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PROPOSED AGROCLIMATIC ASSESSMENT MODELS FOR POLICY DECISION MAKING, ECONOMIC PLANNING AND RURAL DEVELOPMENT IN THAILAND

FINAL REPORT

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FINAL REPORT

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Thailand Meteorological Department
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Bangkok, Thailand

by

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for

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FORWARD

This report by Oranut Paisarnuchapong, Meteorologist, Thailand Meteorological Department, describes agroclimatic assessment models developed for rainfed agriculture in Northeast Thailand. These models can be used to implement a reliable, timely, yet inexpensive weather-based information system in Thailand. Weather analysis and climatic impact assessments can help decision makers including managers, agronomists, economists, agricultural statisticians, agrometeorologists, and extension officials interpret and anticipate weather impacts on the agricultural sector. Specifically, the system will continuously monitor and assess the impact of weather (drought, flooding, high winds, heat stress, etc.) on agriculture. Early warning of potential crop failure due to drought can be provided 30-60 days before crop harvest. This may represent a 3-6 month lead-time to develop strategies for improving food security. Agroclimatic/crop condition assessments can be provided during the crop growing season. These represent additional tools to complement and supplement other information sources used by statisticians and economists to forecast crop production. Soil moisture estimates can be provided to the extension service. These agroclimatic models also offer potential long-term economic benefits related to agricultural planning and rural development, e.g., minimizing climate risk in land and water resource management.

Northeast Thailand was chosen for this pilot study because weather and climate are major factors that help determine potential crop productivity and year-to-year variations in agricultural production levels. Also, this proposed weather assessment system complements ongoing or planned developmental projects involving rainfed agriculture and secondary food crops. The proposed agroclimatic assessment system is ready to be tested and evaluated. After successful testing, the system can be expanded to include other regions in Thailand.

This work is the result of an intensive six week Orientation Program on Agroclimatic Models and Climate Impact Assessment Technology. The program was conducted in Columbia, Missouri, through the joint efforts of the NOAA/NESDIS Assessment and Information Services Center (AISC) - Models Branch and the Atmospheric Science Department, University of Missouri - Columbia. The project was sponsored by the Agency for International Development, Office of U.S. Foreign Disaster Assistance (AID/OFDA), Washington, D.C., as part of a NOAA/AID effort to transfer agroclimatic assessment technology to Southeast Asia. Individuals in these agencies making contributions to this study include: Dr. Wayne L. Decker, Dr. Andres C. Ravelo, Dr. Atanas V. Todorov, Ken Wherry, Judy Trujillo, Betty Whitmarsh and Jerry Wright of the University of Missouri - Columbia; Dr. Clarence M. Sakamoto, Rita Terry and Susan Conrad, NOAA/NESDIS/AISC-Models Branch, Columbia Missouri; and Alan Hankins, AID/ASIA/TR, Robert Ressegule, US/AID Mission Bangkok and Paul Krumpe, AID/OFDA.

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CHAPTER I

INTRODUCTION

Thailand, located in the heart of the Indochinese Peninsula, produces enough food for its population and is also a major source of world agricultural production. Agriculture is important to the national economy of Thailand; about 40 percent of the total land area is devoted to growing crops and approximately 70 percent of the national labor force depends on agriculture. Rice production is the main agricultural activity, with about 62 percent of crop land used for paddy and 22 percent for other field crops. The importance of agriculture to the national economy is further illustrated by the large amount of foreign currency earned by exporting rice, maize, cotton, kenaf, and other agricultural products. However, adverse climate and weather sometimes cause crop failure and a decline in production which affects the national economy and the prosperity of the Thai population. One major goal of Thailand is to increase the level of agricultural production while reducing the losses due to anomalous climate. The focus is on rainfed agriculture. Achieving this goal will contribute major benefits to the economy of Thailand.

The success of cropping practices depends on weather and climate, soil properties and the genetic potential of the plant. These factors limit potential yield. Year-to-year variations in yield are highly determined by climate, particularly with traditional cultural practices for rainfed crops. The climatic hazards for crops are flooding and drought. Depending on severity, the effects of flooding are usually location specific. However, severe drought impacts are usually more widespread. Drought can lead, in extreme cases, to starvation, long-range economic dislocations and social disturbances. For example, the disastrous drought of 1979 severely reduced 1979 crop production levels relative to those of 1978 for rice, cassava and sugarcane. As a result, 1980 agriculture

exports were decreased by about 5 percent relative to the previous year. This crop failure reduced foreign exchange earnings and complicated balance of trade problems associated with the high cost of energy imports. The drought and the increased demand for hydroelectric power (related to the cost of energy imports) reduced water levels in reservoirs. This caused shortages in irrigation supplies and much of the secondary rice crop in the Central Plain could not be planted during early 1980.

This research focused on Northeast Thailand as a "pilot" study area because it is frequently susceptible to crop failures due to flooding and drought. Moreover, because of the poverty of the farmers in this region, most crops are grown by traditional, rainfed cultural practices, i.e., the farmers do not extensively irrigate or apply fertilizers, herbicides or pesticides. The natural fertility of the soil has been decreased by the traditional practices which have also caused soil erosion. Consequently, there is the need to increase agricultural production and reduce climatic vulnerability. It is suggested that the application of agroclimatic data and models can make important contributions.

The purpose of this research is to develop the scientific foundation for a Climatic Impact Assessment Program in Northeast Thailand. Assessments are based on agroclimatic models developed from historic climatic and agricultural data. Assessments primarily focus on potential drought impact as related to short and long-term economic planning needs. In the short-term, decadal or monthly assessment reports on climatic impact can be used by policy decision makers, economic analysts, agricultural forecasters and extension officials to develop strategies to mitigate potential drought impact. These same agroclimatic models can contribute to land and water resource management studies for long-term economic benefits in agricultural planning and rural development. The results of this research can be used by people from various fields as follows:

1) Early warning assessment reports on potential crop failure due to drought or flooding can be used by policy makers and economic analysts to mitigate potential climatic impact on food security and to develop alternative strategies in economic planning. This early warning can represent as much as a 3-6 month lead-time before the occurrence of economic impacts.

2) Crop condition assessments can be used by agricultural statisticians and economists to supplement and complement other information sources (e.g., field reports, probability sampling, crop cutting and market analysis) for forecasting crop production. For example, reliable crop condition information can be provided by about 30 days before the harvest begins.

3) Weather advisories and crop condition reports can be used by extension officials as one source of information for making recommendations to farmers on planting dates, irrigation scheduling, pest management practices and/or fertilizer application.

4) Agroclimatic tools (plant water stress estimates, crop water requirement and climatic risk analysis) can contribute to land and water resource management studies for agricultural planning and rural development.

This report is written to provide background and technical information for those potentially involved with agroclimatic modeling and preparing the assessments. Chapter II provides agroclimatic background information for the Northeast, i.e., the physical environment and agricultural practices. The data bases and methodology are discussed in Chapter III with some analytic results discussed in Chapter IV. Crop modeling results and climatic impact assessment

procedures can be found in Chapters V and VI, respectively. Recommendations for program implementation and future work are discussed in Chapter VII. Chapter VIII provides concluding remarks. Substantial data bases are provided in various Appendices and Supplements.

The goal is to provide users in government agencies with assessments based on these models. Although assessments must be thoroughly tested and evaluated under quasi-operational conditions, this proposed climatic impact assessment program has the potential to provide reliable, timely, yet inexpensive information. This information on climatic impact can be used as an additional information source to complement and supplement existing or planned information sources used for economic planning and decision making.

CHAPTER II

AGROCLIMATIC BACKGROUND FOR NORTHEAST THAILAND

A. Physical Environment

1. Administrative Regions

The Northeast Region of Thailand is approximately located between 14 to 18°N latitude and 101 to 106°E longitude and has an area of 168,854 square kilometers (about 33 percent of the country). It is bounded by the Mekong River on the north and east, and the Phanom Dongrak escarpment and San Kamphaeng mountains on the south, and the Petchabun and Dong Phyayen ridge on the west. According to the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, the 16 provinces in the Northeast Region (Figure 2.1) can be classified into five agroeconomic zones (Table 2.1 and Figure 2.2).

Table 2.1: Agroeconomic Zones in Northeast Thailand

Zone	Provinces
1	Nakhon Phanom, Loei, Nong Khai, Sakhon Nakhon, Udon Thani
2	Ubon Ratchathani, Yasothon
3	Kalasin, Khon Kaen, Roi Et, Maha Sarakham
4	Buri Ram, Si Sa Ket, Surin
5	Chaiyaphum, Nakhon Ratchasima

FIGURE 2.1 Provinces of Northeast Thailand and the Location of Province Cities.

FIGURE 2.2 Agroeconomic Zones of Northeast Thailand.

Four of these provinces are of special interest because rainfall agricultural development work is likely in the future. They are: Chaiyaphum, Si Sa Ket, Roi Et and Nakhon Phanom.

2. Physical Environment

Northeast Thailand is mostly a large plateau region flanked to the west by the Phetchabun Mountains and to the south by the Phanom Dongrak Mountains (Figure 2.3). Elevations range from 800-1300 m on the west to 600-700 m on the south. A secondary mountain range, Phu Phan, separates the Khorat Plateau from the Sakhon Basin which includes Sakhon Nakhon, Nakhon Phanom, Nong Khai and Udon Thani Provinces. The Sakhon Basin and the Khorat Plateau both slope gently to the Mekong River which ultimately drains Northeast Thailand.

Two major rives, the Mun and the Chi, drain about 80 percent of the total area. The Mun River originates near Nakhon Ratchasima and flows eastwards through Ubon Ratchathani to the Mekong River. It drains the northern slopes of the Phanom Dongrak Mountains. The Chi River drains the western portion of the plain and most of the interior. It flows to the southeast until it reaches the Num River near Ubon Ratchathani. The combined drainage area of the two rivers is about 125,500 square kilometers. The northern and eastern fringes of the region are drained by several small rivers such as Nam Loei, Nam Luang and Mae Nam Songkhram. All of these rivers eventually flow into the Mekong River.

3. Climate

The climate of Thailand is affected by two major circulations: the southwest and northeast monsoons. There are well-defined rainy seasons and a transitional season as follows.

NORTHEAST THAILAND

TOPOGRAPHY AND RIVERS

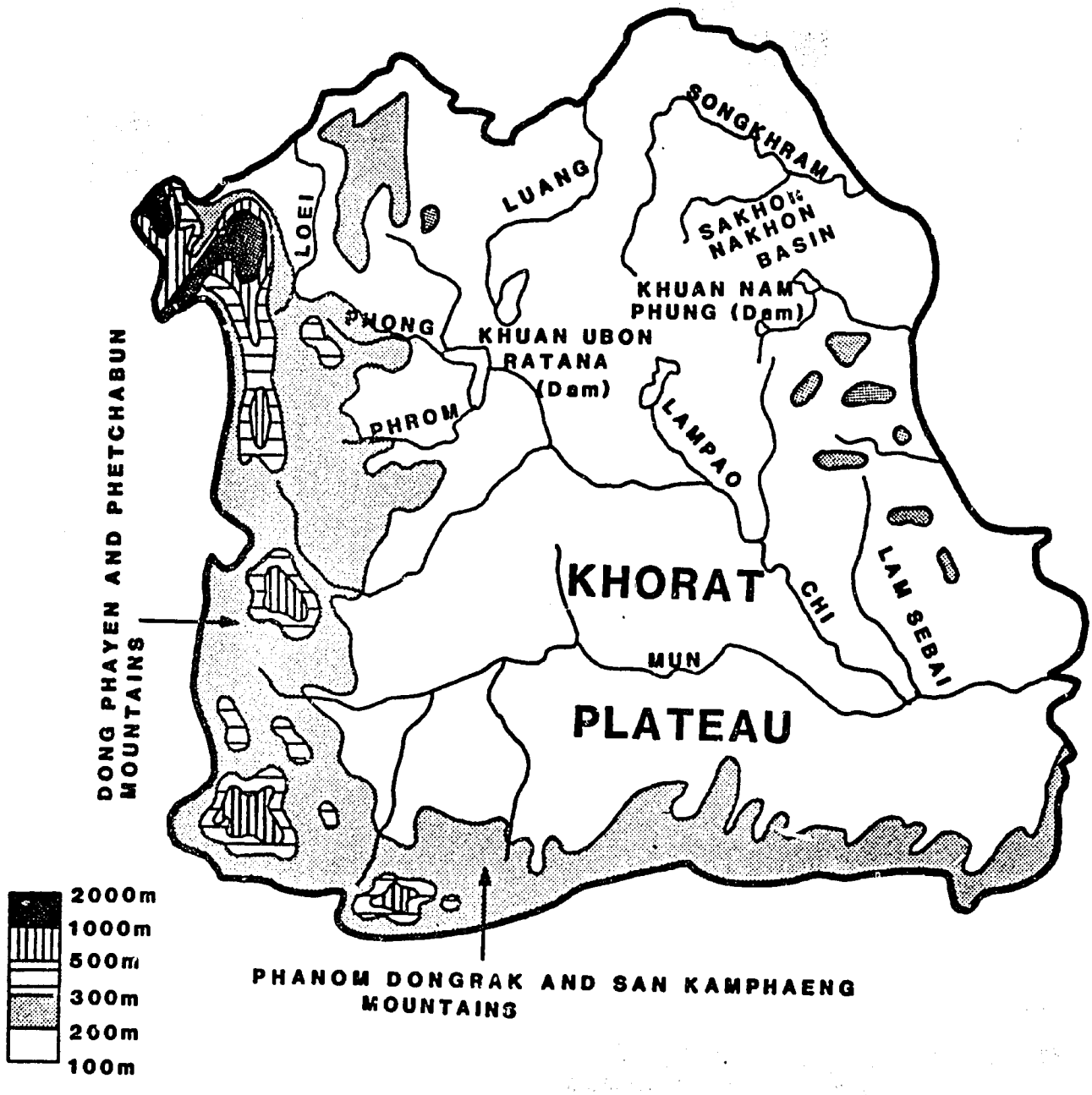

FIGURE 2.3 Topography and Rivers in Northeast Thailand.

1) Rainy Season

The length of the rainy season depends on the duration (onset to retreat) of the southwest monsoon. The onset begins approximately in the middle of May. The rainy season usually ends by the middle of October with the retreat of the monsoon. High humidity and rainfall are associated with the monsoon. Maximum precipitation normally occurs in September (or August in the far northeast area). Abundant rainfall is received from tropical depressions and storms, particularly during August-October.

2) Winter Season

The winter or cool season is determined by the northeast monsoon which prevails from the middle of October to the middle of February. The cool, dry monsoon winds are associated with the Siberian semi-permanent high pressure cell. There is very little rainfall during the winter and December is the driest month.

3) Summer Season

The duration of the summer or hot season is about three months, from the middle of February to the middle of May. This is the period of transition between the northeast and southwest monsoons. The highest temperatures usually occur in April.

The normals for climatic elements are shown in Figures 2.4-2.5 and Tables 2.2.-2.4. The mean annual rainfall in the Northeast ranges from about 1,075 mm at Chok Chai to 2,280 mm at Nakhon Phanom. Notably, the mean annual rainfall increases from west to east in the region. Nakhon Phanom Province in the Sakhon Basin receives about 2300 mm annual rainfall. The drier provinces such as Chaiyaphum, Roi Et and Si Sa Ket in the Khorat Plateau receive 1200, 1400 and 1500 mm annual rainfall, respectively. The annual number of rainy days at these stations ranges from 54 days at Buri Ram to 137 days at Nakhon Phanom (Table 2.3).

NORTHEAST THAILAND
RAINFALL DISTRIBUTION

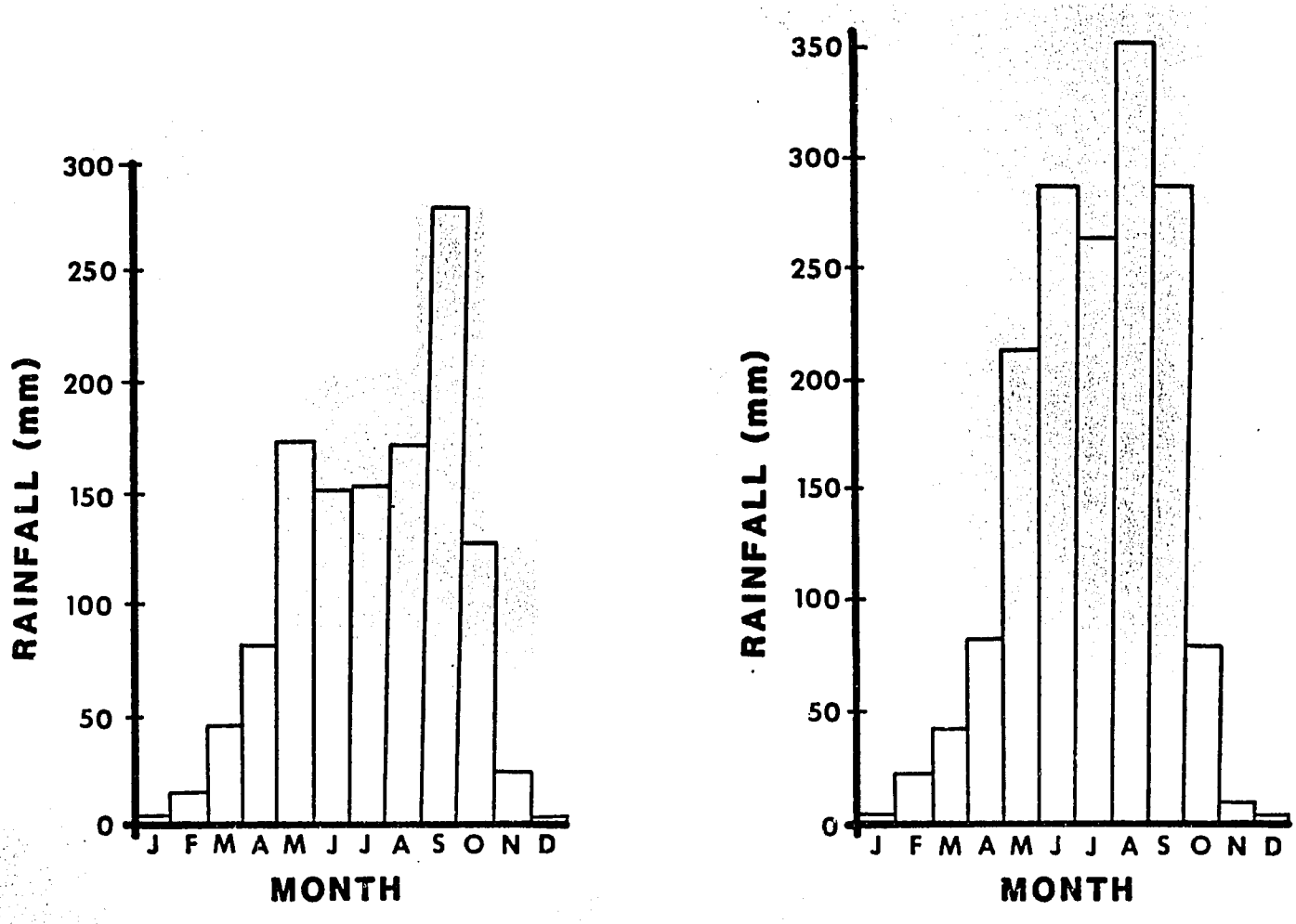

FIGURE 2.4 Mean Rainfall Distributions for West-Central Area (a) and Remainder of Northeast Thailand (b) Defined by 1400mm Mean Annual Isohyet in Figure 2.5.

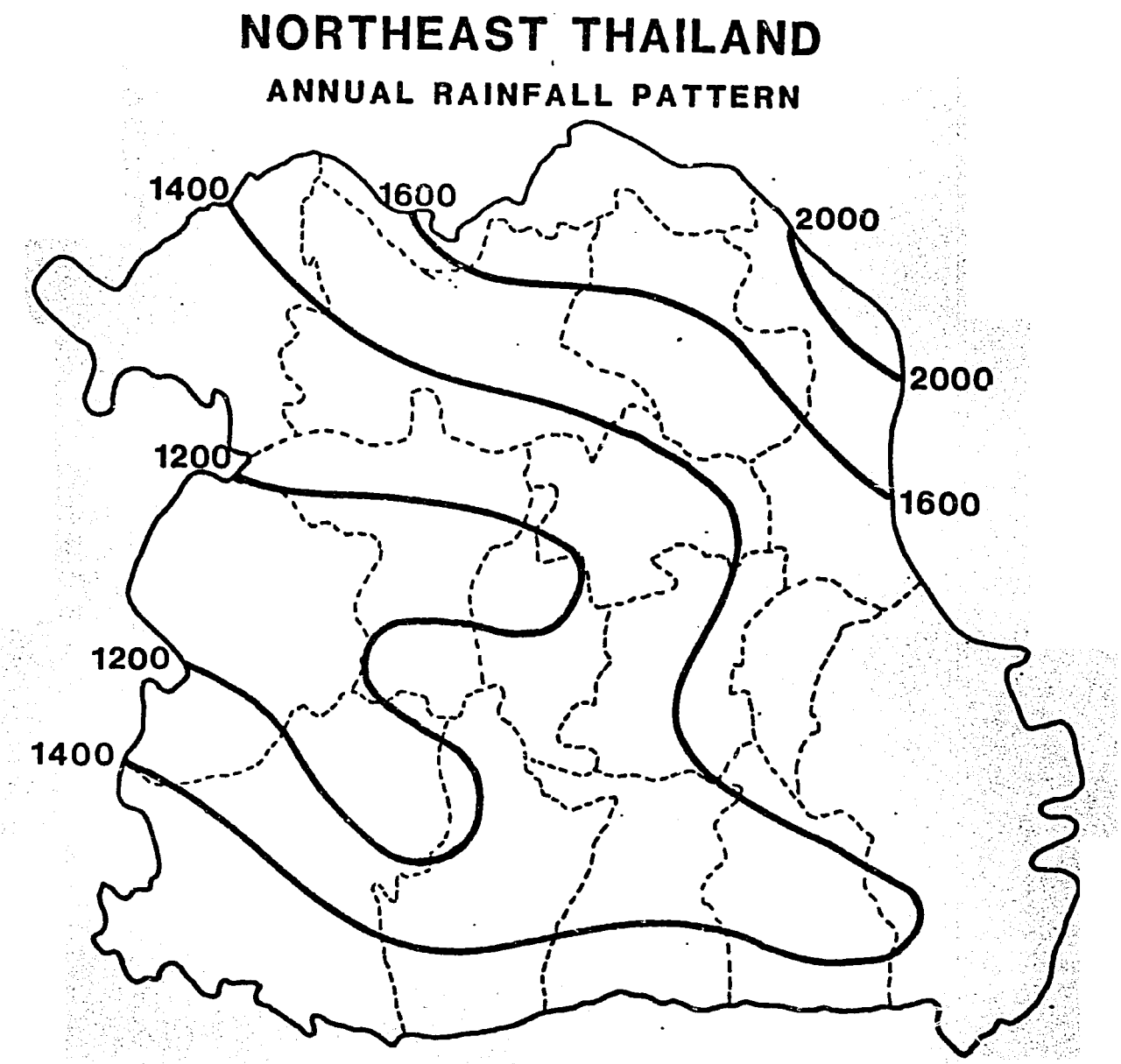

FIGURE 2.5 Annual Rainfall Pattern of Northeast Thailand.

Table 2.2: MEAN MONTHLY RAINFALL (MM) IN NORTHEAST THAILAND

STATION	J	F	M	A	M	J	J	A	S	O	N	D	Annual
NONG KHAI	6	9	29	97	247	295	249	333	301	51	8	4	1629
LOEI	6	16	47	88	195	175	159	193	247	95	12	4	1237
UDON THANI	7	20	39	80	218	241	228	290	283	80	7	3	1496
NAKHON PHANOM	7	19	44	100	240	480	423	593	316	52	5	1	2280
SAKHON NAKHON	7	16	42	85	230	261	208	319	260	62	6	3	1499
MUKDAHAN	4	16	40	87	182	275	244	314	295	63	4	1	1525
KHON KAEN	8	15	34	63	172	181	157	188	277	86	14	3	1198
ROI ET	3	15	29	89	193	193	206	255	326	88	9	1	1407
UBON RATCHATHANI	1	9	43	79	206	253	283	322	279	92	20	2	1589
SURIN	3	9	28	88	182	160	189	201	282	132	22	2	1289
NAKHON RATCHASIMA	4	23	55	70	158	116	131	127	263	158	30	3	1138
CHAIYAPHUM	4	18	51	84	164	147	153	146	310	122	16	4	1219
KALASIN	6	17	30	59	195	233	227	247	286	64	4	2	1370
MAHA SARAKHAM	5	14	40	69	189	190	179	212	293	70	6	3	1270
YASOTHON	5	15	27	66	196	194	224	263	313	84	12	0	1399
KHAM KHUAN KAEO	2	10	34	85	206	210	261	288	316	87	15	0	1514
BURI RAM	3	12	34	69	165	175	155	178	304	132	25	1	1253
SI SA KET	0	7	24	74	181	220	218	264	286	160	23	1	1458
UTHUMPHON PHISAI	2	12	22	51	184	189	205	238	280	99	17	1	1300
CHATTURAT	12	12	53	78	173	119	123	133	259	106	22	3	1093
KOSUM PHISAI	3	11	38	64	160	166	145	174	257	75	8	3	1104
NANG RONG	8	18	38	75	164	150	154	172	284	171	26	3	1263
CHOK CHAI	9	14	37	68	161	109	119	123	252	153	28	2	1075
THA TUM	2	8	29	75	157	178	190	206	298	109	13	1	1266
PHUTIHAISONG	2	19	43	78	195	152	161	206	351	111	20	1	1339

Table 2.3: MEAN MONTHLY NUMBER OF RAINY DAYS (0.1MM) IN NORTHEAST THAILAND

STATION	J	F	M	A	M	J	J	A	S	O	N	D	Annual
NONG KHAI	1.8	2.4	4.8	8.8	16.8	19.1	19.7	21.4	17.9	7.5	1.5	0.6	122.3
LOEI	1.5	3.0	5.7	9.6	18.7	17.9	18.1	20.5	21.3	11.2	2.7	0.8	131.0
UDON THANI	1.3	2.7	4.5	7.8	17.3	17.9	19.6	20.9	19.5	7.9	1.4	0.4	121.2
NAKHON PHANOM	1.1	2.6	5.3	8.9	18.8	23.1	23.9	25.0	19.6	7.4	1.3	0.2	137.2
SAKHON NAKHON	1.2	2.6	5.3	8.3	18.0	19.4	19.7	23.1	19.1	7.1	1.2	0.4	125.4
MUKDAHAN	0.9	2.3	4.3	7.2	16.4	18.3	19.0	22.0	18.8	8.1	1.5	0.4	119.2
KHON KAEN	1.1	2.5	4.3	6.8	13.7	14.7	16.1	17.7	18.2	9.2	1.6	0.6	106.5
ROI ET	0.8	2.2	3.6	6.9	14.5	15.5	15.9	18.1	19.4	8.2	1.8	0.4	107.3
UBON RATCHATHANI	0.5	1.2	3.8	7.5	15.3	18.5	19.5	22.3	20.4	10.6	3.3	0.7	123.6
SURIN	0.6	1.9	4.2	7.8	14.5	17.3	17.8	19.4	20.6	11.5	3.3	0.6	119.5
NAKHON RATCHASIMA	1.2	2.9	6.1	7.9	15.9	15.0	15.6	16.5	19.5	12.1	3.8	0.9	117.4
CHAIYAPHUM	1.0	2.2	5.2	7.7	14.0	13.1	14.6	16.9	19.3	9.6	1.8	0.9	106.3
KALASIN	0.5	1.1	2.0	4.4	10.4	11.1	12.1	13.5	14.7	4.8	0.6	0.2	75.4
MAHA SARAKHAM	0.5	1.2	2.3	4.6	9.8	11.0	10.3	12.5	14.5	5.0	1.0	0.4	73.1
YASOTHON	0.4	1.1	1.9	3.7	9.4	10.2	11.1	13.4	13.0	5.1	0.9	0.1	70.3
KHAM KHUAN KAEO	0.3	1.5	2.8	4.2	9.8	11.1	11.7	14.5	14.3	5.3	0.8	0.2	76.5
BURI RAM	0.3	0.8	2.1	3.0	6.5	6.9	7.4	9.1	10.6	5.2	1.4	0.2	53.5
SI SA KET	0.1	0.4	1.8	3.5	7.8	9.0	8.6	11.4	10.8	5.6	1.5	0.2	60.7
UTHUMPHON PHISAI	0.2	0.6	1.4	3.6	9.2	10.3	10.7	13.7	9.4	5.3	1.4	0.1	65.9
CHATTURAT	0.6	1.0	2.6	3.9	8.4	6.6	7.6	8.2	11.5	5.1	1.2	0.3	57.0
KOSUM PHISAI	0.6	1.7	2.9	5.4	11.0	11.0	11.1	12.7	15.0	6.0	1.0	0.5	78.9
NANG RONG	0.6	1.6	4.1	6.6	12.8	13.8	13.9	16.2	17.9	10.6	3.2	0.7	102.0
CHOK CHAI	1.0	2.0	3.5	6.1	12.4	11.4	11.4	12.8	16.9	10.7	3.3	0.5	92.0
THA TUM	0.3	1.4	2.6	5.8	11.4	14.1	14.3	15.5	17.3	8.5	2.1	0.3	93.6
PHUTTHAISONG	0.3	1.5	2.7	4.9	11.5	10.6	11.5	13.1	14.7	6.5	1.3	0.4	79.0

Table 2.4: CLIMATIC NORMALS (1951-1980) FOR REPRESENTATIVE STATIONS BY AGROECONOMIC ZONE IN NORTHEAST THAILAND

ZONE	STATION	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
							MEAN DAILY AIR TEMPERATURE (°C)							
1	Udon Thani	21.7	24.2	27.2	29.1	28.5	28.1	27.7	27.3	27.0	26.4	24.3	21.9	26.1
2	Ubon Ratchathani	23.9	26.1	28.8	29.9	29.1	28.2	27.8	27.4	27.1	26.7	25.2	23.8	27.0
3	Khon Kaen	23.2	25.7	28.8	30.2	29.4	28.7	28.1	27.7	27.2	26.7	25.0	23.2	27.0
4	Surin	24.3	26.6	29.2	30.0	29.1	28.4	28.0	27.7	27.3	26.9	25.3	24.0	27.2
5	Nakhon Ratchasima	22.9	25.7	28.1	29.0	28.4	28.1	27.6	27.3	26.5	25.9	24.2	22.5	26.4
							MEAN MAXIMUM AIR TEMPERATURE (°C)							
1	Udon Thani	29.6	31.8	34.6	35.9	34.3	32.8	32.4	31.6	31.3	31.3	30.3	29.2	32.1
2	Ubon Ratchathani	31.1	33.2	35.3	35.9	34.4	32.7	32.0	31.4	31.2	31.2	30.7	30.2	32.4
3	Khon Kaen	30.5	32.7	35.4	36.5	34.8	33.2	32.6	32.0	31.5	31.4	30.8	30.0	32.6
4	Surin	31.2	33.3	35.5	36.0	34.5	33.2	32.6	32.2	31.5	31.0	30.4	30.1	32.6
5	Nakhon Ratchasima	31.0	33.5	35.9	36.5	35.0	34.1	33.4	32.9	31.9	30.8	29.8	29.6	32.9
							MEAN MINIMUM AIR TEMPERATURE (°C)							
1	Udon Thani	15.1	17.9	21.3	23.8	24.5	24.8	24.5	24.3	23.9	22.5	19.2	15.8	21.5
2	Ubon Ratchathani	17.0	19.2	22.3	24.2	24.6	24.4	24.2	24.0	23.7	22.5	19.9	17.8	22.0
3	Khon Kaen	16.0	18.8	22.1	24.2	24.7	24.6	24.2	24.1	23.6	22.3	19.2	16.3	21.7
4	Surin	16.6	19.1	22.0	23.7	24.1	23.9	23.6	23.4	23.2	22.5	19.8	17.2	21.6
5	Nakhon Ratchasima	16.2	19.3	22.0	23.5	24.0	23.9	23.6	23.4	23.1	22.3	19.5	16.6	21.5

Table 2.4: CLIMATIC NORMALS (1951-1980) FOR REPRESENTATIVE STATIONS BY AGROECONOMIC ZONE IN NORTHEAST THAILAND (cont.)

