.

6) The models use linear trend as a surrogate for technology. If not objectively specified, the trend term can be very misleading in the development and use of the model. Linear trend is used because the technology data are generally not available or are of low quality. Furthermore, no one has devised a statistical method of combining weather and technology data.

7) Future climate/crop relationships may change from historical relationships used to develop the model. For example, varieties could change such as traditional varieties to high yielding varieties. The climatic responses could be different.

Advantages

1) These models are based on the statistical/agronomic/physical significance between the climatic data and crop yield data. Physical significance means that any weather or climatic variable used in the model has a high degree of biological relationship with known effect on the crop.
2) Models represent straight-forward relationships that make minimal assumptions and permit the yield data and climatic data to define the model according to historical interrelationships. They make the maximum use of historical climatic data and yield which is an integrator of climate.
3) The models are inexpensive to operate and produce useful information, particularly if they are evaluated according to strengths and weaknesses along with other crop yield or crop condition forecast procedures.

C. Agroclimatic/Crop Condition Indices

The usefulness of agroclimatic/crop condition indices as assessment tools to monitor drought and assess climatic impact on crops should not be underestimated. Such indices are particularly useful for assessing relative crop yields (and production) for crops which are vulnerable to drought. Many of these same indices contribute to studies involving land use questions. Some of the traditional indices include:

1) Palmer Drought Index (Palmer, 1965)

   This index has been used as an indicator of climatic impact on general agriculture. The index is categorical and ranges from anomalously wet to extreme drought classes. The PDI has recognized limitations and must be tested to determine its usefulness in a particular region before it is used operationally.

2) R-Index (yao, 1969)

   The R-Index, the ratio of actual evapotranspiration to potential evapotranspiration, has been widely used as a moisture stress indicator for crop assessment and particularly for land use studies (see Ravelo and Steyaert, 1981 and Steyaert et al, 1981).

3) Soil Moisture Index (Ravelo and Decker, 1979)

   The soil moisture index is defined as the ratio of the observed plant available soil moisture to the maximum potential available soil moisture.

4) Z-Index (Palmer, 1965)

The PDI uses the Z-Index which scales observed conditions according to the normal or "regionally appropriate" conditions. Sakamoto (1978) used the Z-Index in statistical climate/crop yield modeling for Australia.

5) Yield Moisture Index (NOAA/CEAS)

The Yield Moisture Index is a very straight forward agroclimatic/crop condition index which is based on weighted cumulative rainfall during the crop growing season. It makes minimal assumptions (e.g. on soil moisture and PET estimation) and is defined as:

$$YMI_j = \sum_{i=1}^{n} P_i KC_{ij}$$

where: YMI_j = the Yield Moisture Index for the jth crop (e.g., maize, wheat, etc.),

Pi is the precipitation for the ith crop growth stage (i=1,N) with Pi $\leq$ soil moisture field capacity, and

KC_{ij} is the appropriate crop coefficient for ith crop growth stage and the jth crop as determined from Table 3.7 with major crop stages of planting (i=1), vegetative (i=2) and the reproductive/flowering (i=3).

As discussed by Steyaert et al (1981), this index uses crop coefficients to weigh rainfall during the growing season according to the relative water requirement between crop stages. For example, Table 3.7 shows that water is of most importance to the crop during the critical flowering stage. This is one of the primary agroclimatic indices used by CEAS in drought/crop condition assessments (Steyaert, Ravelo and Sakamoto, 1980).

The YMI for maize at Huancayo (Figure 4.1) and Jauja (Figure 4.2) in the Mantaro Valley is proposed for test and evaluation. Maize was chosen because it is regionally important, vulnerable to drought and a good indicator of climatic impact on other weather sensitive crops. The YMI was calculated from monthly rainfall (not censored to field capacity), the crop calendar for maize in the Mantaro Valley and the crop coefficients provided in Table 3.7. The index is expressed in percentiles in Figures 4.1 and 4.2. It can also be expressed in raw form (units are millimeters) or as a percent of normal. Tables 4.1 and 4.2 provide the index values expressed in the above manner and for each truncation i.e., Maiz9 = planting, Maiz9-10 = planting/emergence, through Maiz9-2 = planting in September through flowering/silking in February. The index is calculated for each year during the period 1962-1980. Individualized YMI indices can also be computed for other crops which have different water requirements.

This preliminary index must be tested and evaluated at each location to determine the frequency that it detects drought, misses in drought related crop failure or gives a false indication of crop failure due to drought. Episodic data can be used for testing, determining the other factors associated with failure of maize, and "calibrating" the index. That is, the critical threshold values for a "normal" crop, drought impacted crop or crop failure due to drought.

If justified by test and evaluation, this simple index can provide reliable timely, yet quite inexpensive information on potential crop failure. Early warning can be provided by at least 30 days before harvest and this may represent a 1-6 month alert before market prices change. Furthermore, a skilled

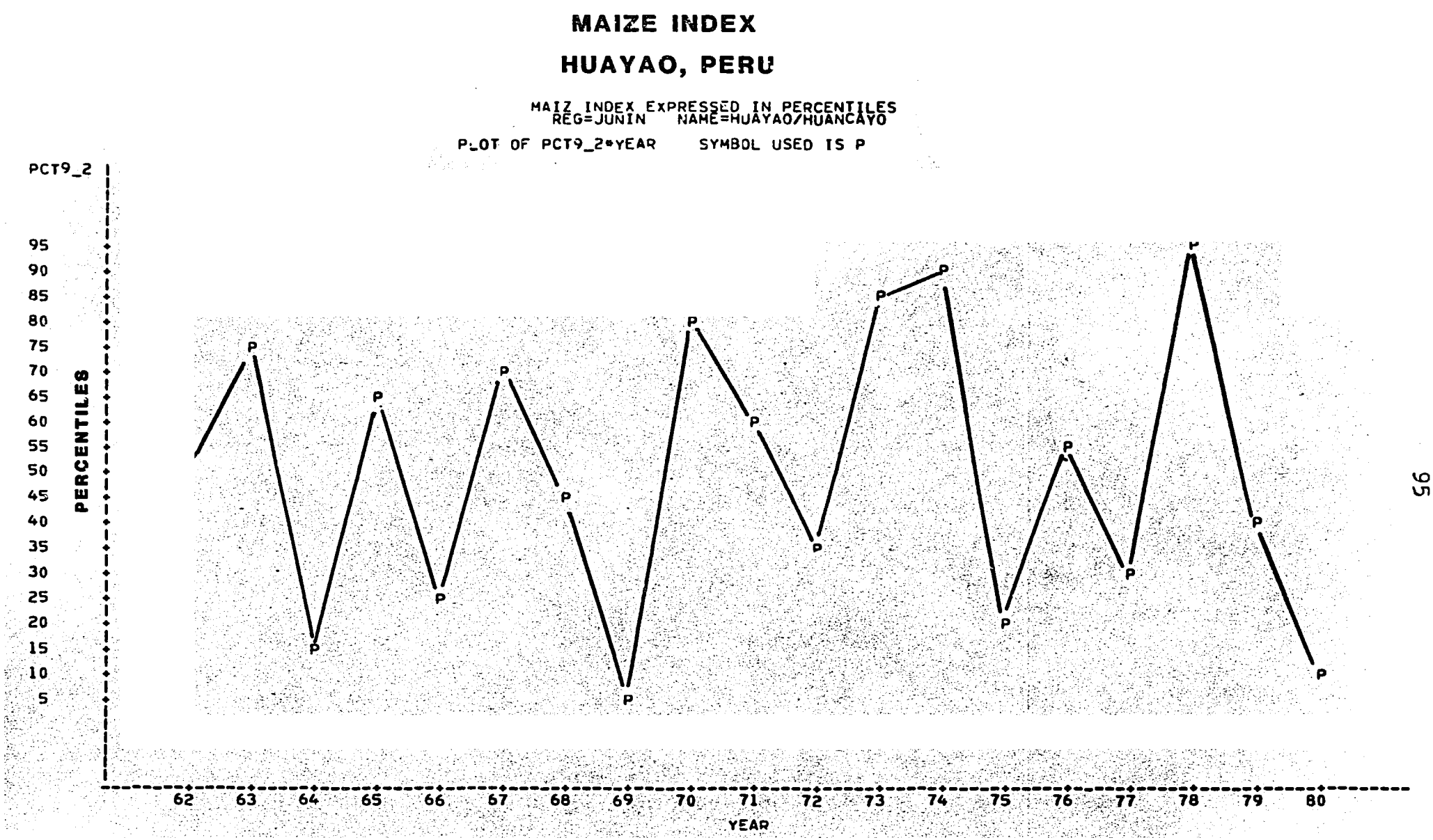


Figure 4.1. Preliminary Agroclimatic/Crop Conditions Index, Expressed in Percentiles for Maize at Huancayo, Peru

Indices Agroclimaticos Sobre las Condiciones del Cultivo de Maiz para Huancayo, Peru, Expresados en Percentiles

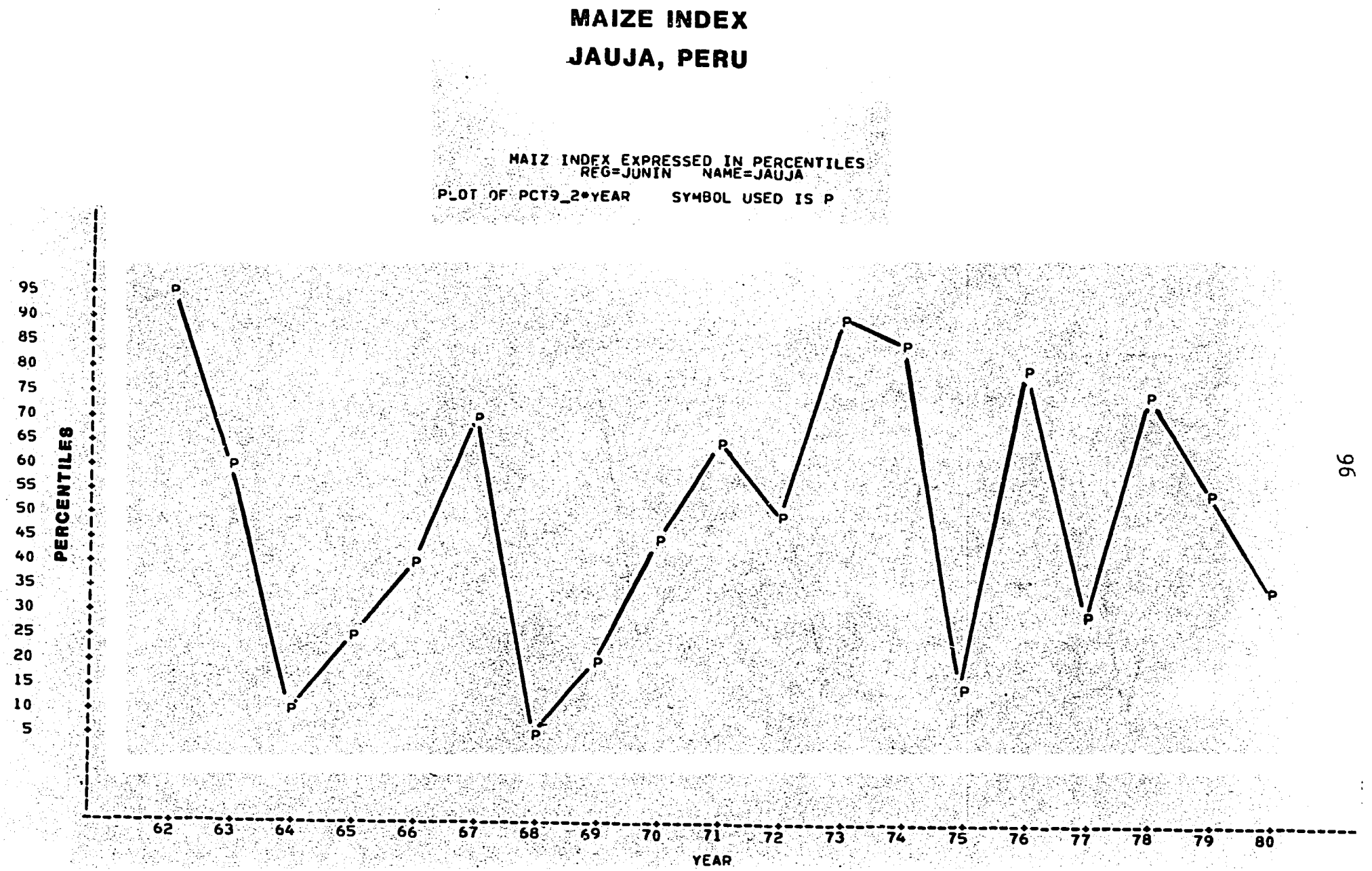


Figure 4.2. Preliminary Agroclimatic/Crop Conditions Index Expressed in Percentiles for Maize at Jauja, Peru

MAIZ INDEX BASED ON CROP COEFFS AND PRCPN

REG=JUNIN NAME=HJAYAO/HUANCAYO

OBS	YEAR	MAIZ9	MAIZ9 T0	MAIZ9 T1	MAIZ9 T2	MAIZ9 T	MAIZ9 Z	NOR9	NOR9 T0	NOR9 T1	NOR9 T2	NOR9 T	NOR9 Z	PNOR9	PNOR9 T0	PNOR9 T1	PNOR9 T2	PNOR9 T	PNOR9 Z	PCT9	PCT9 T0	PCT9 T1	PCT9 T2	PCT9 T	PCT9 Z
1	62	12	25	99	231	331	452	21	55	105	193	320	445	78	46	94	120	103	102	25	5	50	80	45	50
2	63	13	49	102	193	392	518	21	55	105	193	320	445	87	89	97	100	123	116	30	55	60	50	90	75
3	64	14	36	82	171	278	361	21	55	105	193	320	445	96	65	78	89	87	81	37	25	20	30	30	15
4	65	32	98	169	261	362	500	21	55	105	193	320	445	213	179	161	135	113	112	85	95	95	95	75	65
5	66	43	85	136	209	319	367	21	55	105	193	320	445	288	154	129	108	100	82	90	85	80	70	40	25
6	67	21	74	123	226	343	500	21	55	105	193	320	445	141	135	117	117	107	112	55	75	75	75	60	70
7	68	23	76	109	170	334	437	21	55	105	193	320	445	156	138	104	88	104	98	65	80	65	25	55	45
8	69	9	39	70	130	186	272	21	55	105	193	320	445	57	70	67	67	58	61	10	30	10	5	5	5
9	70	17	40	99	196	389	522	21	55	105	193	320	445	114	73	94	102	121	117	50	35	45	55	85	80
10	71	31	68	96	202	293	489	21	55	105	193	320	445	204	123	92	105	91	110	80	65	40	65	35	60
11	72	11	45	96	172	273	407	21	55	105	193	320	445	75	82	92	89	85	92	20	45	35	35	25	35
12	73	10	34	68	197	362	532	21	55	105	193	320	445	66	61	65	102	113	119	15	20	5	60	80	85
13	74	22	71	101	182	350	544	21	55	105	193	320	445	144	130	97	94	109	122	60	70	55	40	70	90
14	75	6	42	83	140	231	363	21	55	105	193	320	445	39	77	79	73	72	82	5	40	25	10	15	20
15	76	45	91	141	243	346	486	21	55	105	193	320	445	203	166	134	126	108	109	95	90	85	85	65	55
16	77	17	30	72	168	261	398	21	55	105	193	320	445	111	55	69	87	82	90	45	15	15	20	20	30
17	78	24	61	155	249	493	596	21	55	105	193	320	445	159	111	148	129	154	134	70	60	90	90	95	95
18	79	27	47	112	193	333	421	21	55	105	193	320	445	183	86	107	100	104	95	75	50	70	45	50	40
19	80	14	27	84	141	207	299	21	55	105	193	320	445	96	48	80	73	65	67	37	10	30	15	10	10

Table 4.1. Preliminary Agroclimatic/Crop Condition Index for Maize at Huayo/Huancayo, Mantaro Valley, Peru.

Indices Agroclimaticos sobre Condiciones del Cultivo de Maiz para Huayao/Huancayo, Valle del Mantaro, Peru

MAIZ INDEX BASED ON CROP COEFFS AND PRCPN

REG=JUNIN NAME=JAUJA

OBS	YEAR	MAIZ9	MAIZ9 T0	MAIZ9 T1	MAIZ9 T2	MAIZ9 T	MAIZ9 Z	NOR9	NOR9 T0	NOR9 T1	NOR9 T2	NOR9 T	NOR9 Z	PNOR9	PNOR9 T0	PNOR9 T1	PNOR9 T2	PNOR9 T	PNOR9 Z	PCT9	PCT9 T0	PCT9 T1	PCT9 T2	PCT9 T	PCT9 Z
1	62	11	24	129	300	509	661	15	51	106	203	341	471	72	46	122	148	149	140	42	10	70	90	95	95
2	63	8	24	90	166	364	530	15	51	106	203	341	471	51	46	84	82	107	112	20	15	40	25	50	60
3	64	11	39	84	159	247	305	15	51	106	203	341	471	75	77	79	78	72	65	52	25	25	15	25	10
4	65	23	82	131	168	263	362	15	51	106	203	341	471	153	160	123	83	77	77	80	95	75	30	30	25
5	66	24	52	74	185	313	402	15	51	106	203	341	471	159	103	70	91	92	85	85	55	15	40	40	40
6	67	10	59	112	221	332	543	15	51	106	203	341	471	66	116	105	109	97	115	30	70	60	65	45	70
7	68	5	66	92	161	222	291	15	51	106	203	341	471	33	129	87	79	65	62	15	75	45	20	5	5
8	69	10	41	85	172	243	349	15	51	106	203	341	471	69	80	80	85	71	74	35	30	30	35	20	20
9	70	21	48	65	209	364	475	15	51	106	203	341	471	141	93	61	103	107	101	75	45	10	60	55	45
10	71	9	47	88	193	366	538	15	51	106	203	341	471	63	92	83	95	107	114	25	40	35	45	60	65
11	72	17	58	101	257	387	480	15	51	106	203	341	471	114	114	95	127	113	102	65	65	55	80	70	50
12	73	20	51	92	194	448	619	15	51	106	203	341	471	132	100	87	95	131	131	70	50	50	50	85	90
13	74	11	75	116	226	450	618	15	51	106	203	341	471	75	147	110	112	132	131	52	85	65	70	90	85
14	75	1	13	49	80	227	331	15	51	106	203	341	471	6	26	46	40	67	70	5	5	5	5	10	15
15	76	29	77	165	261	369	575	15	51	106	203	341	471	195	151	155	129	108	122	90	90	90	85	65	80
16	77	11	44	80	150	242	386	15	51	106	203	341	471	72	87	76	74	71	82	42	35	20	10	15	30
17	78	17	57	154	206	404	563	15	51	106	203	341	471	111	112	146	101	118	120	60	60	85	55	75	75
18	79	38	72	181	314	430	523	15	51	106	203	341	471	255	140	171	154	126	111	95	80	95	95	80	55
19	80	3	36	133	229	302	401	15	51	106	203	341	471	21	71	125	113	89	85	10	20	80	75	35	35

Table 4.2. Preliminary Agroclimatic/Crop Condition Index for Maize at Jauja, Montaro Valley, Peru

Indices Agroclimatic sobre Condiciones del Cultivo de Maiz para Jauja, Valle del Mantaro, Peru

assessor can convert the relative crop yield information into a maize production estimate. This can be used to supplement and complement crop forecast information obtained from other sources (e.g., area frame probability sampling, the farmer, economic analysis, or statistical climate/crop yield forecast models).

D. Statistical Climate Crop Yield Forecast Models for the Mantaro Valley

Statistical climate/crop yield models were developed for wheat, barley, sweet corn, field corn, green peas, dry peas, green lima beans, dry lima beans and potatoes in the Mantaro Valley (Table 4.3). Although these preliminary models require thorough test and evaluation, they are very promising. Testing should include evaluation of independent predictions for years not in the data base. The predictor variables in the models should be validated to ensure that they are biologically related to the crop and reflect vulnerability of the crop to climate anomalies which lead to yield losses.

Two types of variables were used to develop these linear regression models. Monthly precipitation and temperature were used as predictor variables for the barley, wheat, dry and green lima beans models shown in Figures 4.3-4.8, respectively. Derived variables (R-Index and Z-Index) were used to develop additional models, for example, Figure 4.9-4.12.

The linear regression models have the form:

$$\hat{Y} = a_0 + a_1 \text{ (Trend)} + \sum_{i=2}^{N} a_i X_i$$

where:

$\hat{Y}$ is the predicted yield (mt/ha),

a_0 is the regression constant (i.e., intercept),

a_1 is the estimated regression coefficient for the linear "trend"

TABLE 4.3

PERU

Preliminary Statistical Climate/Crop Yield Forecast Models for the Mantaro Valley, Peru.[1]

Crop	Crop Variable	Bo	Trend	Weather Variables B1	B2	B3	R^2%	Standard Error of Estimate	Harvest Month	Crop Forecast Month
Barley	XYLD1	1.3240		P2-4 .00098	T2 -.0402		80.0	.0363	Jun	May 1
Barley	XYLD1	.7579		P2-4 .00132	T2 -.0945	T4 .0976	93.2	.0237	Jun	May 1
Wheat	XYLD3	.9051	.0278	LP11-1 .00074			79.6	.0533	Jun	Feb 1
Wheat	XYLD3	.9067	.0357	LP12-1 .00081			76.8	.0568	Jun	Feb 1
Field Corn	XYLD4	1.0488	.0136	P1 .00071			67.8	.0350	May	Feb 1
Sweet Corn	XYLD5	6.5478		P2-4 .0036			66.1	.1418	Mar	May 1
Dry Field Peas	XYLD6	1.6474	.0212	LT10 -.0511			68.0	.0507	Apr	Nov 1
Dry Field Peas	XYLD6	.9793		LP11 .0018			54.4	.0506	Apr	Dec 1
Green Peas	XYLD7	-9.9718	.1578	LT11 1.1127			73.6	.5619	Mar	Dec 1
Dry Lima Beans	XYLD8	2.8108	.0646	LT11 -.1585			86.0	.0850	Apr	Dec 1
Dry Lima Beans	XYLD8	.7174		LP11 .0055			81.9	.0894	Apr	Dec 1
Green Lima Beans	XYLD9	6.9740	.0780	P2-3 -.0097			93.4	.1572	Mar	Apr 1
Green Lima Beans	XYLD9	8.6425	.1662	LT11 -.3643			76.2	.2987	Mar	Dec 1
Traditional Potatoes	XLYD10	1.6873	.4942	P2-4 .0056			99.5	.1000	May	May 1
HYV Potatoes	XYLD11	4.8649		P1-3 .0101			76.4	.3555	Apr	Apr 1

Note[1]: Bo is constant; Trend is "Trend coeff"; B1, B2, B3 are weather variable coefficents, R2 is explained variance; standard error of estimate is in mt/ha.

variable defined as time (1, 2, 3,.....) and acting as a surrogate for technology if technological trend was in the yield data, and

a_i is the ith estimated regression coefficient for the ith meteorological predictor variable, X_i.

Table 4.3 summarizes all of the models which were developed. The variable, coefficients, explained variance (R^2), standard error and forecast months are indicated. Statistics are also indicated on each Figure.

These models are all statistically significant. The physical or biological significance of the predictor variable has to be verified. This is particularl true for models based on derived indices. However, at the time of this report, the available information on agricultural practices in the valley, the known vulnerability of crops to climate and also results of field experiments suggest that the models based on rainfall and temperature are valid. The algebraic signs on the coefficients appear to be agronomically and biologically meaningful. Additional years should be added to the models to account for a larger range of climatic conditions.