ZONE	STATION	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
						MEAN RELATIVE HUMIDITY (%)								
1	Udon Thani	64.0	62.0	60.0	63.0	73.0	79.0	79.0	82.0	82.0	74.0	69.0	67.0	71.0
2	Ubon Ratchathani	66.0	64.0	63.0	67.0	76.0	80.0	81.0	83.0	83.0	77.0	72.0	69.0	73.0
3	Khon Kaen	63.0	62.0	60.0	63.0	72.0	76.0	77.0	80.0	82.0	76.0	70.0	66.0	70.0
4	Surin	65.0	62.0	62.0	66.0	75.0	79.0	80.0	82.0	84.0	80.0	75.0	69.0	73.0
5	Nakhon Ratchasima	67.0	65.0	65.0	68.0	76.0	76.0	77.0	78.0	83.0	81.0	76.0	69.0	73.0
						MEAN DAILY AND TOTAL ANNUAL CLASS A PAN EVAPORATION (MM)								
1	Udon Thani					NO OBSERVATION								
2	Ubon Ratchathani	5.8	6.4	7.1	7.1	6.2	5.6	5.5	5.0	4.6	5.6	6.1	5.8	2155.4
3	Khon Kaen	5.2	6.0	7.0	7.5	6.6	5.6	5.5	4.9	4.6	5.2	5.3	5.2	2083.9
4	Surin	6.4	6.8	7.4	7.2	6.3	5.7	5.8	5.2	4.7	5.7	6.1	6.1	2226.9
5	Nakhon Ratchasima	4.7	5.4	6.2	6.5	5.9	5.8	5.4	5.2	4.4	4.4	4.5	4.5	1915.5
						MEAN SUNSHINE DURATION (HR)								
1	Udon Thani					NO OBSERVATION								
2	Ubon Ratchathani	272.0	233.0	245.1	254.7	237.0	192.3	193.9	160.3	160.5	230.2	254.5	263.9	2697.4
3	Khon Kaen	275.3	242.8	243.1	255.9	247.2	196.9	183.5	162.3	163.6	243.5	255.6	286.1	2755.8
4	Surin	268.8	246.2	255.6	238.0	230.2	145.5	189.5	171.9	177.0	243.4	253.4	273.4	2692.9
5	Nakhon Ratchasima	283.0	244.7	248.4	245.3	244.5	207.4	194.7	185.8	166.1	225.0	258.6	277.1	2780.6

Table 2.4: CLIMATIC NORMALS (1951-1980) FOR REPRESENTATIVE STATIONS BY AGROECONOMIC ZONE IN NORTHEAST THAILAND (cont.)

ZONE	/ STATION	J	F	M	A	M	J	J	A	S	O	N	D	ANNUAL
						MEAN WIND SPEED (KNOTS)								
1	Udon Thani	2.7	3.1	3.2	3.4	3.2	3.0	3.3	3.0	2.9	2.8	2.9	2.8	-
2	Ubon Ratchathani	4.3	3.8	3.6	3.6	3.6	4.2	4.4	4.4	3.2	4.5	6.1	5.6	-
3	Khon Kaen	3.2	3.0	3.5	3.7	3.6	3.9	4.1	3.8	2.8	3.4	3.8	3.6	-
4	Surin	3.1	3.0	3.1	3.2	3.2	3.5	3.5	3.2	2.8	3.4	3.8	3.7	-
5	Nakhon Ratchasima	2.5	2.6	2.5	2.9	2.8	3.7	3.8	3.6	2.4	2.7	3.2	2.9	-

The daily mean air temperature is lowest in December and highest in April. The mean minimum temperature is about 16-18°C while the mean maximum temperature is about 29-30°C. The mean relative humidity shown in Table 2.4 reaches a minimum of about 60 percent in March and rises to a maximum of about 84 percent in September. The annual pan evaporation (class A) ranges from about 1,900-2,200 mm with the highest and lowest daily mean rates in March/April and September, respectively. The annual sunshine duration ranges from about 2,700-2,800 hours with the highest monthly mean occurring in December/January and the lowest in August/September. The mean wind speed ranges from 2.4-6.1 knots.

4. Soils and Natural Vegetation

Soils

The soils of the Northeast have been studied by the Soil Survey Division, Department of Land Development. The soils are differentiated according to soil-landscape relationships as follows:

1) Soils on flood plains consist of very deep soils developed from recent alluvium. These soils are poorly drained with fine texture and are located along the river flood plains. They are used for rice cultivation.
2) Soils on low natural terraces are somewhat poorly drained and are extensively used for rice cultivation.
3) Soils on middle-high natural terraces are well drained and are used for upland crop production or remain as forest areas.
4) Soils on eroded surfaces are for the most part located in the southern and western areas of the Northeast and are used for upland rice and other crop cultivation or remain covered by natural forests.
5) Soils on hilly areas are quite variable in their diagnostic properties and classification characteristics.

Soils information from several experimental stations in the Northeast is shown in Table 2.5. The available moisture storage capacity ranges from 60-150mm of water in the upper meter of soil. Additionally, most of the soils i this region are sandy, have low fertility and are not well suited for cultivation.

Natural Vegetation

About 50 percent of the area in the Northeast is covered by natural vegetation. Tropical evergreen forests are found along the mountain ranges in the west and south (Figure 2.6). Small areas with coniferous forest are located in the northwestern and southeastern areas. Three-fourths of the natural vegetation is broadleaved, deciduous forest which is located mostly along the northern and eastern boundaries with small areas sparsely distributed in the central areas of the region. The remaining areas are used for agriculture land.

B. Agricultural Practices

1. Agriculture and National Economy

The economy of Thailand is dominated by the agricultural sector which contributes more than 70 percent to the total value of exports. About 40 percent of the total land area in Thailand is used for agriculture. Approximately 70 percent of the national labor force works in agriculture. About 60 percent of the cropland is devoted to paddy and 22 percent to field crops.

About 34 percent of the nation's population live in the Northeast and approximately 60 percent of the people in the region engage in agriculture. Thus, agriculture is the major economic sector. Although the Northeast has the largest agricultural land holdings (about 42 percent of the country), modern technology and mechanization are at a comparatively low level. The average farmer's income is quite poor and traditional cultural practices are used. For example, only 13 percent of the cropland in this region is under irrigation.

Table 2.5: SOIL INFORMATION FOR INDICATED AREAS*

PROVINCE	LOCATION	SOIL CLASSIFICATION	TOTAL AVAILABLE MOISTURE STORAGE (upper meter of soil) (mm)	AVERAGE MEAN BULK DENSITY (upper meter of soil) (grams/cm cubed)
Khon Kaen	Tha Phra	Gray Podzolic Soil	85.3	1.64
	Khon Kaen Field Crop Exp. Stn.	Red Yellow Latosol	110.9	1.48
Surin	Surin Horticulture Exp. Stn.	Gray Podzolic Soil	153.8	1.62
	Surin Rice Exp. Stn.	Low Humic Grey Soil	103.0	1.62
Ubon Ratchathani	Ubon Field Crop Exp. Stn.	Gray Podzolic Soil	111.6	1.55
	Ubon Rice Exp. Stn.	Low Humic Grey Soil	128.5	1.57
Roi Et	Roi Et Field Crop Exp. Stn.	Gray Podzolic Soil	89.9	1.61
Nakhon Ratchasima	Pak Chong	Reddish Brown Lateritic Soil	61.6	1.20

*Obtained from Data Book on Physical Properties of Upland Soils in Thailand (1979)

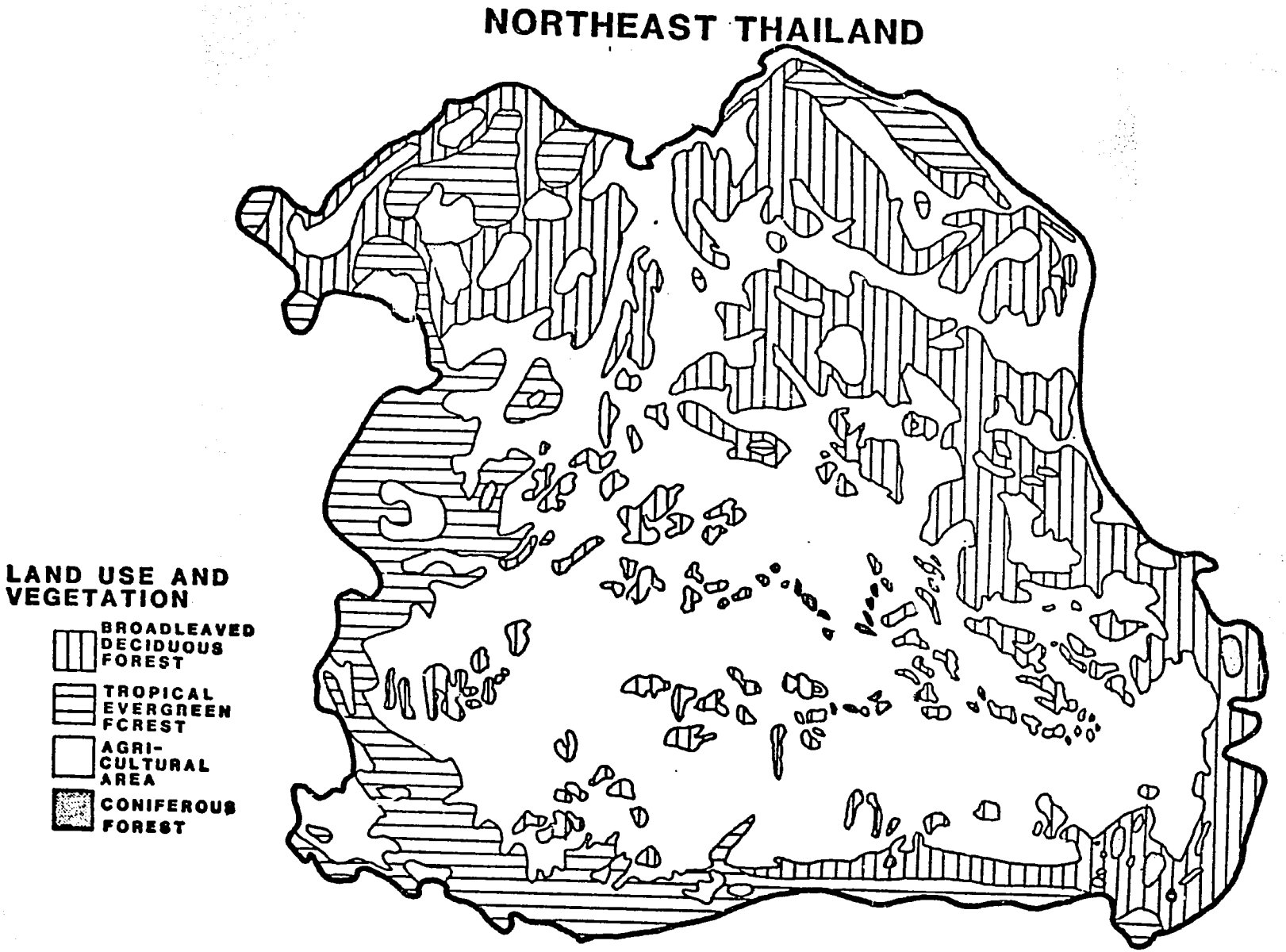

FIGURE 2.6 Land Use and Vegetation Map of Northeast Thailand.

This means that crop yield and production are highly dependent on the weather. The limiting meteorological factor for crops is rainfall, which must be distributed adequately during the growing season for high agricultural productivity. Thus, rainfall is a good indicator of crop productivity.

2. Cultural Practices

Traditional cultural practices are still used in the region. Very little modern farm technology has been introduced. Because the areas under irrigation are small, crops are generally grown in non-irrigated fields during the rainy season. Paddy fields are puddled and then plowed in preparation for planting. Fields for other crops are only plowed. Field preparations begin after the first rains soften the soil. Irrigated rice is sown in special nurseries. When the plants reach about 15-20 cm in height, they are transplanted into the permanent fields. Rainfed rice, as well as all other crops, are sown directly into the fields.

3. Crop Season, Regions and Calendars

The major growing season coincides with the rainy season, approximately May to October. The major planting occurs after the beginning of the rainy season. However, planting is delayed in some years by the late arrival of the rains. Thus, the success of any growing season depends on the timely beginning of the rainy season as well as the amount and distribution of rainfall during the growing season. Although the water requirement for each phenological stage of a crop must be met, the demand for water during flowering and reproduction stages is particularly critical.

Crops are distributed in the region according to the climatic condition and soil quality. Rice is a major crop and is grown in all provinces. Other widely distributed crops include cassava, groundnuts and kenaf. Some crops are grown

only in particular provinces, e.g., maize and sorghum. Table 2.6 shows the total planted area of each crop during 1980/1981 for each province in Northeast Thailand. Table 2.7 shows the relative importance of each crop within each province according to the percentage contribution made to total planted area in the province for all crops. In contrast, Table 2.8 shows how the regional planted area for the individual crops is distributed among the provinces. Figures 2.7a-b also illustrate the distribution of crops throughout the Northeast.

In Chaiyaphum Province, kenaf is the most widespread crop and accounts for about 18 percent of the regional planted area. In Si Sa Ket Province three crops prevail including rice and maize. Each accounts for about 6.5 and 4 percent of the regional planted area. In Roi Et Province, rice is the main crop and occupies about 9 percent of the regional planted area. Nakhon Phanom Province has two major crops, rice and sugarcane, which occupy about 4 and 5 percent of their regional planted areas, respectively.

Crop calendars for the Northeast and each agroeconomic zone are shown in Table 2.9.

4. Technology Changes

Modern agricultural technology is gradually being introduced into the Northeast. For example, irrigation has increased to 13 percent of the total irrigated area within Thailand. However, it is still inadequate to meet the needs in the Northeast. Rainfed agriculture is dominant.

Several crop varieties are being released which are drought or flood resistant, have a high yielding potential or exhibit good fertilizer responsiveness. For example, at least ten varieties of rice have been released by experiment stations, but only two varieties are widely grown: Khao Dawk Mali 105 (KDML) and Niaw San Patong (NSPT). Both varieties have a good grain quality

Table 2.6: PLANTED AREA (RAI) DURING 1980/81 FOR VARIOUS AGRICULTURAL CROPS IN THE PROVINCES OF NORTHEAST THAILAND

PROVINCE \ CROP	MAJOR RICE	CASSAVA	GROUND NUTS	MAIZE	MUNG BEAN	SUGAR CANE	SOY BEANS	SORGHUM	KENAF	COTTON	TOTAL AREA
Nakhon Phanom	1,119,615	104,420	3,773	-	-	13,694	-	-	12,558	263	1,254,323
Sakhon Nakhon	1,620,694	119,883	8,086	-	175	1,456	-	-	11,762	7,976	1,770,032
Nong Khai	905,442	339,504	2,921	-	207	397	-	-	4,409	7,067	1,259,947
Udon Thani	2,630,497	308,939	4,474	230,907	2,224	165,667	14	-	110,795	2,075	3,455,592
Loei	388,096	28,339	7,201	814,691	24,917	5,314	27,554	-	1,219	77,369	1,374,700
Ubon Ratchathani	3,439,767	47,199	5,251	41,298	-	-	-	-	130,443	7,779	3,671,737
Yasothon	986,211	55,558	1,996	-	-	546	-	-	47,707	1,182	1,093,200
Roi Et	2,472,082	150,310	6,942	-	-	84	-	-	17,308	-	2,646,[illegible]26
Kalasin	1,046,481	378,376	11,240	-	-	33,680	-	-	29,071	518	1,499,366
Maha Sarakham	1,527,066	252,173	1,019	-	-	729	-	-	65,055	-	1,846,042
Khon Kaen	1,968,014	380,784	2,835	54,752	14,244	49,473	61	-	139,966	-	2,610,129
Si Sa Ket	1,721,098	54,267	6,110	111,227	1,076	-	-	-	11,469	-	1,905,247
Surin	2,448,030	63,280	12,835	-	-	-	-	-	84,990	-	2,609,135
Buri Ram	2,462,552	281,390	21,723	69,712	413	21,208	-	28	69,401	16	2,926,443
Nakhon Ratchasima	2,059,111	1,670,823	[illegible]	785,525	18,620	470	8,044	30,129	46,038	60,403	4,724,658
Chaiyaphum	1,428,975	299,370	9,409	158,890	25,698	1,317	-	-	167,958	203	2,091,820
Total Area	28,223,731	4,534,615	151,310	2,267,002	87,574	294,035	35,673	30,157	950,149	164,851	36,739,097

Table 2.7: THE PERCENTAGE CONTRIBUTION OF EACH CROP TO THE TOTAL CROP AREA DURING 1980/81 IN EACH PROVINCE OF NORTHEAST THAILAND.

PROVINCE \ CROP	MAJOR RICE	CASSAVA	GROUND NUTS	MAIZE	MUNG BEAN	SUGAR CANE	SOY BEANS	SORGHUM	KENAF	COTTON	TOTAL PERCENTA
Nakhon Phanom	89.26	8.33	0.30	-	-	1.09	-	-	1.00	0.02	100
Sakhon Nakhon	91.56	6.77	0.46	-	0.01	0.08	-	-	0.67	0.45	100
Nong Khai	71.86	26.95	0.23	-	0.02	0.03	-	-	0.35	0.56	100
Udon Thani	76.12	8.94	0.13	6.68	0.06	4.80	0	-	3.21	0.06	100
Loei	28.23	2.06	0.52	59.26	1.81	0.39	2.01	-	0.09	5.63	100
Ubon Ratchathani	93.68	1.29	0.14	1.13	-	-	-	-	3.55	0.21	100
Yasothon	90.21	5.08	0.18	-	-	0.05	-	-	4.37	0.11	100
Roi Et	93.40	5.68	0.26	-	-	0	-	-	0.66	-	100
Kalasin	69.79	25.24	0.75	-	-	2.25	-	-	1.94	0.03	100
Maha Sarakham	82.72	13.66	0.06	-	-	0.04	-	-	3.52	-	100
Khon Kaen	75.40	14.59	0.11	2.10	0.55	1.89	0	-	5.36	-	100
Si Sa Ket	90.33	2.85	0.32	5.84	0.06	-	-	-	0.60	-	100
Surin	93.83	2.42	0.49	-	-	-	-	-	3.26	-	100
Buri Ram	84.15	9.62	0.74	2.38	0.01	0.73	-	0	2.37	0	100
Nakhon Ratchasima	43.58	35.36	0.96	16.63	0.40	0.01	0.17	0.64	0.97	1.28	100
Chaiyaphum	68.31	14.31	0.45	7.60	1.23	0.06	-	-	8.03	0.01	100

Table 2.8: PERCENTAGE CONTRIBUTION OF CROP AREA IN EACH PROVINCE TO NORTHEAST THAILAND'S TOTAL PLANTED AREA FOR THE INDICATED CROPS IN 1980/81

PROVINCE \ CROP	MAJOR RICE	CASSAVA	GROUND NUTS	MAIZE	MUNG BEAN	SUGAR CANE	SOY BEANS	SORGHUM	KENAF	COTTON
Nakhon Phanom	3.97	2.30	2.49	-	-	4.66	-	-	1.32	0.16
Sakhon Nakhon	5.74	2.64	5.34	-	0.20	0.49	-	-	1.24	4.84
Nong Khai	3.21	7.49	1.93	-	0.24	0.13	-	-	0.46	4.29
Udon Thani	9.32	6.81	2.96	10.19	2.54	56.34	0.04	-	11.66	1.26
Loei	1.37	0.62	4.76	35.94	28.45	1.81	77.24	-	0.13	46.93
Ubon Ratchathani	12.19	1.04	3.47	1.82	-	-	-	-	13.73	4.72
Yasothon	3.49	1.23	1.32	-	-	0.19	-	-	5.02	0.72
Roi Et	8.76	3.31	4.59	-	-	0.03	-	-	1.82	-
Kalasin	3.71	8.34	7.43	-	-	11.45	-	-	3.06	0.31
Maha Sarakham	5.41	5.56	0.67	-	-	0.25	-	-	6.85	-
Khon Kaen	6.97	8.40	1.87	2.41	16.27	16.83	0.17	-	14.73	-
Si Sa Ket	6.10	1.20	4.04	4.91	1.23	-	-	-	1.21	-
Surin	8.67	1.40	8.48	-	-	-	-	-	8.94	-
Buri Ram	8.73	6.21	14.36	3.07	0.47	7.21	-	0.09	7.30	0.01
Nakhon Ratchasima	7.30	36.85	30.07	34.65	21.26	0.16	22.55	99.91	4.85	36.64
Chaiyaphum	5.06	6.60	6.22	7.01	29.34	0.45	-	-	17.68	0.12
Total Percentage	100	100	100	100	100	100	100	100	100	100

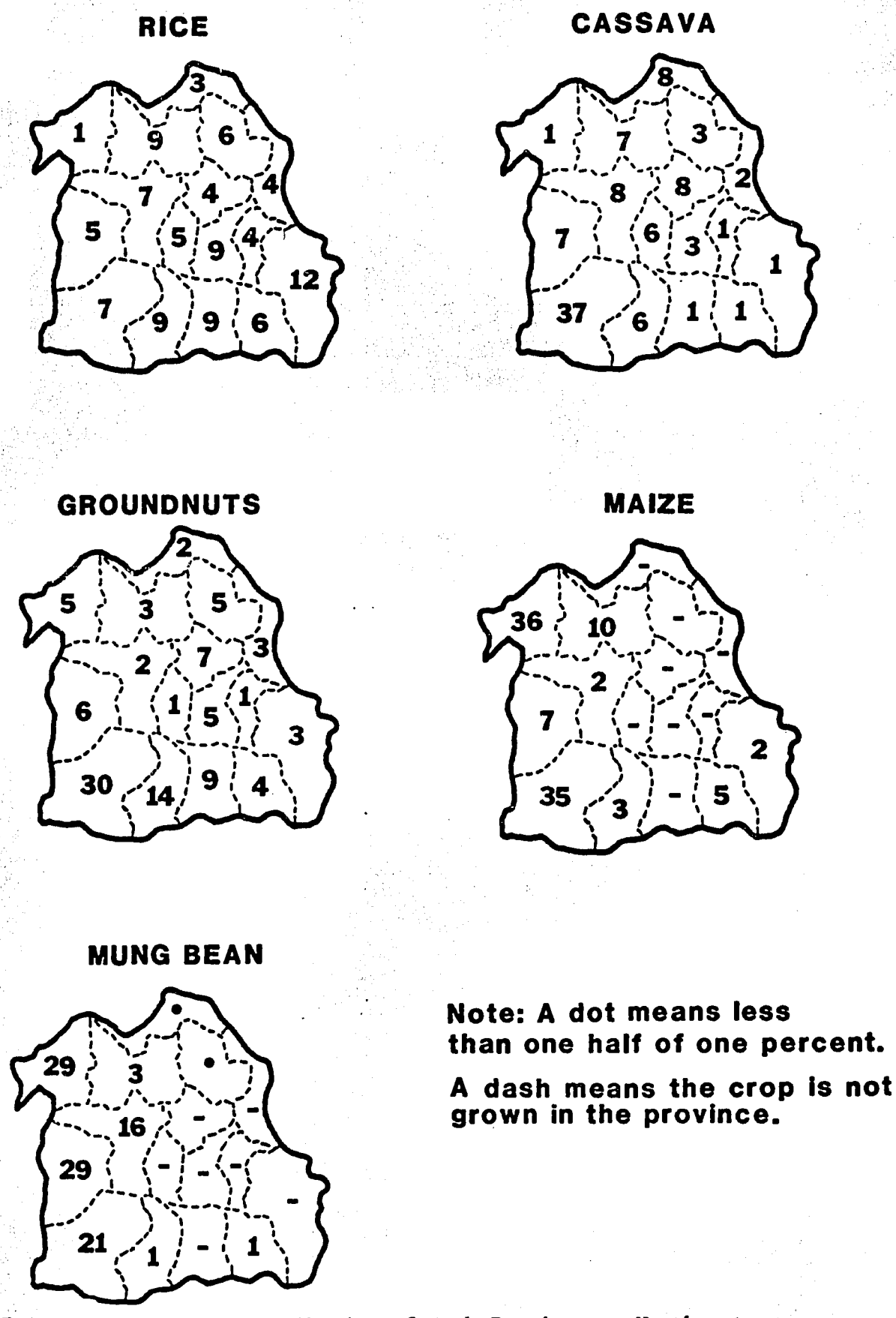

FIGURE 2.7a The Percentage Contribution of Each Province to Northeast Thailand's Total Planted Area for the Indicated Crop in 1980/81.

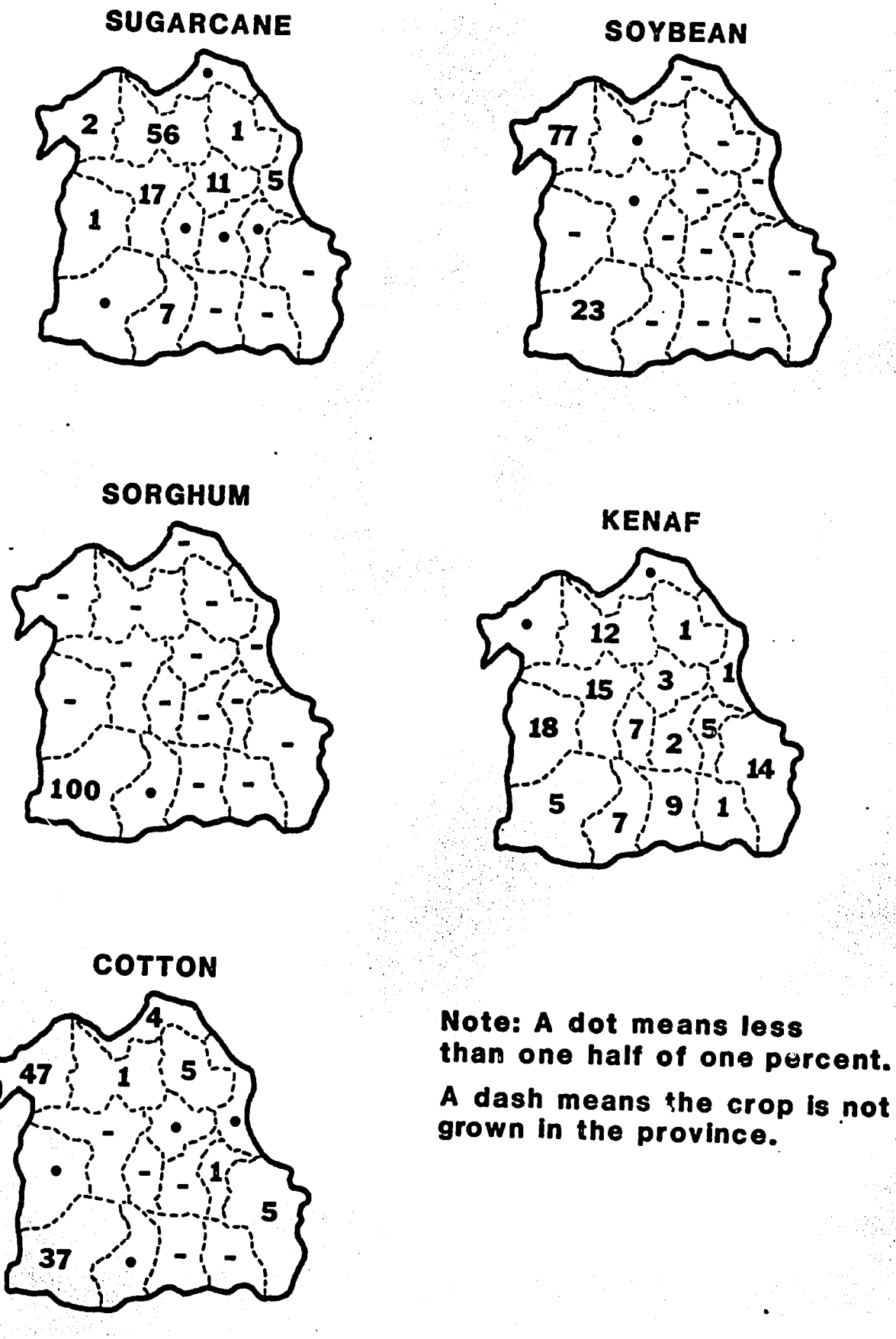

FIGURE 2.7b The Percentage Contribution of Each Province to Northeast Thailands's Total Planted Area for the Indicated Crop in 1980/81.

Table 2.9 Crop Calendars: Average For The Northeast Region
And For Each Agroeconomic Zone Within The Region

REGION	CROP	J	F	M	A	M	J	J	A	S	O	N	D
NE Region	Rice	0000				////	////	———					0000
	Maize				////	////			0000	0000			
	Cotton	0000					////	////					0000
	Kenaf				////					0000	0000		
	Sugarcane	0000	0000	0000	////								
	Sorghum				////			0000					
	Cassava			0000	////								
Zone 1	Rice					////							0000
	Maize				////				0000				
	Cotton						////						0000
	Kenaf				////					0000			
	Ground Nuts			0000		////							
	Mung Bean								////				0000
	Sugarcane		0000		////								
Zone 2	Rice						////						0000
	Maize					////			0000				
	Cotton						////					0000	
	Kenaf				////					0000			
	Ground Nuts						////			0000			
Zone 3	Rice						////						0000
	Maize					////				0000			
	Cotton	0000					////						
	Kenaf				////					0000			

NOTES: //// planting 0000 harvesting ——— transplanting

Table 2.9 Crop Calendars Continued:

REGION	CROP	J	F	M	A	M	J	J	A	S	O	N	D
	Ground Nuts					////				0000			
Zone 3	Mung Bean						////			0000			
	Sugarcane			0000	////								
	Rice	0000					////						
	Maize					////			0000				
	Cotton		0000								////		
Zone 4	Kenaf				////						0000		
	Ground Nuts					////			0000				
	Mung Bean									////			0000
	Rice												
	Maize					////				0000			
	Cotton							////					0000
	Kenaf				////						0000		
	Ground Nuts				////			0000					
	Mung Bean					////				0000			
Zone 5	Sugarcane	0000			////								
	Sorghum				////			0000					
	Cassava			0000	////								
	Castor Bean				////						0000		
	Soy Bean				////				0000				
	Jute					////			0000				

NOTES: //// planting 0000 harvesting _____ transplanting

and are somewhat drought resistant, but have a poor response to fertilizer and are susceptible to disease and insect infestations.

In recent years, the use of fertilizers, insecticides and pesticides has gradually increased. For example, fertilizer usage expressed as a percent of usage for the whole country slowly increased from 22 to 24 percent during the period 1976-1979.

5. Climatic Vulnerability

Due to the orientation of the mountain ranges and the great distance from the sea, the Northeast is not influenced by the warm, moist maritime air as are the other regions in Thailand. Precipitation is usually low and irregular. Moreover, most of the soils have low fertility and a low available moisture storage capacity. Consequently, the water available in the soil to meet crop needs is usually inadequate. Soil erosion has become a major problem and has probably increased drought vulnerability by reducing the soil depth and decreasing the soil water holding capacity.

The Northeast frequently experiences drought and flooding problems. In the summer, the weather is seasonally hot and dry. In the rainy season, there are usually drought or flooding problems. Flash floods occur due to heavy monsoon rains and tropical depressions. In the winter, the weather is dry and sometimes very cold due to the influence of the northeast monsoon and the Siberian anti-cyclone.

CHAPTER III

METHODOLOGY AND ANALYTIC TOOLS

A. Data Sources

1. Meteorological Data

The meteorological data used in this study were obtained from various types of stations located in Northeast Thailand as shown in Figures 3.1-3.2 and Tables 3.1-3.2. These stations include:

Synoptic stations: Monthly rainfall and temperature data (1951-1980) were used from 12 stations (Figure 3.1 and Table 3.1). In addition, climatological normals were available from the base period 1951-1980. The monthly normals data include the mean of the maximum temperature, minimum temperature, dew point temperature, wind speed, sunshine duration, relative humidity, precipitation and U.S. Class A Pan evaporation.

Rainfall and hydro-meteorological stations: Monthly rainfall data were available at 13 additional stations (with different record lengths) as indicated in Table 3.2 and Figure 3.2.

Agrometeorological stations: Monthly meteorological data obtained from three stations were used to investigate methods for estimating potential evapotranspiration and soil moisture. The available data included precipitation, mean maximum and minimum temperatures, U.S. Class A Pan evaporation, wind speed and sunshine duration. The locations of the three additional agrometeorological stations are also shown in Figure 3.2.

2. Agricultural Data

Although rice is the major crop grown in Northeast Thailand, many other rainfed crops are also extensively grown as shown in Figures 2.7a-b. The annual national, regional and provincial agricultural data (acreage, production and yield) of the crops were available but with different record lengths as shown in Tables 3.3a-b.

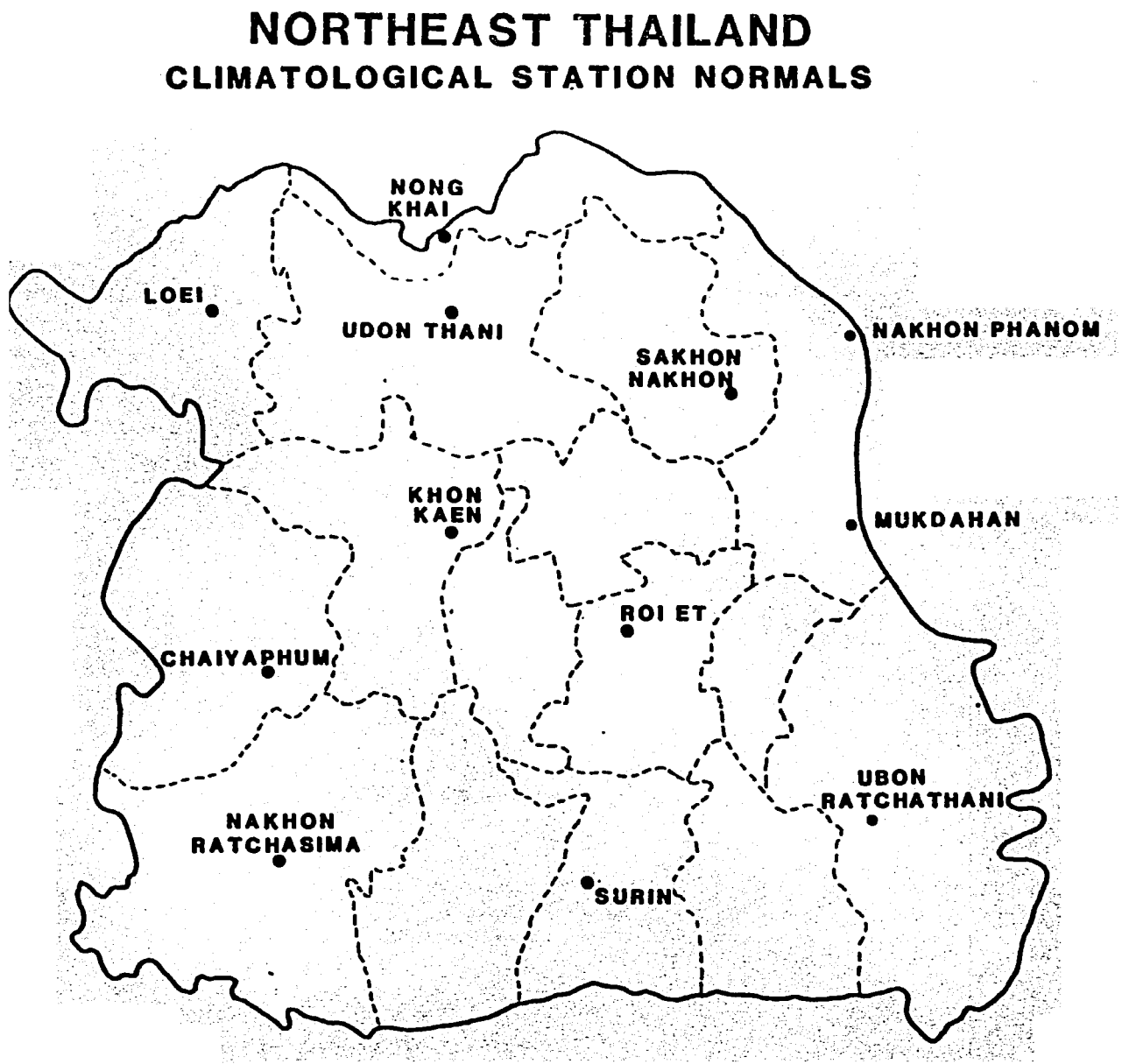

FIGURE 3.1 The Synoptic Stations in Northeast Thailand.

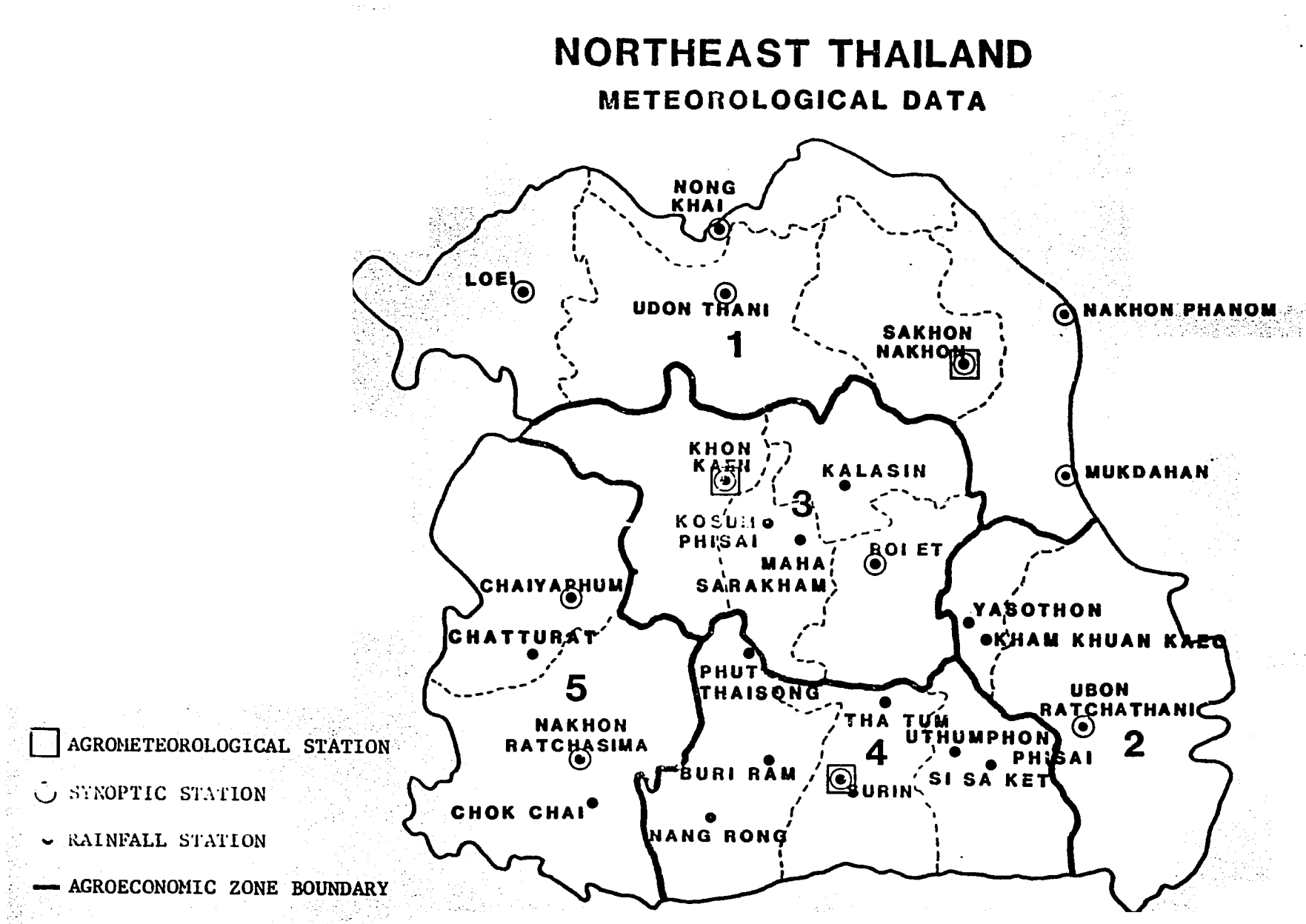

FIGURE 3.2 Synoptic, Rainfall and Agroeconomic Stations in Northeast Thailand

Table 3.1: INFORMATION ON SYNOPTIC STATIONS IN NORTHEAST THAILAND

STATION	LATITUDE	LONGITUDE	ELEVATION (m)	RECORD PERIOD
Nong Khai	17° 52' N	102° 43' E	174.00	1965-79
Loei	17° 27'	101° 44'	252.52	1954-80
Udon Thani	17° 23'	102° 48'	176.98	1951-80
Nakhon Phanom	17° 25'	104° 47'	140.00	1953-80
Sakhon Nakhon	17° 09'	104° 08'	171.00	1951-80
Mukdahan	16° 32'	104° 43'	138.00	1951-80
Khon Kaen	16° 26'	102° 50'	164.63	1951-80
Roi Et	16° 03'	103° 41'	140.00	1951-80
Ubon Ratchathani	15° 15'	104° 52'	123.00	1951-80
Surin	14° 53'	103° 30'	146.00	1951-80
Nakhon Ratchasima	14° 58'	102° 05'	187.00	1951-80
Chaiyaphum	15° 48'	102° 02'	182.00	1957-80

Table 3.2 Period of Record for Rainfall, Hydro-Meteorological and Agro-Meteorological Stations in Northeast Thailand

TYPE	STATION	PERIOD OF RECORD
Rainfall Station	Kalasin	1952-1980
	Maha Sarakham	1952-1980
	Yasothon	1952-1975
	Kham Khuan Kaeo	1952-1980
	Bumi Ram	1952-1977, 1980
	Si Sa Ket	1952-1970, 1973-1976
	Uthumphon Phisai	1953-1967, 1970-1980
Hydro-Meteorological Station	Chattural	1957-1980
	Kosum Phisai	1956-1980
	Nang Rong	1956-1980
	Chok Chai	1956-1980
	Tha Tum	1956-1980
	Phuttaisong	1956-1978, 1980
Agro-Meteorological	Surin	1967-1981
	Tha Phra Khon Kaen	1967-1981
	Sakhon Nakhon	1967-1981

Table 3.3a NORTHEAST THAILAND CROP YIELD DATA INVENTORY

PROVINCE	MAIN RICE	MAIZE	CASSAVA	SUGARCANE	MUNGBEAN	SORGHUM	SOYBEANS	GROUNDNUTS	COTTON	KENAF
	(PERIOD OF RECORD)									
NAKHON PRANOM	1973-79	1978-79	1973-79	1973-79	1973-78	1977	1973-74	1973-79	1973-79	1973-79
NONG KHAI	1975-79	1975-79	1973-79	1975-79	1974-79	—	1974-78	1973-79	1973-79	1973-79
UDON THANI	1973-79	1975-79	1973-79	1973-79	1973-79	—	1973-79	1973-79	1973-79	1973-79
LOEI	1973-79	1973-79	1973-79	1976-79	1973-79	—	1975-79	1973-79	1973-79	1973-79
YASOTHON	1973-79	1975-77	1973-79	—	1973-78	—	1977	1973-79	1973-79	1973-79
UBON RATCHATHANI	1973-79	1975-79	1973-79	—	1973-78	—	1973-74	1973-79	1973-79	1973-79
KALASIN	1973-79	1975-76	1973-79	1976-79	1974-75	—	1973-74	1973-79	1973-79	1973-79
KHON KAEN	1973-79	1975-79	1973-79	1976-79	1973-79	—	1973-79	1973-79	1973-77	1973-79
MAHA SARAKHAM	1973-79	1978	1973-79	—	1973-74	—	—	1973-78	1973-75	1973-79
ROI ET	1973-79	1975-78	1973-79	1975-79	1973-76	—	1974	1973-79	1973-77	1973-79

Table 3.3b NORTHEAST THAILAND CROP YIELD DATA INVENTORY

PROVINCE	MAIN RICE	MAIZE	CASSAVA	SUGARCANE	MUNGBEAN	SORGHUM	SOYBEANS	GROUNDNUTS	COTTON	KENAF
	(PERIOD OF RECORD)									
BURI RAM	1973-79	1975-79	1973-79	1973-79	1973-78	1979	1974-75	1973-79	1973-77	1973-79
SI SA KET	1973-79	1973-79	1973-79	—	1973-78	—	1974-77	1973-79	1973-74	1973-79
SURIN	1973-79	1978-79	1973-79	—	1973-78	—	1973	1973-79	—	1973-79
CHAIYAPHUM	1973-79	1973-79	1973-79	1976	1974-79	1975-79	1973-79	1973-79	1973-79	1973-79
NAKHON RATCHASIMA	1973-79	1973-79	1973-76	1976	1973-79	1975-79	1974-79	1973-79	1973-79	1973-79
SAKHON NAKHON	—	1975-79	1973-79	1976-79	1973-79	—	1974	1973-79	1973-79	1973-79
NORTHEAST	1968-81	1967-81	1973-81	1967-81	—	—	—	—	1969-81	1975-81

NOTE: Acreage, Production and Yield Data are also available at the regional level (Northeast, North, East, Central and South) for the years 1962/63-1976/77.

Different crop varieties are used throughout the region according to local environment and climate. Some varieties are drought resistent while others are somewhat responsive to fertilizer. Some important crop varieties are shown in Table 3.4.

The amount of fertilizer applied has gradually increased at national and regional levels. The only available data for Northeast Thailand are for the years 1976, 1978 and 1979. Table 3.5 shows that regional fertilizer usage has slightly increased during the four year periods. However, most of the fertilizer was applied on rice, the main crop in Northeast Thailand.

3. Episodic Events

Selected episodic events occurring in Thailand are shown in Tables 3.6a-h. These events include both weather and non-weather impacts on agriculture such as pest damages. Both drought and flooding can seriously affect crop production. Drought during the critical flowering or reproduction stage of the crop is quite harmful. Weather impact due to flooding usually occurs during heavy monsoon rains and tropical depressions.

Sometimes weather indirectly affects the crop by creating favorable environmental conditions for both pest and plant disease outbreaks.

These episodic event data can be qualitatively used in statistical crop yield modeling to determine possible reasons for fluctuations in crop yield or production data. Episodic event data can also be used to select and interpret agroclimatic indices such as the Palmer Drought Index (PDI), Yield Moisture Index (YMI), and Generalized Monsoon Index (GMI).

Table 3.4 Crop Varieties Used in Northeast Thailand

CROP	VARIETIES
Rice	RD6
	RD7
	RD8
	RD9
	Niaw San Pator
	Khao Dawk Mali
Maize	Suwan 1
Cassava	Rayong 1
Sorghum	Late Hegari
Kenef	Ton Khiew
	Khiew Yai
Jute	Non Sung 1
Cotton	Sri Samrong 3
	Tak Fa 1

Table 3.5: FERTILIZER (METRIC TONS) USED FOR CROPS IN NORTHEAST THAILAND IN THE YEARS 1976, 1978 AND 1979

YEAR	PERCENT OF FERTILIZER USED (NATIONAL LEVEL)	METRIC TONS AND PERCENT OF FERTILIZER USED IN NORTHEAST THAILAND		
		PADDY	OTHER CROPS	VEGETABLES
1976	21.6	113,212 (79%)	23,054 (16%)	6,497 (5%)
1978	22.6	147,060 (83%)	22,568 (13%)	6,288 (4%)
1979	24.3	167,523 (87%)	16,941 (9%)	7,115 (4%)

DATA SOURCE: Division of Agriculture Economics, Ministry of Agriculture and Co-operatives

TABLE 3.6a: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
1952-53		The outlook for crops is not favorable. Early drought was followed by very heavy rains and the crop is anticipated to be some 300,000 tons less than the preceding one.
1954-55		The crops began poorly due to drought which was reported to have been particularly severe in Northern and Northeastern Thailand. Commodity reports on rice subsequently reported a decline in Thailand's rice production due to drought.
1957-58		The largest fluctuations took place in Burma and Thailand where crops were more than three million tons less than the previous year and well below average. Thailand's exports in 1958 were the smallest since 1954, reflecting the exceptionally poor crop.
1958		Thailand was badly affected by the drought. The crop was officially estimated at only 5.7 million tons against the bumper 8.2 million tons produced in the preceding year.
1958-59		In Thailand, the rice was affected by low rainfall late in the season. The crop was slightly below the average of 7.2 million tons.
1960		This was a record year for Thailand's crops.
1963-64		Favorable weather conditions led to a record crop.
1964		Excellent weather resulted in a bumper harvest in 1964.
		While production of most of the major commodities increased, heavy floods occurred over some of the major rice growing regions of the country and caused paddy production to decline during 1964; about 5.2% below the 1963 figure. Note: This conflicts with above reports.

TABLE 3.6b: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
1965	Oct	Weather conditions remained favorable. It is unlikely that Thailand will suffer from any rice shortage either for domestic consumption or exports.
1966		There is a drought in the main growing areas of the Northeast.
		Crops were affected by pests and wind.
1967-68		The Northern and Northeastern parts of the country suffered a severe drought during the summer and it was thought that rice production might be down as much as 15%. There were good rains in September and October and there was a recovery in crops which were replanted. There was subsequently, however, a shortage of irrigation water for rice farmers in the Central Plain. Average rice yields remain very low and the drought caused a drop in exports of rice and maize during the year and a rise in the domestic price of rice.
1968-69		In Thailand, the crop had been reported as growing well and a near record output was predicted. Following drought and insect damage, however, the production is now expected to be not more than 11.2 million tons of paddy, and may even be less. It is also reported that the milling quality of the new crop is poor, the yield of white rice being 4-5% below normal.
1972		Drought reduced agricultural output in most countries in the Far East and Oceania during 1972. India, Thailand and Australia showed the largest decreases.
1974	May	Crop conditions are above average and are early. The harvest and rain are normal. Good rice and maize crops are expected.
	Jun	June was dry.
	Jul*	In the Northeast, there were heavy rains in May and April. These helped early rice and other crop plantings.

TABLE 3.6c: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
	Sep	Normal conditions exist.
1975	Jan	January was normal, but the rice crop was damaged by floods in the Southern Region.
		The weather system during the period from Jan 3 to 8, 1975 produced one of the wettest northeast monsoons ever recorded in the country and caused widespread floods over southern Thailand.
	Feb	A record rice crop was harvested.
	Dec	There was slight damage to the rice crop due to flooding.
1976		The 1976 main rice crop was 4% less than 1975.
	Jan	Early plantings and good crop conditions brought about a record rice crop.
	Feb	Crop conditions were good and plantings were early.
	Apr*	Light showers in March in the Central Plains favored spring planting. The harvest of 1975/1976 main rice crop is completed. A large secondary rice crop was planted. The 1976 main rice production was 4% below 1975 because of drought.
	Jun	A drought affects the maize and rice crop outlook.
	Aug	Rains interrupted previous dry spell and are benefitting maize and rice crops.
	Sep	Rains relieved crop stress.
		Flooding is reported.
	Dec	Harvesting of the main season rice crop is underway.
		The northeast monsoon is active over the gulf of Thailand and the south is receiving scattered showers.
		There are floods in the south.

TABLE 3.6d: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
1977		The drought affected about 15% of the total rice area in the country. The 7 provinces hardest hit were in the North, Northeast and the Central Regions.
	Feb	Normal conditions exist.
	Apr	Maize for 1977 is expected to be good due to higher domestic prices, cheaper fertilizers, and local availability of insecticides.
	Jul	The drought continued into the first half of July.
	Aug	Rice transplanting was delayed, but later in August, moderate rains fell in some areas. However, the drought continues and 76% of the rice area is being affected.
	Sep	Most areas received adequate rains, but due to serious damage from typhoon and the prolonged previous drought, serious food shortages exist.
		Heavy rains and floods broke the drought which had affected almost the whole country. At the end of the month rice sowing and transplanting are progressing.
	Nov*	Typhoons in July and September aggravated the crop prospects and the food situation which were already critical because of war, cold winter and drought.
	Oct	The drought reduced the harvest.
1978		Tropical storm Bess dissipated over Thailand's Northeast Region. On two tropical depressions tracked along the same path within a week of each other during July.
	Jan	Dry weather persisted in the North and Northeast, while floods damaged some of the rice crop in 6 southern provinces.
	Feb*	The drought in the north and the floods in the south are affecting the 1977 main season paddy. Water shortages are affecting the secondary paddy crop that is harvested in May. With lower rice production, exporters must sell more to the government stockpile.

TABLE 3.6e: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
	Apr*	There were good February and March rains for secondary rice that is to be harvested in May.
	May	There is an insecure state of area around Khlong Yai, Thailand, as a result of land mines, ambushes and shelling, that have effectively cut it off from the rest of the country. The farmland between Trat and Khlong Yai lies nearly idle because fishermen who usually raise crops there are fearful of Cambodian attack.
	Jun	The drought continues in some areas and irrigation supplies are insufficient.
		There is increased secondary rice area.
	Jul	Heavy rains relieved the drought in most areas. The planting of main rice and maize is underway and nearly complete in the North and Northeast. The record secondary rice production for 1978 is attributed to the new strain of rice (Kor Khor) which requires less water.
	Aug	Flooding in 15 provinces in the Northeast and North Regions destroyed 140,000 hectares of paddy. Aid is requested.
		There is a large planting of 1978/1979 main rice and maize due to above average rains.
		A depression on August 22 caused 184 mm rainfall at Sakhon Nakhon, 166 mm at Udon Thani and 148 mm at Loei. Flooding has been extensive, but the crops may survive. Relief was provided.
	Oct	Floods in 29 provinces of the North, Northeast and Central Regions affected crops. However, the main rice crop (which was planted in August and September) is looking good. There was government relief for flood victims.

TABLE 3.6f: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
	Nov	The Thai government is increasing efforts to get sugar-cane growers to switch to another crop due to prospect of a sugar surplus of nearly 500,000 tons in 1979.
1979		Due to drought in 1979 the main paddy crop declined.
	*	The 1978 main rice crop was a record 10 million tons and maize was 3 million tons.
		FAO/WFP aid is in operation for the flood victims and Indo-Chinese refugees.
	Jan	Secondary rice is being planted.
	*	The northeast monsoon began the first fortnight of December. Rains should benefit rice crop in the south. The secondary crop is due for planting in January/February.
	Feb	Scattered rains were received during the first fortnight of February. Secondary rice is being planted. Maize for 1979 was 8% higher than 1978 production.
	Apr	Rains in mid-April relieved the prolonged drought. It had affected 19 provinces in the South and East. More rains are needed as secondary paddy is affected by drought and tight irrigation water supplies.
		Dry weather persists. Aid is still being provided to flood victims and refugees.
	May	The drought continues as secondary paddy crop is being harvested. Aid continues.
		Good monsoon rains eased the drought and 800 government water pumps were sent to drought-affected North and Northeast. Planting of the 1979 main rice crop is underway. More fertilizers are being used.
	Jun	Thailand is the world's fifth largest sugar exporter, but bad weather compounded by poor planning, resulted in acute shortages at markets by June, 1979.

TABLE 3.6g: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
	Jul	There are localized floods which are affecting the 1979 production for the secondary rice crop.
		Heavy rains since mid-May relieved the drought and helped the newly planted main rice crop for 1979.
	Sep*	Floods during the second week of August in northeast and southern provinces damaged the rice crop and infrastructure. There is government relief assistance for areas cut off by floods. Heavy rains in other areas helped off-set below normal rains of the first and third weeks of August. Secondary paddy crop and maize production are up.
	Dec	There is normal dry weather in December. Inadequate monsoon rains and low levels in dams and reservoirs may limit the area of secondary rice to be planted next month. The 1979 main rice crop is being harvested.
1979-80		The 1979-80 sugarcane harvest season was hit hard by an early drought. Sugarcane yields this season are down 37.5%.
1980		The 1979 main paddy production was below that of 1978.
	Jan	The secondary rice area (planted in January) is likely to decline due to lack of water in dams and reservoirs. The government is providing pumps for rice irrigation.
	Feb	Inadequate water supplies in dams and reservoirs and dry weather affected the planting of the secondary rice, normally harvested in May/June.
	Mar	Good rains in mid-March eased drought conditions over many parts but because of severe rainfall deficiency since October 1979, more rain is needed. The 1980 secondary paddy, normally harvested in May/June, was affected by insufficient irrigation water supplies and previous drought.

TABLE 3.6h: EPISODIC EVENT DATA FOR THAILAND

Year	Month	Episodic Event
	Apr	April rains benefitted the 1980 secondary rice crop in some northern areas. For the most part, however, irrigation water remained in short supply for the growth of the newly transplanted rice crop.
	May	Widespread rains in May and during first half of June partially relieved drought conditions. In most growing areas, irrigation water remains in short supply for secondary paddy. Due to the drought, the 1980 secondary paddy will be less than last year.
	Jun	Good monsoon rains continued during June, favoring the newly planted 1980 main rice crop.
		Weather problems in Thailand last year seriously damaged the sugarcane crop.
		Crop and weather problems in India and Thailand will cut total world sugar production below consumption this year.
	Jul*	Most areas received below-average rains during the first week of July causing some reduction of crop growth. However, adequate moisture supplies are available for both the 1980 main rice and maize crops due to ample rains in May and June.
	Sep	Torrential rains caused the Mekong River to overflow today and flood at least 16,000 acres of farmland in two northeast provinces.
	Oct	Nearly 60% of Thailand has been hit by monsoon floods that have caused heavy damage to crops; 44 out of Thailand's 74 provinces were either completely or partly submerged.

NOTE: This indicates the month the episodic event was reported. The date of occurrence is in the text.

4. Capabilities and Limitation of Data

The meteorological data used in this study are of good quality. The monthly mean rainfall data are determined from at least 28 daily observations while the monthly mean temperature and humidity are obtained from at least 25 daily observations. Quality control of the monthly meteorological data was undertaken to delete erroneous cases. Observations were compared to their normal and with other meteorological elements.

One of the limitations of using monthly data instead of daily data is that monthly data do not indicate the distribution of rainfall during the month. The assumption for using monthly data is that rains are evenly distributed during the period. Sometimes this assumption is not valid.