The explained variance of the models ranges from about 54.4 percent for one of the dry field peas models to 99.5 percent for the model on traditional potatoes. Most of the R^2 values are in the 80 percent range. Because technology trend in the yield data may account for a large portion of the R^2, this statistic can be somewhat misleading. A 60-70 percent R^2 for a model with no yield technology time trend is potentially a very useful model. In the case of the traditional potatoes model, most of R^2 is due to trend; however, fluctuations in yield appear to be related to rainfall during February-April.

BARLEY CROP YIELD MODEL
MANTARO VALLEY, PERU

MODEL: MODEL01
DEP VAR: XYLD1

SSE	0.006593243	F RATIO	10.15
DFE	5	PROB>F	0.0173
MSE	0.001318649	R-SQUARE	0.8024

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	1.324375	0.228438	5.7975	0.0022
P2_4	1	0.0009812133	0.0002707045	3.6247	0.0151
T2	1	-0.040197	0.017405	-2.3095	0.0690

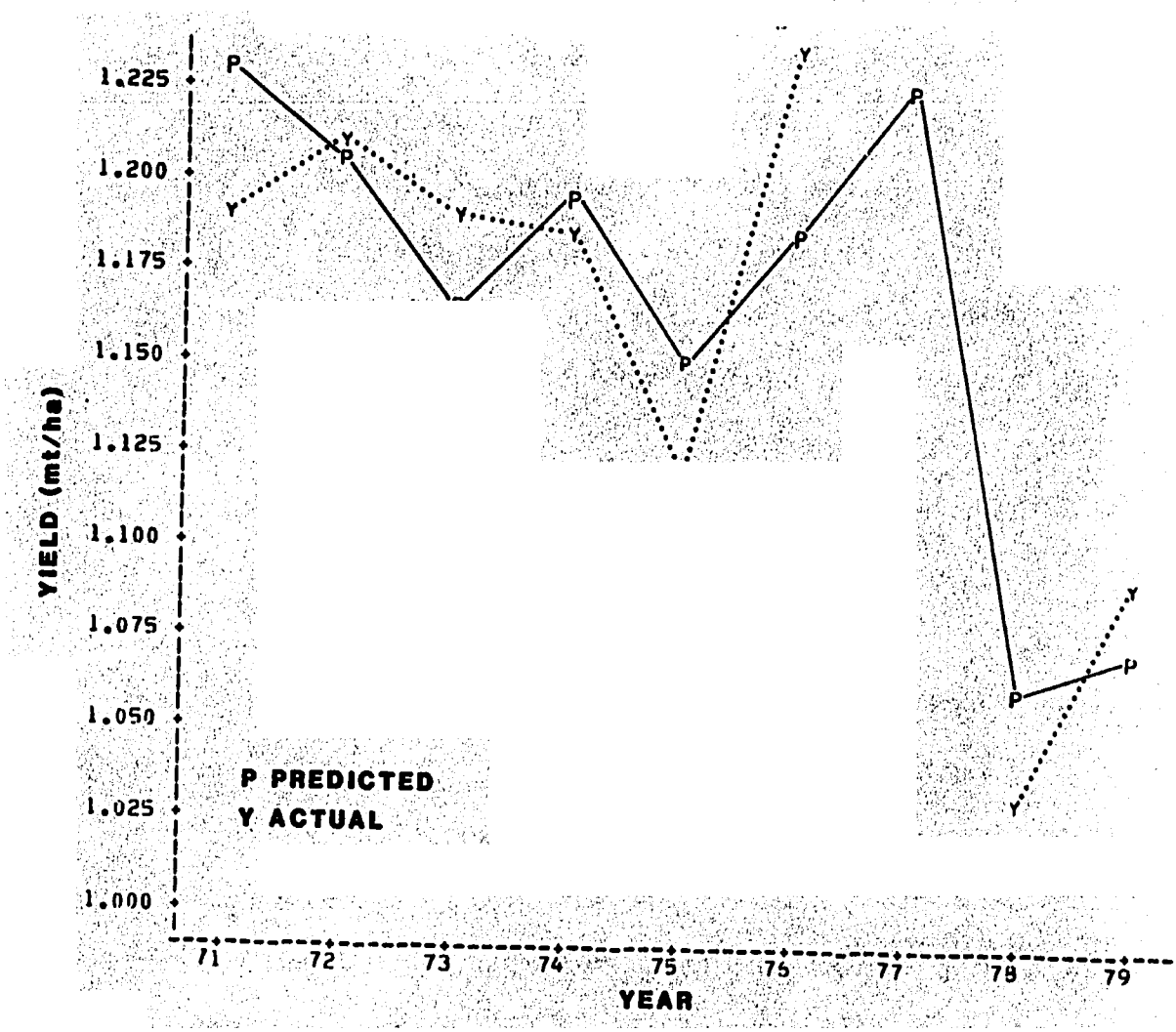


Figure 4.3. Comparison of Actual Barley Yield (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on the Cumulative Precipitation February-April and the February Temperature

Comparacion entre los Rendimientos de Cebada en el Valle del Mantaro y los Rendimientos Estimados Basados en la Precipitacion Acumalada en los Meses Febrero-Abil y la Temperatura de Febrero

BARLEY CROP YIELD MODEL
MANTARO VALLEY, PERU

MODEL: MODEL01	SSE	0.002245317	F RATIO 18.48
DEP VAR: XYLD1	DFE	4	PROB>F 0.0083
	MSE	0.005613292	R-SQUARE 0.9327

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	0.757471	0.252283	3.0041	0.0398
P2-4	1	0.00131948	0.0002143995	6.1543	0.0035
T2	1	-0.094493	0.022574	-4.1860	0.0139
T4	1	0.097639	0.035082	2.7831	0.0497

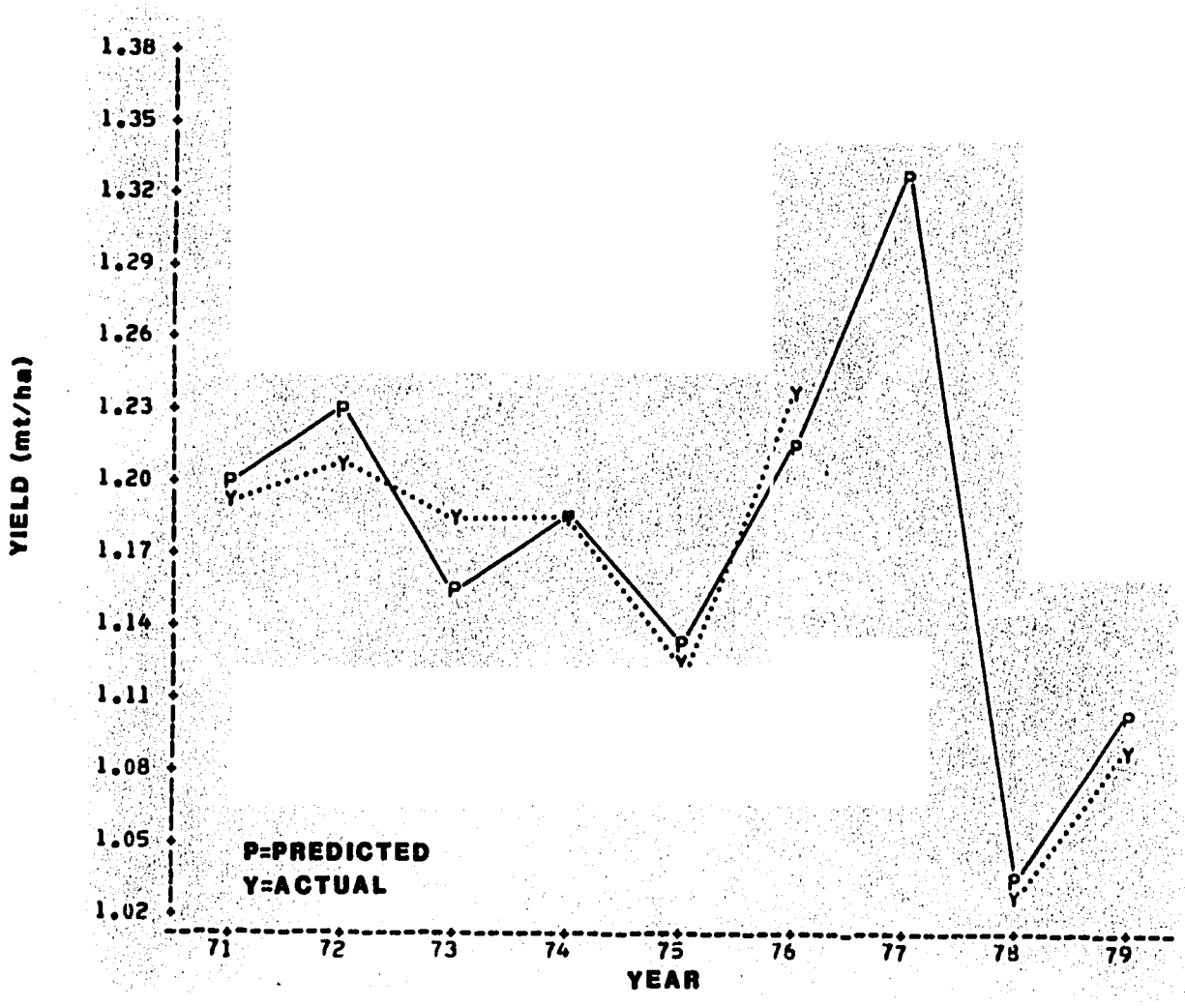


Figure 4.4. Comparison of Actual Barley Yield (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on Cummulative Precipitation February-April, February Temperature and April Temperature

Comparacion entre los Rendimientas Observados de Cebada en el Valle del Mantaro, y los rendimientos Estimados Basados en la Precipitacion Acumuloda en la Meses Febrero-Abril y las Temperaturas de los Meses Febrero y Abril

WHEAT CROP YIELD MODEL
MANTARO VALLEY, PERU

MODEL:	MODEL01	SSE	0.016184	F RATIO	11.81
DEP VAR:	XYLDJ	DFE	5	PROB>F	0.0083
		MSE	0.002697315	R-SQUARE	0.7974

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	0.894587	0.097178	9.2057	0.0001
TRND	1	0.026182	0.006713744	3.8997	0.0080
LP11_1	1	0.0007919815	0.000293714	2.6964	0.0357

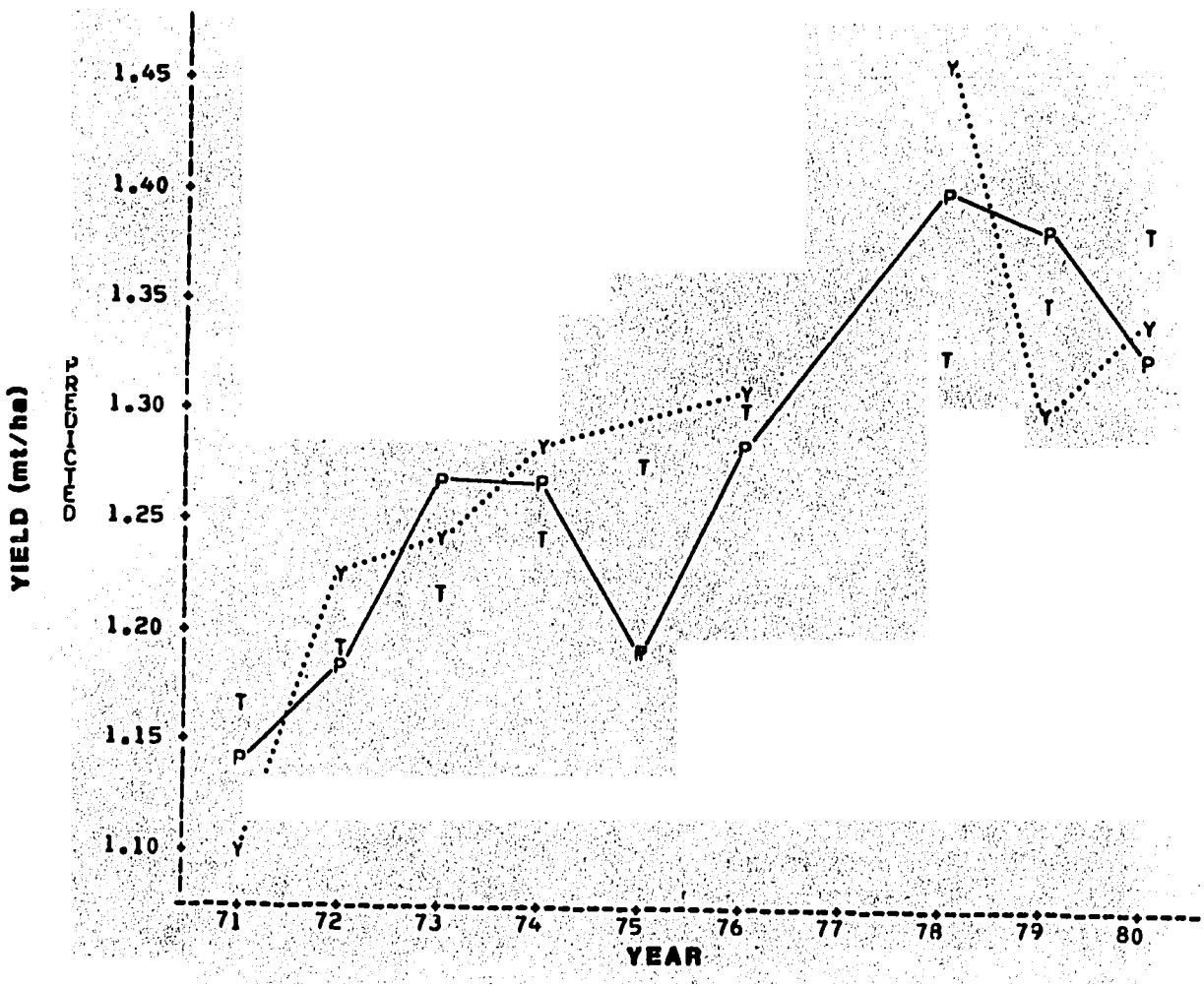


Figure 4.5. Comparison of Actual Wheat Yields (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on Cummulative Precipitation November-January

Comparacion entre los Rendimientos Observados de Trigo en el Valle del Mantaro y los Rendimientos Estimados Basados en la Precipitacion accumulada en los Meses Noviembre-Enero

LIMA BEANS (DRY)

CROP YIELD MODEL MANTARO VALLEY, PERU

MODEL: MODEL01
DEP VAR: XYLD8

SSE	0.044183	F RATIO	17.93
DFE	5	PROB>F	0.0029
MSE	0.007364175	R-SQUARE	0.8567

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	2.859346	0.694542	4.1163	0.0062
TRND	1	0.063966	0.011266	5.6776	0.0013
LT11	1	-0.162242	0.055969	-2.9040	0.0272

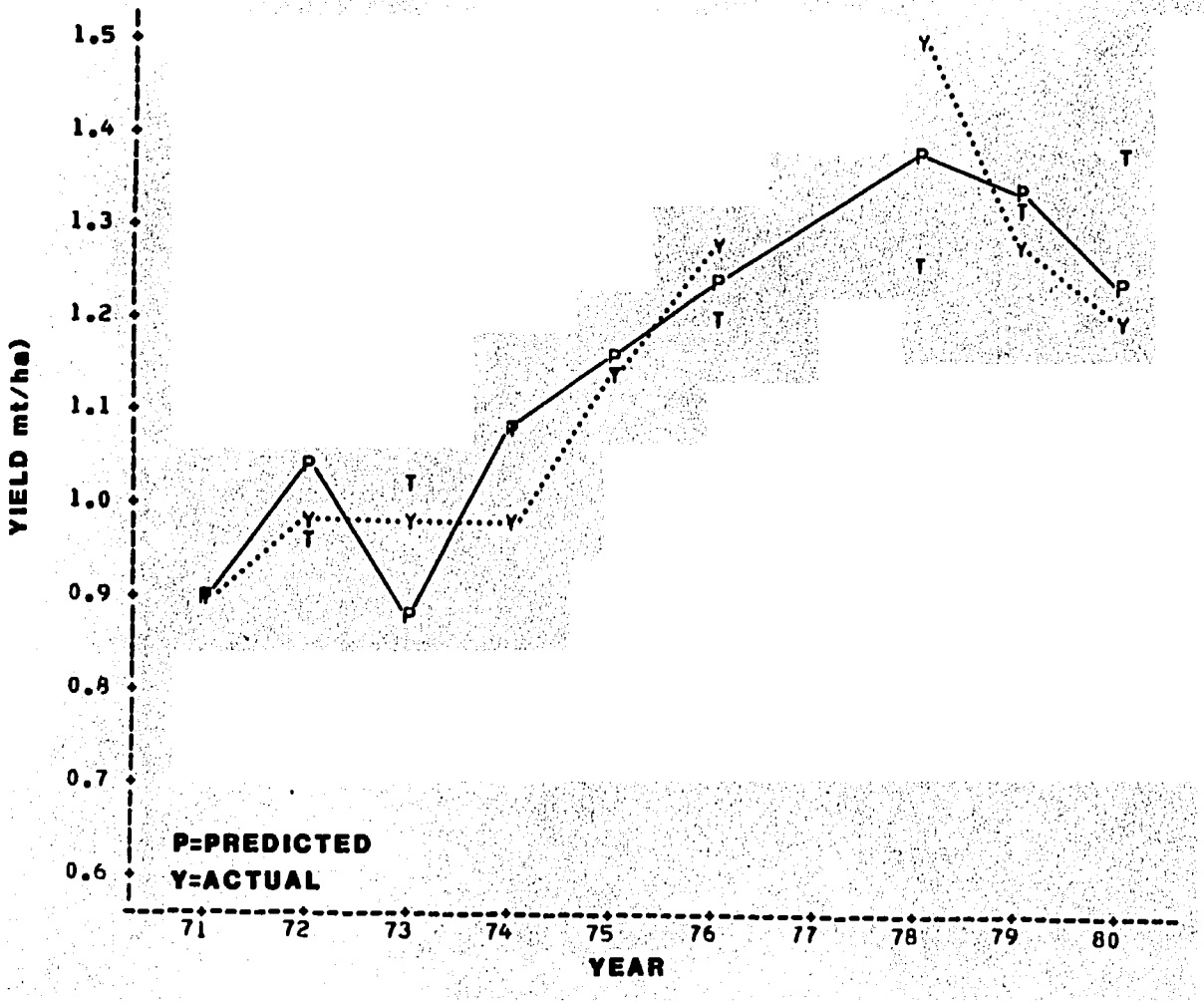


Figure 4.6. Comparison of Actual Lima Beans (Dry) Yields (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on November

Comparacion entre los Rendimientios Observados de Haba (Grano Seco) en el Valle del Mantaro y los Rendimiento Estimados Basados en la Temperatura de Noviembre

LIMA BEANS (DRY)

CROP YIELD MODEL MANTARO VALLEY, PERU

MODEL:	MODEL01	SSE	0.057435	F RATIO	30.57
		DFE	7	PROB>F	0.0009
DEP VAR:	XYLD8	MSE	0.008205 01	R-SQUARE	0.8137

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	0.718771	0.082006	8.7647	0.0001
LP11	1	0.00545122	0.0009859513	5.5289	0.0009

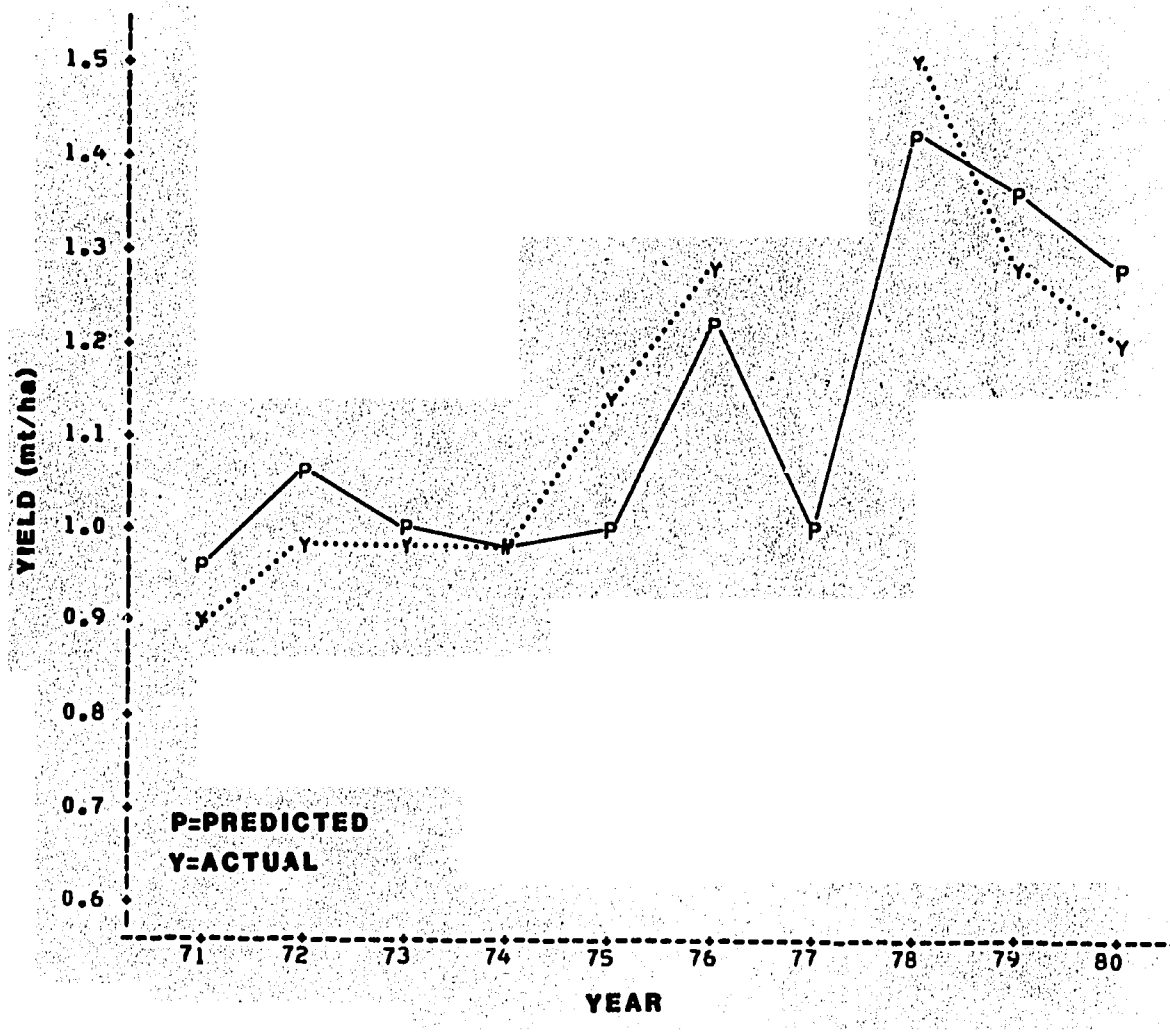


Figure 4.7. Comparison of Actual Lima Beans (Dry) Yields (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on November Precipitation

Comparacion entre los Rendimientios Observados de Haba (Grano Seco) en el Valle del Mantaro y los Rendimiento Estimados Basados en la Precipitacion de Noviembre

LIMA BEANS (GREEN)

CROP YIELD MODEL MANTARO VALLEY, PERU

MODEL: MODEL01		SSE	0.135197	F RATIO	46.15
		DFE	5	PROB>F	0.0002
DEP VAR: XYLDY		MSE	0.022533	R-SQUARE	0.9390

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	7.128948	0.521549	13.6662	0.0001
TRND	1	0.069293	0.023575	2.9392	0.0260
P2_3	1	-0.010168	0.001739874	-5.8444	0.0011