The source of all of the yield data is the Center for Agricultural Statistics, Office of Agricultural Economics, Ministry of Agriculture and Cooperatives. Data were collected through their surveys and through other sources. The quality of the yield data is quite good. Fluctuations in the yield data result from both weather and non-weather impacts. Year-to-year variations in yield are usually associated with drought, flooding and pests in the Northeast Region. There is also evidence that changes in technology cause changes in yield.

B. Analytic Methods

1. Rainfall Distribution

Monthly rainfall data available from each weather station were averaged to obtain the distribution of the monthly means (Figure 3.3 and Appendix). Each distribution is positively skewed during the rainy season, May to October. The seasonal rainfall during May to October is dominant in the southern areas while May to September rainfall dominates in the rest of the region. The largest amount of rainfall usually occurs during September except along the

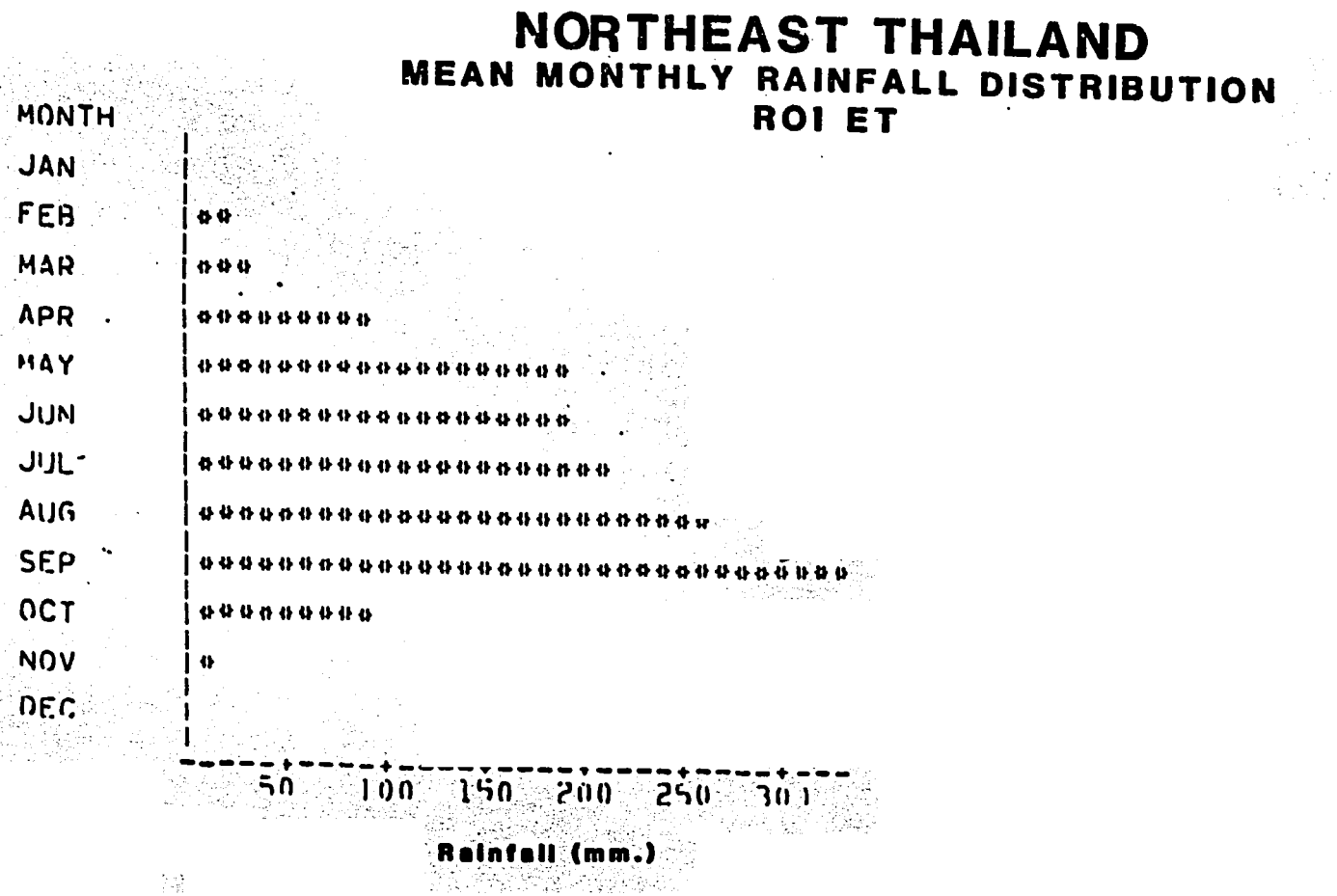

FIGURE 3.3 Mean Monthly Rainfall Distribution at Roi Et in Northeast Thailand.

the northern and eastern boundaries where maximums occur in August. The highest amount of monthly rainfall is approximately 590 mm in August at Nakhon Phanom.

2. Potential Evapotranspiration (PET)

Evapotranspiration (ET) is defined as the sum of the evaporation of water directly from the surface of water, soil and vegetation (dew) and the transpiration by plants. If soil water is not limiting, the evapotranspiration from a complete plant canopy is called the potential evapotranspiration (PET).

There have been many methods proposed for estimating PET from meteorological data. One of the simplest models is to approximate PET by 80 percent of pan evaporation (from U.S. Class A pan). Some of the other major methods include the following.

Penman Formula (1948)

Penman's method is derived from the physical laws governing the evapotranspiration process. The approach involves obtaining an empirical estimate of the transfer of mass (water vapor) from a wet surface and incorporating this estimate into an expression defining the surface energy budget. The Penman formula (Frere, 1972) for the rate of PET from an extensive and uniform wet surface can be written as:

$$PET = (mH + 0.66Ea)/(m + 0.66)$$

where: PET is the potential evapotranspiration (mm/day),

m is the slope of the saturation vapor pressure curve for water at mean air temperature in $mb°C^{-1}$.

H is the net radiation in evaporation equivalent of mm/day,

0.66 is the psychrometric constant in $mb°C^{-1}$, and

E_a is $0.26\ (e_s - e_a)(1 + 0.54\ U_2)$ mm/day

with e_s the saturation vapor pressure (mb) at the mean air temperature,

e_a the actual vapor pressure (mb), and

U_2 the mean wind speed at 2 meters in m/sec.

The main problem with the Penman method is that the data for net radiation, vapor pressure deficit, and wind speed are not available for most meteorological stations. Because of incomplete meteorological data at most weather stations, other empirical methods for estimating PET have also been proposed.

Thornthwaite Method

Thornthwaite (1948) derived an empirical relationship between PET and mean air temperature. PET is expressed as an exponential function of mean monthly air temperature or:

$$PET = 1.6\ (10\ T/I)^A$$

where PET is the potential evapotranspiration (cm/month),

T is the mean air temperature (°C), normally a month,

I is a heat index which represents the sum of 12 monthly indices (i) and may vary from 0-160,

$$I = \sum_{i=1}^{12} (T_i/5)^{1.5.4}$$

A is a cubic function of I for a given location which may vary from 0-4.25 and is defined as:

$$A = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2}\ I + 0.49$$

The values of PET are for a day length of 12 hours and a 30 day month; an adjustment must be made to estimate PET for a particular month and place.

This method has been used worldwide because only temperature and the local latitude are required for input. However, considerable criticism has been offered because the mean air temperature does not relate to the surface energy balance. Also, the method was designed only for making monthly PET estimates.

Hargreaves Method

Hargreaves (1977) used air temperature and solar radiation as the main meteorological elements to estimate PET as follows:

$$PET = 0.0075\ (RSM)(TF)$$

where: PET is the potential evapotranspiration (mm/day),

RSM is solar radiation in evaporation equivalent (mm/day), and

TF is the daily mean air temperature (°F)

When solar radiation is not available, it can be estimated from sunshine hours or extraterrestial radiation.

Antal Method

Antal (1973) developed a model based on temperature and vapor pressure deficit to estimate the rate of evapotranspiration, measured by lysimeters defined as:

$$PET = 0.9\ (e_s - e_a)^{0.7}(1 + bT)^{4.8}$$

where PET is the rate of potential evapotranspiration (mm/day),

e_s is saturated vapor pressure at temperature T in the instrument shelter,

e_a is the actual vapor pressure in the shelter, and

b is 1/273

Linacre Method

Linacre (1977) simplified the Penman formula for estimating PET as follows:

$$E = ([700(T + 0.006h)/(100-A)] + 15\ (T-Td))/(80-T)$$

where: E is the evaporation rate in mm/day,

T is the mean air temperature (°C),

Td is the mean dew point temperature (°C),

A is the latitude in degrees, and

h is the elevation of the station in meters.

This formula requires only geographical data (A and h), the mean air temperature and the mean dew point temperature.

Priestley and Taylor Method

Priestley and Taylor (1982) established a method to calculate the PET. Their formula is a simplified version of Penman's equation:

$$PET = S(AR_n)/(S+G)$$

where: PET is the potential evapotranspiration (mm/day),

S is the slope of the saturation water vapor pressure curve at mean air temperature ($mb°C^{-1}$)

G is the psychrometric constant (0.66 $mb°C^{-1}$)

R_n is the net radiation in evaporation equivalent (mm/day), and

A is the empirical constant (1.44)

Evaluating Methods for Estimating PET

Because PET is one of the fundamental agroclimatic analysis tools for the study of moisture stress on crops, reliable methods must be determined to estimate PET. This is difficult even with optimum data. The previously discussed methods provide PET estimates. These contrast with measured PET which is usually determined by field experiments with a lysimeter.

In this study for Northeast Thailand, monthly data from the agrometeorological stations were used to estimate PET by the Penman, Hargreaves, Thornthwaite, Priestley, Antal and Linacre methods. These were compared to each other and with

80 percent of pan evaporation. The sample means, variances and time series of individual monthly estimates were compared.

Because actual measurements of PET are not available, definite conclusions cannot be made. However, some inferences can be drawn from comparisons with pan evaporation. Crop calendar information can also be used to interpret PET (moisture demand) and rainfall (moisture supply) relationships. If crops are successfully grown in most years, rainfall should generally exceed PET during the crop growing season. If estimated PET during the crop season is consistently larger than rainfall, and observed crop yields are favorable, the PET method is suspect for that region. Because the Penman method is a physically based procedure that determines PET, more emphasis is usually placed on results from that method.

One problem common to all methods is that baseline data are not usually available to confirm the appropriate method. Also, data for the Penman method are not always readily available. Finally, some of the methods may be totally inappropriate for climatic conditions in Northeast Thailand.

In spite of these limitations, recommended procedures need to be developed for test and evaluation. The most "appropriate" method needs to be determined. Alternative methods or ways to adjust PET estimates to conform with the "appropriate" method are required. Interpolating PET to data sparse locations is important. Determining when PET normals can be used instead of individual monthly (or weekly, etc.) values is necessary. For example, if the variance of rainfall is much greater than the variance of PET, then PET normals should suffice. These are some of the questions to be investigated.

There are at least two important studies relating to PET methods for Northeast Thailand. First, Rasmidatta (1981) has used a modified Penman

equation to estimate normal PET for stations in Thailand. These results are addressed in this study. Second, the report, Assessment of Rainfed Irrigation in Northeast Thailand, prepared by the Asian Institute for Technology for the Committee for Coordination and Acceleration of Water Resources Development, the Secretariat of the Prime Minister, 1981, discusses application of the Jensen-Haise formula for estimating PET. These results are also considered.

3. Soil Moisture Budgeting

The growth and development of crops depend on the water available for their consumption. The sources of the water come from rainfall, water stored in the soil and irrigation. Precipitation recharges soil moisture in successive soil layers from the surface downward. Precipitation in excess of that required to bring the crop root zone to the water holding capacity is removed by lateral runoff and percolation. For a short dry period, crops are not seriously affected, even in the critical growth period, if there is sufficient soil moisture to support the demand for water. Thus, the soil moisture level may be as good or better an indicator of crop conditions as rainfall. Since the soil moisture is difficult to measure directly in the field, several methods have been proposed for estimating its value. Two procedures are described as follows.

One-Layer Water Balance Method

Thornthwaite's model is based on simple water balance equations for gains and losses within a single layer as follows:

$$S_i = S_{i-1} + P_i - (PET_i\ (S_{i-1})/FC)$$

where: S_i is the soil moisture estimate for the current period,

S_{i-1} is the soil moisture for the previous period,

P_i is the precipitation,

PET_i is potential evapotranspiration for the current period, and

FC is the field capacity of the soil.

Two-Layer Model

In contrast to the one-layer model, Palmer (1965) proposed a two-layer model which makes two assumptions:

1) The upper layer is equivalent to the plough layer and is assumed to hold about 2.5 cm of plant available water. The soil water in the surface layer (SS) is lost at a potential rate.

2) The underlying layer extends from the base of the plough layer to the depth of rooting for a particular crop. Soil water in the underlying layer (SU) is lost at the potential rate when the profile is at field capacity. The available water in this layer depends on the depth of the root system and on the soil characteristics.

The soil moisture budget is:

$$S_i = SS_i + SU_i = SS_{i-1} + SU_{i-1} + P_i - AET_i - RO_i$$

where: SS_i and SU_i are the soil water in the surface and underlying layers, respectively,

i is the current time period and i-1 is the previous time period,

S_i is the soil water in both surface (SS_i) and Underlying (SU_i) layers,

P_i is the rainfall received during the current time period,

AET_i is the actual water loss by evapotranspiration, and

RO_i is the runoff.

The actual water losses by evapotranspiration and runoff are estimated by:

a) If $P_i < PET_i$ then:

$$AET_i = P_i + LS_i + LU_i = P_i + \text{Minimum}\ (SS_{i-1},\ PET_i - P_i)$$
$$+ \text{Minimum}\ (SU_{i-1},\ (PET_i - P_i - LS_i)\ SU_{i-1}/(PAW_{max} - 2.5))$$

where:

LS_i and LU_i are the water losses from the surface and underlying layers in the current time period, respectively,

PET_i is the estimated potential evapotranspiration, and

PAW_{max} is the maximum possible plant available water in the total soil profile.

The runoff is zero.

b) If $P_i > PET_i$ then:

$AET_i = PET_i$

$RO_i = P_i - AET_i - RE_i$

where:

RE_i (Soil water recharge) is estimated by:

$RE_i = \text{Minimum}\ ((P_i - AET_i), (PAW_{max} - S_i))$

The budget begins at a time when the soil moisture is at field capacity and water is lost from the upper layer first. Note that if SU_{i-1} is zero then the loss from the underlying layer (LU_i) is also zero. All units are in cm.

4. Crop Coefficients

Doorenbos and Pruitt (1977) defined the crop coefficient (KC) for a given crop as:

$$KC = AET_c/PET.$$

The crop coefficient relates to the evapotranspiration (AET_c) of a disease free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given environment. PET is the reference potential evapotranspiration as defined in previous sections. Factors affecting the value of the KC are mainly the crop characteristics, crop planting or sowing data, rate of crop development, length of growing season and climatic conditions. Thus, crop coefficients are defined for each crop development stage. Usually, the coefficients of a given crop are largest for the flowering/reproductive stage relative to other stages, for example, planting and early vegetative stages.

Some of the crop coefficients for selected crops as provided by Doorenbos and Pruitt are given in Table 3.7. These were determined from field experiments with lysimeters. Although the appropriate crop coefficients for environmental and cropping practices in Northeast Thailand would have to be locally determined, the data in Table 3.7 can be carefully used in agroclimatic studies. The coefficients should be adjusted for local conditions, e.g., crop calendars and cultural practices.

The KC can be used to estimate the crop water requirement for different crops at various stages of development by:

$$\text{Crop Water Requirement (CWR)} = AETc = KC(PET)$$

The CWR for each growth stage and the growing season of a particular crop can be estimated from historic meteorological data. The CWR can be compared with rainfall and soil moisture to determine the appropriate crops and planting dates to avoid or minimize drought vulnerability. In contrast to this type of land use study, the CWR can be used in real-time applications such as irrigation advisories during the growing season.

5. Climatic Diagrams

The climatic diagram is a useful tool for investigating the availability of moisture for crops. It is a graphical plot of monthly decadal, weekly or even daily rainfall, soil moisture, PET, AET and other parameters such as pan evaporation. The crop coefficient could be used to adjust PET, thereby providing an estimate for the crop water requirement. The diagram can be based on data for a particular season or from climatic normals or both. For example, moisture supply and demand relationships can be monitored during the growing season by comparing real-time values to normal data. This can be an important tool for crop condition assessment. The diagram can also be used for land use studies which investigate optimum planting dates, crop selection, irrigation requirements and others.

Table 3.7 CROP COEFFICIENTS (kc)

CROP	Crop Development stages					Total growing period
	Initial	Crop development	Mid-season	Late season	At harvest	
Banana						
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0.9 -1.0	0.75-0.85	0.7 -0.8
subtropical	0.5 -0.65	0.8 -0.9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
Bean						
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
Cabbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
Cotton	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
Grape	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
Groundnut	0.4 -0.5	0.7 -0.8	0.95-1.1	0.75-0.85	0.55-0.6	0.75-0.8
Maize						
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
grain	0.3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
Onion						
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
Pea, fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
Pepper, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
Potato	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
Rice	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
Safflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
Sorghum	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
Soybean	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
Sugarbeet	0.4 -0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -0.7	0.8 -0.9
Sugarcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
Sunflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
Tobacco	0.3 -0.4	0.7 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85	0.85-0.95
Tomato	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
Water melon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
Wheat	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.2 -0.25	0.8 -0.9
Alfalfa	0.3 -0.4				1.05-1.2	0.85-1.05
Citrus						
clean weeding						0.65-0.75
no weed control						0.85-0.9
Olive						0.4 -0.6

The PET is estimated by the appropriate method. The AET is determined from the soil moisture budget.

6. Derived Agroclimatic Indices

Agricultural drought indices are defined as derived numbers or classification identifications which express the degree to which growing plants have been adversely affected by an abnormal moisture deficiency. The deficiency may result either from an unusually small moisture supply or an unusually large moisture demand. The sources of moisture supply are precipitation and water stored in the soil while the moisture depletion is caused by crop evapotranspiration to meet the CWR during the growing season. Rainfall, evapotranspiration, potential evapotranspiration and soil moisture are some of the variables that can be used for calculating these indices.

This study examines five different agroclimatic indices: Yield Moisture Index (YMI), Generalized Monsoon Index (GMI), R-Index, Soil Moisture Index (SMI), and the Palmer Drought Index (PDI). These are some of the indices used by the NOAA/Assessment and Information Services Center (AISC) for drought/early warning assessments. The details on each index are as follows.

<u>Yield Moisture Index (YMI)</u>

One of the primary agroclimatic indices used by AISC is the Yield Moisture Index which is defined as:

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

where:

YMI_j is the Yield Moisture Index for the jth crop (e.g., maize, rice, beans, etc.),

P_i is the precipitation which occurred during the ith crop stage (e.g., for planting, i=2 for vegetative, i=3 for reproductive/flowering, for maturity), and

KC_{ij} is the appropriate crop coefficient for the jth crop and ith crop stage as estimated from Table 3.7 for local conditions.

As discussed by Steyaert et al (1981), and Achutuni et al (1982), this drought index uses crop coefficients to weight rainfall during the growing season according to the relative water requirement between crop stages. For example, the crop coefficients for maize at planting and reproductive/flowering are about 0.35 and 1.05, respectively; water is about three times more important during flowering than at planting. Thus, the YMI is based on objectively weighted rainfall and should represent an improvement on cumulative rainfall during the growing season. The index can be calculated at the end of planting, vegetative, flowering and maturity crop stages. Usually water is beneficial to the crop at these times; however, caution must be exercised in the late maturity stage. If rainfall tends to adversely affect the crop during the final stages (grain drying), this stage should not be used in the YMI.

Generalized Monsoon Index (GMI)

The Generalized Monsoon Index was developed by Achutuni, Steyaert and Sakamoto (1982) to assess rainfed crops which are grown during the monsoon. In a sense, it is a generalized YMI which is defined for the southwest monsoon and also for the northeast monsoon (peninsular areas only).

The GMI for the southwest monsoon during June-September is defined as:

$$GMI_{SW} = 0.125P_6 + 0.125P_7 + 0.50P_8 + 0.25P_9$$

The GMI_{NE} for the northeast monsoon period during October to January is also defined as:

$$GMI_{NE} = 0.125P_{10} + 0.125P_{11} + 0.50P_{12} + 0.25P_1$$

where: GMI_{SW} is the GMI for the southwest monsoon,

GMI_{NE} is the GMI for the northeast monsoon in peninsular regions, and

P_i is the rainfall in the ith month (i=1 for Jan, i=6 for Jun, etc.).

The index attaches most significance to rainfall occurring during the flowering/reproductive crop stages. Although these weights have been determined through objective analysis of historic data, they are not crop coefficients. The GMI is useful for assessing drought as well as flooding situations.

R-Index

The R-Index was developed by Yao (1969) and is defined as the ratio of AET to PET or: $R = AET/PET$.

The index ranges from 0 to 1. Values near zero indicate extreme moisture stress while values near unity indicate no stress. The index can be used in crop condition assessments and also as a tool for land use studies. For example, Yao (1973) used the R-Index to demonstrate that groundnuts could not be grown in Tanzania due to drought vulnerability. This simple agroclimatic analysis could have saved British investers several millions of dollars in 1948. Ravelo and Steyaert (1981) used the R-Index to estimate optimum crop calendars for Haiti and to eliminate erroneous crop calendars cited in the literature.

Soil Moisture Index

Ravelo and Decker (1979) proposed a Soil Moisture Index (SMI) which is defined as:

$$SMI = PAW/PAW_{max}$$

where

PAW is the plant available soil moisture, and

PAW_{max} is the maximum plant available soil moisture.

The SMI is defined for values ranging from zero through 1. The SMI has been used by AISC as a crop condition assessment tool.

Palmer Drought Index

One method for combining precipitation and temperature as predictor variables was developed by Palmer (1965). The Palmer Drought Index (PDI) is universal in that persistently normal temperature and precipitation produce an index of zero for all seasons and all climates. The completed analysis breaks the meteorological record into separate periods of drought, abnormally wet or near normal. Positive values of the index indicate wetter than normal conditions while negative values represent drought. Table 3.8 lists the descriptive terms which have been assigned to describe the character of the weather represented by various intervals of the index.

Interpretation of Indices

Indices can be computed from historic data over a 15-30 year period and then expressed in several forms: raw value, percent of normal and percentile. The indices must be tested and evaluated to determine how each should be interpreted and the potential for use as an operational index to monitor general agricultural conditions. The threshold values for the indices can be established by using historic yield data and episodic data. The historic indices for each station can be plotted and the records of episodic data then used to identify the weather impact years and the critical values of the index assoccated with, for example, normal crops, moderate drought impact on crops (slightly below normal yields), drought impact on crops (reduced yields) and severe drought impact on crops (drastically reduced yields or crop failure). The index values for such years will be considered as a threshold value for each category.

Decisions should be made on which index or indices will be appropriate for an area of interest or for a particular purpose. Guidelines for determing the appropriate method are discussed in subsequent chapters in this report. The

Table 3.8: PALMER DROUGHT INDEX CLASSES FOR WET AND DRY PERIOD

INDEX	CHARACTER OF RECENT WEATHER
> 4.00	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
< -4.00	Extreme drought

assessment then can be made by calculating the indices using the observed weather data, interpreting the index values in terms of similar values in the historic record and finally evaluating the results along with other information. The indices are mainly useful in assessing drought impact on agricultural crops, not the flooding impact or crop conditions in irrigated areas. Drought causes physiologic damage to a crop. Excessive moisture due to flooding can cause physical and also physiologic damage. Thus, flooding is a more complex assessment problem. Also, wind damage is sometimes associated with floods.

C. Application of Agroclimatic Tools

These agroclimatic tools can be used to develop agroclimatic assessment models including: 1) drought early warning and crop condition assessment, 2) crop monitoring to determine irrigation scheduling requirements and 3) land and water resource management applications. Examples of these models and their application are provided in this report.

CHAPTER IV

ANALYTIC RESULTS

A. Overview

Four major types of agroclimatic analyses for Northeast Thailand were performed including: 1) investigating and evaluating various methods for estimating potential evapotranspiration, 2) estimating soil moisture and calculating the Palmer Drought Index, 3) developing historic agroclimatic/crop condition indices for use in assessments and 4) developing preliminary statistical climate/crop yield models for main rice and maize crops for the NE region. The PET results are discussed in this Chapter. The agroclimatic/crop condition indices and statistical modeling results are discussed in Chapter V. The use of crop index models, statistical models, soil moisture and other assessment tools for making assessments are discussed in Chapter VI. The following summarizes the types of analysis.

1. Potential Evapotranspiration

The methods for estimating PET discussed in Chapter III were investigated using two sets of stations: 1) monthly data at three agrometeorological stations and 2) monthly rainfall data and climatological normals for PET calculations at the synoptic stations. The estimated PET values were compared to each other and to pan evaporation. Mean values, variances and ratios were determined as appropriate for each station. The goal was to investigate the "appropriate" method for estimating PET, to determine if PET normals can be used instead of individual monthly values, and to determine how to interpolate or estimate PET at data sparse locations.

2. Soil Moisture and the PDI

The results of the PET analysis were used to estimate moisture using the Palmer two-layer model and then to calculate the PDI. The soil moisture estimates are integral to the assessment program. The PDI shows promise as a potential index for monitoring climatic conditions at individual stations.

3. Agroclimatic/Crop Condition Indices

These indices are based on monthly rainfall data at synoptic stations and represent primary tools for assessing drought impact in the Northeast.

4. Statistical Models

These preliminary models require test and evaluation and should be used with caution.

B. PET Results

1. Agrometeorological Stations

Figures 4.1a-c show the monthly mean PET estimates obtained from the Penman, Thornthwaite and Hargreave's methods using data at Sakhon Nakhon, Surin and Tha Phra (Khon Kaen). The monthly mean rainfall and pan evaporation are also included for comparison. In general, PET estimates during the dry season are larger than PET in the wet season. The methods tend to show the least scatter during the wet season.

The general relationship between PET and rainfall suggests general moisture supply and demand relationships for the crops: rainfall greater than PET usually suggests moisture excess while rainfall below PET usually suggests moisture deficits. The diagrams show why crops are grown in the wet season and why irrigation is needed in the dry season. Rainfall is usually adequate at Surin and Sakhon Nakhon but crops probably experience some drought stress at Tha Phra, particuarly at the beginning of planting because average PET and rainfall are about equal.

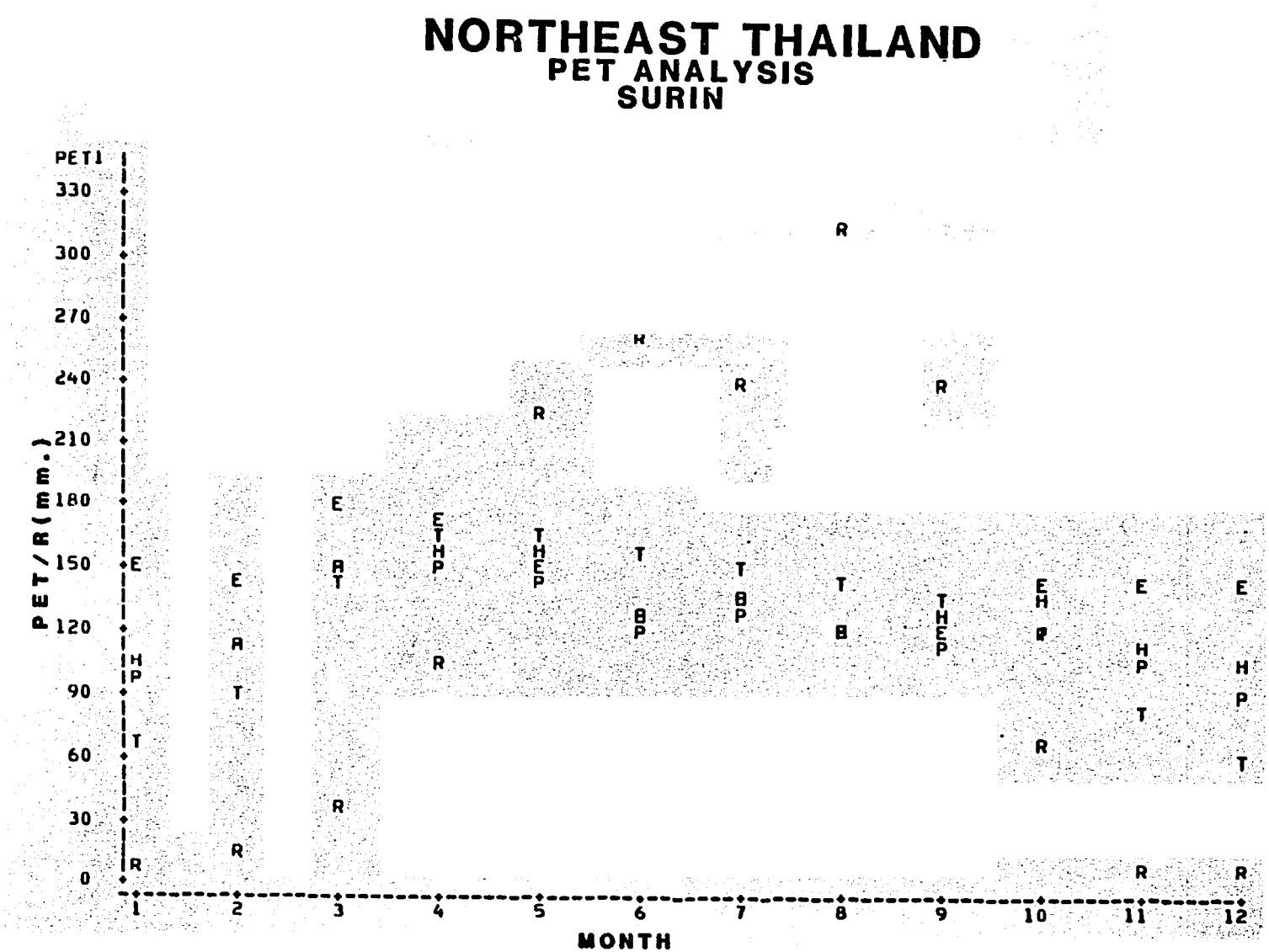

FIGURE 4.1a Potential Evapotranspiration Comparisons for Surin (P=Penman, T=Thornthwaite, H=Hargreaves, E=Pan Evaporation and R=Rainfall).

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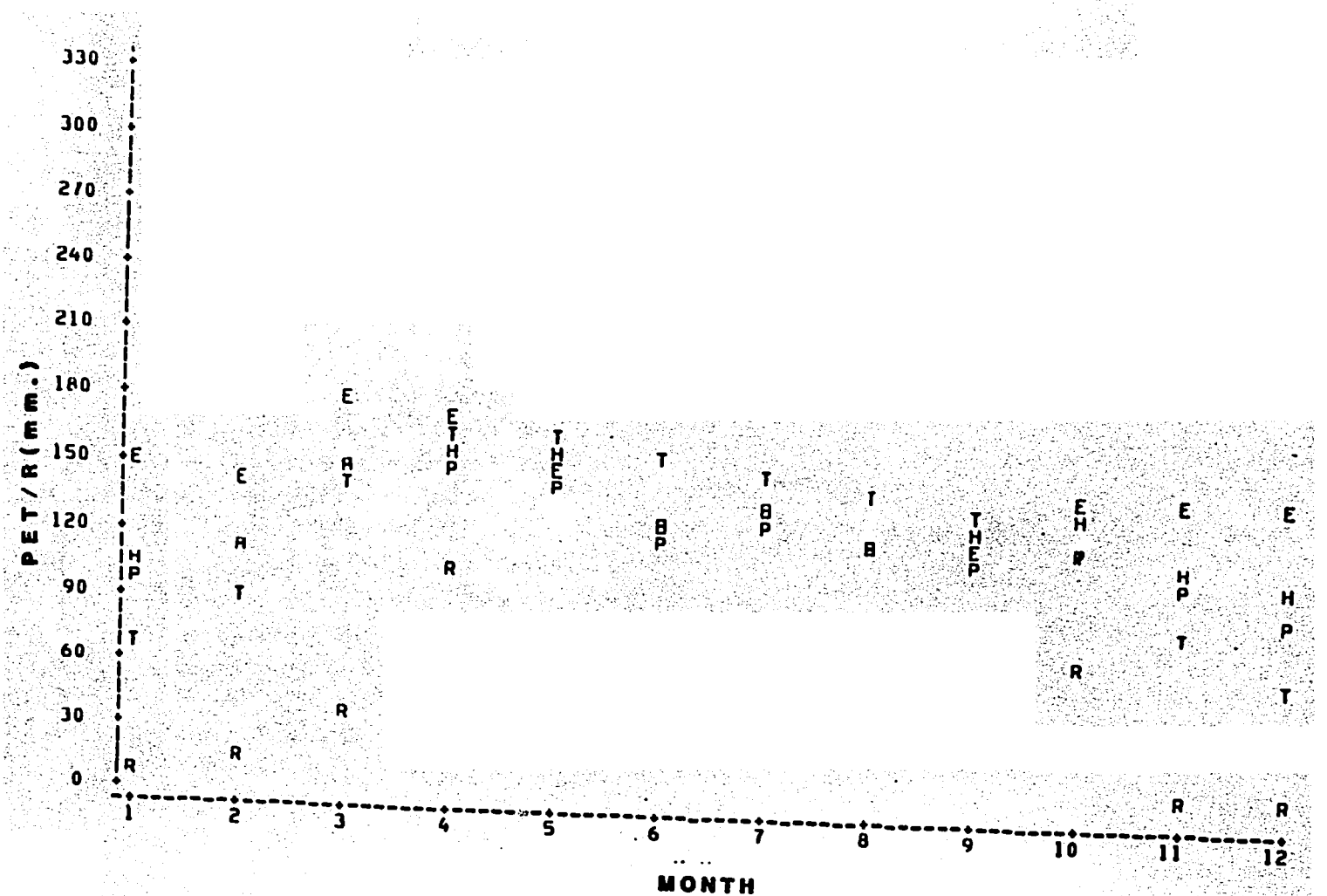

FIGURE 4.1b Potential Evapotranspiration Comparisons for Sakhon Nakhon (P=Penman, T=Thornthwaite, H=Hargreaves, E=Pan Evaporation and R=Rainfall).

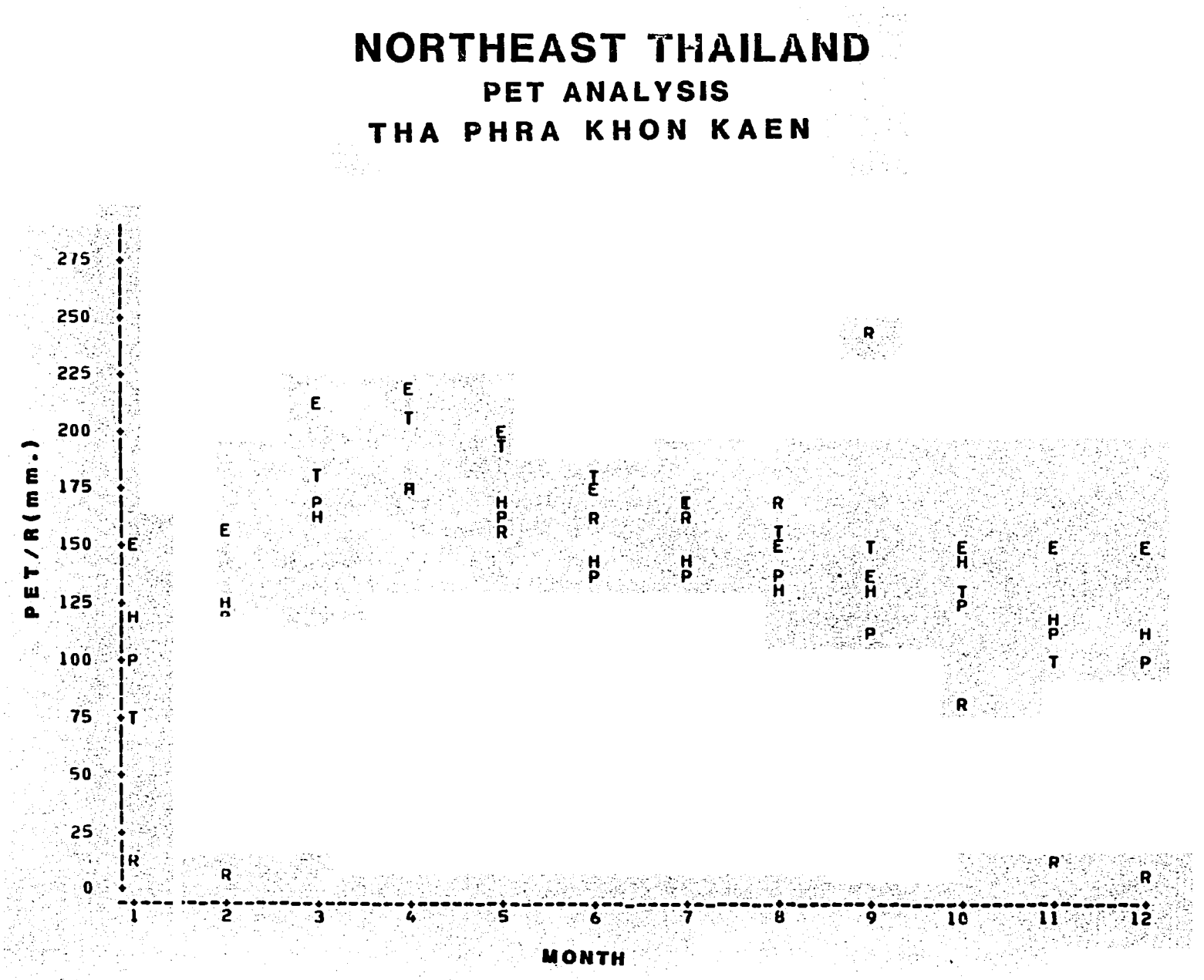

FIGURE 4.1c Potential Evapotranspiration Comparisons for Tha Phra Khon Kaen (P=Penman, T=Thornthwaite, H=Hargreaves, E=Pan Evaporation and R=Rainfall).

Tables 4.1a-c show the simple statistics (mean, standard deviation, etc.) for these climatic variables and PET at each station. The number of years in the data base is indicated by "N". If the standard deviation is squared, the variances between PET, Pan and rainfall can be compared if one assumes the distributions are identical. In general the rainfall variance is about 10,000 mm^2 while PET and Pan are about 100-500 mm^2. On an order of magnitude basis, rainfall is about 100 times more variable than either PET or pan evaporation. The variables that determine PET do not change very much from year-to-year for a given month. This suggests that for some applications, sample mean PET can be used instead of individual calculations for each month (or decade). For example, this finding could be used in soil moisture budget analysis or in crop water requirement calculations using crop coefficients.

Figures 4.2a-c and 4.3 demonstrate more characteristics of PET variability. Figures 4.2a-c show the individual monthly climatic variables during 1967-1981 for January, June and September at Surin, respectively. The time-series for January and June have greater scatter than during September (even though the scales are different). Large amounts of rainfall during September probably dampens variability of the other parameters. In Figure 4.3, the mean and standard deviations for Penman, PET at Surin are shown. The standard deviations are generally smaller during the wet season.

Table 4.2 and Figures 4.4a-c show the ratios of Penman, Hargreaves and Thornthwaite PET to pan evaporation and 80 percent of pan evaporation. These ratios suggest how the methods can be adjusted if pan is used as a reference criteria. In this case, 80 percent of pan evaporation is used as the most simple PET model. In general, Penman and Hargreave's PET estimates are below pan values. However, Thornthwaite PET estimates are frequently greater. The Thornthwaite estimated PET values are well above pan during the wet season and

NORTHEAST THAILAND

PET, PAN EVAPORATION AND RAINFALL STATISTICS

SURIN

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM
P1	15	3.2666667	9.4089370	0.000000	36.800000	2.4293771	49.00000
P2	15	15.8400000	20.0445147	0.000000	57.700000	5.1754715	237.60000
P3	14	29.7142857	29.6212205	0.500000	80.000000	7.9166042	416.00000
P4	15	90.8066667	49.0388107	32.700000	204.000000	12.6617665	1362.10000
P5	14	167.3357143	88.6420338	29.000000	329.100000	23.6905801	2342.70000
P6	15	182.4266667	71.1178747	76.200000	277.200000	18.3625563	2736.40000
P7	15	206.2800000	78.1156304	111.400000	369.300000	20.1693690	3094.20000
P8	15	210.2600000	83.6076022	86.800000	377.200000	21.5873901	3153.90000
P9	15	306.2733333	106.2686788	128.900000	528.600000	27.4384549	4594.10000
P10	15	108.4200000	71.0563881	0.000000	271.300000	18.3466805	1626.30000
P11	15	20.2866667	22.5579529	0.000000	80.400000	5.8244384	304.30000
P12	15	1.2266667	3.9506720	0.000000	15.400000	1.0200591	18.40000
E1	15	150.8666667	18.2523058	124.000000	179.800000	4.7127251	2263.00000
E2	15	155.8666667	20.7833267	117.600000	182.000000	5.3662319	2338.00000
E3	14	192.4214286	22.2039213	158.100000	226.300000	5.9342476	2693.90000
E4	15	199.0000000	24.2044860	156.000000	258.000000	6.2495714	2985.00000
E5	14	194.6357143	45.0084028	120.900000	319.300000	12.0290016	2724.90000
E6	15	169.8000000	28.2746732	123.000000	204.000000	7.3004892	2547.00000
E7	15	166.3666667	32.5903944	117.800000	244.900000	8.4148037	2495.50000
E8	15	159.3400000	21.2783525	133.300000	195.300000	5.4940470	2390.10000
E9	15	140.2000000	20.6127561	105.000000	192.000000	5.3221907	2103.00000
E10	15	141.1533333	19.5664022	93.000000	173.600000	5.0520233	2117.30000
E11	15	145.4000000	17.5613211	114.000000	177.000000	4.5343136	2181.00000
E12	15	145.2866667	17.6091643	108.500000	176.700000	4.5466667	2179.30000
THORT1	15	88.7797950	25.3842214	52.504026	146.242863	6.5541778	1331.69693
THORT2	15	121.2562218	22.9194093	81.676692	157.008291	5.9177660	1818.84333
THORT3	14	179.7545215	27.7870668	133.854529	217.406953	7.4264060	2516.56330
THORT4	15	210.4067315	28.6957794	167.062130	269.544224	7.4092184	3156.10097
THORT5	14	197.4777750	20.4658203	172.876877	251.589493	5.4697205	2764.68885
THORT6	15	182.4392955	15.2470147	155.609690	218.542061	3.9367623	2736.58943
THORT7	15	168.0582783	10.5898656	151.262666	185.117206	2.7342915	2520.87417
THORT8	15	165.5481797	21.1088168	147.051496	233.252533	5.4502731	2483.22270
THORT9	15	151.0510120	9.4074226	133.841504	168.315370	2.4289861	2265.76518
THORT10	15	133.8930458	14.8259215	110.872844	164.925813	3.8280365	2008.39569
THORT11	15	99.6399271	15.7942842	73.808248	135.969543	4.0780666	1494.59891
THORT12	15	79.8778286	17.7900862	50.094798	110.087759	4.5933805	1198.16743
PENMAN1	14	96.8435949	10.2569248	77.290383	111.948985	2.7412785	1355.81033
PENMAN2	15	107.9247591	9.0697320	89.989131	122.217642	2.3402455	1618.87139
PENMAN3	13	139.5712327	15.2749582	114.709983	167.037472	4.2365112	1814.42603
PENMAN4	13	142.9800892	13.8686038	117.182181	169.931709	3.8464586	1858.74116
PENMAN5	14	146.5786238	11.4587659	130.168179	171.114890	3.0624840	2052.10073
PENMAN6	13	131.0531237	13.2205356	113.727264	154.288007	3.6667168	1703.69061
PENMAN7	14	128.2964581	9.9452757	112.354220	146.007260	2.6579867	1796.15041
PENMAN8	14	127.0943948	7.0864892	114.494316	139.526881	1.8939439	1779.32153
PENMAN9	15	109.1601900	8.9301003	94.721394	127.868805	2.3057420	1637.40285
PENMAN10	15	110.5579484	8.4104326	96.934698	123.983602	2.1715644	1658.36923
PENMAN11	15	96.9261051	4.3878193	86.426141	103.037928	1.1329301	1453.89158
PENMAN12	15	92.0887219	7.5447272	80.766554	106.464685	1.9480402	1381.33083
HARGRS1	14	125.9409955	5.9236870	113.858762	138.603559	1.5831720	1763.17394
HARGRS2	15	131.7222392	6.0166273	117.748560	142.126802	1.5534865	1975.83359
HARGRS3	14	163.7192215	8.4307804	147.711328	177.073702	2.2532209	2292.06910
HARGRS4	15	171.1305726	7.9827805	159.632988	183.032604	2.0611451	2566.95859
HARGRS5	14	172.8197843	11.2390221	161.002340	205.035360	3.0037550	2419.47698
HARGRS6	15	147.4420714	15.2131393	124.793431	177.106507	3.9280157	2211.63107
HARGRS7	15	146.4735329	12.8107312	128.401167	167.419804	3.3077166	2197.10299
HARGRS8	15	141.5417686	8.6612186	123.511023	157.471757	2.2363170	2123.12653
HARGRS9	15	133.5520651	9.3509627	117.185271	150.408379	2.4144082	2003.28098
HARGRS10	15	140.9855305	10.9753093	123.197554	154.059143	2.8338127	2114.78296
HARGRS11	15	123.6142080	6.2093819	112.301517	139.384241	1.6032555	1854.21312
HARGRS12	15	117.0521910	6.3994362	106.875465	128.009485	1.6523273	1755.78287

NORTHEAST THAILAND

PET, PAN EVAPORATION AND RAINFALL STATISTICS

SAKHON NAKHON

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM
P1	15	7.3600000	11.3328095	0.000000	33.400000	2.9261188	110.40000
P2	15	12.2733333	13.8541622	0.000000	41.500000	3.5771293	184.10000
P3	15	40.5933333	41.2852528	0.100000	111.000000	10.6598064	608.90000
P4	15	104.5333333	45.2598634	28.600000	181.000000	11.6860465	1568.00000
P5	15	222.4866667	115.8612771	74.700000	525.600000	29.9152531	3337.30000
P6	15	261.4333333	96.3266071	73.000000	464.100000	24.8714230	3921.50000
P7	15	237.5600000	94.0820220	118.700000	453.900000	24.2918736	3563.40000
P8	15	315.6200000	196.2535103	123.600000	863.100000	50.6724385	4734.30000
P9	15	242.7466667	101.6827620	96.100000	428.400000	26.2543763	3641.20000
P10	15	64.2066667	67.8432591	0.000000	267.100000	17.5170542	963.10000
P11	15	3.9800000	7.0608781	0.000000	28.000000	1.8231109	59.70000
P12	15	4.0800000	11.3946228	0.000000	42.800000	2.9420790	61.20000
E1	15	147.3533333	13.1973410	130.200000	170.500000	3.4075388	2210.30000
E2	15	144.1066667	14.6208983	120.400000	162.400000	3.7750997	2161.60000
E3	15	182.6933333	28.8784514	130.200000	232.500000	7.4563841	2740.40000
E4	15	174.8000000	17.9092953	144.000000	198.000000	4.6241602	2622.00000
E5	15	153.3466667	20.3235566	102.300000	186.000000	5.2475197	2300.20000
E6	15	127.8000000	18.9668884	93.000000	174.000000	4.8972295	1917.00000
E7	15	134.7466667	11.8257508	111.600000	151.900000	3.0533957	2021.20000
E8	15	119.2466667	13.6574347	96.100000	136.400000	3.5263345	1788.70000
E9	15	123.4000000	11.9928550	102.000000	141.000000	3.0965418	1851.00000
E10	15	143.2200000	9.5332651	124.000000	164.300000	2.4614785	2148.30000
E11	15	140.8000000	13.4387499	108.000000	165.000000	3.4698703	2112.00000
E12	15	142.8066667	7.6354873	127.100000	155.000000	1.9714743	2142.10000
THORT1	15	65.2682640	17.0779785	42.738189	98.606773	4.4095151	979.02396
THORT2	15	91.2990337	22.8539029	55.650728	122.874497	5.9008523	1369.48551
THORT3	15	141.9826898	28.8034554	93.146914	195.307175	7.4370202	2129.74035
THORT4	15	168.1084469	18.2831806	134.165412	198.475351	4.7206969	2521.62670
THORT5	15	163.0205516	12.2634577	147.173921	183.236041	3.1147714	2445.30827
THORT6	15	156.6732001	14.5282889	142.678447	202.781225	3.7511881	2350.09800
THORT7	15	149.6209446	12.6682084	131.560016	172.926642	3.2709173	2244.31417
THORT8	15	142.0801186	12.3152634	122.686518	161.206421	3.1797873	2131.20178
THORT9	15	138.3173612	9.2371406	121.195682	160.365529	2.3850195	2074.76042
THORT10	15	117.5657479	13.0313804	96.517179	134.345055	3.3646880	1763.48622
THORT11	15	83.7193745	15.7908744	54.769717	108.467644	4.0771862	1255.79062
THORT12	15	62.3414150	15.2504374	32.379959	87.506041	3.9376460	935.12122
PENMAN1	12	96.0975103	14.4832207	75.997147	122.949229	4.1809457	1153.17012
PENMAN2	11	113.3543091	16.2086339	90.236482	142.352203	4.8870870	1246.89740
PENMAN3	12	152.6300750	34.2312592	107.177254	219.020495	9.8817134	1831.56090
PENMAN4	13	151.5277457	18.2467847	124.144294	194.869012	5.0607475	1969.86069
PENMAN5	13	140.9179407	9.7664175	121.727721	155.065895	2.7087168	1831.93323
PENMAN6	12	121.8339623	16.2509592	106.787666	162.192185	4.6912478	1462.00755
PENMAN7	12	124.7028539	10.8208940	110.864030	145.486568	3.1237230	1496.43425
PENMAN8	12	117.2062396	16.6923617	96.167219	154.933538	4.8186698	1406.47488
PENMAN9	12	113.8791813	8.6312762	99.176338	134.314275	2.4916348	1366.55018
PENMAN10	12	119.9439540	11.1156877	103.863617	141.600042	3.2088226	1439.32745
PENMAN11	13	103.6883814	12.8406401	80.750244	121.836495	3.5613528	1347.94896
PENMAN12	13	92.7340294	11.4516499	75.692829	109.673107	3.1761162	1205.54238
HARGRS1	15	107.5567001	10.2570584	77.975528	118.206913	2.6483611	1613.35050
HARGRS2	14	114.5996971	8.0789747	99.818692	127.051244	2.1591968	1604.39576
HARGRS3	14	147.6486839	10.8648705	122.193207	163.059350	2.9037588	2067.08158
HARGRS4	15	158.0390734	7.9234994	146.720275	172.982075	2.0458387	2370.58610
HARGRS5	15	155.2421571	10.6665121	134.588383	172.538185	2.7540816	2328.63236
HARGRS6	14	130.0515652	14.7811644	113.304398	155.647895	3.9504324	1820.72191
HARGRS7	14	134.5108867	12.0190748	111.752294	159.989603	3.2122329	1883.15241
HARGRS8	14	121.9800315	13.8854552	102.892084	146.705701	3.7110440	1707.72044
HARGRS9	14	128.6556635	8.8766624	109.338956	141.134215	2.3723878	1801.17927
HARGRS10	15	132.6479351	6.5264672	117.988780	142.580925	1.6851266	1989.71903
HARGRS11	15	113.1436839	4.4866228	105.569650	122.876544	1.1584410	1697.15526
HARGRS12	15	103.8179782	6.2056398	93.464465	116.118371	1.6022893	1557.26967

TABLE 4.1D PET, Pan Evaporation and Rainfall Statistics for Sakhon Nakhon.

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NORTHEAST THAILAND

PET, PAN EVAPORATION AND RAINFALL STATISTICS

THA PHRA KHON KAEN

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM
P1	15	9.6933333	19.0831065	0.000000	65.000000	4.9272369	145.40000
P2	15	6.5400000	8.5927544	0.000000	33.300000	2.2186397	98.10000
P3	15	22.0400000	17.0858254	0.000000	49.300000	4.4115411	330.60000
P4	15	75.7933333	44.1012061	20.400000	145.500000	11.3868825	1136.90000
P5	15	156.7000000	94.8871887	29.600000	371.300000	24.4997668	2350.50000
P6	15	162.7466667	88.1420029	26.600000	333.600000	22.7581673	2441.20000
P7	15	165.3333333	92.9469716	34.600000	388.100000	23.9988049	2480.00000
P8	15	168.5866667	71.2403664	60.600000	292.900000	18.3941835	2528.80000
P9	15	241.0666667	125.7138114	55.000000	534.900000	32.4591665	3616.00000
P10	15	80.7533333	61.7700791	0.000000	188.400000	15.9489658	1211.30000
P11	15	13.9733333	20.0543713	0.000000	56.300000	5.1780164	209.60000
P12	15	7.9866667	19.1246612	0.000000	71.600000	4.9379663	119.80000
E1	15	150.8666667	23.7152653	124.000000	217.000000	6.1232552	2263.00000
E2	15	158.6666667	18.2588791	120.400000	193.200000	4.7144223	2380.00000
E3	15	209.7666667	32.2303465	161.200000	279.000000	8.3218397	3146.50000
E4	15	219.2000000	31.6570913	189.000000	285.000000	8.1738258	3288.00000
E5	15	198.4000000	36.3412792	127.100000	269.700000	9.3832779	2976.00000
E6	15	176.4000000	28.0784615	138.000000	222.000000	7.2498276	2646.00000
E7	15	171.3266667	18.3573055	142.600000	201.500000	4.7398359	2569.90000
E8	15	152.1066667	20.2083952	117.800000	192.200000	5.2177852	2281.60000
E9	15	138.4000000	13.0208624	120.000000	168.000000	3.3619722	2076.00000
E10	15	152.7266667	11.4482355	133.300000	167.400000	2.9559217	2290.90000
E11	15	147.4000000	13.6476058	129.000000	171.000000	3.5237967	2211.00000
E12	15	147.9733333	10.1109888	136.400000	164.300000	2.6106461	2219.60000
THORT1	15	76.4876781	19.3583402	49.378285	115.532175	4.9983019	1147.31517
THORT2	15	110.9795010	23.1384342	70.472646	150.794792	5.9743180	1664.69251
THORT3	15	179.4884039	31.5150979	131.704512	235.531685	8.1371633	2692.32606
THORT4	15	208.8129400	27.4731308	163.574753	269.107262	7.0935319	3132.19410
THORT5	15	196.6914293	21.2230673	165.724356	247.113435	5.4797724	2950.37144
THORT6	15	183.1111178	22.2665539	160.124974	242.546847	5.7491995	2746.66677
THORT7	15	168.2739595	13.4393085	146.345425	191.875273	3.4700145	2524.10939
THORT8	15	156.9076981	10.1740498	140.352727	174.991913	2.6269284	2353.61547
THORT9	15	147.6997981	10.9464699	126.077788	165.914555	2.8263664	2215.49697
THORT10	15	133.7549346	12.1813750	112.051160	153.958485	3.1452175	2006.32402
THORT11	15	97.5866483	14.8887268	69.313888	125.312700	3.8442527	1463.79973
THORT12	15	72.9142292	16.8283495	45.363819	100.765334	4.3450612	1093.71344
PENMAN1	7	100.4019125	4.1230869	93.707694	107.391263	1.5583804	702.81339
PENMAN2	7	115.7368333	10.2827049	102.760022	134.173887	3.8864971	810.15783
PENMAN3	8	171.4572811	14.7104446	139.881743	188.074519	5.2009276	1371.65825
PENMAN4	6	177.0366310	27.8674502	151.307193	227.236199	11.3768389	1062.21979
PENMAN5	9	164.9052315	9.7927196	156.894554	183.989390	3.2642399	1484.14708
PENMAN6	8	138.0502140	15.7767221	118.351480	168.836214	5.5779136	1104.40171
PENMAN7	8	137.2579599	10.2248759	124.578360	153.683333	3.6150396	1098.06368
PENMAN8	8	138.4535182	23.4741032	115.297227	188.692290	8.2993488	1107.62815
PENMAN9	8	115.5506137	12.8365584	102.588369	138.844481	4.5384087	924.40491
PENMAN10	9	122.4188967	4.9339272	113.978675	128.370428	1.6446424	1101.77007
PENMAN11	9	110.9876017	7.9146552	99.929987	120.200904	2.6382184	998.88842
PENMAN12	8	97.1859420	4.6890500	89.466338	101.398630	1.6578295	777.48754
HARGRS1	15	116.4397373	7.6280677	97.849858	126.428245	1.9695586	1746.59606
HARGRS2	15	125.4616539	6.9065528	111.721634	140.077755	1.7832643	1881.92481
HARGRS3	15	163.2308691	11.3442737	143.682048	182.419891	2.9290789	2448.46304
HARGRS4	14	172.2360519	8.1736173	160.129209	187.932165	2.1844911	2411.30473
HARGRS5	15	170.4033277	9.2461501	157.967860	189.061275	2.3873457	2556.04992
HARGRS6	15	146.2470444	15.3472878	126.738964	174.136178	3.9626527	2193.70567
HARGRS7	15	141.1648403	13.3744092	121.699910	164.639755	3.4532576	2117.47260
HARGRS8	15	133.0766751	10.9771458	116.816048	153.329303	2.8342869	1996.15013
HARGRS9	15	130.3698072	9.2330894	111.972295	146.241206	2.3839734	1955.54711
HARGRS10	15	141.2685632	7.4800761	127.862394	155.089983	1.9313473	2119.02845
HARGRS11	15	119.7715260	6.6633087	110.869205	136.809107	1.7204589	1796.57289
HARGRS12	15	112.3693030	6.2695867	101.013408	125.482871	1.6188003	1685.53955

TABLE 4.1c PET, Pan Evaporation and Rainfall Statistics for Tha Phra Khon Kaen.

NORTHEAST THAILAND

JANUARY PET ANALYSIS
SURIN

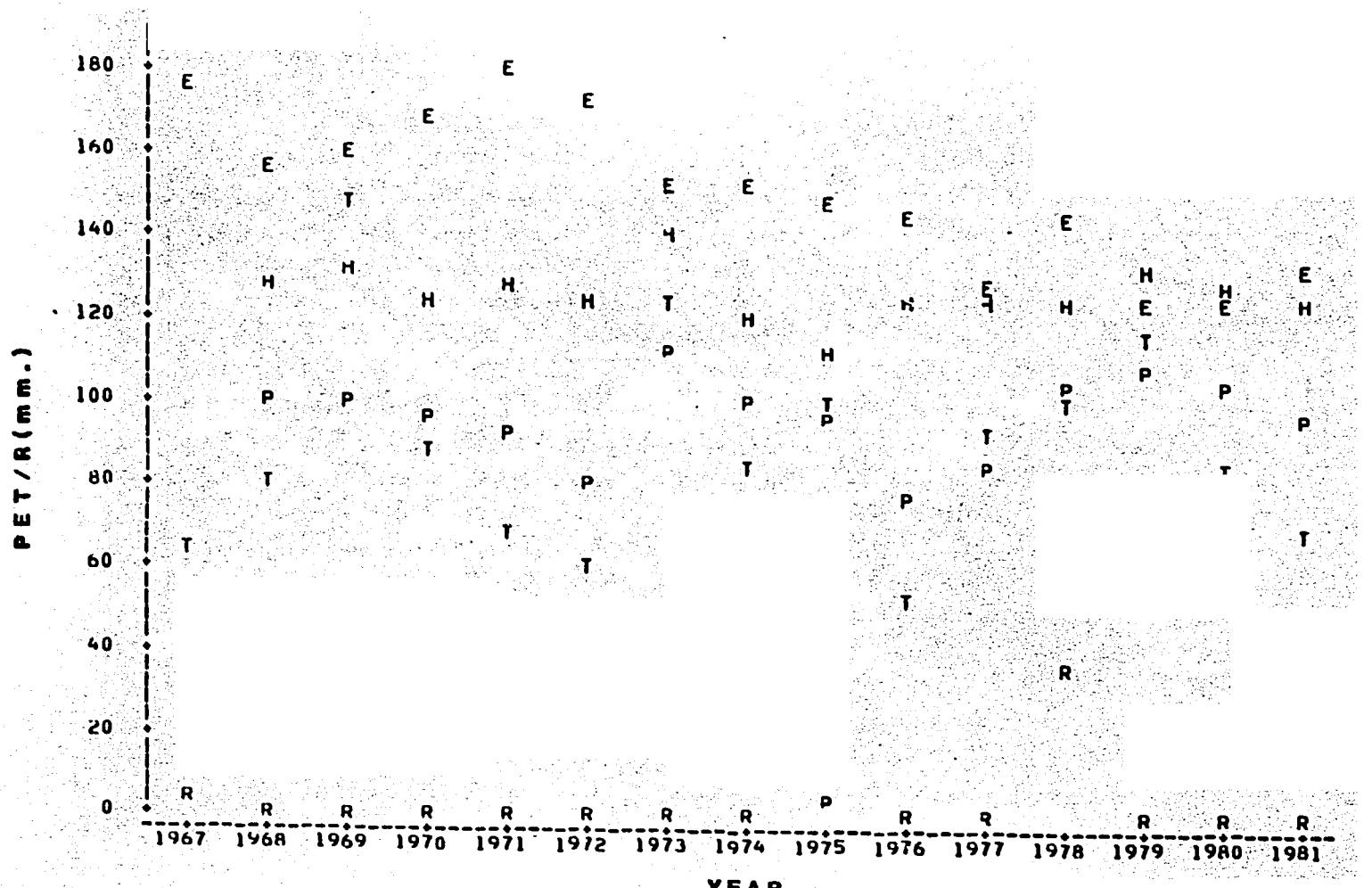

FIGURE 4.2a Comparison of Historical Potential Evapotranspiration Estimates for January by the Penman (P), Thornthwaite (T) and Hargreaves (H) Methods at Surin. Monthly Rainfall (R) and Pan Evaporation Values (E) Are Also Indicated.