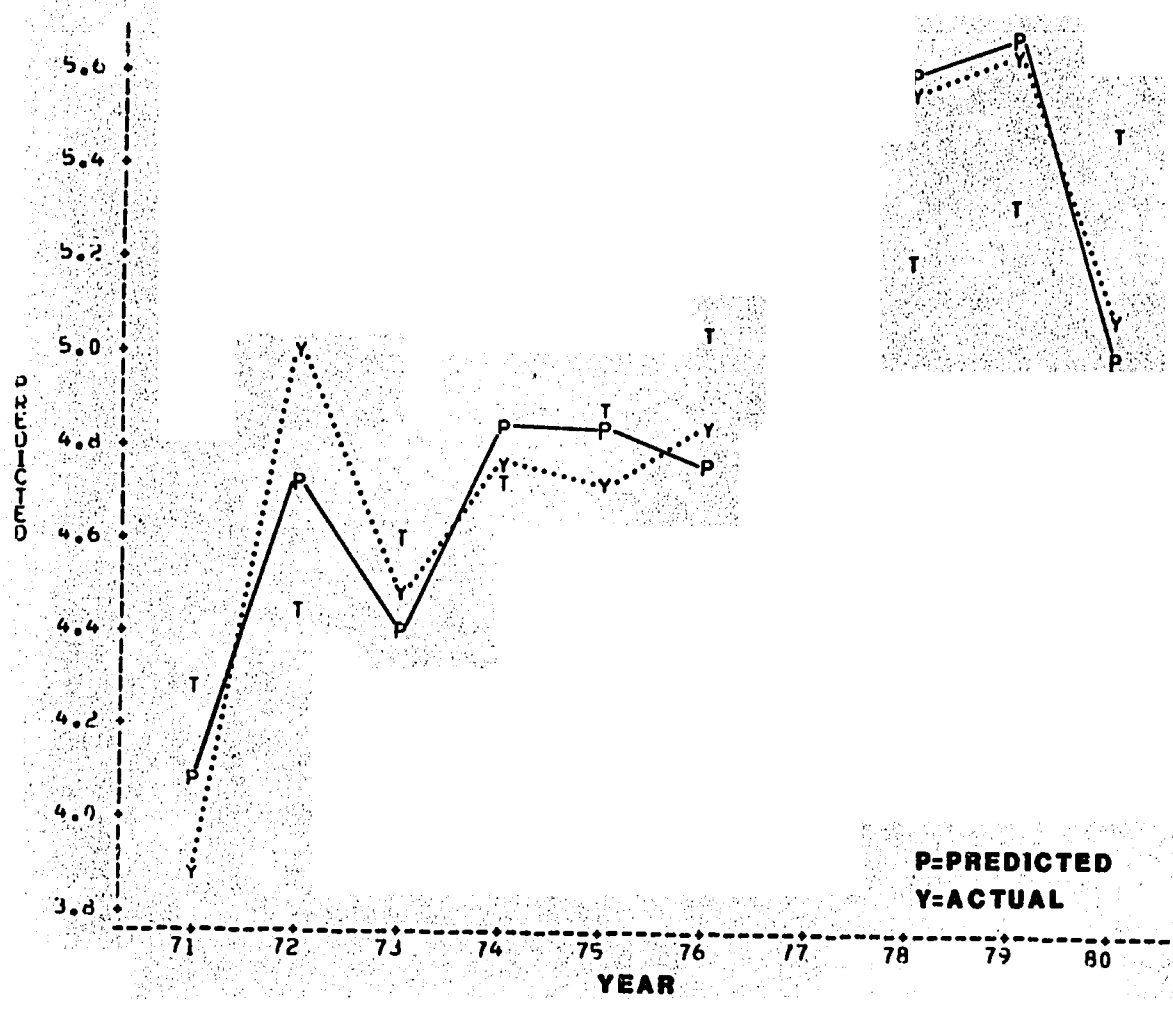


Figure 4.8. Comparison of Actual Lima Beans (Green) Yields (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on Cummulative Precipitation February-March

Comparacion entre los Rendimientos Observados de Haba (Grano Verde) en el Valle del Mantaro y los Rendimientos Estimados Basados en la Precipitacion Acumulada en los Meses Febrero-Marzo

WHEAT CROP YIELD MODEL
MANTARO VALLEY, PERU

MODEL: MODEL01		SSE	0.021744	F RATIO	8.02
		DFE	6	PROB>F	0.0202
DEP VAR: XYLDJ		MSE	0.003624011	R-SQUARE	0.7279

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	0.983472	0.088983	11.0524	0.0001
LRI10	1	0.304892	0.154539	1.9691	0.0965
TRND	1	0.028394	0.007798959	3.6407	0.0108

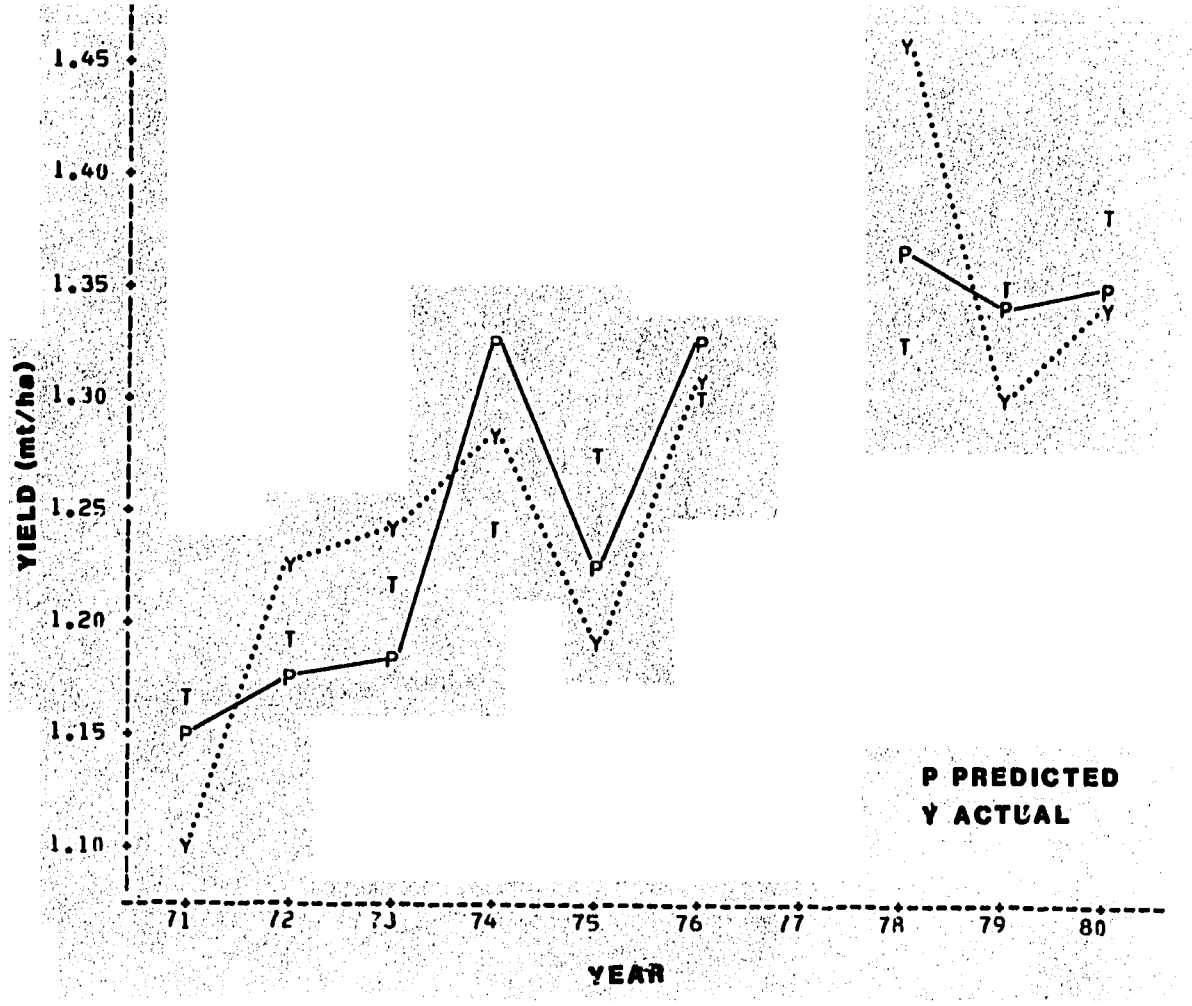


Figure 4.9. Comparison of Actual Wheat Yields (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on the RI-Index for October

Comparacion entre los Rendimientos Observados de Trigo en el Valle del Mantaro y los Rendimientos Estimados Basados en el Indice-RI para el Mes de Octubre

WHEAT CROP YIELD MODEL
MANTARO VALLEY, PERU

MODEL: MODEL01 SSE 0.019412 F RATIO 9.10
DEP VAR: XYLD3 DFE 6 PROB>F 0.0152
MSE 0.003301455 R-SQUARE 0.7520

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	1.160920	0.043247	26.8438	0.0001
ZINDEX3	1	-0.00102634	0.000466485	-2.2002	0.0701
TRND	1	0.024146	0.007539984	3.2025	0.0185

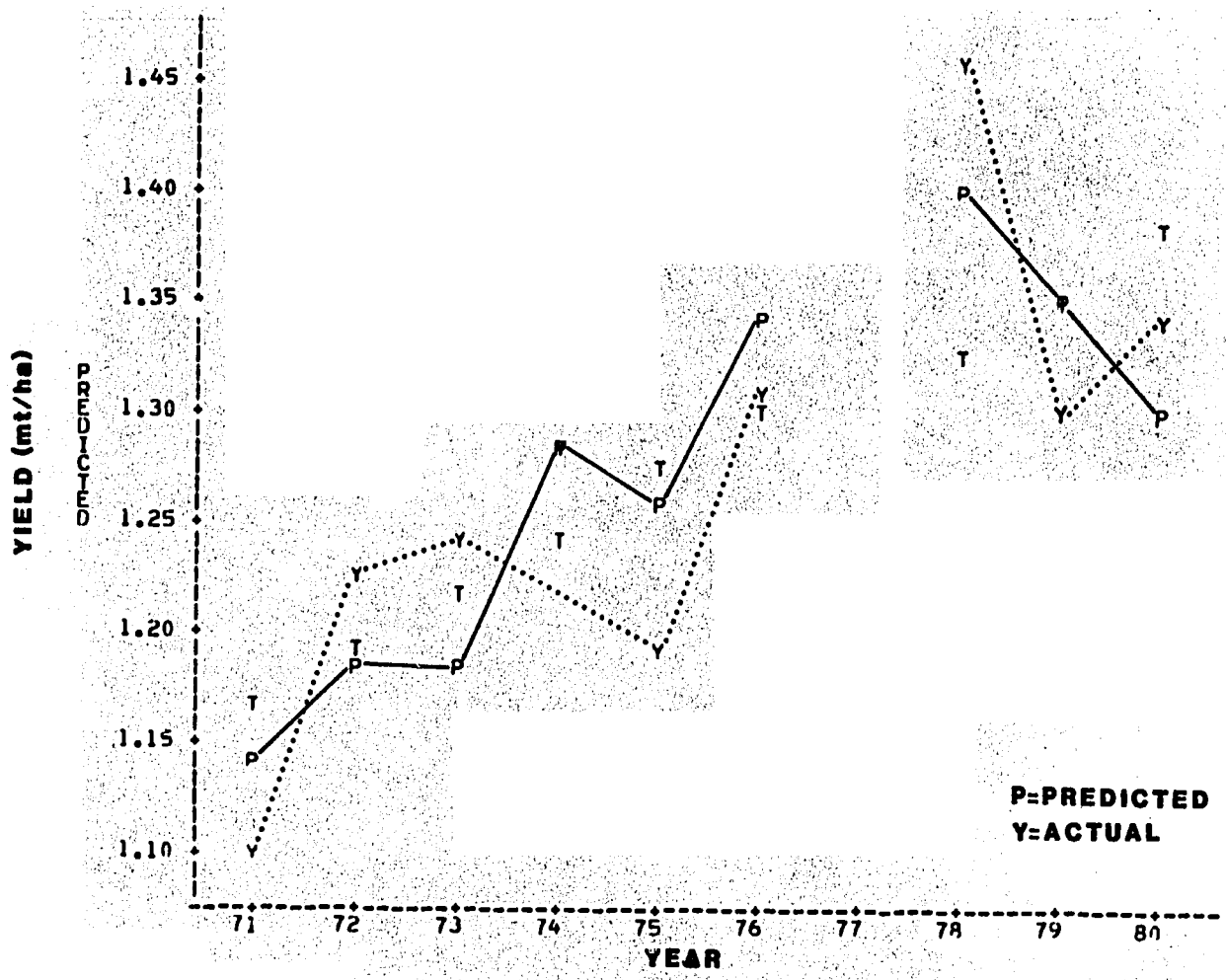


Figure 4.10.. Comparison of Actual Wheat Yield (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on the Z-Index for March

Comparacion entre los Rendimientos Observados de Trigo en el Valle del Mantaro y los Rendimientos Estimados Basados en el Indice-Z (Palmer) para el Mes de Marzo

LIMA BEANS (DRY)
CROP YIELD MODEL MANTARO VALLEY, PERU

MODEL: MODEL01
DEP VAR: XYLDB

SSE	0.045260	F RATIO	17.43
DFE	5	PROB>F	0.0032
MSE	0.007543346	R-SQUARE	0.8532

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	0.898813	0.065367	13.7504	0.0001
ZINDEX3	1	-0.00200549	0.0007050745	-2.8444	0.0294
TRND	1	0.052222	0.011395	4.5824	0.0038

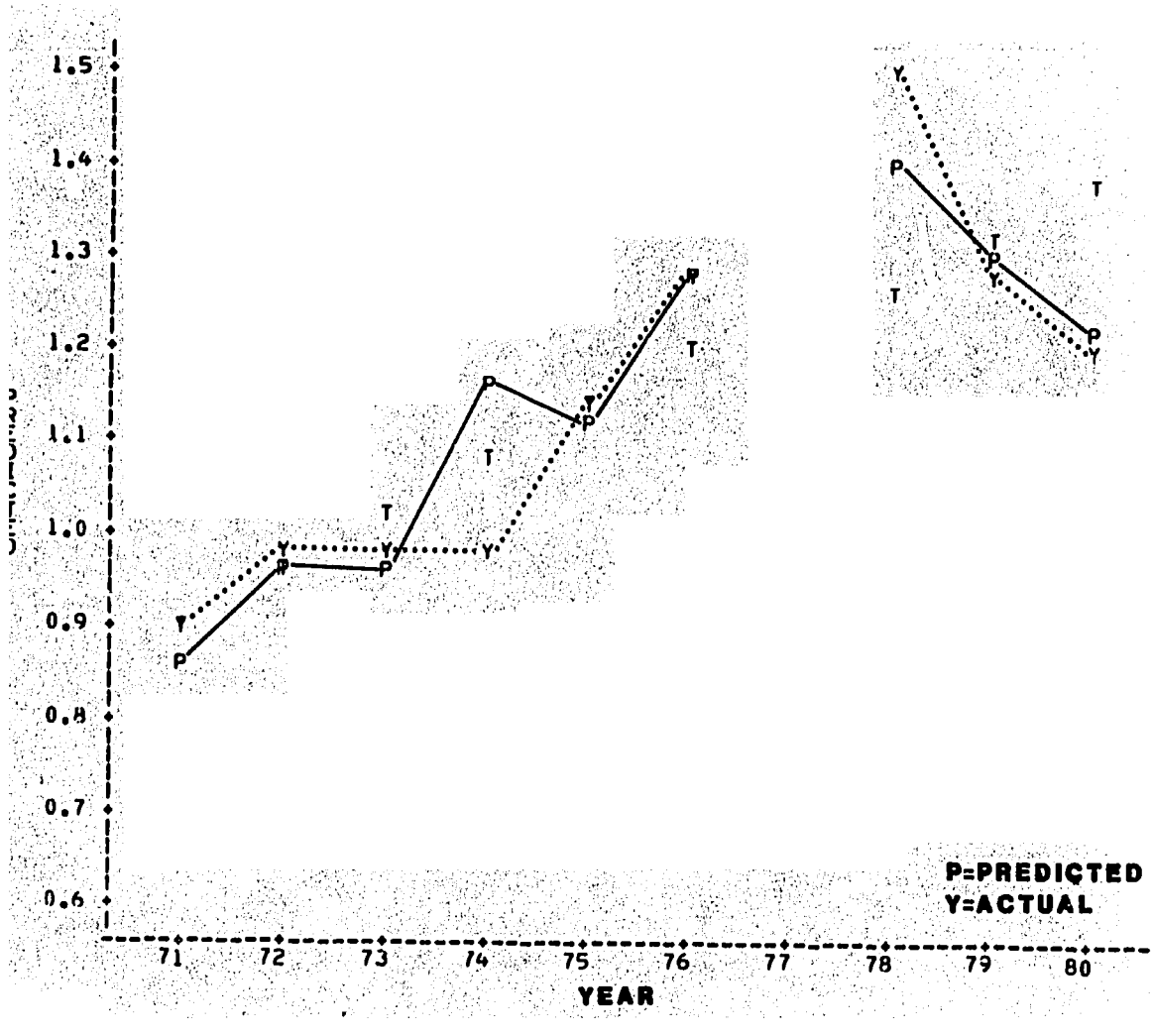


Figure 4.11. Comparison of Actual Lima Beans (Dry) Yield (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on the March Z-Index

Comparacion entre los Rendimientos Observados de Haba (Grano Seco) en el Valle del Mantaro y los Rendimientos Estimados Basados en el Indice-Z del mes de Marzo

LIMA BEANS (DRY)

CROP YIELD MODEL MANTARO VALLEY, PERU

MODEL: MODEL01
DEP VAR: XYLD8

SSE	0.052765	F RATIO	14.53
DFE	5	PROB>F	0.0050
MSE	0.008794385	R-SQUARE	0.8288

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	0.229743	0.260508	0.8827	0.4114
ET2	1	0.00474948	0.001925221	2.4670	0.0487
TRND	1	0.072993	0.013543	5.3896	0.0017

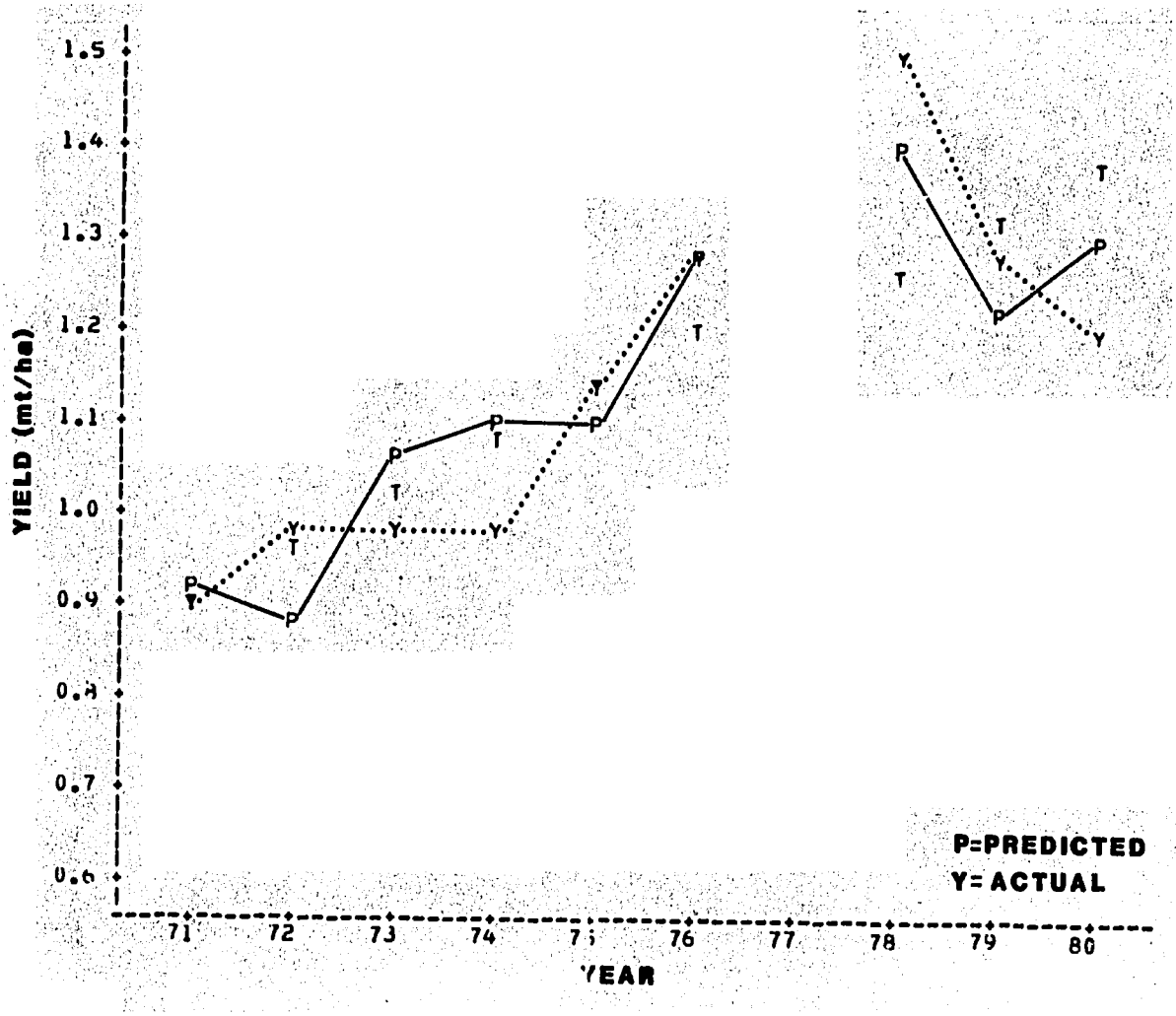


Figure 4.12. Comparison of actual Lima Beans (Dry) Yields (MT/Ha) for the Mantaro Valley, Peru, and Regression Model Fit for Predicted Yields Based on February PET

Comparacion entre los Rendimientos Observados de Haba (Grano Seco) en el Valle del Mantaro, y los Rendimientos Estimados Basados en la ETP de Febrero

As indicated in Table 4.3, the forecast leadtime (i.e., date of forecast compared to harvest dates) is quite good. Two to three month lead times are not unusual.

E. The agroclimatic/crop condition indices and statistical models can potentially be used to provide climatic impact assessments for decision makers. Several different types of models should be used.

These can include:

1) monthly rainfall maps expressed in total rainfall and as a percent of normal. These should be interpreted according to crop calendars and known crop vulnerability.
2) the YMI, PDI and other indices.
3) the statistical/climate crop yield models.

CHAPTER V

RECOMMENDATIONS FOR PROGRAM IMPLEMENTATION AND FUTURE WORK IN PERU

This training in Agrometeorological Assessment Models at NOAA/CEAS, Columbia, Mo., is part of a proposed National Agrometeorological Assessment Project for Peru, in which the following Institutions will participate:

- Instituto Nacional de Investigacion y Promocion Agraria - INIPA (Institute for Agricultural Research and Extension of the Ministry of Agriculture, Lima).
- Servicio Nacional de Meteorologia e Hidrologia (National Weather Service, Lima).
- Universidad Nacional Agraria - La Molina (National Agrarian University - La Molina, Lima).

The main goal of this project is to increase the national agricultural production through an optimum use of the agroclimatic resources of the country and by mitigating the impact of weather and climate anomalies to crops.

Project phases

The project consists of the following phases:

1. Training: Training in Agrometeorological Assessments Models at NOAA/CEAS, in Columbia, Missouri (USA).
2. Test and Evaluation of Models: The models developed during the training are to be tested and evaluated with future yield. Additional meteorological and crop yield data should be considered for testing purposes before the models may be released to users.