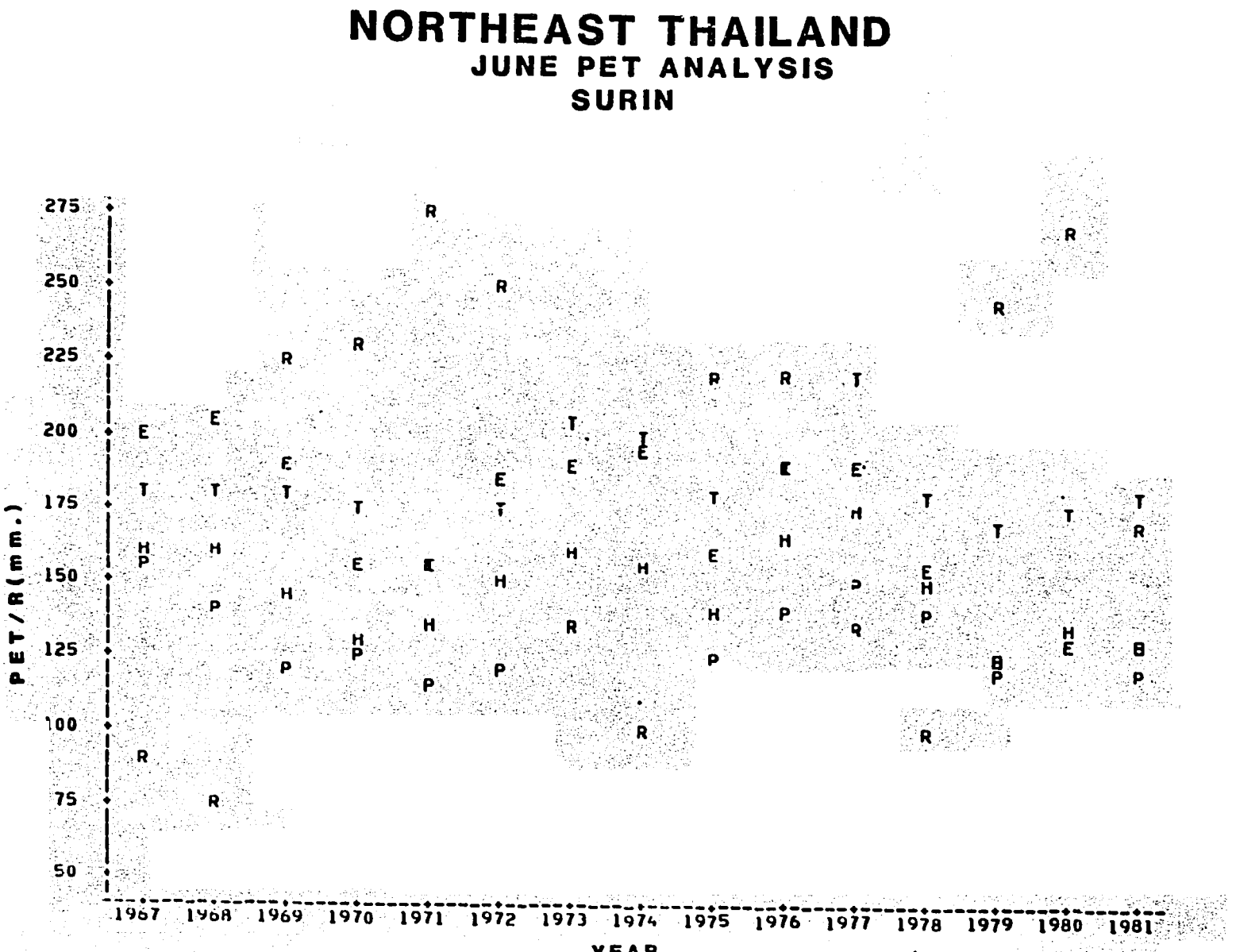

FIGURE 4.2b Comparison of Historical Potential Evapotranspiration Estimates for June by the Penman (P), Thornthwaite (T) and Hargreaves (H) Methods at Surin. Monthly Rainfall (R) and Pan Evaporation Values (E) Are Also Indicated.

NORTHEAST THAILAND
SEPTEMBER PET ANALYSIS
SURIN

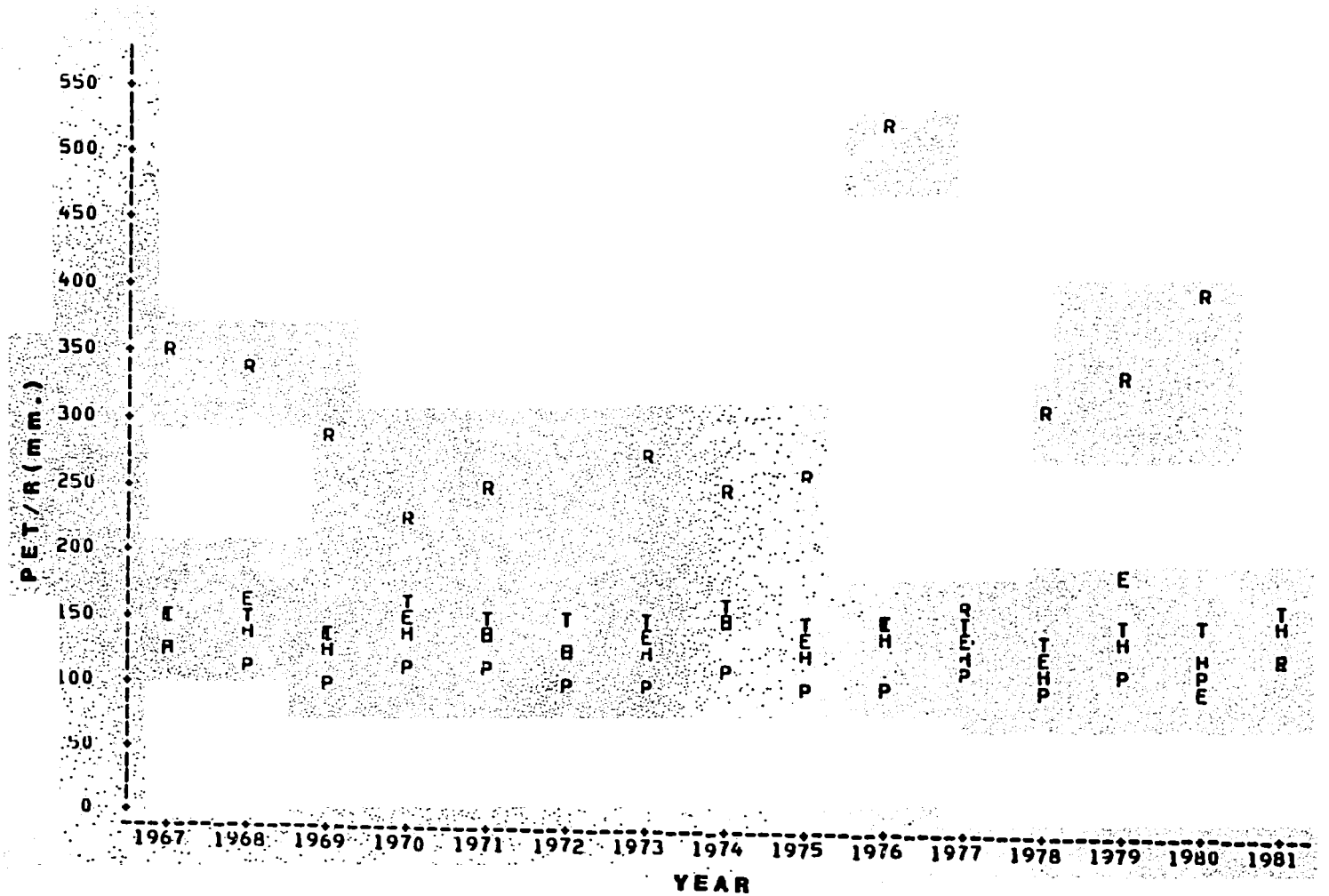

FIGURE 4.2c Comparison of Historical Potential Evapotranspiration Estimates for September by the Penman (P), Thornthwaite (T) and Hargreaves (H) Methods at Surin. Monthly Rainfall (R) and Pan Evaporation Values (E) Are Also Indicated.

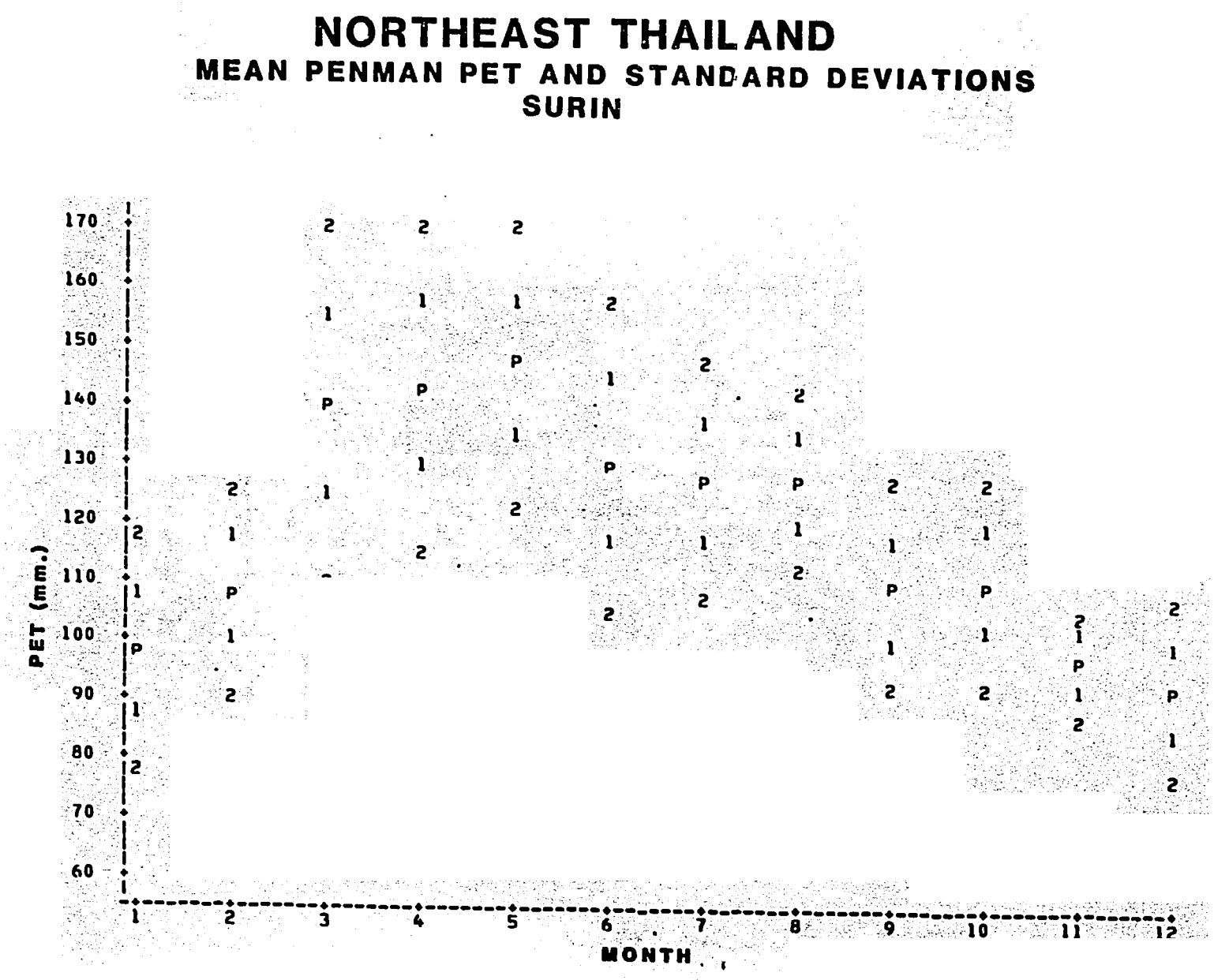

FIGURE 4.3 Mean Monthly Penman Potential Evapotranspiration Values Showing the 1 and 2 Standard Deviation Limits.

NORTHEAST THAILAND

PET RATIOS

SAKHON NAKHON, SURIN AND THA PHRA KHON KAEN

SAKHON NAKHON

OBS	MON	RP_E	RP_8E	RH_E	RH_8E	RT_E	RT_8E
1	1	0.652157	0.81520	0.72992	0.91240	0.44294	0.55367
2	2	0.786600	0.98325	0.79524	0.99405	0.63355	0.79194
3	3	0.835444	1.04431	0.80818	1.01022	0.77716	0.97146
4	4	0.866864	1.08358	0.90411	1.13014	0.95172	1.20215
5	5	0.918950	1.14869	1.01236	1.26545	1.06309	1.32886
6	6	0.953317	1.19165	1.01762	1.27202	1.22592	1.53241
7	7	0.925462	1.15683	0.99825	1.24781	1.11039	1.38798
8	8	0.982889	1.22861	1.02292	1.27865	1.19148	1.48935
9	9	0.922846	1.15356	1.04259	1.30324	1.12089	1.40111
10	10	0.837480	1.04685	0.92618	1.15773	0.82088	1.02609
11	11	0.736423	0.92053	0.80358	1.00447	0.59460	0.74325
12	12	0.649368	0.81171	0.72698	0.90873	0.43654	0.54568

SURIN

OBS	MON	RP_E	RP_8E	RH_E	RH_8E	RT_E	RT_8E
13	1	0.641915	0.802394	0.834783	1.04348	0.58847	0.73558
14	2	0.692417	0.865521	0.845096	1.05637	0.77795	0.97244
15	3	0.725341	0.906677	0.850837	1.06355	0.93417	1.16771
16	4	0.718493	0.898116	0.859953	1.07494	1.05732	1.32165
17	5	0.753092	0.941365	0.887914	1.10989	1.01460	1.26825
18	6	0.771809	0.964761	0.868328	1.08541	1.07444	1.34305
19	7	0.771167	0.963959	0.880426	1.10053	1.01017	1.26271
20	8	0.797630	0.997038	0.888300	1.11038	1.03896	1.29870
21	9	0.778603	0.973254	0.952582	1.19073	1.07740	1.34675
22	10	0.783247	0.979059	0.998811	1.24851	0.94856	1.18571
23	11	0.666617	0.833271	0.850166	1.06271	0.68528	0.85660
24	12	0.633842	0.792302	0.805664	1.00708	0.54979	0.68724

THAPHRA KHON KAEN

OBS	MON	RP_E	RP_8E	RH_E	RH_8E	RT_E	RT_8E
25	1	0.665501	0.83188	0.771805	0.96476	0.50699	0.63374
26	2	0.729434	0.91179	0.790725	0.98841	0.59945	0.87431
27	3	0.817371	1.02171	0.778154	0.97269	0.85566	1.06957
28	4	0.807649	1.00956	0.785749	0.98219	0.95261	1.19077
29	5	0.831176	1.03897	0.858888	1.07361	0.99139	1.23924
30	6	0.782598	0.97825	0.829065	1.03633	1.03804	1.29756
31	7	0.801148	1.00143	0.823951	1.02994	0.98218	1.22773
32	8	0.910240	1.13780	0.874890	1.09361	1.03156	1.28945
33	9	0.834903	1.04363	0.941978	1.17747	1.06720	1.33399
34	10	0.801555	1.00194	0.924976	1.15622	0.87578	1.09472
35	11	0.752969	0.94121	0.812561	1.01570	0.56205	0.82757
36	12	0.656780	0.82098	0.759389	0.94924	0.49275	0.61594

TABLE 4.2 PET Ratios for Sakhon Nakhon, Surin and Tha Phra Khon Kaen. (RP_E=P/E, RP_8E=P/.8E, RH_E=H/E, RH_8E=H/.8E, RT_E=T/E and RT_8E=T/.8E).

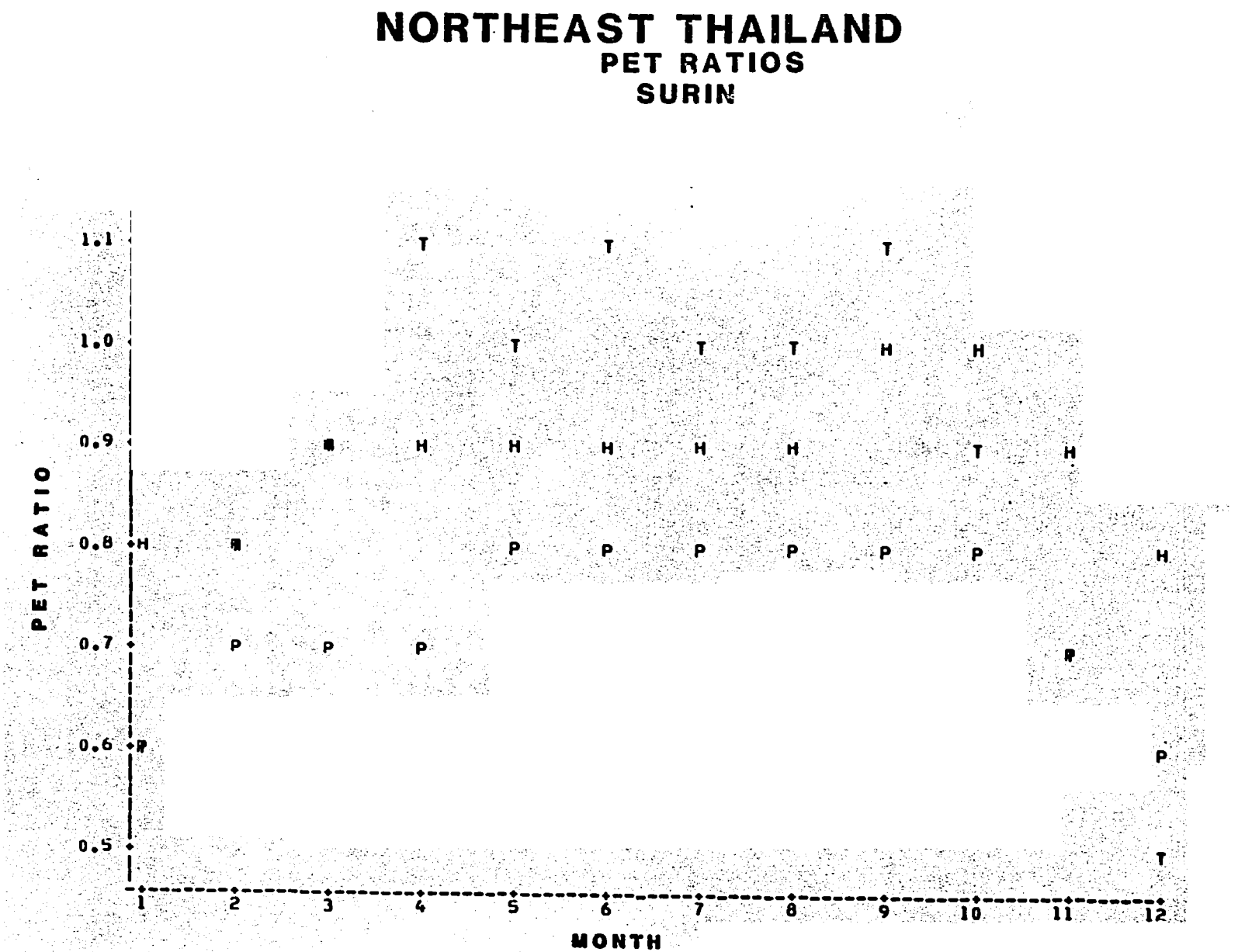

FIGURE 4.4a Comparison of Mean Monthly PET Ratios (P=Penman/Pan, H=Hargreaves/Pan and T=Thornthwaite/Pan) for Surin.

NORTHEAST THAILAND
PET RATIOS
SAKHON NAKHON

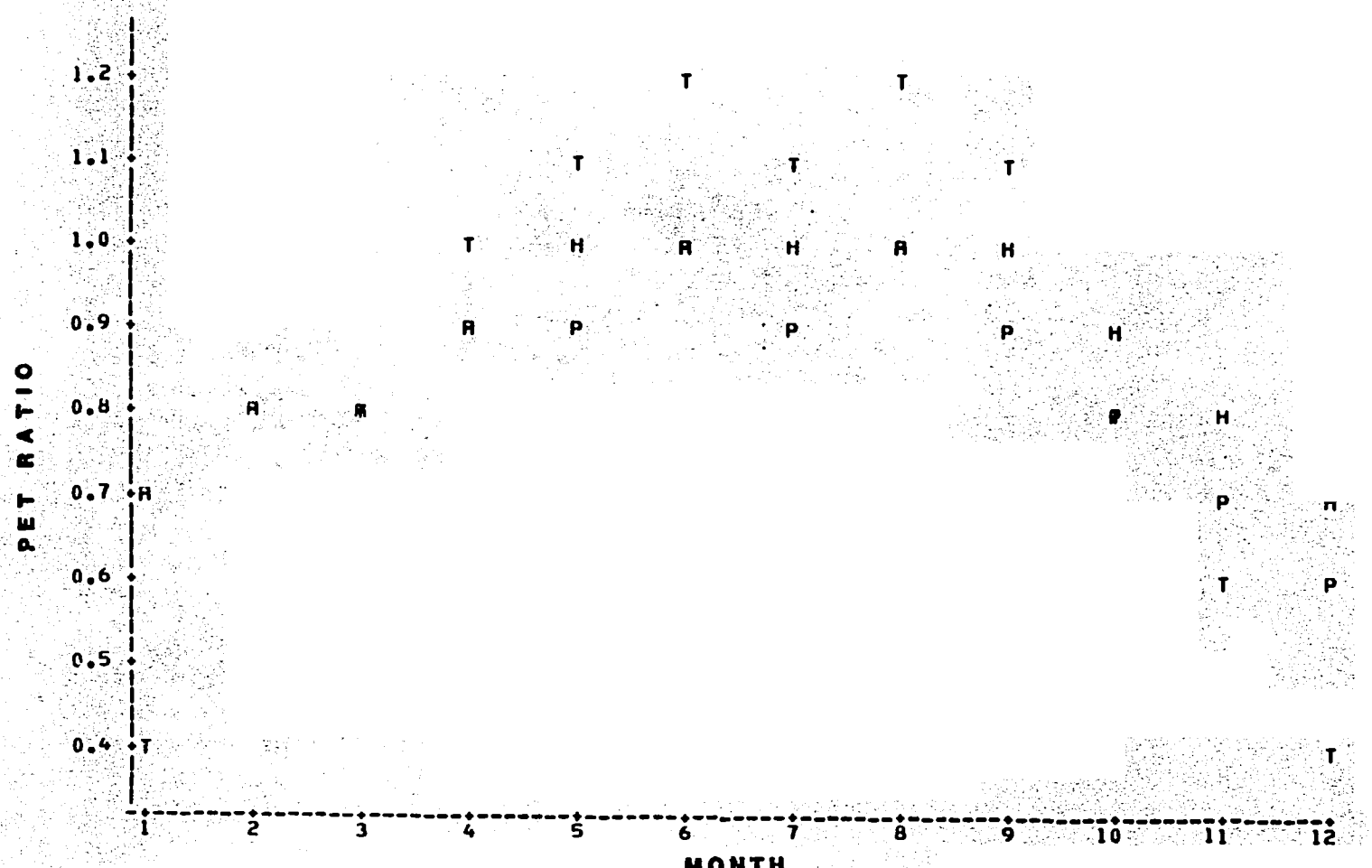

FIGURE 4.4b Comparison of Mean Monthly PET Ratios (P=Penman/Pan, H=Hargreaves/Pan and T=Thornthwaite/Pan) for Sakhon Nakhon.

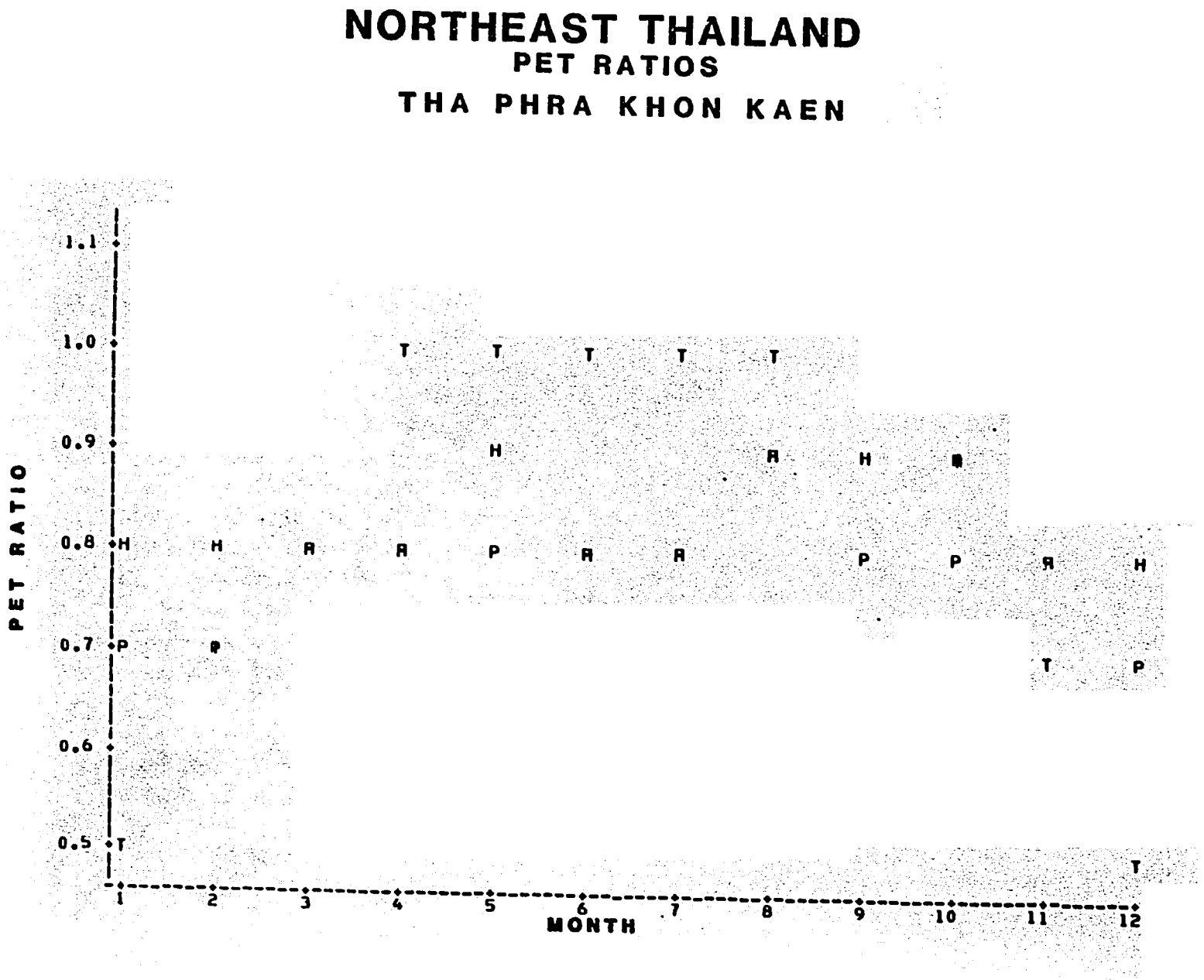

FIGURE 4.4c Comparisons of Mean Monthly PET Ratios (P=Penman/Pan, H=Hargreaves/Pan and T=Thornthwaite/Pan) for Tha Phra Khon Kaen.

well below pan during the dry season. Penman and Hargreaves PET compare favorably with 80 percent of pan. However, there are differences at local stations.

Some comments are in order. The large variability of PET during the dry season as compared to PET variability during the wet season seems to be associated with temperature variability. For example, during the rainy season, station mean temperatures vary by about 2-3°C from year-to-year, but as much 6-7°C during the dry season. Evaporation rates are also higher during the dry seasons (5-8 mm per day) compared to the wet season (4-7 mm per day).

Preliminary findings include:

1) The modified Penman method and 80 percent pan evaporation appear to be acceptable models for estimating PET in Northeast Thailand. The Hargreaves method produces the next best results and the Thornthwaite method probably underestimates PET during the dry season and overestimates PET during the wet season.

2) Mean PET values can probably be used instead of individual calculations for many applications, e.g., soil moisture budget calculations. Rainfall is much more variable than PET or Pan.

3) PET can be estimated at data sparse locations by adjusting estimated PET's with the ratios of PET to pan or by interpolating PET and accounting for elevation changes.

4) Local station characteristics must be considered when interpolating or estimating PET for soil moisture or land use studies.

C. PET Estimates at Synoptic Stations

The above findings at the agrometeorological stations suggested that monthly mean PET could be estimated at selected synoptic stations. Figures 4.5a-h

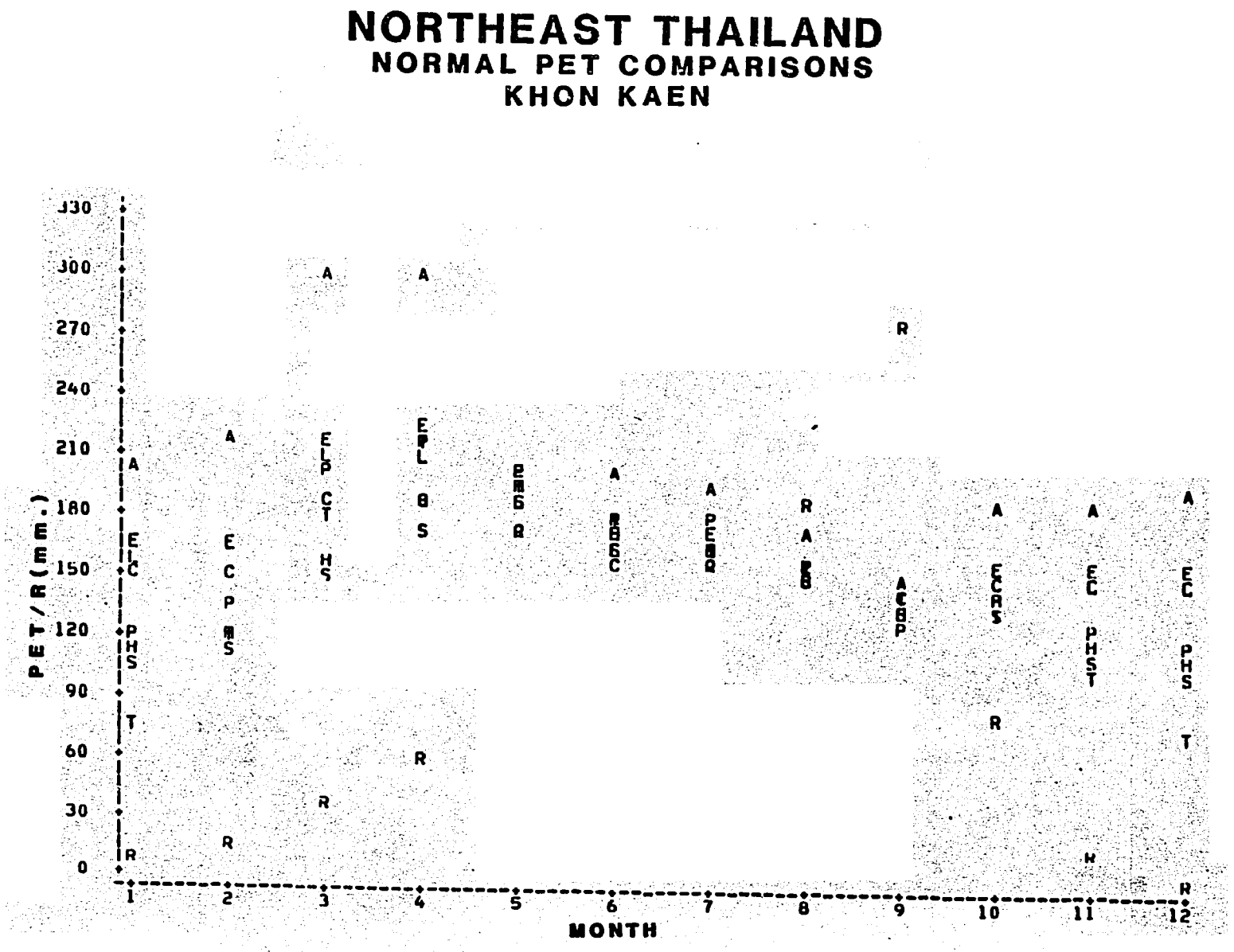

FIGURE 4.5a Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Khon Kaen. Normal Rainfall(R) and Pan Evaporation (E) Values are also Shown.

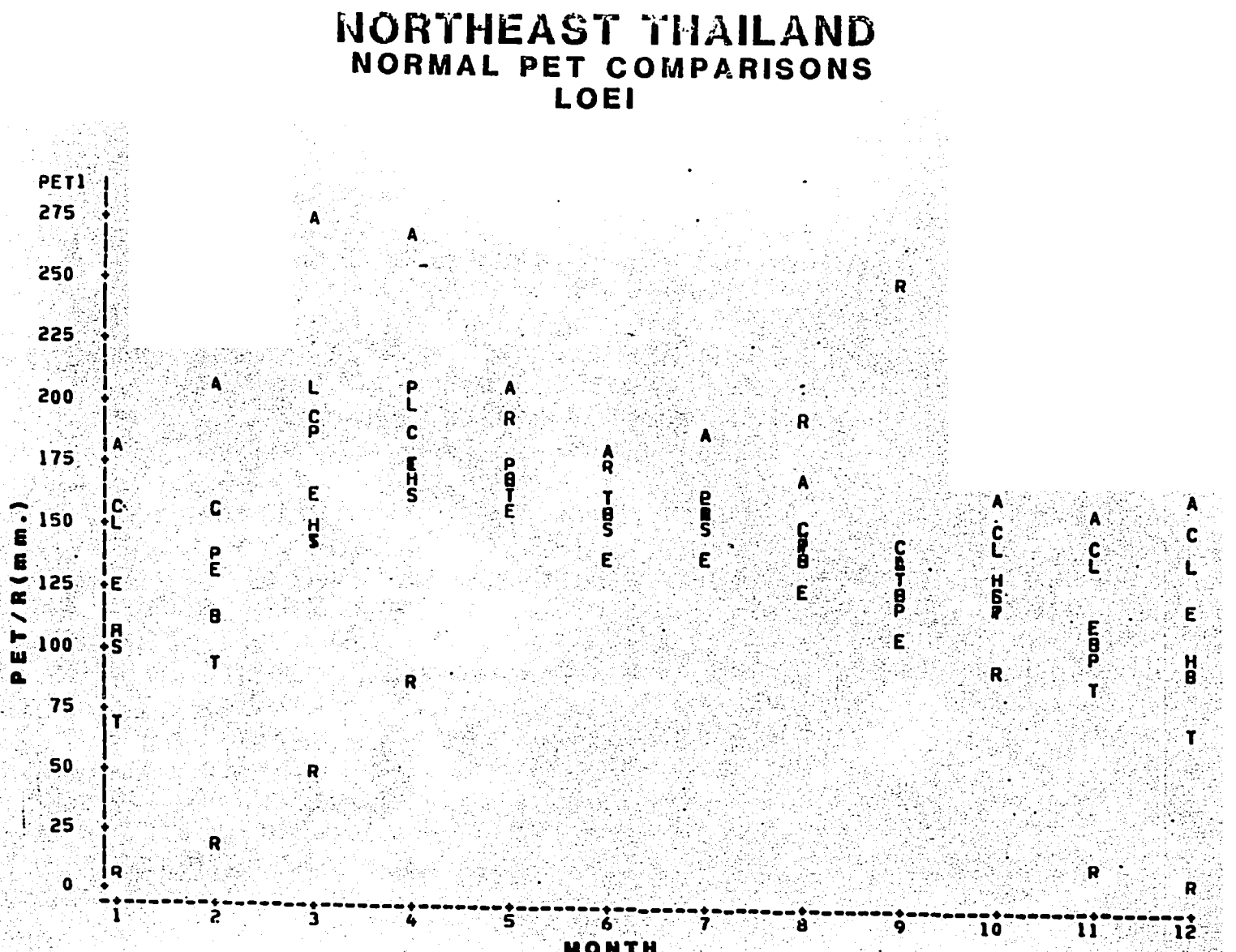

FIGURE 4.5b Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Loei. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

NORTHEAST THAILAND
NORMAL PET COMPARISONS
NAKHON RATCHASIMA

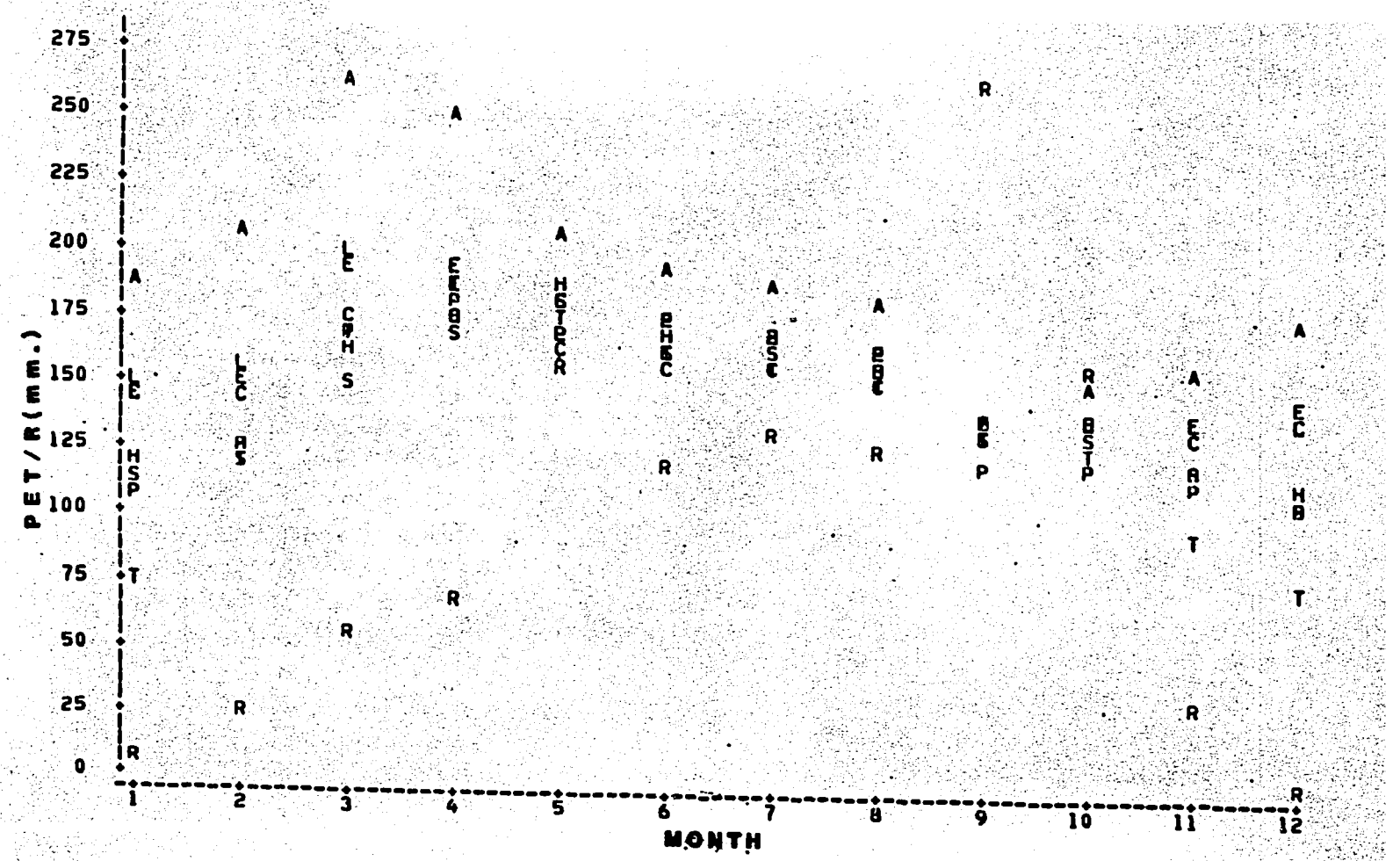

FIGURE 4.5c Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Nakhon Ratchasima. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

NORTHEAST THAILAND
NORMAL PET COMPARISONS
NAKHON PHANOM

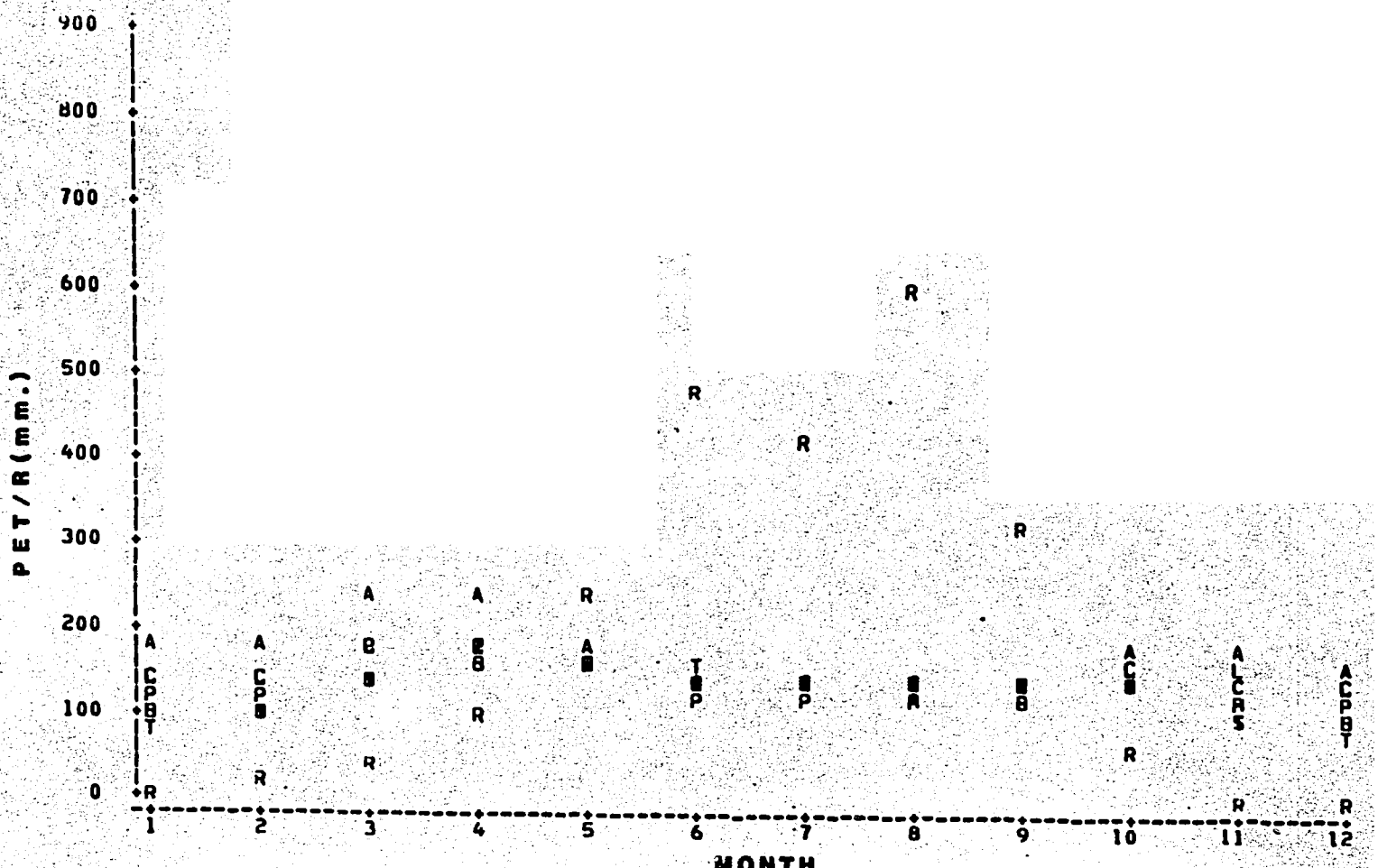

FIGURE 4.5d Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Nakhon Phanom. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

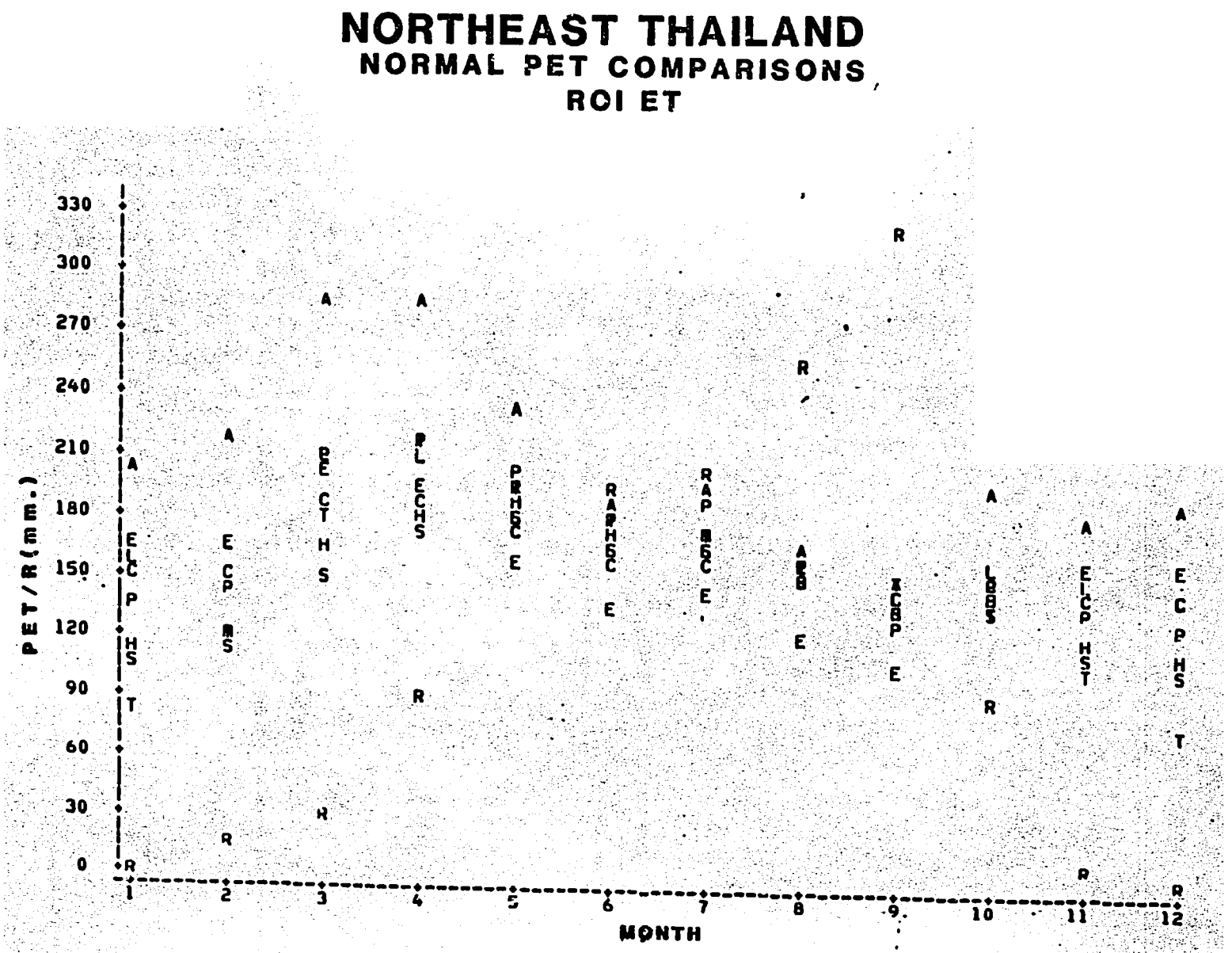

FIGURE 4.5e Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Roi Et. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

NORTHEAST THAILAND
NORMAL PET COMPARISONS
SAKHON NAKHON

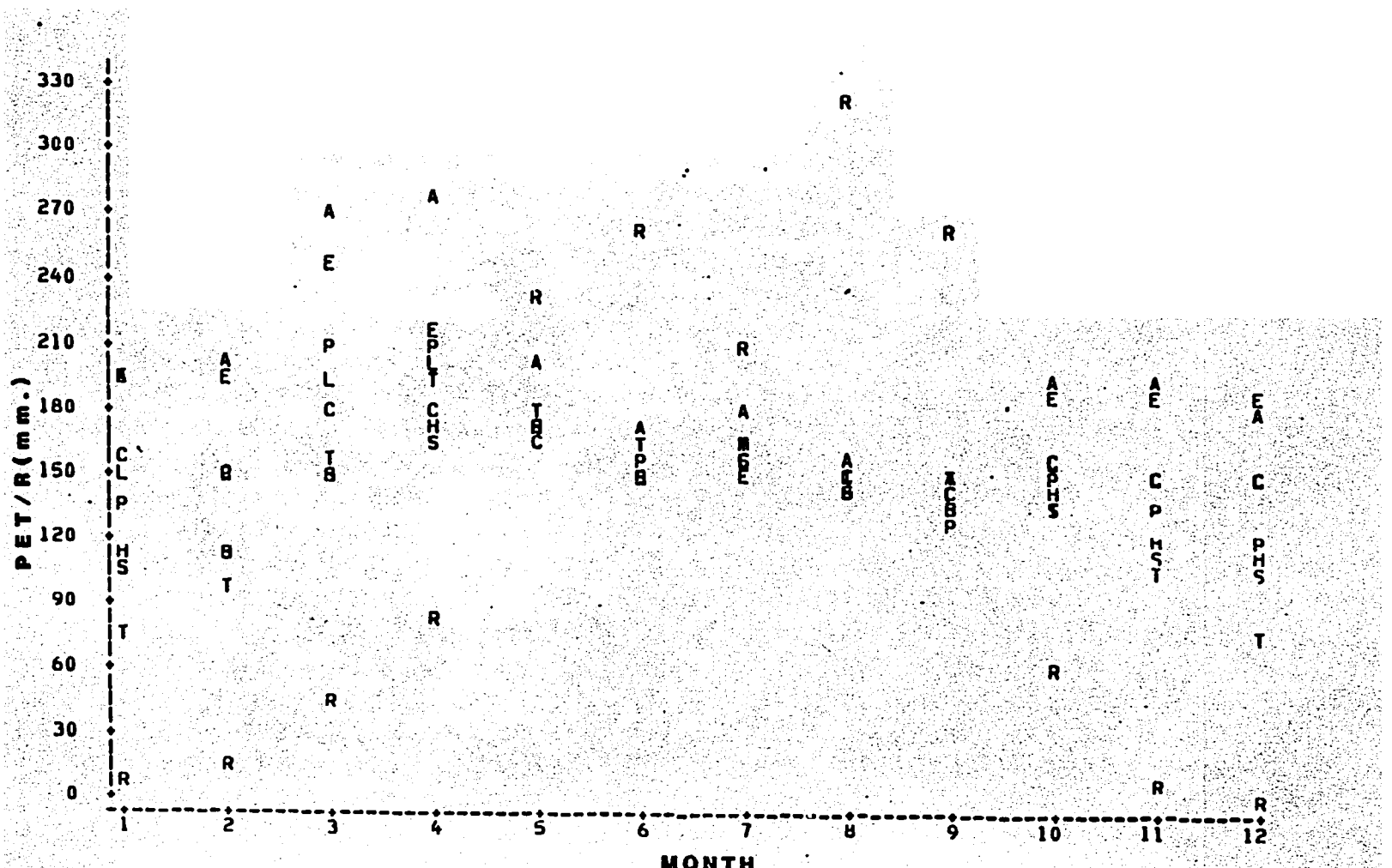

FIGURE 4.5f Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Sakhon Nakhon. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

NORTHEAST THAILAND
NORMAL PET COMPARISONS
SURIN

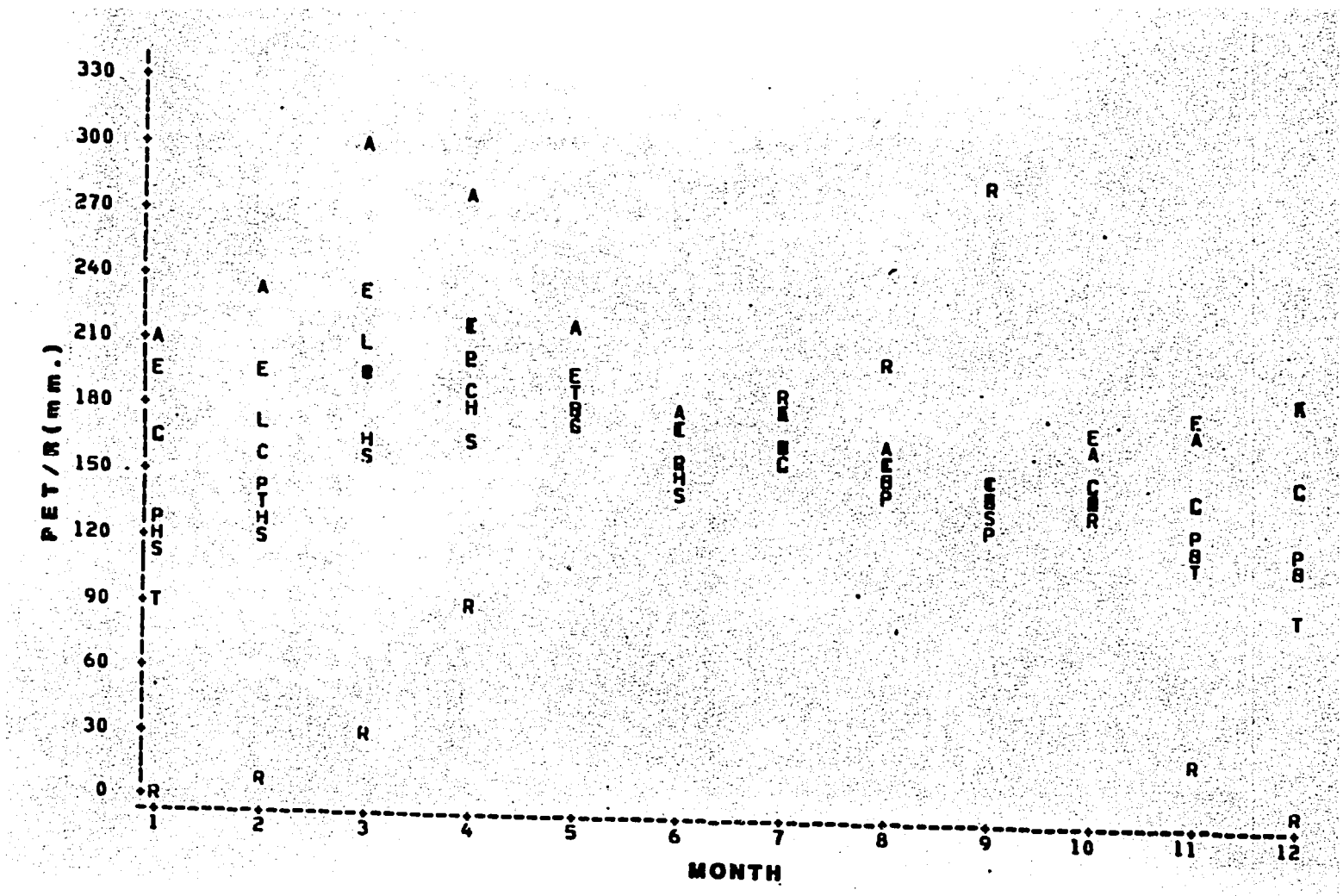

FIGURE 4.5g Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H), Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Surin. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

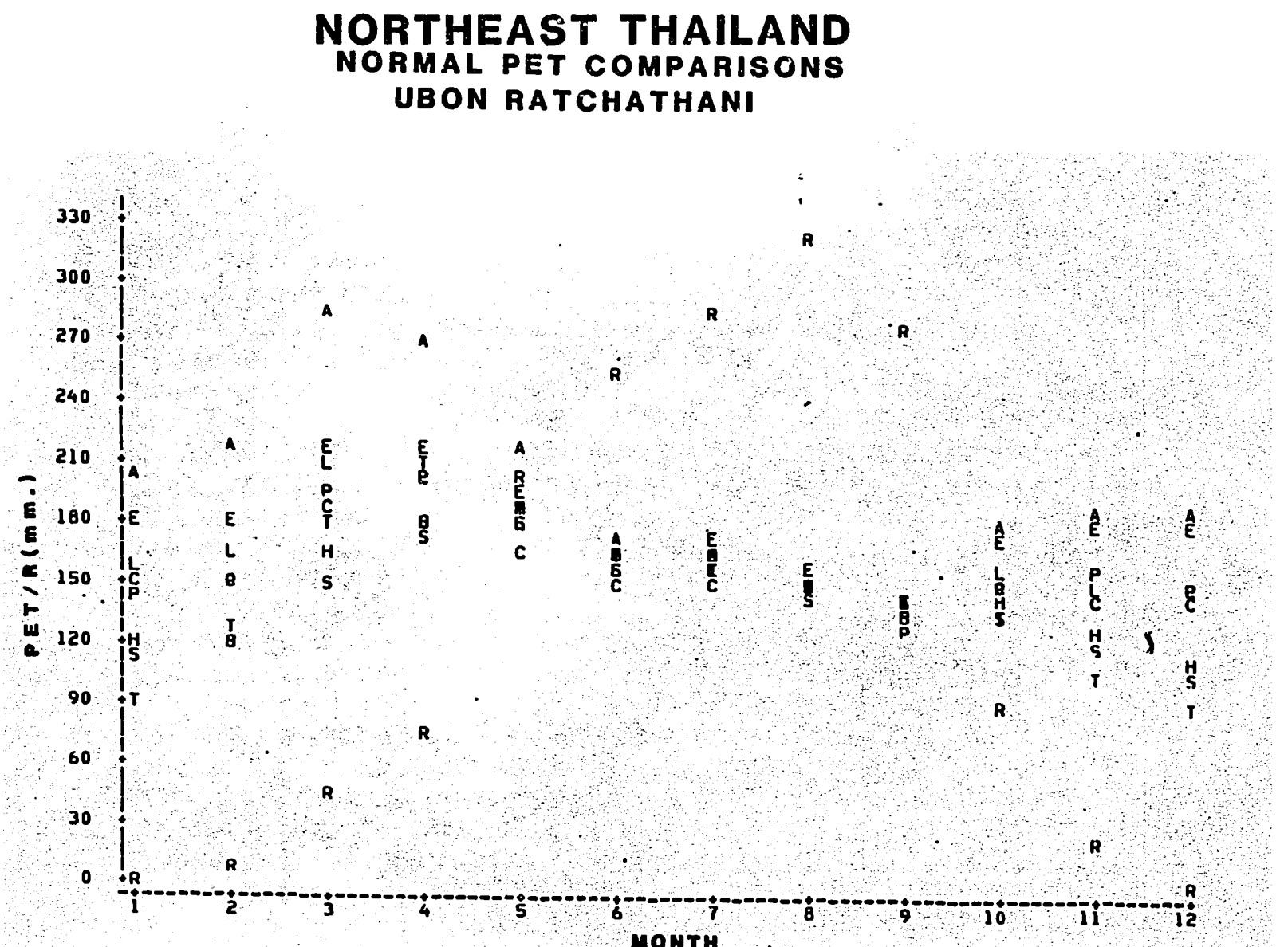

FIGURE 4.5h Normal PET Comparisons for Penman (P), Thornthwaite (T), Hargreaves (H). Linacre (L), Modified Linacre (C), Antal (A) and Priestley (S) Methods at Ubon Ratchathani. Normal Rainfall (R) and Pan Evaporation (E) Values are also Shown.

are similar to Figures 4.1a-c and show PET estimates (Penman, Hargreaves, Thornthwaite, Priestley, modified Linacre and Antal), pan evaporation and rainfall. The findings are similar except the Antal and modified Linacre methods are considered to be suspect.