3. Regional Assessment: The Mantaro Valley of Peru was selected to perform the agrometeorological assessment. In this phase the agrometeorology of the major crops of the Valley will be determined in order to make further adjustments to the models, if needed.

4. National Assessments: Here we must include agrometeorological assessments for other agricultural regions in Peru, especially those with different agroclimatic conditions than those of the Mantaro Valley. At this point, it is hoped that the agrometeorological assessments will not constitute the subject of a project, rather one of the main tasks of one Institution in Peru. This means it should have permanent staff as well as its own budget.

Parallel to these steps, there is a need for constant improvement and availability of climatological and agricultural data needed for modeling. There is also the need for a good network of agrometeorological observation stations. Information concerning the phenological stages of the main crops in each region or sub-region should be obtained and analyzed together with the available climatological information. More weather stations for basic measurement of extreme temperatures should be installed in each agricultural area of the Sierra and Selva. Knowledge of local agricultural practices constitutes an important requirement for the modeling as well as for testing the models.

Implementation needed for an Agrometeorological Assessment in Peru

If it is not possible to improve the network of weather stations, then meteorological satellite information would be useful. This is especially true for Peru where many natural factors such as ocean surface, the Andes and the great jungle (Selva) limit and make it difficult to coordinate surface

weather information from different regions. Meteorological satellite information would permit us to monitor weather systems, rainfall, drought conditions, the stage of development of crops or the different types of vegetation. It is recommended very strongly that satellite information be made available to those involved in the assessment project.

Due to the amount and nature of the calculations, regressions, tests, and manipulation of the data, it is necessary to use a computer. In this case, there are two possibilities so that the computing part of the project may be eased. First, we should use a language which will not require much time for programming. This is the case with the SAS language which has several statistical subroutines and procedures to manipulate the data easily. Because modeling requires the use of different statistical procedures, it would be recommended to obtain such a system as SAS. A second possibility is to have an inexpensive, easy to handle microcomputer. It is highly desirable that the modeler have direct and easy "hands on" access to such a small computer. One may ask if the country is able to support this kind of project, especially considering these requirements. That is why it would be desirable and of great benefit to Peru should we get some technical and financial support from other countries which are working along these lines. Thus, support for the implementation as well as for answering specific questions of assessments, especially during the first stages of the project, are needed. Later on, as the project itself shows some positive results, the government of Peru may or should partake in the assessment of all regions of the country which are involved in agricultural production.

CHAPTER VI

CONCLUDING REMARKS

Three types of agroclimatic assessment models were developed for the Mantaro Valley, Junin Department, Peru and are ready for test and evaluation. These include: 1) Preliminary models for providing early warning crop/frost advisories to farmers so that possible actions can be taken to mitigate disastrous frost damage to crops, 2) crop water demand and water balance models to estimate potential evapotranspiration by methods appropriate for land use studies in the Valley and possibly other areas in the Sierra and 3) statistical climate/crop yield forecast models and agroclimatic/crop condition indices to provide crop yield and production information by at least 30 days before harvest.

Recommendations on how these agroclimatic models can be used to support the planning, development and implementation of a National Agrometeorological Assessment Project for Peru are discussed. The models can be used to prepare climatic impact assessments. Timely, reliable, yet inexpensive assessment information can be provided to decision makers and planners involved with economic analysis and forecasting, land use studies, agricultural planning and rural development. This information on climatic impact can supplement information derived from other sources in a complementary manner.

The data and technical resources to implement a project already exist in Peru. Minimal support is needed for a regional project which can demonstrate the economic benefit and value to decision makers and users. This can lead to a national program which derives maximum benefit from agroclimatic models and assessments.

REFERENCES

Bernui, J.F., 1978: Estudio del Regimen de Precipitacion en el Valle del Mantaro (Study of the Precipitation Regime in the Mantaro Valley), Tesis de Ingeniero Agricola, Universidad Nacional Agriria - La Molina, Lima, Peru.

Carrion, O.P., 1975: "Estudio de Heladas Meteorologicas y Temperaturas Minimas en el Valley del Mantaro" (Study of the Meteorological frosts and Minimum Temperatures in the Mantaro Valley), Tesis de Ingeniero Agronomo, Universidad Nacional del Centro del Peru, Huancayo, Peru.

Doorenbos, J. and W.O. Pruitt, 1977: "Guidelines for Predicting Crop Water Requirements." FAO Irrigation and Drainage Paper 24, Rome, 144pp.

Frere, M. and G. Popov, 1977: A Program for Monitoring Crop Conditions and Crop Forecasting in the Sahelian Region. FAO Special Report, AGP: Ecol/9: 9pp.

Hargreaves, G.H., 1975: "Water Requirements Manual for Irrigated Crops and Rainfed Agriculture," Agriculture and Irrigation Engineering Department, Utah State University, Logan, Utah, 94pp.

Nyrop, R.F., 1981: Peru, a country study, American University (Washington, D.C.), Foreign Area Studies, 303pp.

Palmer, W.C., 1965: "Meteorological Drought," Research Paper No. 45., U.S. Department of Commerce, Washington, D.C.

Penman, H.L., 1948: "Natural Evaporation from Open Water, Bare Soil and Grass," Royal Soc., London Proc., Ser. A., 193: 120-146.

Ravelo, A.C. and L.T. Steyaert, 1981: "An Agroclimatic Technique for Crop Calendar Simulation and Verification in the Caribbean Basin," Paper Presented at the 15th Conference on Agriculture and Forest Meteorology, Anaheim, California, 144-145p.

Rosenberg, N.J., 1974. MICROCLIMATE: The Biological Environment. John Wiley & Sons, New York, 315pp.

Sakamoto, M.S., 1978: "The Z-Index as a Variable for Crop Yield Estimation," Agricultural Meteorology, 19:305-313.

Sanchez, W.A., 1981: La Sequia como Fenomeno Meteorologico: Caso Especifico: La Anomalia de la Precipitacion de Noviembre (Study of the Precipitation Anomaly of November). Cuadernos de Fisica y Meteorologia, Universidad Nacional Agraria, La Molina, Lima.

Steyaert, L.T., V.R. Achutuni, and A.C. Ravelo, 1979: A Study of the Caribbean Basin Drought/Food Production Problem. Final Report to U.S. Department of State, Agency for International Development, Office of Foreign Disaster Assistance, Washington, D.C. by the NOAA/CEAS, Climatic Impact Assessment Division - Models Branch and the Atmospheric Science Department, University of Missouri-Columbia.

Steyaert, L.T., C.M. Sakamoto, J.C. Hock and P.F. Krumpe, 1981: "Agroclimate as a Resource for Food Security and Economic Development," Interciencia, Vol. 6 (4): 215-220p.

Thornthwaite, C.W., 1948: "An Approach Toward a Rational Classification of Climate," Geographic Rev., Vol. 38: 55-94p.

World Meteorological Organization (WMO), 1969: "Practical Soil Moisture Problems in Agriculture," Technical Note No. 97, Geneva Switzerland.

Yao, A.Y.M., 1969: "The R-Index for Plant Water Requirements," Agricultural Meteorology 6: 259-273p.

APPENDIX A

Statistical Analysis and Monthly Meteorological Data for the Mantaro Valley

MONTHLY AND ANNUAL PRECIPITATION IN MILLIMETERS AND TEMPERATURES IN DEGREES CENTIGRADE 1
T1 TO T12 ARE MEAN MONTHLY TEMPERATUES TO THE NEAREST TENTH OF A DEGREE CENTIGRADE
TANNUAL IS THE MEAN ANNUAL TEMPERATURE 11:30 MONDAY, MARCH 22, 1982
PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

---------- STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION= ----------

YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	PANNUAL	PCUM1	PCUM2	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	TANNUAL
1960	88	113	39	67	16	0	10	21	31	50	115	51	601	196	.	12.0	11.5	11.5	11.2	10.7	9.6	10.2	10.9	11.7	12.4	12.1	12.9	11.4
1961	200	165	101	64	63	0	0	16	26	25	98	144	903	150	416	10.9	11.2	11.7	11.3	10.6	10.0	9.7	9.7	11.6	12.8	12.2	11.4	11.1
1962	92	110	141	63	38	1	4	2	29	69	71	99	718	168	346	12.4	12.0	11.0	10.3	10.5	8.6	10.4	10.4	12.3	12.7	12.8	12.3	11.3
1963	184	114	14	70	13	2	0	20	32	40	62	97	778	134	397	11.1	10.9	11.6	11.1	10.2	8.9	9.8	11.2	11.7	12.4	13.0	12.6	11.2
1964	99	75	127	50	39	0	1	27	71	125	94	100	808	290	271	13.1	12.8	11.2	11.0	9.8	8.1	9.5	10.9	11.2	11.5	10.8	10.8	10.9
1965	94	125	117	60	11	0	10	16	96	78	68	80	755	242	319	10.9	11.0	10.9	11.1	10.1	9.5	9.9	10.7	11.9	12.7	12.8	12.5	11.2
1966	102	43	68	25	42	6	0	4	47	100	55	112	614	212	225	12.5	12.4	11.2	11.7	11.1	9.8	9.5	10.9	11.8	12.0	12.2	11.8	11.4
1967	108	143	185	40	42	2	23	23	52	99	44	66	827	195	363	11.2	10.9	10.9	10.2	9.9	8.3	8.4	9.8	10.9	11.0	12.4	11.7	10.5
1968	152	94	118	41	2	4	21	68	19	57	42	65	683	118	312	11.0	11.2	10.4	10.0	8.9	8.8	9.1	10.4	11.4	12.1	12.2	11.7	10.6
1969	52	78	59	65	6	13	22	14	38	44	78	106	575	160	195	12.1	12.0	12.1	11.9	11.8	10.5	8.9	10.1	11.3	12.5	12.4	11.7	11.4
1970	175	121	70	41	25	6	4	1	68	70	38	115	737	176	405	11.0	11.4	11.2	11.6	11.4	9.6	9.7	10.0	10.8	12.3	11.9	11.4	11.0
1971	84	178	150	45	5	4	6	79	25	64	68	82	791	157	377	11.1	10.8	10.3	9.8	9.7	9.1	8.4	9.9	10.8	11.2	11.0	10.8	10.2
1972	94	122	148	136	28	4	9	17	22	45	46	140	811	113	298	10.7	11.5	10.3	11.1	9.9	8.9	9.8	9.6	.	12.2	12.7	12.0	10.8
1973	153	154	137	97	1	4	24	21	48	94	40	88	861	182	447	11.6	12.1	12.0	11.0	9.7	10.0	9.2	10.2	10.4	11.7	12.1	10.8	10.9
1974	155	177	68	57	1	26	3	30	13	69	54	62	715	136	420	10.5	10.5	10.8	10.1	9.2	9.0	12.9	.	.	.	11.8	12.1	10.8
1975	84	120	163	38	31	4	1	39	101	85	66	111	944	253	266	11.0	11.4	11.0	10.1	9.9	9.2	8.1	10.2	11.0	10.9	11.5	10.8	10.4
1976	96	127	134	31	17	15	2	25	37	25	55	104	670	119	334	10.6	10.6	11.0	10.1	10.1	9.2	8.7	10.3	11.2	12.5	12.2	11.7	10.7
1977	86	125	124	125	23	2	7	7	53	70	126	102	850	249	315	12.4	11.3	11.5	11.0	9.3	8.7	9.6	10.3	11.4	12.3	11.7	12.1	11.0
1978	225	93	66	25	6	2	3	0	61	37	87	88	694	185	421	11.3	12.1	11.6	11.5	10.2	8.7	8.7	9.6	11.3	11.7	11.9	12.5	10.9
1979	129	80	109	72	22	1	3	21	32	23	76	62	630	131	297	11.6	11.6	11.4	10.9	9.8	8.8	9.1	10.9	11.9	12.5	12.9	12.6	11.2
1980	61	84	186	34	19	0	8	3	18	124	53	77	567	195	207	12.8	12.4	11.6	10.9	10.0	9.1	9.5	10.9	11.6	11.5	12.5	12.1	11.2

N=21

SIMPLE STATISTICS ON MONTHLY PRECIPITATION IN MILLIMETERS AND TEMPERATURE IN DEGREES CENTIGRADE
STATISTICS GIVEN ARE MEAN, MINIMUM VALUE, MAXIMUM VALUE, RANGE, SUM, AND N
FOR PRECIPITATION AND TEMPERATURE 11:30 MONDAY, MARCH 22, 1982
PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

---------- STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION= ----------

MTHNO	MEAN_P	N_P	STDDEV_P	MIN_P	MAX_P	RANGE_P	CV_P	SUM_P	MEAN_T	N_T	STDDEV_T	MIN_T	MAX_T	RANGE_T	CV_T
JAN	120	21	47.4	52	226	174	39.6	2517	11.5	21	.770	10.5	13.1	2.6	6.69
FEB	116	21	34.9	43	178	135	30.0	2441	11.5	21	.634	10.5	12.8	2.3	5.51
MAR	117	21	41.9	39	186	147	35.8	2454	11.2	21	.506	10.3	12.1	1.8	4.52
APR	59	21	29.7	25	136	111	49.9	1247	10.9	21	.618	9.8	11.9	2.1	5.69
MAY	21	21	16.6	1	63	62	77.4	450	10.1	21	.702	8.9	11.8	2.9	6.93
JUN	5	21	6.3	0	26	26	138.4	96	9.2	21	.598	8.1	10.5	2.4	6.53
JUL	8	21	8.0	0	24	24	104.8	161	9.5	21	.993	8.1	12.9	4.8	10.5
AUG	22	21	20.2	0	79	79	93.4	454	10.3	20	.495	9.6	11.2	1.6	4.78
SEP	44	21	24.4	13	101	88	55.8	919	11.4	19	.469	10.4	12.3	1.9	4.12
OCT	69	21	30.2	23	125	102	45.5	1395	12.0	20	.581	10.9	12.8	1.9	4.82
NOV	69	21	24.2	38	126	88	35.1	1447	12.1	21	.579	10.8	13.0	2.2	4.77
DEC	93	21	24.7	51	144	93	26.6	1951	11.8	21	.647	10.8	12.9	2.1	5.47
ANNUAL	740	21	94.0	575	903	328	12.7	15532	.	0	.	.	.	.	.
PCUM1	179	21	49.1	113	290	177	27.4	3761	.	0	.	.	.	.	.
PCUM2	332	20	74.6	195	447	252	22.5	6631	.	0	.	.	.	.	.

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	PANNUAL	PCUM1	PCUM2
1960	-31.86	-3.24	-77.86	7.62	-5.43	-4.57	2.33	-0.52	-12.76	-16.43	46.10	-41.90	-138.62	16.90	.
1961	80.14	48.76	-15.86	4.62	41.57	-4.57	-7.67	-5.52	-17.76	-40.43	29.10	51.10	163.38	-29.10	84.45
1962	-27.86	-6.24	24.14	3.62	15.57	-3.57	-3.67	-19.52	-14.76	1.57	2.10	6.10	-21.62	-11.10	14.45
1963	64.14	-2.24	27.14	10.62	-8.43	-2.57	-7.67	-1.52	-11.76	-26.43	-6.90	4.10	38.38	-45.10	65.45
1964	-20.86	-41.24	10.14	-9.38	17.57	-4.57	-6.67	5.38	27.24	58.57	25.10	7.10	68.38	110.90	-60.55
1965	-25.86	8.76	0.14	0.62	-10.43	-4.57	2.33	-5.52	52.24	11.57	-0.90	-12.90	15.38	62.90	-12.55
1966	-17.86	-73.24	-48.86	-34.38	20.57	1.43	-7.67	-17.52	3.24	33.57	-3.90	19.10	-125.62	32.90	-106.5
1967	-11.86	25.76	68.14	-19.38	20.57	-2.57	15.33	1.38	8.24	32.57	-24.90	-26.90	87.38	15.90	31.45
1968	32.14	-22.24	1.14	-18.38	-19.43	-0.57	13.33	46.38	-24.76	-9.43	-26.90	-27.90	-56.62	-61.10	-19.55
1969	-67.86	-38.24	-57.86	5.62	-15.43	8.43	14.33	-7.52	-5.76	-22.43	9.10	13.10	-164.62	-19.10	-136.5
1970	58.14	4.76	-46.86	-18.38	3.57	1.43	-3.67	-20.52	24.24	3.57	-30.90	22.10	-2.62	-3.10	73.45
1971	-35.86	61.76	33.14	-13.38	-15.43	-0.57	-1.67	57.38	-18.76	-2.43	-0.90	-10.90	51.38	-22.10	45.45
1972	-25.86	5.76	31.14	76.62	5.57	-0.57	1.33	-4.52	-21.76	-21.43	-22.90	47.10	71.38	-66.10	-33.55
1973	33.14	37.76	20.14	37.62	-20.43	-0.57	16.33	-0.52	4.24	27.57	-28.90	-4.90	121.38	2.90	115.45
1974	35.14	60.76	-48.86	-2.38	-20.43	21.43	-4.67	8.38	-30.76	2.57	-14.90	-30.90	-24.62	-43.10	88.45
1975	-35.86	3.76	46.14	-21.38	9.57	-0.57	-6.67	17.38	57.24	19.57	-2.90	18.10	104.38	73.90	-65.55
1976	-23.86	10.76	17.14	-28.38	-4.43	10.43	-5.67	3.38	-6.76	-40.43	-12.90	11.10	-69.62	-60.10	2.45
1977	-33.86	8.76	7.14	65.62	1.57	-2.57	-0.57	-14.62	9.24	3.57	57.10	9.10	110.38	69.90	-16.55
1978	106.14	-23.24	-50.86	-34.38	-15.43	-2.57	-4.67	-21.52	17.24	-29.43	18.10	-4.90	-45.62	5.90	89.45
1979	9.14	-36.24	-7.86	12.62	0.57	-3.57	-4.67	-0.62	-11.76	-43.43	7.10	-30.90	-109.62	-48.10	-34.55
1980	-58.86	-32.24	69.14	-25.38	-2.43	-4.57	0.33	-18.52	-25.76	57.57	-15.90	-15.90	-72.62	15.90	-124.5

RANKING OF EACH MONTH OVER ALL YEARS
MONTHS ARE RANKED FROM LOWEST TO HIGHEST
TIED MONTHLY PRECIPITATION VALUES ARE ASSIGNED TO A MEAN RANK VALUE
PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

YEAR	P1	RANKP1	P2	RANKP2	P3	RANKP3	P4	RANKP4	P5	RANKP5	P6	RANKP6	P7	RANKP7	P8	RANKP8	P9	RANKP9	P10	RANKP10	P11	RANKP11	P12	RANKP12	PANNUAL	ANNLRANK	PCUM1	CUM1RANK	PCUM2	CUM2RANK
1960	84	27	113	40	39	4	67	72	16	40	0	13	10	74	21	59	31	36	50	36	115	90	51	4	601	9	196	72	.	.
1961	200	90	105	36	101	31	64	63	63	95	0	13	0	9	16	38	26	27	26	11	98	86	144	95	903	95	150	31	416	80
1962	92	31	110	36	141	68	63	59	38	77	1	29	4	47	2	13	29	31	68	49	71	53	99	54	718	45	168	45	346	57
1963	184	86	114	45	144	72	70	77	13	36	2	43	0	9	20	49	32	43	40	22	62	40	97	49	778	59	134	22	397	71
1964	99	49	75	9	127	54	50	45	39	81	0	13	1	20	27	77	71	86	125	95	94	81	100	59	808	68	290	95	271	23
1965	94	38	125	65	117	40	60	54	11	31	0	13	10	74	16	38	96	90	78	68	68	56	80	31	755	54	242	81	319	47
1966	102	54	43	4	68	20	25	5	42	88	6	79	0	9	4	22	47	59	100	86	65	45	112	81	614	13	212	77	225	14
1967	108	59	143	77	185	90	40	27	42	88	2	43	23	90	23	69	52	68	99	81	44	18	66	22	827	77	195	65	363	61
1968	152	68	94	31	118	45	41	34	2	13	4	63	21	81	68	90	19	13	57	40	42	13	65	18	683	31	118	9	312	38
1969	52	4	78	13	59	9	65	68	6	24	13	86	22	86	14	31	38	54	44	27	78	72	106	72	575	4	160	40	195	4
1970	174	81	121	54	70	27	41	34	25	63	6	79	4	47	1	9	68	81	70	61	38	4	115	86	737	49	176	49	405	76
1971	84	15	178	95	150	81	46	40	5	18	4	63	6	54	79	95	25	22	64	45	68	56	82	36	791	63	157	36	377	66
1972	94	38	122	59	148	77	136	95	28	68	4	63	9	68	17	45	22	18	45	31	46	22	140	90	811	72	113	4	298	33
1973	153	72	154	81	137	63	97	85	1	6	4	63	24	95	21	59	48	63	94	77	40	9	88	43	861	90	182	54	447	95
1974	155	77	177	90	68	20	57	49	1	6	26	95	3	36	30	81	13	4	69	54	54	31	62	11	715	40	136	27	420	85
1975	84	15	120	49	163	86	38	22	31	72	4	63	1	20	39	86	101	95	86	72	66	49	111	77	844	81	253	90	266	19
1976	96	45	127	72	134	59	31	13	17	45	15	90	2	27	25	72	37	49	26	11	56	36	104	68	670	27	119	13	334	52
1977	86	22	125	65	124	49	125	90	23	59	2	43	7	59	7	27	53	72	70	61	126	95	102	63	850	86	249	86	315	42
1978	226	95	93	27	66	13	25	6	6	24	2	43	3	36	0	4	61	77	37	18	87	77	88	43	694	36	185	59	421	90
1979	129	43	80	18	109	36	72	81	22	54	1	29	3	36	21	59	32	43	23	4	76	68	62	11	630	18	131	18	297	28
1980	61	9	84	22	186	95	34	15	19	49	0	13	8	63	3	15	18	9	124	90	53	27	77	27	667	22	195	65	207	9

FREQUENCY PLOT OF ANNUAL PRECIPITATION 11:30 MONDAY, MARCH 22, 1982 5
PRECIPITATION IS IN MILLIMETERS

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

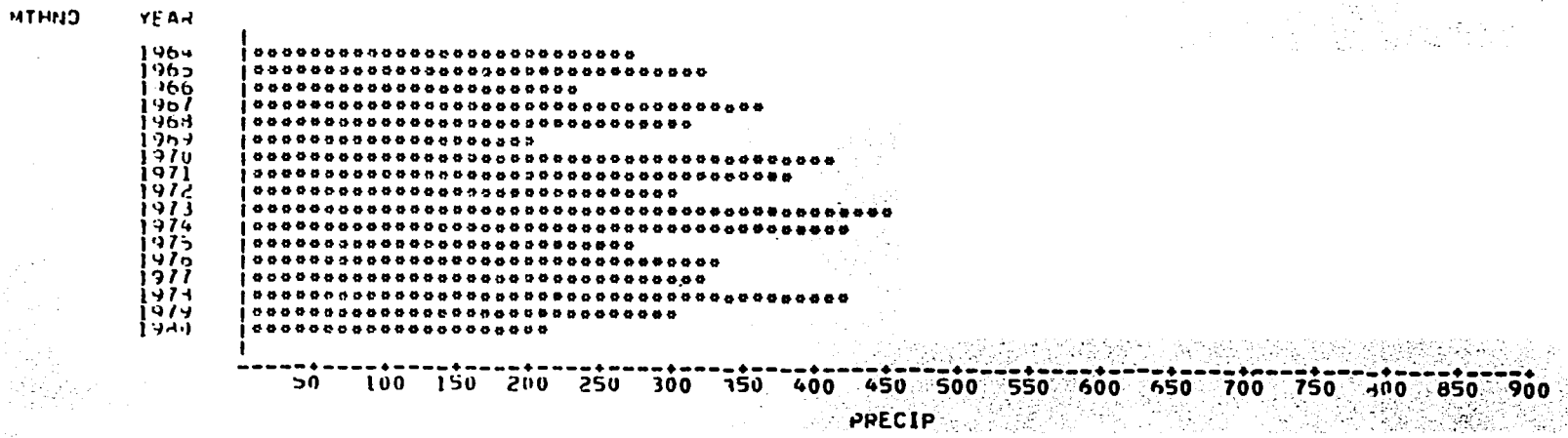
BAR CHART OF PRECIP

FREQUENCY PLOT OF ANNUAL PRECIPITATION
PRECIPITATION IS IN MILLIMETERS

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

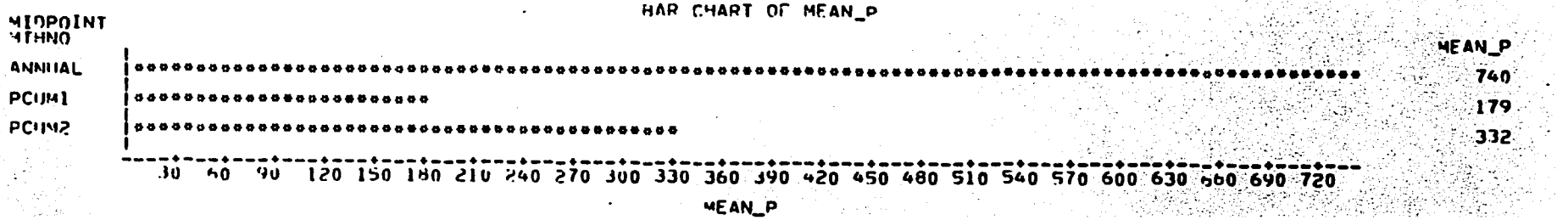
BAR CHART OF PRECIP



FREQUENCY PLOT OF SAMPLE MEAN PRECIPITATION 11:30 MONDAY, MARCH 22, 1982
PRECIPITATION IS IN MILLIMETERS

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB
STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

BAR CHART OF MEAN_P



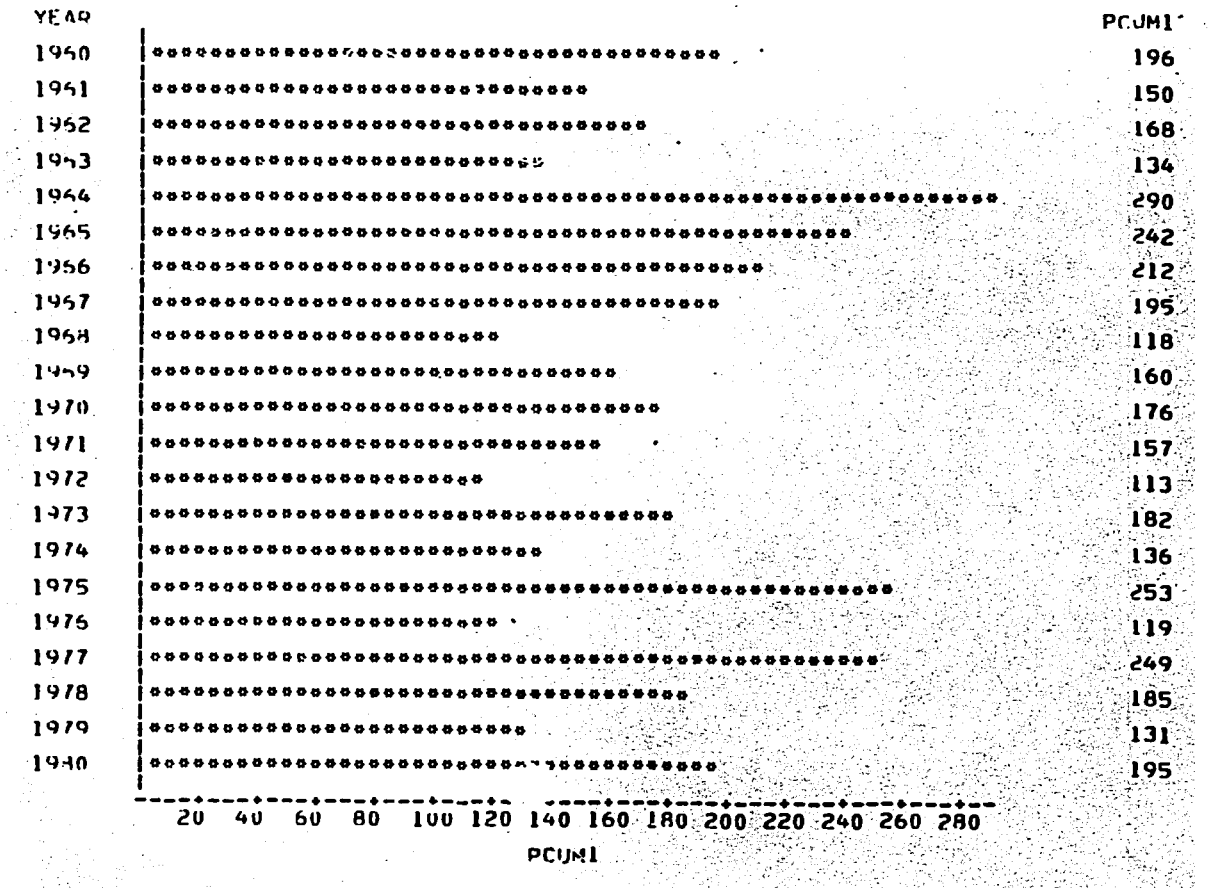
SEP TO NOV CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR EACH YEAR

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

11:30 MONDAY, MARCH 22, 1982

8

BAR CHART OF PCUMI

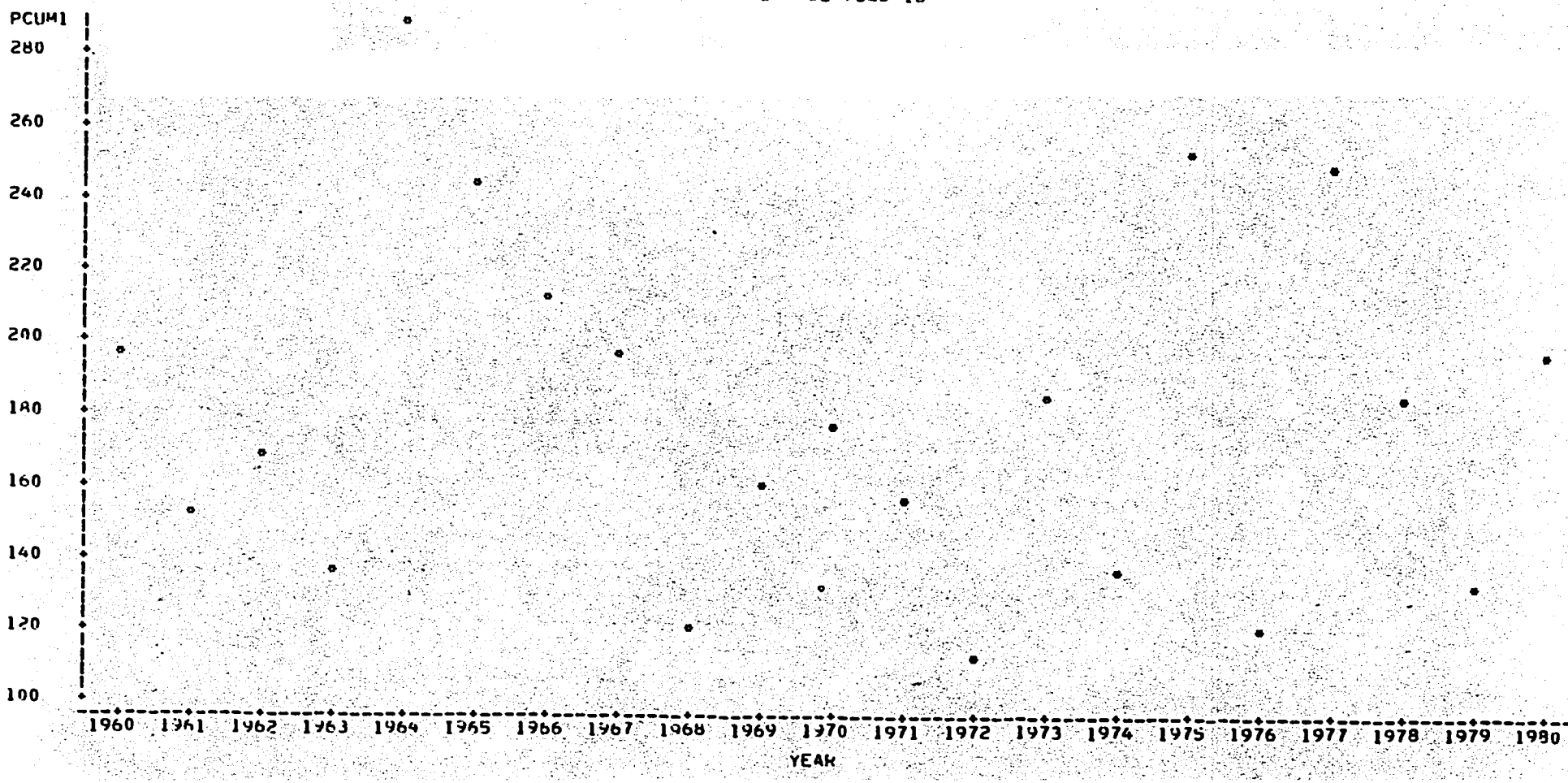


SEP TO NOV CUMMULATIVE PRECIPITATION IN MILLIMETERS PLOTTED BY YEAR

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

11:30 MONDAY, MARCH 22, 1982 9

PLOT OF PCUM1*YEAR SYMBOL USED IS *

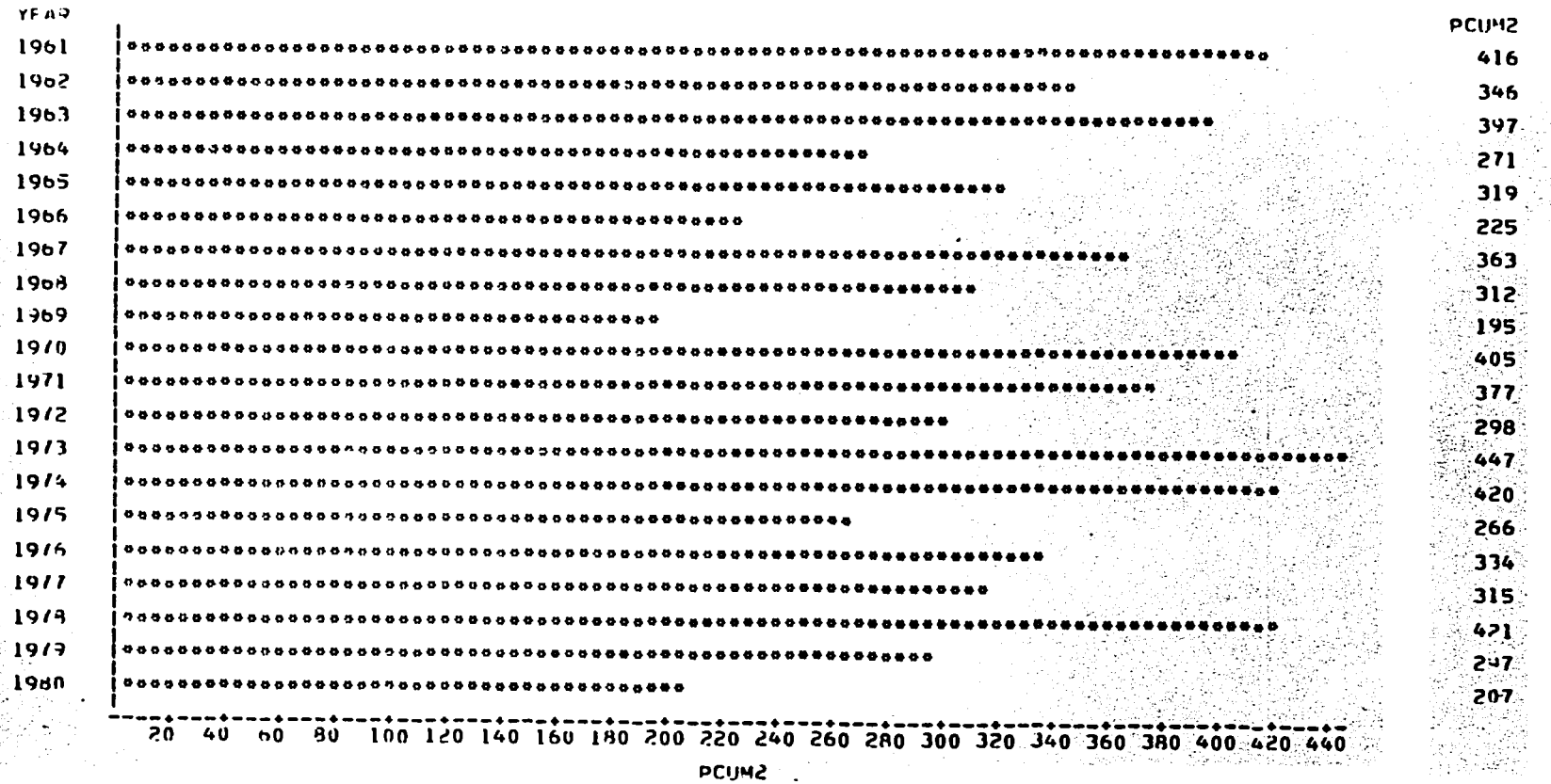


DEC TO FEB CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR EACH YEAR

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

11:30 MONDAY, MARCH 22, 1982

BAR CHART OF PCUM2



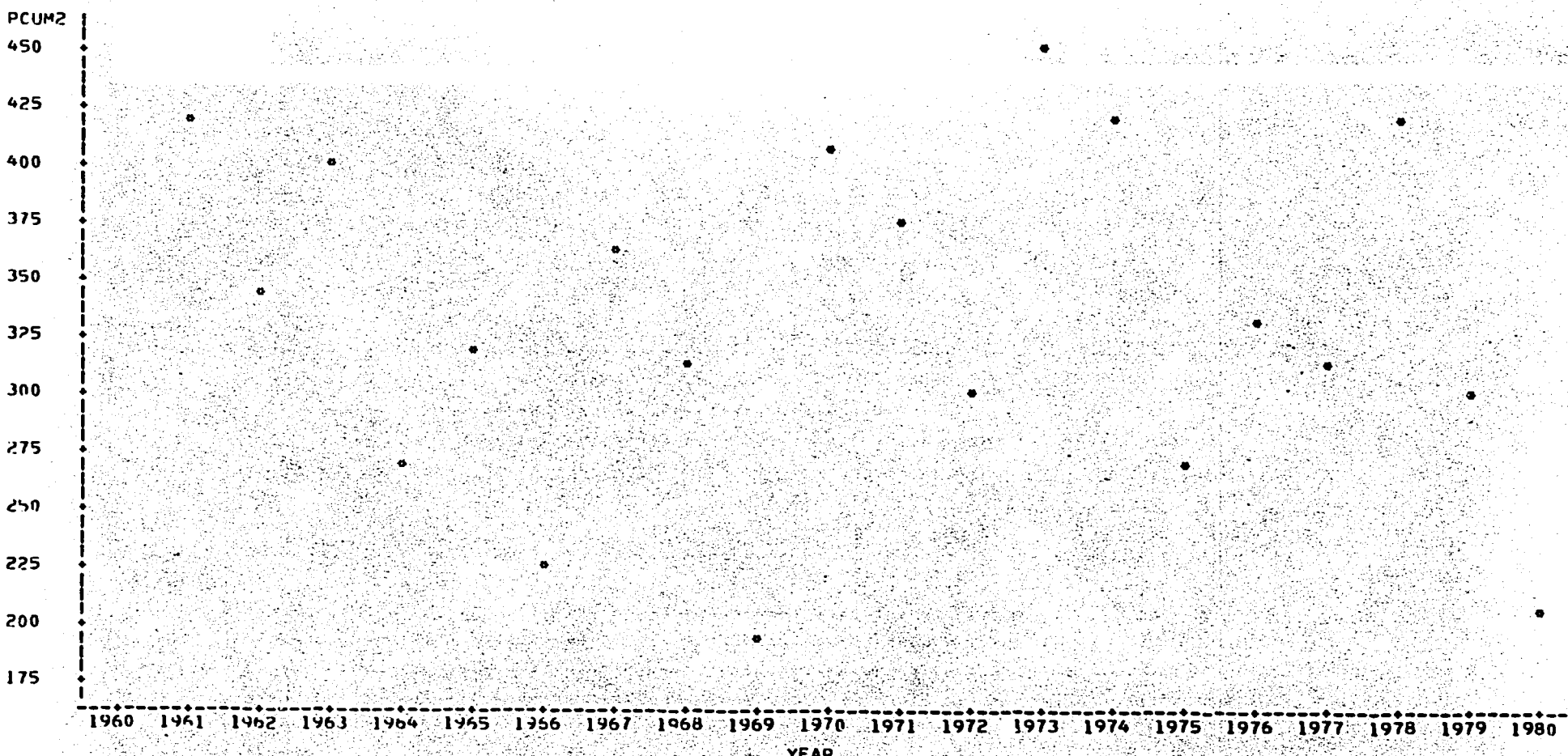
DEC TO FEB CUMMULATIVE PRECIPITATION IN MILLIMETERS PLOTTED BY YEAR

11:30 MONDAY, MARCH 22, 1982

11

STN=. COUNTRY=PERU STNNAME=HUAYAO/HUANCAYO REGION=

PLOT OF PCUM2*YEAR SYMBOL USED IS *



NOTE: 1 OBS HAD MISSING VALUES

MONTHLY AND ANNUAL PRECIPITATION IN MILLIMETERS AND TEMPERATURES IN DEGREES CENTIGRADE
T1 TO T12 ARE MEAN MONTHLY TEMPERATUES TO THE NEAREST TENTH OF A DEGREE CENTIGRADE
TANNUAL IS THE MEAN ANNUAL TEMPERATURE
PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

11:31 MONDAY, MARCH 22, 1982

---------- STN=. COUNTRY=PERU STNNAME=JAUJA REGION= ----------

YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	PANNUAL	PCUM1	PCUM2	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	TANNUAL
1960	150	130	50	60	20	0	10	20	10	60	120	60	690	190	.	11.8	11.9	12	12	11	10.1	10.3	10.3	11.8	12.1	11.1	12.1	11.4
1961	158	138	112	67	14	0	0	7	24	24	141	186	871	189	356	13.0	12.0	13	13	13	12.0	12.0	12.0	13.0	15.0	13.0	13.0	12.8
1962	193	138	287	68	12	0	0	7	17	30	98	83	923	135	517	14.0	13.0	12	12	13	11.0	12.0	12.0	13.0	14.0	14.0	13.0	12.8
1963	183	151	179	54	4	1	1	4	25	53	59	82	796	137	417	12.0	11.0	12	12	12	11.0	11.0	12.0	13.0	13.0	13.0	13.0	12.1
1964	81	53	136	45	20	0	0	1	51	111	65	41	604	227	216	14.0	14.0	13	13	12	11.0	11.0	12.0	12.0	12.0	12.0	12.0	12.3
1965	88	90	91	65	0	0	1	22	53	54	29	120	613	136	219	13.0	12.0	12	13	13	12.0	12.0	12.0	13.0	14.0	14.0	14.0	12.8
1966	119	81	88	65	24	1	0	4	22	93	70	119	686	185	320	14.0	14.0	13	14	13	12.0	12.0	13.0	13.0	13.0	13.0	13.0	13.1
1967	103	191	141	39	19	15	15	14	11	115	35	75	773	161	413	12.0	11.0	12	12	12	11.0	10.0	11.0	12.0	12.0	14.0	13.0	11.8
1968	56	63	133	11	16	1	14	33	23	57	59	95	561	139	194	13.0	13.0	12	12	12	11.0	11.0	12.0	13.0	13.0	14.0	14.0	12.5
1969	66	96	96	57	2	8	14	5	47	50	23	157	621	120	257	13.0	13.0	13	13	13	12.0	11.0	11.0	12.0	14.0	14.0	13.0	12.7
1970	143	101	63	56	1	0	1	4	21	71	54	115	630	145	401	13.0	13.0	12	12	12	12.0	11.0	12.0	12.0	14.0	13.0	13.0	12.4
1971	160	156	130	36	14	2	0	21	38	77	57	170	861	172	431	12.0	11.0	12	11	10	11.0	10.0	11.0	12.0	13.0	13.0	12.0	11.5
1972	120	85	143	128	8	0	11	0	44	59	55	110	753	158	375	11.0	13.0	11	12	11	11.0	11.0	11.0	12.0	13.0	14.0	13.0	11.9
1973	236	155	128	36	11	4	11	17	25	120	55	120	918	200	501	13.0	13.0	13	12	12	12.0	11.0	11.0	11.0	12.0	13.0	12.0	12.1
1974	207	153	104	62	0	17	.	.	2	23	48	34	650	73	480	11.0	11.0	12	11	11	11.0	10.0	11.0	11.0	13.0	13.0	13.0	11.5
1975	136	94	144	45	18	0	0	38	65	90	117	105	852	272	264	12.0	12.0	12	12	11	10.0	10.0	11.0	12.0	12.0	13.0	12.0	11.6
1976	100	187	97	23	4	11	0	9	24	63	48	76	642	135	392	12.0	11.0	11	12	12	10.0	10.0	11.0	12.0	14.0	13.0	13.0	11.8
1977	85	.	.	.	.	0	0	3	.	76	.	56	220	.	.	13.0	12.0	12	.	.	10.0	11.0	12.0	13.0	13.0	12.0	13.0	12.1
1978	183	145	94	66	9	3	9	0	85	63	146	144	946	294	384	12.0	13.0	12	12	12	10.0	10.0	11.0	12.0	13.0	13.0	14.0	12.0
1979	108	.	.	.	.	.	.	1	7	62	129	105	412	198	.	13.0	.	.	.	.	.	.	.	14.0	.	.	14.0	13.7
1980	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13.0	13.0	.	.	.	.	.	.	.	.	.	.	13.0

N=21

SIMPLE STATISTICS ON MONTHLY PRECIPITATION IN MILLIMETERS AND TEMPERATURE IN DEGREES CENTIGRADE
STATISTICS GIVEN ARE MEAN, MINIMUM VALUE, MAXIMUM VALUE, RANGE, SUM, AND N
FOR PRECIPITATION AND TEMPERATURE 11:31 MONDAY, MARCH 22, 1982
PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

---------- STN=. COUNTRY=PERU STNNAME=JAUJA REGION= ----------

MTHNO	MEAN_P	N_P	STDDEV_P	MIN_P	MAX_P	RANGE_P	CV_P	SUM_P	MEAN_T	N_T	STDDEV_T	MIN_T	MAX_T	RANGE_T	CV_T
JAN	134	20	49.7	56	236	180	37.1	2675	12.6	21	.873	11.0	14	3.0	6.92
FEB	123	18	40.8	53	191	138	33.3	2207	12.3	20	1.01	11.0	14	3.0	8.18
MAR	123	18	51.7	50	287	237	42.0	2216	12.2	19	.602	11.0	13	2.0	4.95
APR	55	18	24.5	11	128	117	44.8	983	12.2	18	.732	11.0	14	3.0	5.99
MAY	11	18	7.8	0	24	24	71.2	196	11.9	18	.873	10.0	13	3.0	7.31
JUN	3	19	5.4	0	17	17	162.4	63	11.1	19	.773	10.0	12	2.0	6.99
JUL	5	18	6.0	0	15	15	125.9	86	10.9	19	.749	10.0	12	2.0	6.90
AUG	11	19	11.3	0	38	38	101.9	210	11.5	19	.623	10.8	13	2.2	5.41
SEP	31	19	21.5	2	85	83	68.7	594	12.3	20	.751	11.0	14	3.0	6.09
OCT	68	20	27.6	23	120	97	40.9	1351	13.1	19	.869	12.0	15	3.0	6.62
NOV	74	19	38.2	23	146	123	52.0	1398	13.1	19	.795	11.1	14	2.9	6.06
DEC	103	20	41.1	34	186	152	40.0	2053	13.0	20	.679	12.0	14	2.0	5.24
ANNUAL	702	20	181	220	946	726	25.8	14032	.	0	.	.	.	.	.
PCUM1	172	19	52.7	73	294	221	30.7	3267	.	0	.	.	.	.	.
PCUM2	361	17	101	194	517	323	28.0	6137	.	0	.	.	.	.	.

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	PANNUAL	PCUM1	PCUM2
1960	16.25	7.39	-73.11	5.39	9.11	-3.32	5.22	8.95	-21.26	-7.55	46.42	-42.65	-11.6	18.05	.
1961	24.25	15.39	-11.11	12.39	3.11	-3.32	-4.78	-4.05	-7.26	-43.55	67.42	83.35	169.4	17.05	-5.00
1962	59.25	15.39	163.89	13.39	1.11	-3.32	-4.78	-4.05	-14.26	-37.55	14.42	-19.65	221.4	-36.95	156.00
1963	49.25	28.39	55.89	-0.61	-6.89	-2.32	-3.78	-7.05	-6.26	-14.55	-14.58	-20.65	94.4	-34.95	56.00
1964	-52.75	-69.61	12.89	-9.61	9.11	-3.32	-4.78	-10.05	19.74	43.45	-8.58	-61.65	-97.6	55.05	-145
1965	-45.75	-32.61	-32.11	10.39	-10.89	-3.32	-3.78	10.95	21.74	-13.55	-44.58	17.35	-88.6	-35.95	-142
1966	-14.75	-41.61	-35.11	10.39	13.11	-2.32	-4.78	-7.05	-9.26	25.45	-3.58	16.35	-15.6	13.05	-41.00
1967	-30.75	68.39	17.89	-15.61	8.11	11.68	10.22	2.95	-20.26	47.45	-38.58	-27.65	71.4	-10.95	52.00
1968	-77.75	-59.61	9.89	-43.61	5.11	-2.32	9.22	21.95	-8.26	-10.55	-14.58	-7.65	-140.6	-32.95	-167
1969	-67.75	-26.61	-27.11	2.39	-5.89	4.68	9.22	-6.05	15.74	-17.55	-50.58	54.35	-80.6	-51.95	-104
1970	9.25	-21.61	-60.11	1.39	-9.89	-3.32	-3.78	-7.05	-10.26	3.45	-19.58	12.35	-71.6	-25.95	40.00
1971	26.25	33.39	6.89	-18.61	3.11	-1.32	-4.78	9.95	6.74	9.45	-16.58	67.35	159.4	0.05	70.00
1972	-13.75	-37.61	19.89	73.39	-2.89	-3.32	6.22	-11.05	12.74	-8.55	-18.58	7.35	61.4	-13.95	14.00
1973	102.25	32.39	4.89	-18.61	0.11	0.68	6.22	5.95	-6.26	52.45	-18.58	17.35	216.4	28.05	140.00
1974	73.25	30.39	-19.11	7.39	-10.89	13.68	.	.	-29.26	-44.55	-25.58	-68.65	-51.6	-98.95	119.00
1975	2.25	-28.61	20.89	-9.61	7.11	-3.32	-4.78	26.95	33.74	22.45	43.42	2.35	150.4	100.05	-97.00
1976	-33.75	64.39	-26.11	-31.61	-5.89	7.68	-4.78	-2.05	-7.26	-4.55	-25.58	-26.65	-59.6	-36.95	31.00
1977	-48.75	.	.	.	.	-3.32	-4.78	-8.05	.	8.45	.	-46.65	-481.6	.	.
1978	49.25	22.39	-29.11	11.39	-1.89	-0.32	3.22	-11.05	53.74	-4.55	72.42	41.35	244.4	122.05	23.00
1979	-25.75	.	.	.	.	.	.	-10.05	-24.26	-5.55	55.42	2.35	-289.6	26.05	.
1980	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

RANKING OF EACH MONTH OVER ALL YEARS
MONTHS ARE RANKED FROM LOWEST TO HIGHEST
TIED MONTHLY PRECIPITATION VALUES ARE ASSIGNED TO A MEAN RANK VALUE
PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

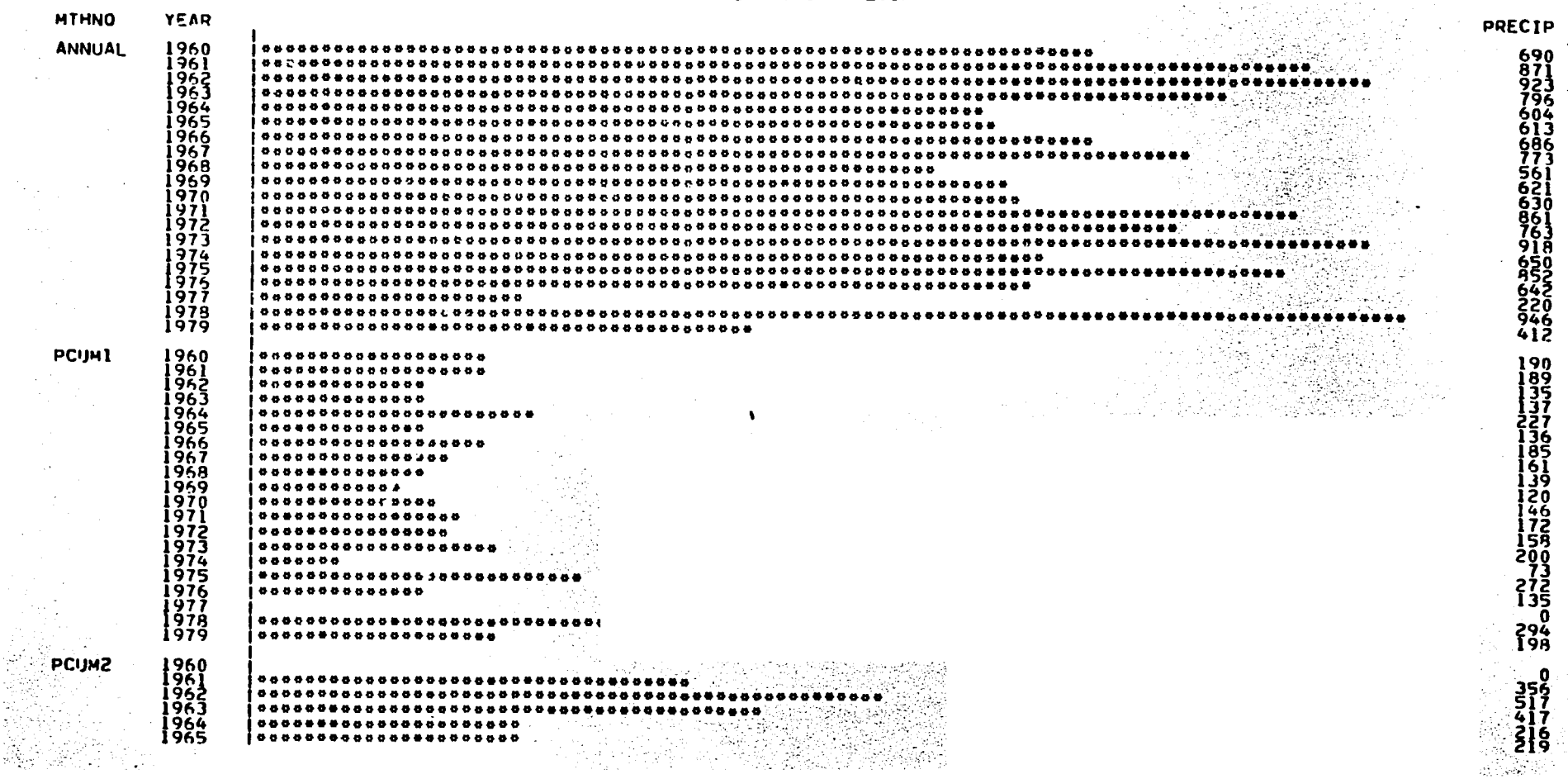
YEAR	P1	RANKP1	P2	RANKP2	P3	RANKP3	P4	RANKP4	P5	RANKP5	P6	RANKP6	P7	RANKP7	P8	RANKP8	P9	RANKP9	P10	RANKP10	P11	RANKP11	P12	RANKP12	PANNUAL	ANNRANK	PCUM1	CUM1RANK	PCUM2	CUM2RANK
1960	150	61	130	47	50	5	60	57	20	86	0	25	10	68	20	75	10	15	60	42	120	80	60	19	690	52	190	70	.	.
1961	158	66	138	55	112	47	67	84	14	60	0	25	0	23	7	52	24	47	24	9	141	90	186	95	871	80	189	65	356	38
1962	193	85	138	55	287	94	69	89	12	52	0	25	0	23	7	52	17	25	30	14	88	70	83	38	923	70	135	17	517	94
1963	183	78	151	68	179	89	5[illegible]	42	4	28	1	55	1	52	4	35	25	57	53	23	59	52	82	33	796	66	137	30	417	72
1964	81	14	53	5	136	68	45	34	20	86	0	25	0	23	1	17	51	80	111	85	65	60	41	9	604	19	227	85	216	11
1965	88	23	90	26	91	21	65	71	0	7	0	25	1	52	22	85	53	85	54	28	29	10	120	73	613	23	136	25	219	16
1966	119	42	81	15	88	15	65	71	24	94	1	55	0	23	4	35	22	35	93	80	70	65	119	66	686	47	185	60	320	33
1967	103	33	191	94	141	73	39	26	19	78	15	90	15	94	14	55	11	20	115	90	35	15	75	23	773	51	161	50	413	66
1968	56	4	63	10	133	63	11	5	16	68	1	55	14	86	33	90	23	40	57	33	59	52	95	42	561	14	139	35	194	5
1969	66	9	95	36	96	31	57	52	2	21	8	80	14	86	5	45	47	75	50	19	23	5	157	85	621	28	120	10	257	22
1970	143	57	101	42	63	10	55	47	1	15	0	25	1	52	4	35	21	30	71	61	54	30	115	61	630	33	146	40	401	61
1971	160	71	156	84	130	57	35	18	14	60	2	65	0	23	21	80	38	65	77	71	57	45	170	90	861	76	172	55	431	77
1972	120	47	85	21	143	78	129	94	8	36	0	25	11	76	0	7	44	70	59	30	53	37	110	57	763	57	158	45	375	44
1973	236	95	155	78	128	52	35	18	11	47	4	75	11	76	17	70	25	57	120	95	55	37	120	73	918	85	200	80	501	88
1974	207	90	153	73	104	42	62	53	0	7	17	95	.	.	.	.	2	5	23	4	48	22	34	4	650	42	73	5	480	83
1975	136	52	94	31	144	84	45	34	18	73	0	25	0	23	38	95	65	90	90	76	117	75	105	49	852	71	272	90	264	27
1976	100	28	187	89	97	36	23	10	4	28	11	85	0	23	9	60	24	47	63	54	48	22	76	28	642	38	135	17	392	55
1977	85	19	.	.	.	.	.	.	.	.	0	25	0	23	3	25	.	.	76	66	.	.	56	14	220	4	.	.	.	.
1978	183	78	145	63	94	26	65	75	9	42	3	70	8	63	0	7	85	95	63	54	146	95	144	80	946	95	294	95	384	50
1979	108	38	.	.	.	.	.	.	.	.	.	.	.	.	1	17	7	10	62	47	129	85	105	49	412	9	198	75	.	.
1980	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

FREQUENCY PLOT OF ANNUAL PRECIPITATION
PRECIPITATION IS IN MILLIMETERS

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

BAR CHART OF PRECIP



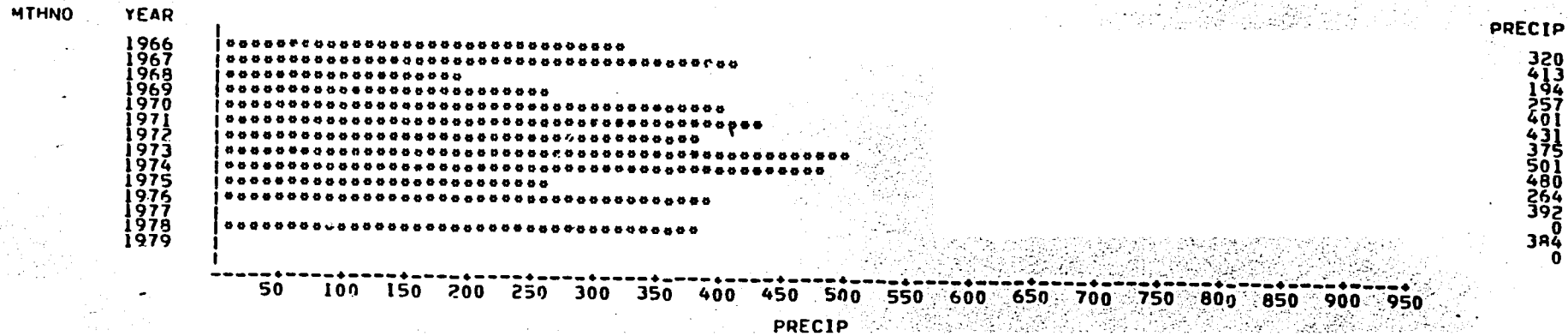
MTHNO	YEAR	PRECIP
ANNUAL	1960	690
	1961	871
	1962	923
	1963	796
	1964	604
	1965	613
	1966	686
	1967	773
	1968	561
	1969	621
	1970	630
	1971	861
	1972	763
	1973	918
	1974	650
	1975	852
	1976	642
	1977	220
	1978	946
	1979	412
PCUM1	1960	190
	1961	189
	1962	135
	1963	137
	1964	227
	1965	136
	1966	185
	1967	161
	1968	139
	1969	120
	1970	146
	1971	172
	1972	158
	1973	200
	1974	73
	1975	272
	1976	135
	1977	0
	1978	294
	1979	198
PCUM2	1960	0
	1961	356
	1962	517
	1963	417
	1964	216
	1965	219

FREQUENCY PLOT OF ANNUAL PRECIPITATION 11:31 MONDAY, MARCH 22, 1982 6
PRECIPITATION IS IN MILLIMETERS

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

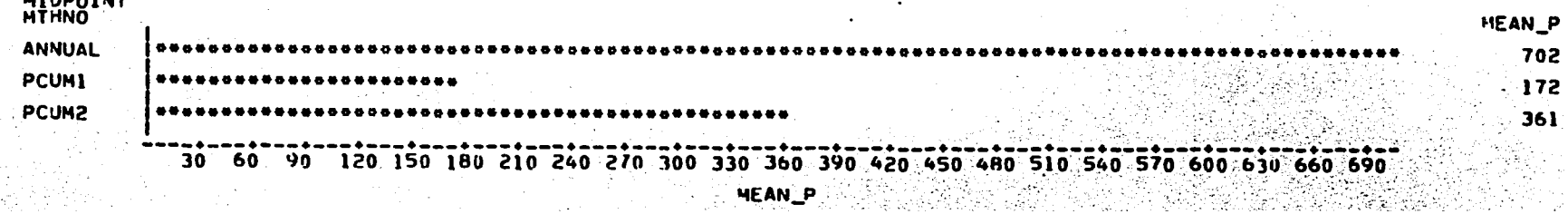
BAR CHART OF PRECIP



FREQUENCY PLOT OF SAMPLE MEAN PRECIPITATION
PRECIPITATION IS IN MILLIMETERS

PCUM1 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR SEP TO NOV
PCUM2 IS CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR DEC TO FEB
STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

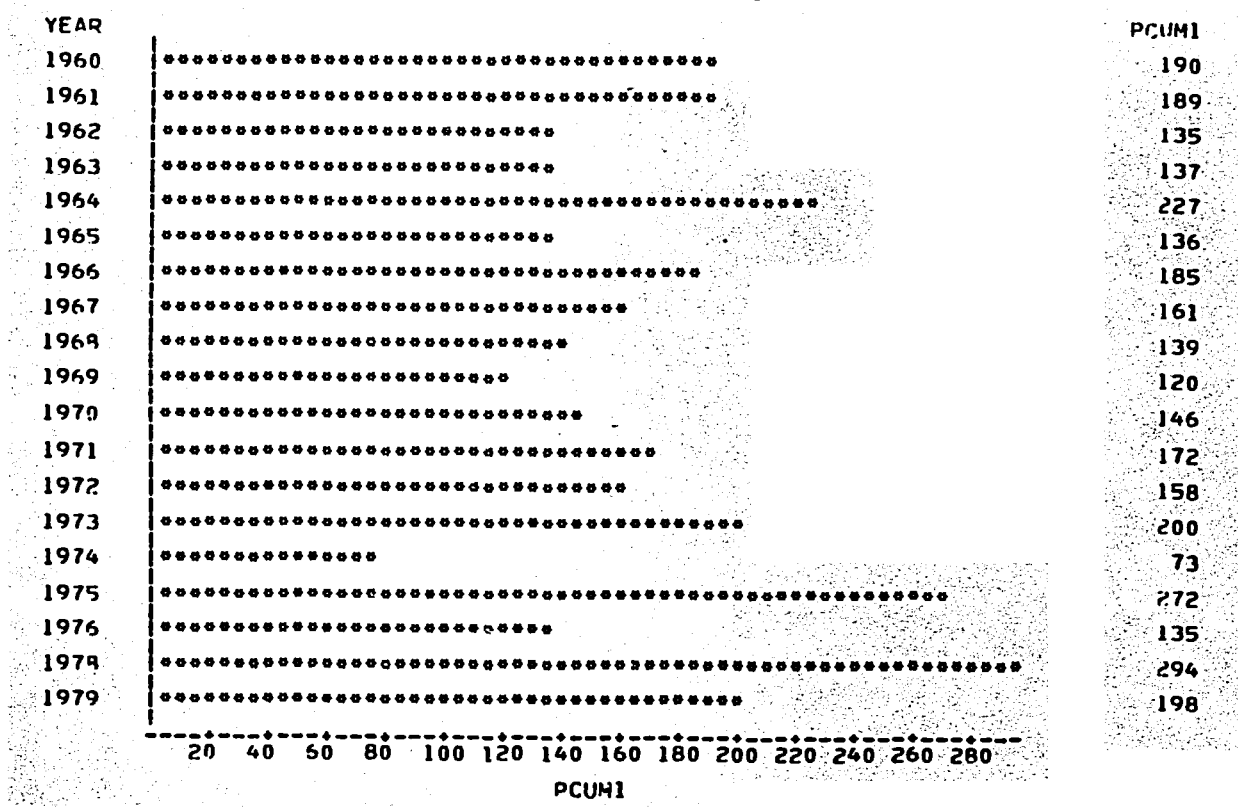
BAR CHART OF MEAN_P



SEP TO NOV CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR EACH YEAR 11:31 MONDAY, MARCH 22, 1982 8

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

BAR CHART OF PCUM1

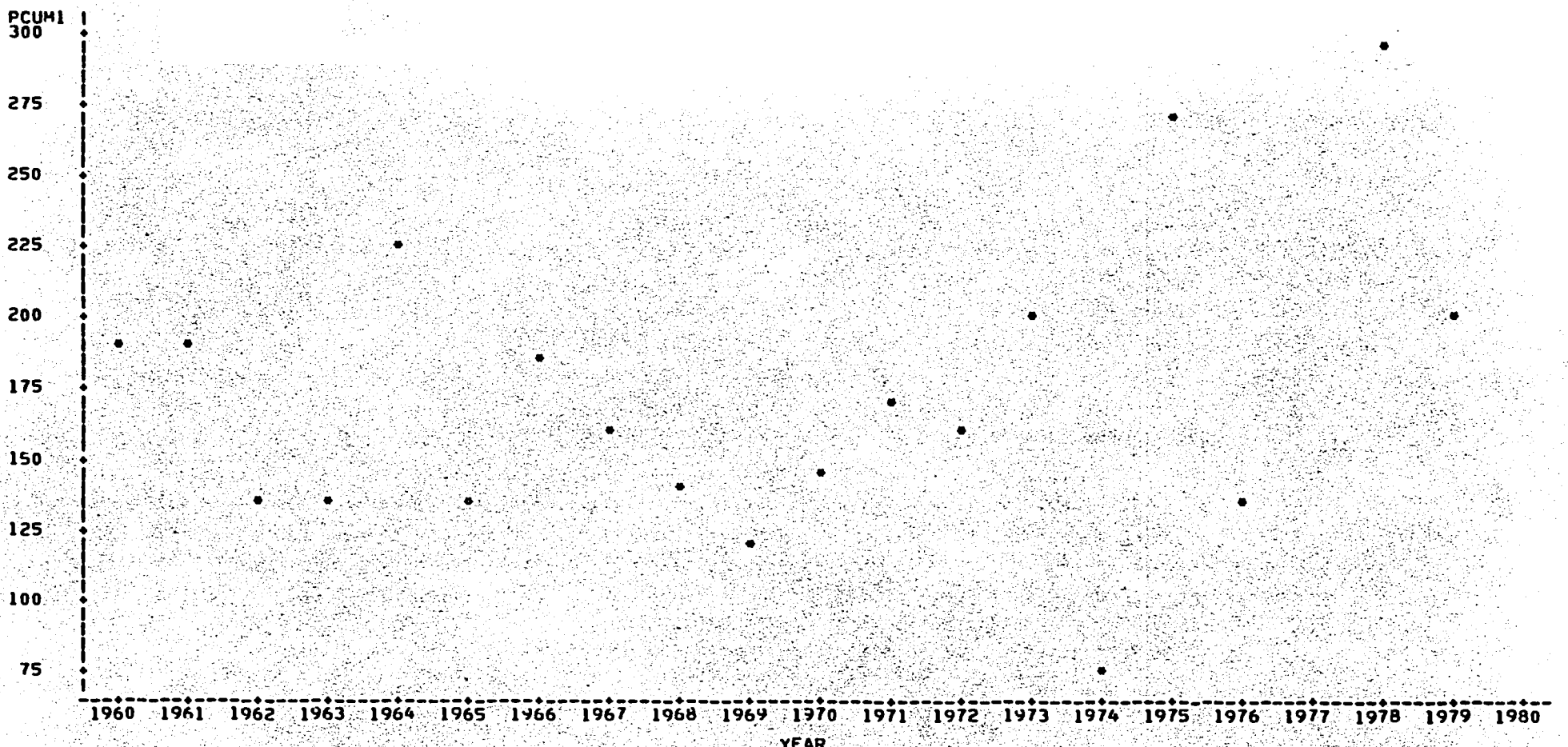


SEP TO NOV CUMMULATIVE PRECIPITATION IN MILLIMETERS PLOTTED BY YEAR

11:31 MONDAY, MARCH 22, 1982

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

PLOT OF PCUM1*YEAR SYMBOL USED IS *



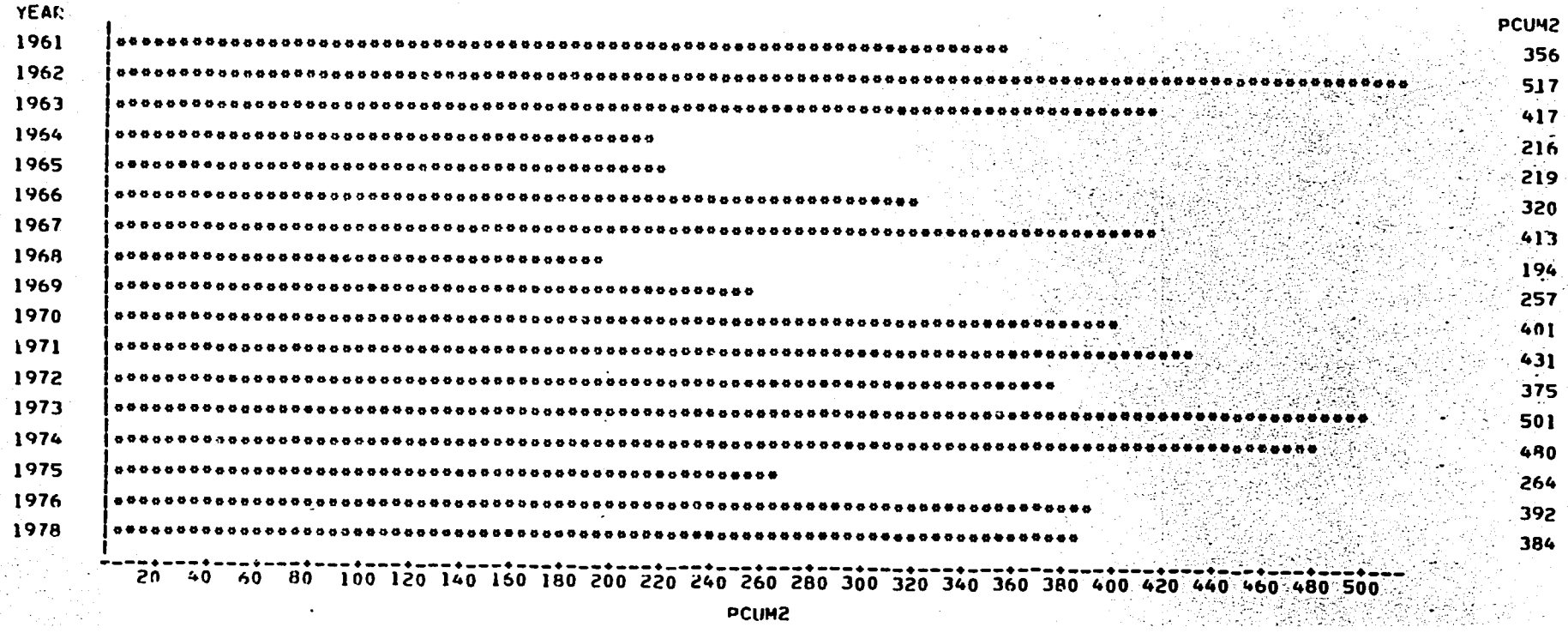
NOTE: 2 OBS HAD MISSING VALUES

DEC TO FEB CUMMULATIVE PRECIPITATION IN MILLIMETERS FOR EACH YEAR

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

11:31 MONDAY, MARCH 22, 1982

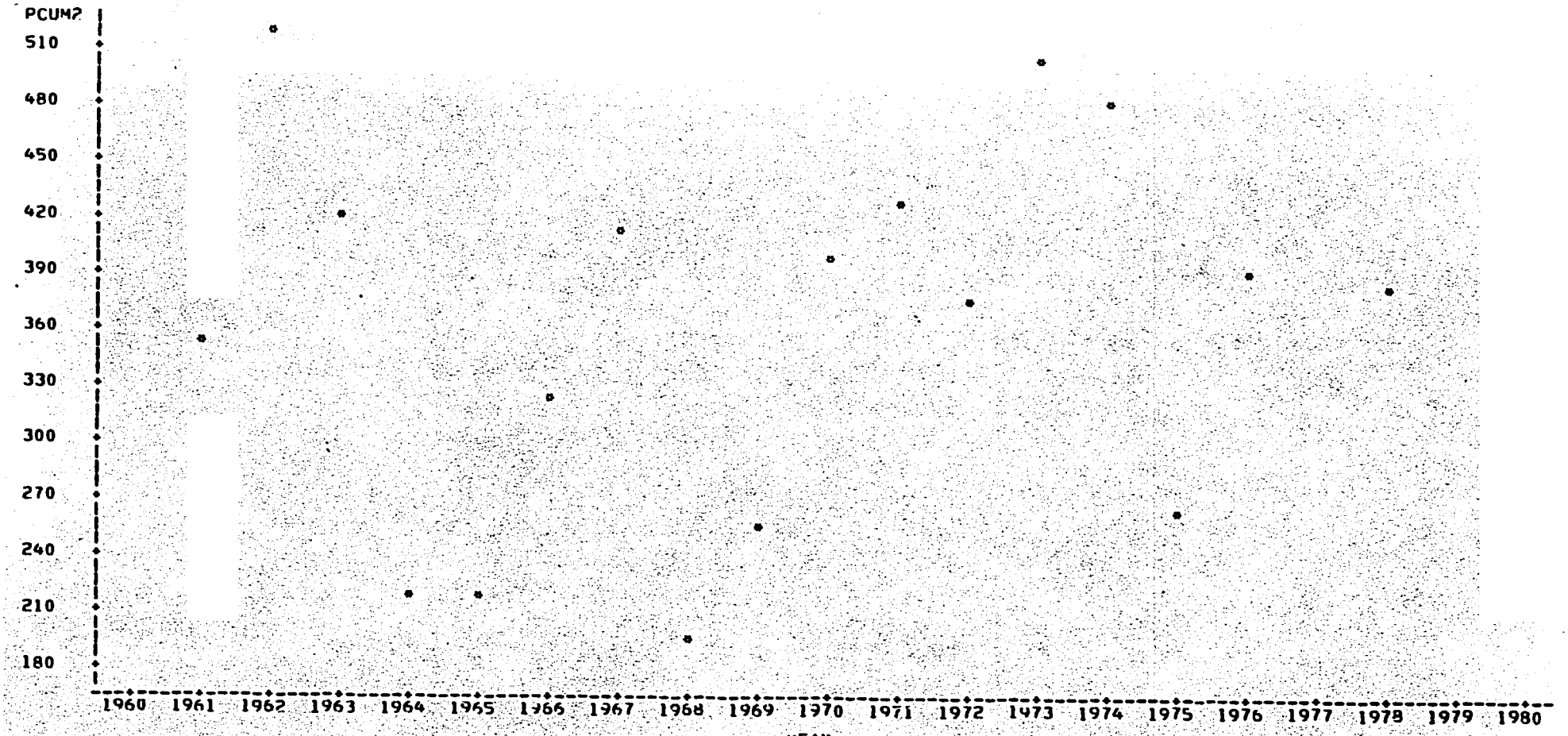
BAR CHART OF PCUM2



DEC TO FEB CUMMULATIVE PRECIPITATION IN MILLIMETERS PLOTTED BY YEAR 11:31 MONDAY, MARCH 22, 1982 11

STN=. COUNTRY=PERU STNNAME=JAUJA REGION=

PLOT OF PCUM2*YEAR SYMBOL USED IS *



NOTE: 4 OBS HAD MISSING VALUES

APPENDIX B

Decadal Means of Potential Evapotranspiration (mm/day)

Promedios Decadarios de Evapotranspiracion Potencial (mm/dia)

HUAYAO/HUANCAYO P E R U 1960-77
MODEC=I

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
PENMAN	13	4.62538893	0.34089573	4.14127359	5.15392315	0.09454746
PENMANA	13	4.74859451	0.36570803	4.23007935	5.33837962	0.10142916
THORT	13	1.73105475	0.09536983	1.56656955	1.86813578	0.02645083
HARGRS	13	3.88051885	0.42439528	3.24917438	4.44912066	0.11770607
EV	13	5.34917094	0.79641739	3.78000000	6.74000000	0.22088644
MODEC=1.33						
PENMAN	13	4.69893731	0.33463268	4.11228286	5.17905720	0.09281041
PENMANA	13	4.83144411	0.33513541	4.22449783	5.29114042	0.09294984
THORT	13	1.66695858	0.17595393	1.37632379	1.95384741	0.04880084
HARGRS	13	3.89631676	0.58464957	2.92840476	4.99596759	0.16215262
EV	13	5.12047009	1.09228574	3.71800000	7.27000000	0.30294556
MODEC=1.67						
PENMAN	13	4.65543084	0.23219274	4.31383497	5.05147906	0.06439865
PENMANA	13	4.78773189	0.24408536	4.43901320	5.18790006	0.06769710
THORT	13	1.68608749	0.14014649	1.43628270	1.89719239	0.03886964
HARGRS	13	3.90462482	0.31354106	3.42633105	4.26065631	0.08696064
EV	13	5.03434266	0.60294485	4.09181818	5.91272727	0.16722681
MODEC=2						
PENMAN	16	4.63896427	0.36353498	3.86154294	5.22040998	0.09088375
PENMANA	16	4.77181011	0.36711095	3.99323829	5.36853675	0.09177774
THORT	16	1.86353216	0.13005774	1.67564266	2.09721224	0.03251444
HARGRS	16	3.87323306	0.44351568	3.22331839	4.75335871	0.11087892
EV	16	5.23756250	0.98983231	3.91600000	7.30400000	0.24745808
MODEC=2.33						
PENMAN	16	4.47322005	0.31115594	3.91617568	5.06311020	0.07778899
PENMANA	16	4.60443657	0.31985112	4.03519784	5.22281989	0.07996278
THORT	16	1.86190593	0.09651067	1.65185712	2.05431494	0.02412767
HARGRS	16	3.79780249	0.38696904	3.22715374	4.63775837	0.09674226
EV	16	4.99148437	0.77318141	3.79200000	6.70200000	0.19329535
MODEC=2.67						
PENMAN	16	4.45789892	0.21261303	3.94865089	4.77703491	0.05315326
PENMANA	16	4.59253694	0.21919274	4.05196178	4.89747425	0.05479819
THORT	16	1.82671372	0.12615097	1.64919713	2.07591758	0.03153774
HARGRS	16	3.72652467	0.34980116	3.18633619	4.37865877	0.08745029
EV	16	4.64000000	0.62801862	3.91875000	5.98000000	0.15700465

HUAYAO/HUANCAYO P E R I O 1960-77
MODEC=3

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
PENMAN	16	4.42151555	0.29524086	4.00279274	4.96193242	0.07381022
PENMANA	16	4.55361990	0.31107291	4.11361214	5.15787091	0.07776823
THORT	16	1.63432612	0.10375581	1.46789563	1.88003690	0.02593895
HARGRS	16	3.67965493	0.36908786	3.24210451	4.44177851	0.09227196
EV	16	4.85918750	0.73286317	3.75300000	5.93000000	0.18321579
MODEC=3.33						
PENMAN	15	4.48584555	0.26488566	3.98698426	4.94712797	0.06839318
PENMANA	15	4.62481684	0.27936580	4.10622777	5.06519610	0.07213194
THORT	15	1.64502739	0.11438046	1.43349838	1.81591374	0.02953291
HARGRS	15	3.74914557	0.32964071	3.00727380	4.50384473	0.08511287
EV	15	5.08777037	0.50435347	3.85300000	6.06000000	0.13022351
MODEC=3.67						
PENMAN	16	4.23377456	0.34449296	3.58878184	4.78963025	0.08612324
PENMANA	16	4.35732331	0.36139884	3.68987654	4.97287928	0.09034971
THORT	16	1.62777097	0.11673889	1.43511332	1.83820887	0.02918472
HARGRS	16	3.65561595	0.35204850	2.82008108	4.15257066	0.08801213
EV	16	4.68141234	0.57585529	3.84272727	6.03181818	0.14396382
MODEC=4						
PENMAN	17	4.07356324	0.34388205	3.46592222	4.62604304	0.08340365
PENMANA	17	4.18300935	0.36215178	3.55044499	4.71880309	0.08783471
THORT	17	1.66522504	0.11998213	1.47419148	1.90359958	0.02909994
HARGRS	17	3.61336023	0.35811031	3.07981853	4.18595488	0.08685451
EV	17	4.92545276	0.72609696	3.51100000	6.06600000	0.17610438
MODEC=4.33						
PENMAN	17	3.97190634	0.29546530	3.35209832	4.43645159	0.07166086
PENMANA	17	4.07474813	0.31151424	3.42773122	4.53448329	0.07555330
THORT	17	1.65431104	0.13197892	1.41614168	1.88897962	0.03200959
HARGRS	17	3.65516462	0.26170945	3.15624945	4.06904893	0.06347387
EV	17	4.67377124	0.47608541	3.60200000	5.74100000	0.11546767
MODEC=4.67						
PENMAN	17	3.70120562	0.24511168	3.25352147	4.04634517	0.05944831
PENMANA	17	3.78982189	0.25679806	3.33347543	4.13026387	0.06228268
THORT	17	1.58077049	0.15495129	1.34501562	1.85984435	0.03758121
HARGRS	17	3.50589787	0.28695804	2.96213112	4.04816431	0.06959755
EV	17	4.83684967	0.67642727	3.88700000	6.19800000	0.16405771

HUAYAO/HUANCAYO P E R U 1960-77

MODEC=5

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
PENMAN	16	3.45608011	0.26375590	3.01671146	3.91687914	0.06593897
PENMANA	16	3.52849544	0.27197155	3.09107147	3.96846070	0.06799289
THORT	16	1.51905027	0.15169103	1.34117167	1.80406399	0.03792276
HARGRS	16	3.47768543	0.23548939	2.99831083	3.85009953	0.05887235
EV	16	4.83868750	0.68850376	3.33500000	6.33800000	0.17212594

MODEC=5.33

PENMAN	16	3.21536579	0.20679751	2.75912048	3.62923959	0.05169930
PENMANA	16	3.27446598	0.21392305	2.79156124	3.66931936	0.05348077
THORT	16	1.50960024	0.15629678	1.12290284	1.75489841	0.03907420
HARGRS	16	3.25265418	0.23464510	2.69765127	3.50229117	0.05866128
EV	16	4.90065278	0.77472479	3.47200000	6.23000000	0.19368120

MODEC=5.67

PENMAN	16	3.10533540	0.22827673	2.79612914	3.51109287	0.05706918
PENMANA	16	3.15625618	0.24343911	2.83129693	3.57762991	0.06085978
THORT	16	1.37557740	0.14228688	1.07163616	1.69533484	0.03557172
HARGRS	16	3.30526375	0.23094548	2.97574202	3.75302927	0.05773637
EV	16	5.01119318	0.77974289	4.04545455	6.80000000	0.19493572

MODEC=5

PENMAN	16	2.86141927	0.33086893	2.52406051	3.90673160	0.08271723
PENMANA	16	2.89897542	0.35135790	2.53832523	4.02095482	0.08783948
THORT	16	1.44164225	0.13874102	1.21322932	1.82257544	0.03468526
HARGRS	16	3.13909805	0.23308694	2.65195429	3.50166607	0.05827173
EV	16	4.95931250	0.68275742	3.89300000	6.23800000	0.17068936

MODEC=6.33

PENMAN	16	2.85366240	0.42464025	2.53178546	4.30908181	0.10616006
PENMANA	16	2.89118474	0.44538168	2.55337113	4.42980598	0.11134542
THORT	16	1.36379179	0.18529448	1.08106130	1.67461281	0.04632362
HARGRS	16	3.09376481	0.23428620	2.76168047	3.40294768	0.05857155
EV	16	5.04106250	0.63110501	3.98000000	6.04000000	0.15777625

MODEC=6.67

PENMAN	16	2.73986250	0.35433858	2.39080133	3.92242190	0.08858464
PENMANA	16	2.76578631	0.37552603	2.40734584	4.03005561	0.09388151
THORT	16	1.27325329	0.15735585	1.02745951	1.54715861	0.03933896
HARGRS	16	3.06843943	0.17488621	2.80764513	3.51300012	0.04372155
EV	16	5.29056250	0.57343956	4.27800000	6.39200000	0.14335989

HUAYAO/HUANCAYO P E R I 1960-77
MODEC=7

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
PENMAN	14	2.81217893	0.20698215	2.43939105	3.17239120	0.05531831
PENMANA	14	2.84096586	0.20418260	2.46944799	3.20435528	0.05457010
THORT	14	1.29523406	0.16597191	1.08971912	1.59507298	0.04435786
HARGRS	14	3.11165290	0.19739480	2.79875611	3.41638193	0.05275598
EV	14	5.23215079	0.55238103	4.32400000	5.94000000	0.14763004
MODEC=7.33						
PENMAN	14	2.94410119	0.15215178	2.66821183	3.28810566	0.04066427
PENMANA	14	2.96678712	0.14493415	2.70674276	3.30689707	0.03873528
THORT	14	1.40254819	0.15234650	1.19361689	1.71126089	0.04071631
HARGRS	14	3.22730190	0.21200764	2.76019200	3.57215181	0.05666143
EV	14	5.63650000	0.69598704	4.61100000	7.04000000	0.18601036
MODEC=7.67						
PENMAN	14	3.10821207	0.24725826	2.66310185	3.46278529	0.06608255
PENMANA	14	3.13739477	0.24442663	2.70151767	3.51859720	0.06532576
THORT	14	1.37653052	0.17261477	0.99921257	1.63844000	0.04613324
HARGRS	14	3.33743531	0.13291007	3.16593488	3.59618257	0.03552171
EV	14	5.87772727	0.50031570	4.90000000	6.50000000	0.13371499
MODEC=8						
PENMAN	14	3.48614040	0.24113356	3.02680050	3.87297016	0.06444566
PENMANA	14	3.53065727	0.24334857	3.05461487	3.90772143	0.06503764
THORT	14	1.41656255	0.13471139	1.08968179	1.57737355	0.03600313
HARGRS	14	3.49094286	0.22612343	3.03633404	3.76791183	0.06043403
EV	14	6.02550000	0.58088682	4.98400000	7.21800000	0.15524853
MODEC=8.33						
PENMAN	14	3.68413070	0.25985556	3.23339400	4.19649283	0.06944932
PENMANA	14	3.73176822	0.26924859	3.24598737	4.26134761	0.07195971
THORT	14	1.48944816	0.13114921	1.24940242	1.68558713	0.03505110
HARGRS	14	3.68935463	0.27969120	3.21073467	4.13328482	0.07475062
EV	14	6.38321429	0.76347245	4.51900000	7.31400000	0.20404660
MODEC=8.67						
PENMAN	14	3.93748895	0.23263189	3.50695028	4.24878017	0.06217349
PENMANA	14	3.99024114	0.23977829	3.54175363	4.30255887	0.06408344
THORT	14	1.63853139	0.11404330	1.34093027	1.85941976	0.03047935
HARGRS	14	3.73461903	0.25226267	3.23707036	4.16120386	0.06742004
EV	14	6.47610390	0.81457616	5.00272727	7.83090909	0.21770464

HUAYAO/HUANCAYO P E R U 1960-77

MODEC=9

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
PENMAN	15	4.29298239	0.43152722	3.32533696	5.15976024	0.11141985
PENMANA	15	4.36744698	0.43413253	3.38538256	5.22931447	0.11209254
THORT	15	1.68308342	0.10003634	1.51857470	1.85858975	0.02582927
HARGRS	15	3.90841684	0.39545476	3.21699571	4.69692921	0.10210598
EV	15	6.42781886	0.67410686	5.34555556	7.64800000	0.17405364

MODEC=9.33

PENMAN	15	4.33051299	0.43179321	3.65244097	4.99237782	0.11148853
PENMANA	15	4.41162987	0.44751051	3.73445474	5.08996195	0.11554672
THORT	15	1.70220815	0.12162911	1.51185681	1.90862825	0.03140450
HARGRS	15	3.82515982	0.31707975	3.28570437	4.23811267	0.08186964
EV	15	6.15433333	0.68993733	4.96100000	7.03000000	0.17814105

MODEC=9.67

PENMAN	15	4.58940334	0.24746557	4.20455716	5.02162490	0.06389534
PENMANA	15	4.67291554	0.25355838	4.28511654	5.09942089	0.06546849
THORT	15	1.80132393	0.12954078	1.53021038	2.02489606	0.03344729
HARGRS	15	4.16445162	0.30323335	3.53268184	4.51905945	0.07829451
EV	15	6.65986667	0.56114919	5.84000000	7.61000000	0.14488810

MODEC=10

PENMAN	16	4.78203900	0.44665046	3.64347616	5.44061150	0.11166261
PENMANA	16	4.87264652	0.46767395	3.68443534	5.56074305	0.11691849
THORT	16	1.76266878	0.16343637	1.48189732	1.99662912	0.04085909
HARGRS	16	4.27135641	0.46554139	3.40332140	4.95418353	0.11638535
EV	16	6.70343750	0.69802015	5.69800000	7.89000000	0.17450504

MODEC=10.33

PENMAN	16	4.79512368	0.36453306	3.95099310	5.29798963	0.09113326
PENMANA	16	4.89492398	0.37101415	4.06007301	5.40105643	0.09275354
THORT	16	1.76230022	0.14326569	1.50294817	1.99783094	0.03581642
HARGRS	16	4.18985729	0.44729535	3.42270796	4.86860057	0.11182384
EV	16	6.40487500	0.76625591	4.71400000	7.71400000	0.19156398

MODEC=10.67

PENMAN	16	4.89559657	0.41640834	4.00962574	5.40150076	0.10410208
PENMANA	16	4.99744299	0.43042855	4.09988685	5.52595443	0.10760714
THORT	16	1.83117324	0.09603729	1.64022900	1.98828878	0.02400932
HARGRS	16	4.50604693	0.48449802	3.61292933	5.17410297	0.12112450
EV	16	6.78232891	0.69134320	5.76454545	8.43636364	0.17283580

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MODEC=11

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
PENMAN	16	4.99777177	0.33613000	4.37501546	5.54541181	0.08403250
PENMANA	16	5.10912766	0.34918502	4.46452520	5.67323743	0.08729626
THORT	16	1.83146638	0.14747139	1.48080731	2.06105068	0.03686785
HARGRS	16	4.48291993	0.46915944	3.67265719	5.07750957	0.11728986
EV	16	6.60570139	0.78342697	5.00000000	7.87000000	0.19585674

MODEC=11.33

PENMAN	16	5.05399112	0.36508903	4.49600123	5.64823495	0.09127226
PENMANA	16	5.15360517	0.37656583	4.58531534	5.73978837	0.09414146
THORT	16	1.89481360	0.15721549	1.63729571	2.19907391	0.03930387
HARGRS	16	4.61069003	0.47232838	3.83807295	5.37986561	0.11808209
EV	16	6.92512500	0.88263128	5.18300000	8.00600000	0.22065782

MODEC=11.67

PENMAN	16	4.92325155	0.32266441	4.20210940	5.36448534	0.08066610
PENMANA	16	5.02572200	0.33801421	4.28657537	5.45703239	0.08450355
THORT	16	1.87212165	0.11491752	1.60301724	2.04046732	0.02872938
HARGRS	16	4.33008696	0.34418906	3.53477595	4.88199907	0.08604727
EV	16	6.57255556	0.75931363	5.54500000	8.14600000	0.18982841

MODEC=12

PENMAN	16	4.77258315	0.42768234	3.99531449	5.69445138	0.10692058
PENMANA	16	4.88490005	0.44298868	4.05761468	5.91819286	0.11074717
THORT	16	1.71652828	0.14346274	1.45925974	1.90331268	0.03586568
HARGRS	16	4.10046555	0.47190449	3.29173423	4.92414153	0.11797612
EV	16	5.79002083	0.80442498	4.06700000	6.76800000	0.20110624

MODEC=12.33

PENMAN	16	4.86603543	0.32253716	4.20937315	5.57995902	0.08063429
PENMANA	16	4.97953977	0.31919636	4.30134986	5.66717833	0.07979909
THORT	16	1.74799656	0.13107821	1.49040561	2.00062682	0.03276955
HARGRS	16	4.26151251	0.47122708	3.53444388	5.28628417	0.11780677
EV	16	6.06682812	1.14191100	4.09900000	8.76000000	0.28547775

MODEC=12.67

PENMAN	16	4.76030144	0.44965822	4.00024268	5.28794079	0.11241456
PENMANA	16	4.87598625	0.45968954	4.07586505	5.41688251	0.11492238
THORT	16	1.75096662	0.13663420	1.53053010	1.92495057	0.03415855
HARGRS	16	4.09256225	0.58104606	3.18872036	5.17713588	0.14526152
EV	16	5.80762987	1.17216048	3.91090909	8.02000000	0.29304012

APPENDIX C

Monthly Means of Estimates of Potential Evapotranspiration (mm) and Associated Standard Deviations

Promedios Mensuales de Los Valores Estimados de Evapotranspiracion Potencial (mm) y sus Respectivas Desviaciones Standard

HUAYAO/HUANCAYO P E R U 1960-77

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
MO=1						
SPEN	13	144.5076923	7.95705372	130.2000000	158.1000000	2.20711151
STHOR	13	52.4615385	3.68138073	46.5000000	58.9000000	1.02103131
THORTM	13	52.5230769	3.74235974	47.5000000	57.9000000	1.03794384
SHAR	13	120.1846154	10.89815322	99.2000000	139.5000000	3.02260386
HARGRM	13	120.1837467	10.81421548	100.2690108	140.4749586	2.99932372
SEV	13	159.7692308	22.12451071	130.2000000	201.5000000	6.13623522
SEV7	13	111.8384615	15.48715750	91.1400000	141.0500000	4.29536465
RTHR_PEN	13	0.3637312	0.02165952	0.3225806	0.3939602	0.00600727
RHAR_PEN	13	0.8305358	0.03826298	0.7701153	0.8885197	0.01061224
REV_PEN	13	1.1045682	0.13161140	0.9347826	1.4130435	0.03650244
RTHR_EV	13	0.3320585	0.02987153	0.2769231	0.3730715	0.00828487
RPEN_EV	13	0.9163981	0.10152214	0.7076923	1.0697674	0.02815718
RHAR_EV	13	0.7584206	0.06348928	0.6171211	0.8531330	0.01760876
MO=2						
SPEN	16	127.0500000	5.09928100	117.6000000	137.2000000	1.27482025
STHOR	16	51.9750000	3.06191661	47.6000000	56.0000000	0.76547915
THORTM	16	51.8625000	2.90238408	47.5000000	57.3000000	0.72559602
SHAR	16	106.4000000	7.85332201	95.2000000	123.2000000	1.96333050
HARGRM	16	106.0475014	7.56292911	95.8067375	121.9959259	1.89073228
SEV	16	139.3000000	15.72327362	114.8000000	168.0000000	3.93081841
SEV7	16	97.5100000	11.00629153	80.3600000	117.6000000	2.75157288
RTHR_PEN	16	0.4083951	0.02045356	0.3804348	0.4488636	0.00511339
RHAR_PEN	16	0.8341842	0.03824490	0.7762085	0.8976675	0.00956123
REV_PEN	16	1.0957799	0.10955696	0.9333333	1.3333333	0.02738924
RTHR_EV	16	0.3755409	0.03537070	0.3041667	0.4494774	0.00884268
RPEN_EV	16	0.9208908	0.08913256	0.7500000	1.0714286	0.02228314
RHAR_EV	16	0.7657557	0.05317704	0.6511819	0.8531797	0.01329426
MO=3						
SPEN	16	136.2062500	7.11144324	127.1000000	148.8000000	1.77786081
STHOR	16	50.5687500	2.93410265	46.5000000	55.8000000	0.73352566
THORTM	16	50.6812500	2.80718572	46.5000000	55.7000000	0.70179643
SHAR	16	114.5062500	8.19938768	99.2000000	130.2000000	2.04984692
HARGRM	16	114.2797348	8.25211194	98.3467890	129.8896451	2.06302798
SEV	16	151.3187500	13.59383285	133.3000000	179.8000000	3.39845821
SEV7	16	105.9231250	9.51568300	93.3100000	125.8600000	2.37892075
RTHR_PEN	16	0.3726702	0.02291323	0.3431709	0.4239631	0.00572831
RHAR_PEN	16	0.8388984	0.04005691	0.7737749	0.9311086	0.01001423
REV_PEN	16	1.1124730	0.09862570	0.9166667	1.2888889	0.02465642
RTHR_EV	16	0.3368903	0.02993752	0.2925473	0.3956989	0.00748438
RPEN_EV	16	0.9057020	0.08239211	0.7758621	1.0909091	0.02059803
RHAR_EV	16	0.7578655	0.05412622	0.6866421	0.8928485	0.01353156

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MO=4

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
SPEN	17	117.3529412	6.69833166	105.0000000	129.0000000	1.62458406
STHOR	17	49.0588235	3.66521807	45.0000000	54.0000000	0.88894590
THORTM	17	48.9588235	3.41193838	43.9000000	54.7000000	0.82751661
SHAR	17	107.8235294	6.74754857	96.0000000	120.0000000	1.63652091
HARGRM	17	107.6509393	6.85914187	95.5794980	120.3034786	1.66358626
SEV	17	144.0000000	13.20511265	123.0000000	174.0000000	3.20271025
SEV7	17	100.8000000	9.24357885	86.1000000	121.8000000	2.24189717
RTHR_PEN	17	0.4182356	0.03460835	0.3603175	0.4809524	0.00839376
RHAR_PEN	17	0.9172891	0.02380434	0.8621545	0.9494084	0.00577340
REV_PEN	17	1.2278211	0.09635126	1.0238095	1.4210526	0.02336861
RTHR_EV	17	0.3420156	0.03308970	0.2771605	0.4105691	0.00802543
RPEN_EV	17	0.8192460	0.06533523	0.7037037	0.9767442	0.01584612
RHAR_EV	17	0.7506344	0.04990442	0.6391267	0.8421044	0.01210360

MO=5

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
SPEN	16	101.1375000	5.64563253	93.0000000	111.6000000	1.41140813
STHOR	16	45.1437500	3.57397421	40.3000000	52.7000000	0.89349355
THORTM	16	45.3750000	3.67178431	39.3000000	54.1000000	0.91794608
SHAR	16	103.8500000	4.93409904	96.1000000	111.6000000	1.23352476
HARGRM	16	103.7844195	5.00105868	95.7686915	113.3139235	1.25026467
SEV	16	152.2875000	19.63469294	117.8000000	192.2000000	4.90867323
SEV7	16	106.6012500	13.74428505	82.4600000	134.5400000	3.43607126
RTHR_PEN	16	0.4494958	0.03897046	0.3841642	0.5453629	0.00974262
RHAR_PEN	16	1.0281055	0.05849744	0.9250297	1.1341954	0.01462436
REV_PEN	16	1.5103172	0.21136314	1.1176471	1.9375000	0.05284078
RTHR_EV	16	0.3016167	0.03720701	0.2185762	0.3769100	0.00930175
RPEN_EV	16	0.6747100	0.09746607	0.5161290	0.8947368	0.02436652
RHAR_EV	16	0.6893064	0.06907844	0.5673591	0.8276581	0.01726961

MO=6

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
SPEN	16	84.5625000	10.28895038	75.0000000	120.0000000	2.57223760
STHOR	16	40.8750000	3.26343377	36.0000000	46.0000000	0.81585844
THORTM	16	40.6812500	3.21438823	35.4000000	47.4000000	0.80359706
SHAR	16	92.6250000	5.35256948	84.0000000	105.0000000	1.33814237
HARGRM	16	93.1226470	4.89743346	85.5194179	104.5952990	1.22435836
SEV	16	152.6250000	16.64481901	129.0000000	180.0000000	4.16120475
SEV7	16	106.8375000	11.65137331	90.3000000	126.0000000	2.91284333
RTHR_PEN	16	0.4862173	0.05896750	0.3275000	0.5756410	0.01474187
RHAR_PEN	16	1.1115380	0.10152251	0.7602087	1.1936233	0.02538063
REV_PEN	16	1.8207353	0.23207666	1.2250000	2.1481481	0.05801917
RTHR_EV	16	0.2684241	0.02587472	0.2269231	0.3046512	0.00646868
RPEN_EV	16	0.5592147	0.08510850	0.4655172	0.8163265	0.02127712
RHAR_EV	16	0.6146295	0.05000762	0.5509777	0.7057537	0.01250190

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MO=7

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
SPEN	14	91.6714286	5.66601591	80.6000000	99.2000000	1.51430645
STHOR	14	42.0714286	3.98003258	34.1000000	49.6000000	1.06370845
THORTM	14	42.1214286	3.45524764	35.4000000	47.9000000	0.92345378
SHAR	14	100.3071429	4.64716031	93.0000000	108.5000000	1.24200583
HARGRM	14	100.3154910	4.79907112	92.8266710	108.0357938	1.28260571
SEV	14	172.7142857	16.51273901	148.8000000	195.3000000	4.41321513
SEV7	14	120.9000000	11.55891730	104.1600000	136.7100000	3.08925059
RTHR_PEN	14	0.4606787	0.04287659	0.3937709	0.5446650	0.01145925
RHAR_PEN	14	1.0961490	0.04979273	0.9981362	1.2197208	0.01330767
REV_PEN	14	1.8818899	0.10043734	1.7500000	2.0322581	0.02684301
RTHR_EV	14	0.2451059	0.02272046	0.2119816	0.2883065	0.00607230
RPEN_EV	14	0.5327849	0.02836442	0.4920635	0.5714286	0.00758071
RHAR_EV	14	0.5837819	0.03708011	0.5323974	0.6362128	0.00991008

MO=8

SPEN	14	114.9214286	6.82046452	102.3000000	127.1000000	1.82284582
STHOR	14	47.3857143	2.55880295	43.4000000	52.7000000	0.68386885
THORTM	14	46.9785714	2.37654519	42.9000000	51.0000000	0.63515842
SHAR	14	112.[illegible]85714	5.6[illegible]601591	105.4000000	120.9000000	1.51430645
HARGRM	14	112.79150[illegible]5	5.52200258	104.1728828	121.0530806	1.47581727
SEV	14	195.742[illegible]571	18.27350812	161.2000000	223.2000000	4.88380047
SEV7	14	137.02[illegible]000	12.79145568	112.8400000	156.2400000	3.41866033
RTHR_PEN	14	0.4095876	0.02351782	0.3755170	0.4569892	0.00628540
RHAR_PEN	14	0.9826848	0.03856703	0.9203008	1.0410803	0.01030747
REV_PEN	14	1.7026686	0.11594159	1.5000000	1.8461538	0.03098669
RTHR_EV	14	0.2416237	0.02189926	0.2092166	0.2847395	0.00585282
RPEN_EV	14	0.5899541	0.04182741	0.5416667	0.6666667	0.01117884
RHAR_EV	14	0.5794319	0.04275309	0.5127390	0.6570819	0.01142624

MO=9

SPEN	15	131.8000000	9.31358455	111.0000000	144.0000000	2.40475719
STHOR	15	51.6000000	2.58567482	48.0000000	57.0000000	0.66761837
THORTM	15	51.8466667	2.52921972	47.0000000	56.8000000	0.65304172
SHAR	15	118.8000000	6.29285309	108.0000000	126.0000000	1.62480768
HARGRM	15	118.6751182	6.52040709	107.1389565	127.2606154	1.68356187
SEV	15	192.2000000	14.54156604	165.0000000	210.0000000	3.75461621
SEV7	15	134.5400000	10.17909623	115.5000000	147.0000000	2.62823134
RTHR_PEN	15	0.3950176	0.03175078	0.3475177	0.4693694	0.00819802
RHAR_PEN	15	0.9019342	0.03489166	0.8489070	0.9912359	0.00900899
REV_PEN	15	1.4629391	0.12759552	1.2500000	1.7027027	0.03294502
RTHR_EV	15	0.2709372	0.02067366	0.2401961	0.3041667	0.00533792
RPEN_EV	15	0.6884207	0.05998977	0.5873016	0.8000000	0.01548929
RHAR_EV	15	0.6193238	0.03739612	0.5760159	0.6801976	0.00965564

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MO=10

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
SPEN	16	149.3812500	9.00023842	127.1000000	164.3000000	2.25005961
STHOR	16	55.2187500	3.04131961	49.6000000	58.9000000	0.76032990
THORTM	16	55.3562500	3.08889813	49.6000000	58.9000000	0.77222453
SHAR	16	134.0750000	9.63829169	120.9000000	151.9000000	2.40957292
HARGRM	16	133.6881732	9.43597819	120.7187784	151.3921372	2.35899455
SEV	16	205.5687500	13.61737707	186.0000000	223.2000000	3.40434427
SEV7	16	143.8981250	9.53216395	130.2000000	156.2400000	2.38304099
RTHR_PEN	16	0.3719314	0.03191115	0.3200000	0.4468922	0.00797779
RHAR_PEN	16	0.8952600	0.03895272	0.8239746	0.9590298	0.00973818
REV_PEN	16	1.3788008	0.09425463	1.2000000	1.5121951	0.02356366
RTHR_EV	16	0.2698115	0.01476895	0.2435718	0.2967742	0.00369224
RPEN_EV	16	0.7285734	0.05167553	0.6612903	0.8333333	0.01291888
RHAR_EV	16	0.6511278	0.03658633	0.5967858	0.7306719	0.00914658

MO=11

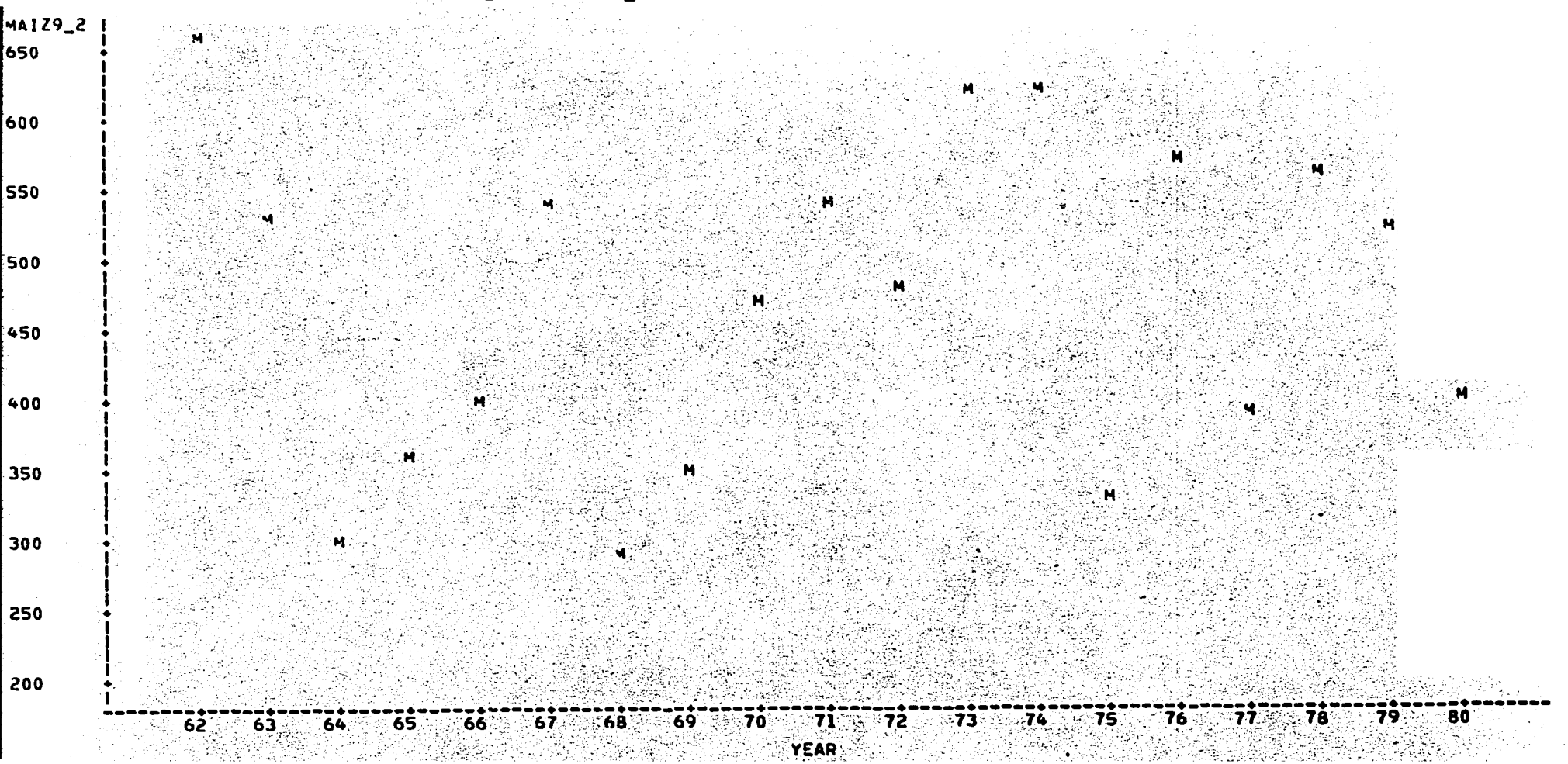
SPEN	16	150.0000000	7.89936706	138.0000000	165.0000000	1.97484177
STHOR	16	56.2500000	3.71483512	48.0000000	60.0000000	0.92870878
THORTM	16	55.9250000	3.32495614	48.5000000	60.5000000	0.83123904
SHAR	16	134.4375000	8.91417411	123.0000000	153.0000000	2.22854353
HARGRM	16	133.8494645	9.46023786	121.3653998	152.7964392	2.36505946
SEV	16	201.1875000	17.64546684	174.0000000	234.0000000	4.41136671
SEV7	16	140.8312500	12.35182679	121.8000000	163.8000000	3.08795670
RTHR_PEN	16	0.3738714	0.03110232	0.3243590	0.4384058	0.00777558
RHAR_PEN	16	0.8918592	0.02854664	0.8444121	0.9424566	0.00713666
REV_PEN	16	1.3416924	0.09955403	1.1372549	1.5294118	0.02488851
RTHR_EV	16	0.2794981	0.02405351	0.2310502	0.3151042	0.00601338
RPEN_EV	16	0.7493406	0.05794526	0.6538462	0.8793103	0.01448632
RHAR_EV	16	0.6672483	0.03954906	0.6123831	0.7555831	0.00988726

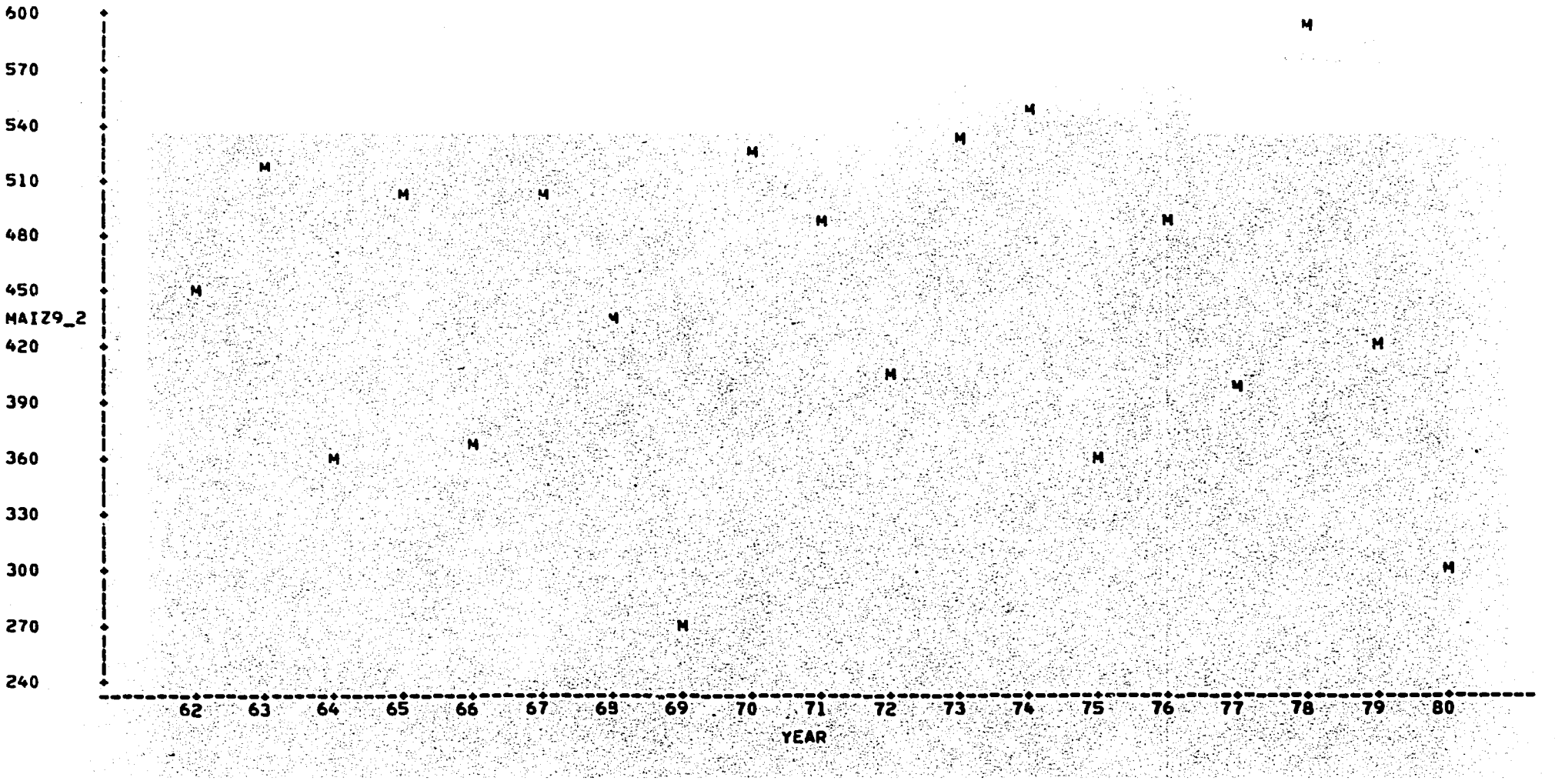
MO=12

SPEN	16	148.9937500	10.02719427	130.2000000	167.4000000	2.50679857
STHOR	16	54.0562500	3.38997911	49.6000000	58.9000000	0.84749478
THORTM	16	53.8000000	3.56557616	48.6000000	60.0000000	0.89139404
SHAR	16	128.4562500	12.44995147	102.3000000	155.0000000	3.11248787
HARGRM	16	128.0585493	12.15039651	102.9828870	153.2862484	3.03759913
SEV	16	182.7062500	22.82152401	145.7000000	232.5000000	5.70538100
SEV7	16	127.8943750	15.97506681	101.9900000	162.7500000	3.99376670
RTHR_PEN	16	0.3620032	0.02638085	0.3199473	0.4285714	0.00659521
RHAR_PEN	16	0.8589933	0.04953210	0.7765569	0.9509072	0.01238303
REV_PEN	16	1.2252746	0.11799574	1.0217391	1.4423077	0.02949893
RTHR_EV	16	0.2973811	0.02889957	0.2375367	0.3432258	0.00722489
RPEN_EV	16	0.8233407	0.08015077	0.6933333	0.9787234	0.02003769
RHAR_EV	16	0.7041902	0.04193119	0.6269120	0.7965368	0.01048280

RAW VALUES IF MAIZ INDEX
REG=JUNIN NAME=JAUJA

PLOT OF MAIZ9_2*YEAR SYMBOL USED IS M



RAW VALUES IF MAIZ INDEX
REG=JUNIN NAME=HJAYAO/HUANCAYO

PLOT OF MAIZ9_2*YEAR SYMBOL USED IS M