D. Climatic Diagrams

The monthly means of PET (Penman method), estimated actual evapotranspiration (AET) and rainfall at each agrometeorological station were plotted as shown in Figures 4.6a-c. The values of AET were determined from the Palmer two-layer model. These plots are called climatic diagrams.

The climatic diagrams illustrate the general water supply (precipitation) and the water demand (AET); hence, general periods of water deficit or water surplus are indicated. The diagrams represent one tool for application in land use studies. For example, in Figure 4.6b, the climatic diagram for the Sakhon Nakhon agrometeorological station suggests that water is adequate for the crops during May to September. This contrasts with October to March when water deficits will usually be experienced. The diagram provides general information on the crop calendar and growing season at Sakhon Nakhon. Planting should begin during May to avoid water deficit problems.

These diagrams could be made more useful if monthly mean soil moisture estimates were included. As previously discussed, the diagram could be determined for a particular crop by using crop coefficients. Finally, diagrams can be determined for other time periods such as decadal or weekly intervals. The diagram can be calculated each season for use in assessments and making an analysis for irrigation scheduling.

The climatic diagrams should be used along with other agroclimatic tools for assessing climatic impact or in land and water resource management studies. For example, the diagrams complement agroclimatic/crop condition index models and

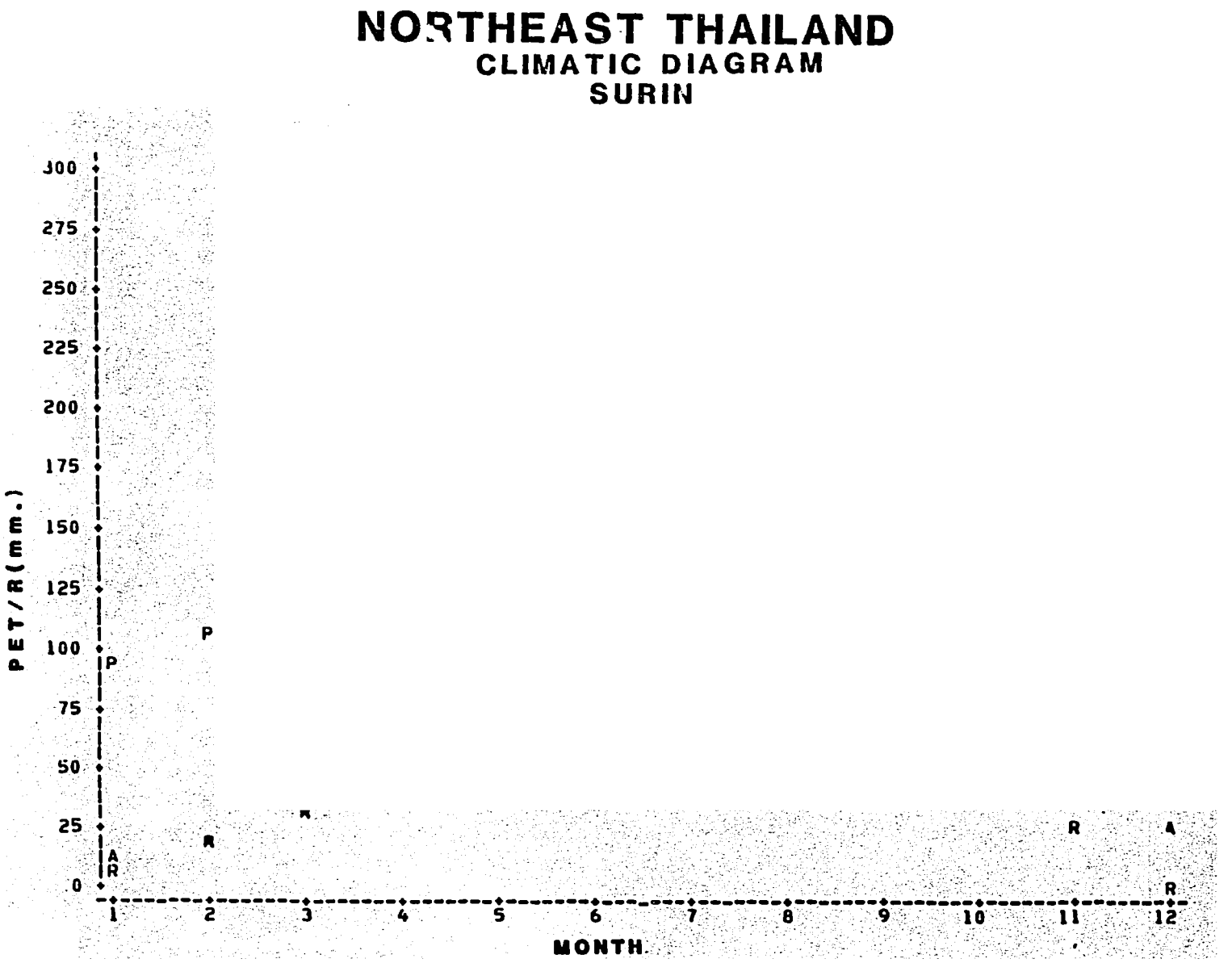

FIGURE 4.6a Climatic Diagram for Surin Showing Normal Precipitation (R), Potential Evapotranspiration (P) and Actual Evapotranspiration (A).

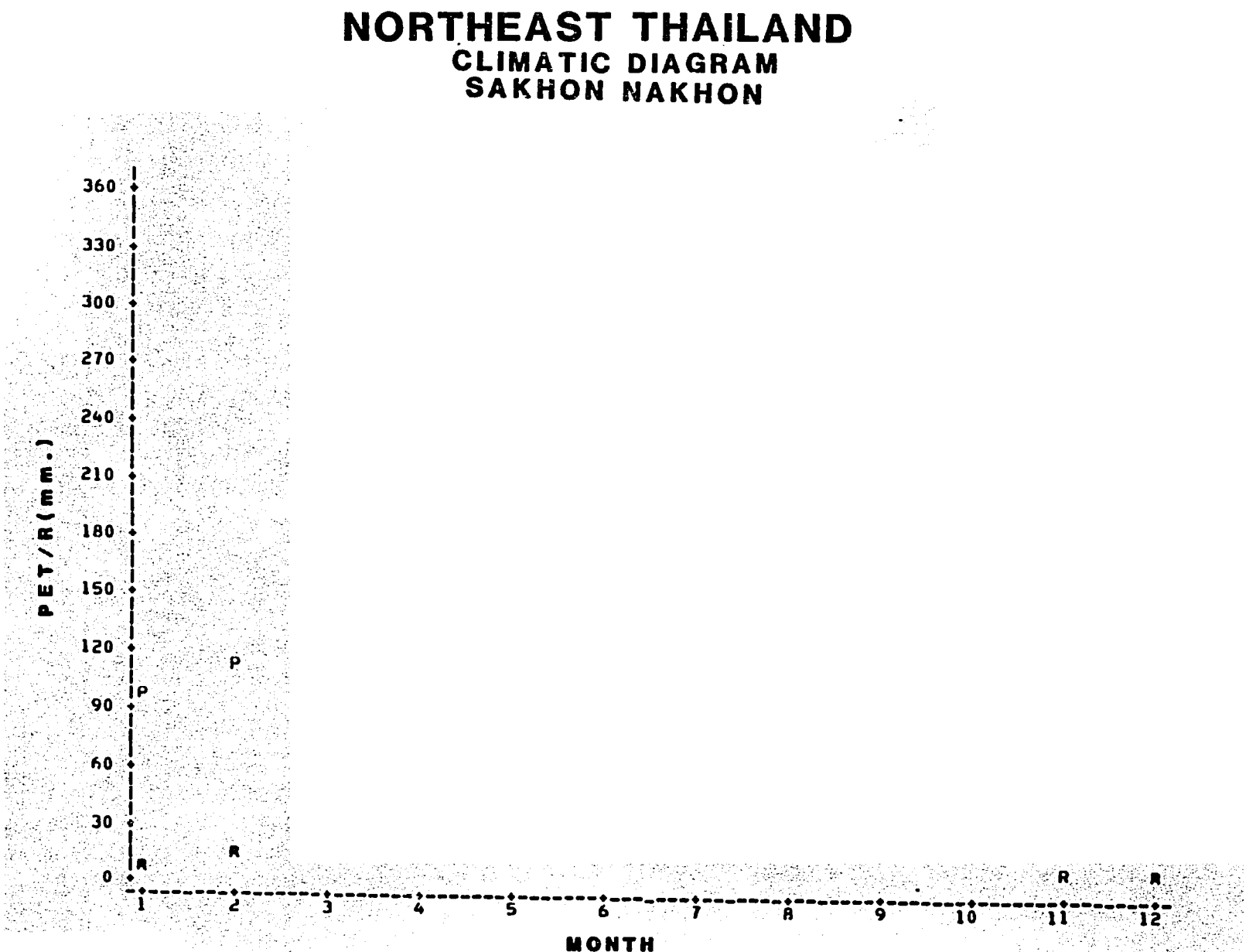

FIGURE 4.6b Climatic Diagram for Sakhon Nakhon Showing Normal Precipitation (R), Potential Evapotranspiration (P) and Actual Evapotranspiration (A).

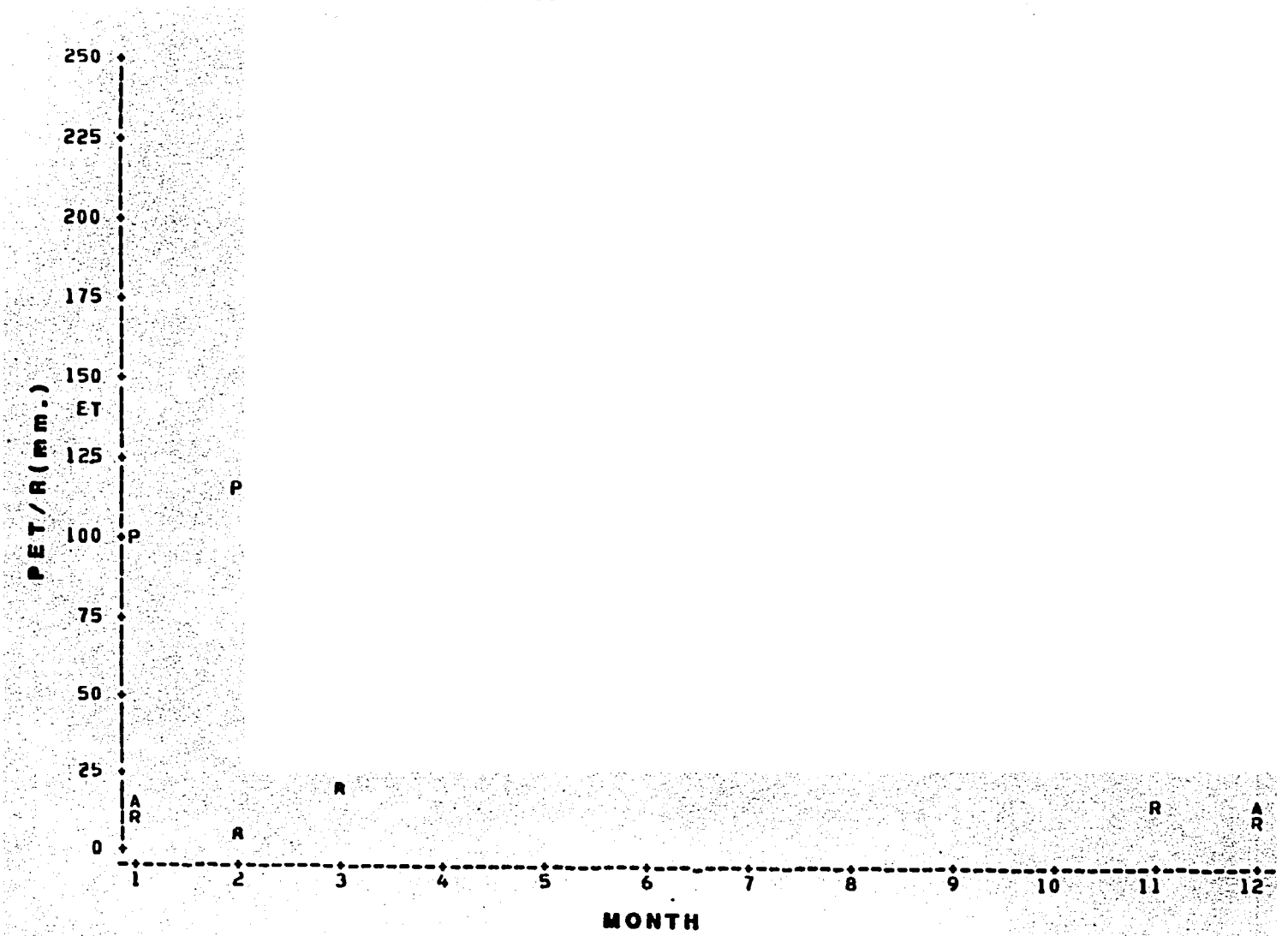

FIGURE 4.6c Climatic Diagram for Tha Phra Khon Kaen Showing Normal Precipitation (R), Potential Evapotranspiration (P) and Actual Evapotranspiration (A).

statistical crop yield forecast models used for assessing climate impact on crops. There are also many different tools for application to land and water management questions. For example, the R-Index has been widely used in land suitability studies.

The Moisture Availability Index (MAI) has been developed by Hargreaves (1977) for use in land classification studies. The MAI is defined as:

$$MAI = PD/PET$$

where PD is the dependable rainfall, and

PET is potential evapotranspiration.

Hargreaves (1977) has shown that PD should be taken as the monthly rainfall amount which has a 0.75 probability level of occurrence, for example as estimated by the gamma probability distribution. He further showed that PD is essentially equivalent to the 75th percentile which can be determined by ranking the monthly rainfall data. If time-series monthly rainfall data are not available, Hargreaves has developed statistical equations which can be used to adjust the "normal" rainfall amount to the 75th percentile estimate.

CHAPTER V

CLIMATIC IMPACT ASSESSMENT MODELING RESULTS

Climatic impact assessment models which were developed for Northeast Thailand include: 1) agroclimatic/crop condition indices for rice and maize, 2) soil moisture assessment procedures and 3) statistical climate/crop yield forecast models for main season rice and maize. These assessment models are based on relationships which 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 all the models require thorough test and evaluation, they provide a foundation for assessing climatic impact on crops during the growing season.

This Chapter includes information on the history of crop yield modeling, analytic steps for model development, discussion on the proposed assessment models for Northeast Thailand 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 impact assessment models for agriculture. The success of 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 climatic impact on crop yields and agricultural production. It has become recognized that these models can supplement and complement other information sources, e.g., crop information sources including farm and marketing reports, probability surveys involving area farm analysis, census, demand side economic analysis and others.

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 (UN/FAO) and the U.S. National Oceanic and Atmospheric Administration, Assessment and Information Services Center (AISC) are two organizations involved in this type of effort. The AISC program provides support to the Office of U.S. Foreign Disaster Assistance, Agency for International Development (AID/OFDA) (Steyaert et al, 1981).

Types of Crop Yield Models

There are essentially three types of crop yield models: 1) statistical climate/crop yield models, 2) agroclimatic/crop condition index models and 3) the phenologic or "process" models.

The statistical model is based on multiple linear regression analysis using historic climatic data and crop yield. These models provide absolute yield forecasts. 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, sugarcane, oil palm and others.

The second type of model is the agroclimatic/crop condition index which is also based on historic climatic data. This approach has become increasingly popular to assess crop conditions and to obtain relative crop yield information. The index is based on an agroclimatic variable such as cumulative precipitation, PET, ET/PET, soil moisture, 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, particularly for drought impact assessment.

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 reliable 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 in marginal, semi-arid production regions where crops are rainfed, 2) information on the appropriate variables determined by regression analysis for similar regions and 3) episodic event 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. Although these models are still in the research and development stage, they show promise. They were designed primarily to simulate the growth and development of a plant, for example, cotton, maize, wheat and sorghum. The models have been used as a farm management tool, for example, to examine various strategies for increasing production. The

models are being tested to determine if they can be used to provide assessment information on crop phenology and relative yields for a large area such as a province. The models work best in the regions where they were developed, but can be potentially adapted for application to other areas.

Applications

The statistical crop models and the agroclimatic/crop condition index models 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 climatic data into simulated yield. Simulated yields can be used to determine the risk of crop failure, estimate probabilities of crop failure (2 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 climatic 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 maize 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 maize 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 and episodic 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 a 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 can be 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 are:

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 often 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 to high yielding. 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. The models should be used to supplement other sources of information.

C. Agroclimatic/Crop Condition Indices

Agroclimatic/crop condition indices based on the GMI and YMI were developed for assessing drought impact. The GMI was calculated at each of the 24 meteorological stations indicated in Figure 3.1. The YMI for main season maize and rice was also calculated at these same stations. Both indices should be used in preparing climatic impact assessments.

1. Generalized Monsoon Index (GMI)

This monsoon index is based on June through September monthly precipitation data. The weights for each month are 0.125 for June, 0.125 for July, 0.50 for August and 0.25 for September. The index is accumulated at the end of each month.

The monthly rainfall data (P1=Jan, P2=Feb, etc.) for 1979 and the associated sample means from the period of record (NP1-Jan, NP2=Feb, etc.) at the meteorological stations are indicated in Table 5.1. These data were also listed by station.

Table 5.2 shows the calculated GMI for 1979 at these stations. The GMI is expressed in millimeters at the end of each time period (GMI_P6, GMI_P7, GMI_P8 and GMI_P9). The "normal" (i.e., sample mean) GMI at each period is provided: NGMI_P6 at the end of June, NGMI_P7 at the end of July, etc. The percent of normal GMI for 1979 at each station is shown: PNGMI_P6 for June, PNGMI_P7 for July, etc. The 1979 GMI values at each station are also expressed in percentiles which were determined from the historic record at each station. The percentile variable is PLGMI_P6 for June, PLGMI_P7 for July, etc.

Table 5.3 shows the GMI at Chaiyaphum for each year during the period 1957-1981. The variables named are the same as in Table 5.2 and the values for 1979 at Chaiyaphum agree in both tables.

OBSERVED AND NORMAL PRECIPITATION (MM.) BY STATIONS

COUNTRY=THAILAND REGION=NORTHEAST YEAR=1979

STATION	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	NP1
BURI RAM	1	56	2	97	178	185	94	104	282	9	0	0	3
CHAIYAPHUM	3	17	0	60	201	152	57	82	323	0	0	0	4
CHATTURAT	0	0	2	100	191	172	110	87	312	64	0	0	12
CHOK CHAI	0	9	0	65	203	204	202	153	255	0	0	0	9
KALASIN	0	0	18	113	417	402	98	219	437	0	0	0	6
KHAM KUAN KAEO	0	19	0	89	244	283	81	212	249	0	0	0	2
KHON KAEN	0	11	0	90	248	153	75	158	245	0	0	0	5
KOSUM PHISAI	0	80	8	68	273	442	121	142	165	5	0	0	7
LOEI	0	18	2	154	330	198	98	147	336	0	0	0	3
MAHA SARAKHAM	1	14	5	90	200	423	123	254	291	0	0	0	6
MUKDAHAN	0	7	0	51	100	86	58	62	230	48	1	0	5
N RATCHASIMA	2	7	17	124	290	495	435	523	200	0	0	0	4
NAKHON PHANOM	4	0	15	72	110	204	229	93	262	3	0	0	3
NANG RONG	1	26	11	84	279	273	103	206	192	2	0	0	7
NONG KHAI													8
PHUTTHAISONG	0	0	5	200	341	188	90	240	285	0	0	0	6
ROI ET	1	13	19	109	458	463	98	266	132	0	0	0	2
SAKHON NAKHON													3
SI SA KET	0	0	0	250	243	222	137	178	215	0	0	0	7
SURIN	0	0	0	143	203	292	166	222	240	0	0	0	0
THA TUM	1	2	3	109	231	463	99	512	292	3	1	0	2
U RATCHATHANI	6	24	3	69	215	167	150	226	106	0	0	0	2
UDON THANI													1
YASOTHON	-	-	-	-	-	-	-	-	-	-	-	-	7
													5

STATION	NP2	NP3	NP4	NP5	NP6	NP7	NP8	NP9	NP10	NP11	NP12
BURI RAM	12	34	69	165	175	155	178	304	132	25	1
CHAIYAPHUM	18	52	84	162	143	151	143	310	122	16	4
CHATTURAT	12	53	78	173	119	123	133	259	165	22	3
CHOK CHAI	14	37	68	161	109	119	123	252	153	28	2
KALASIN	17	30	59	195	233	227	247	286	64	4	2
KHAM KUAN KAEO	10	34	85	206	210	261	288	316	87	15	0
KHON KAEN	15	34	62	174	180	159	188	277	86	14	3
KOSUM PHISAI	10	38	64	160	166	145	174	257	75	8	3
LOEI	16	47	88	195	172	160	192	247	95	12	4
MAHA SARAKHAM	14	40	69	189	190	179	212	293	70	6	3
MUKDAHAN	16	39	86	185	282	244	309	295	63	4	1
N RATCHASIMA	25	53	69	158	114	132	125	263	158	30	3
NAKHON PHANOM	19	43	100	237	485	429	590	316	52	5	1
NANG RONG	18	38	75	164	150	154	172	284	171	26	3
NONG KHAI	9	27	98	250	293	260	331	301	51	8	4
PHUTTHAISONG	19	43	78	194	152	161	206	351	111	20	1
ROI ET	17	29	90	192	190	209	255	326	88	9	1
SAKHON NAKHON	16	43	86	231	263	211	320	260	62	6	3
SI SA KET	7	24	74	181	220	218	264	286	148	23	1
SURIN	10	28	88	181	160	196	201	282	132	22	2
THA TUM	8	29	75	157	178	190	206	298	109	13	1
U RATCHATHANI	9	42	79	205	255	280	320	279	92	20	2
UDON THANI	20	40	80	220	240	229	287	283	80	7	3
YASOTHON	15	27	66	196	194	224	263	313	84	12	0

TABLE 5.1 Northeast Thailand: Observed (P1, P2, etc.) and Normal (NP1, NP2, etc.) Station Rainfall (mm) for 1979.

G E N E R A L I Z E D M O N S O O N I N D E X
(S O U T H W E S T)

GMI COEFFICIENTS: WEIGHT6 = .125 / JUNE
WEIGHT7 = .125 / JULY
WEIGHT8 = .5 / AUGUST
WEIGHT9 = .25 / SEPTEMBER

COUNTRY=THAILAND REGION=NORTHEAST YEAR=1979

STATION	GMI 6	NGMI 6	PNGMI 6	PLGMI 6	GMI 7	NGMI 7	PNGMI 7	PLGMI 7	GMI 8	NGMI 8	PNGMI 8	PLGMI 8	GMI 9	NGMI 9	PNGMI 9	PLGMI 9
BURI RAM		22				41				130				206		
CHAIYAPHUM	23	18	129	71	35	37	95	42	87	108	80	32	157	186	85	28
CHATTURAT	19	15	128	72	26	30	86	32	67	97	69	24	148	161	92	44
CHOK CHAI	22	14	158	84	35	28	124	80	79	90	87	51	157	153	102	65
KALASIN	26	29	88	51	51	58	88	43	127	181	70	24	191	253	76	24
KHAM KUAN KAEO	50	26	192	93	62	59	106	58	172	203	85	27	281	282	100	56
KHON KAEN	35	22	157	81	45	42	107	60	152	136	111	71	214	206	104	54
KOSUM PHISAI	19	21	92	47	28	39	73	23	107	126	85	30	169	190	89	28
LOEI	55	22	257	96	70	42	170	89	142	138	103	68	183	199	92	46
MAHA SARAKHAM	25	24	105	64	37	46	80	32	110	152	73	19	194	225	86	32
MUKDAHAN	53	35	150	90	68	66	104	50	195	220	89	40	268	294	91	36
N RATCHASIMA	11	14	76	40	18	31	59	9	49	93	53	6	106	159	67	8
NAKHON PHANOM	62	61	102	58	116	114	102	62	378	409	92	41	428	488	88	32
NANG RONG	26	19	136	84	54	38	142	84	101	124	81	28	166	195	85	26
NONG KHAI	34	37	93	52	47	59	66	11	150	235	64	5	198	310	64	6
PHUTTHAISONG		19				39				142				230		
ROI ET	24	24	99	57	35	50	69	15	155	177	87	43	226	259	87	35
SAKHON NAKHON	58	33	176	95	70	59	118	73	203	219	93	50	236	284	83	35
SI SA KET																
SURIN	28	20	139	81	45	44	101	46	134	145	92	45	188	216	87	35
THA TUM	36	22	164	83	57	46	124	70	168	149	113	62	228	224	102	60
U RATCHATHANI	58	32	182	93	70	67	105	65	326	227	144	93	399	297	135	90
UDON THANI	21	30	[illegible]	21	40	59	68	9	152	202	75	25	179	273	66	9
YASOTHON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 5.2 Generalized Monsoon Index Analysis During the 1979 Southwest Monsoon Season for Stations in Northeast Thailand.

GENERALIZED MONSOON INDEX
(SOUTHWEST)

GMI COEFFICIENTS: WEIGHT6 = .125 / JUNE
WEIGHT7 = .125 / JULY
WEIGHT8 = .5 / AUGUST
WEIGHT9 = .25 / SEPTEMBER

---------- COUNTRY=THAILAND REGION=NORTHEAST STATION=CHAIYAPHUM ----------

YEAR	GMI P6	NGMI P6	PNGMI6	PLGMI6	GMI67	NGMI67	PNGMI67	PLGMI67	GMI68	NGMI68	PNGMI68	PLGMI68	GMI69	NGMI69	PNGMI69	PLGMI69
1957	18	18	98	51	42	17	115	65	118	108	110	61	222	186	120	76
1958	27	18	148	84	38	37	105	57	179	108	166	96	279	186	150	96
1959	10	18	55	19	33	37	91	36	99	108	92	46	235	186	126	80
1960	26	18	143	80	45	37	121	78	103	108	95	49	141	186	76	22
1961	12	18	69	26	27	37	74	26	82	108	76	19	128	186	69	16
1962	7	18	40	11	44	37	119	73	105	108	98	53	260	186	140	88
1963	15	18	82	40	47	37	128	84	141	108	130	82	202	186	109	60
1964	8	18	47	15	48	37	129	88	130	108	121	76	209	186	113	68
1965	18	18	99	51	37	37	100	49	119	108	110	65	193	186	104	48
1966	15	18	83	40	23	37	62	15	160	108	148	88	202	186	109	60
1967	14	18	76	32	26	37	72	23	112	108	103	57	167	186	90	40
1968	29	18	161	88	54	37	147	92	77	108	71	15	103	186	56	4
1969	30	18	166	92	43	37	117	69	95	108	88	38	249	186	134	84
1970	22	18	125	63	36	37	97	46	97	108	90	42	166	186	90	36
1971	19	18	108	57	32	37	88	30	141	108	131	82	217	186	117	72
1972	25	18	140	76	33	37	90	36	68	108	63	11	112	186	60	8
1973	16	18	87	46	38	37	104	57	124	108	115	73	194	186	105	52
1974	4	18	21	3	14	37	38	3	65	108	60	7	119	186	64	12
1975	22	18	123	63	38	37	103	57	83	108	77	24	178	186	96	44
1976	11	18	64	23	25	37	69	19	87	108	81	32	141	186	76	22
1977	14	18	80	32	22	37	61	11	123	108	114	69	202	186	109	60
1978	23	18	130	71	77	37	210	96	175	108	162	92	278	186	150	92
1979	23	18	129	71	35	37	95	42	87	108	80	32	157	186	85	28
1980	34	18	192	96	45	37	121	78	83	108	77	24	158	186	85	32
1981	6	18	32	7	17	37	46	7	47	108	43	3		186		
1982																
1983	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 5.3 Historical Generalized Monsoon Index (Southwest) Analysis for Chaiyaphum

Tables similar to Table 5.3 have been developed for other stations and there are provisions at the bottom of each table for calculating the GMI to make assessments during the period after 1981.

Figure 5.1 shows the time-series plot of the GMI (expressed in percentiles) at Chaiyaphum during the period 1957 and at the end of each assessment month (6=June, 7=July, etc.). Similar plots have been developed for the other stations. This graphical plot is a most useful way to view the year-to-year variations of the GMI at a particular station.

For example, the percentiles of the GMI at the end of June, July, August and September during 1981 at Chaiyaphum were all below the 10th percentile. This suggests extremely dry conditions during the growing season, possibly severe drought impact at Chaiyaphum. Episodic event data can be used to verify these conditions. The GMI for 1980 suggests good monsoon conditions during June and July, but below normal conditions during August and September. Because the GMI at the end of the heavy monsoon rainfall months of August and September is about the 30th percentile in 1980, there is a suggestion of moderate drought impact.

The GMI is primarily designed to assess drought impact. However, GMI values above the 80-90th percentiles may be indicating flooding situations. These need to be verified by using episodic data and local experience.

One of the primary tasks to be accomplished during test and evaluation is the "calibrated interpretation" of the GMI (this also applies to the other index models). Again, episodic event data and local experience are useful guides. A preliminary criteria for the critical thresholds for interpreting the GMI could be: 1) 90-100th percentile range for possible excessive moisture; 2) 60-90th percentile range for possible above normal crops, 3) 40-60th percentile range for normal crops, 4) 30-40th percentile range for moderate drought impact on crops, 5) 20-30th percentile range for drought impact on crops and somewhere

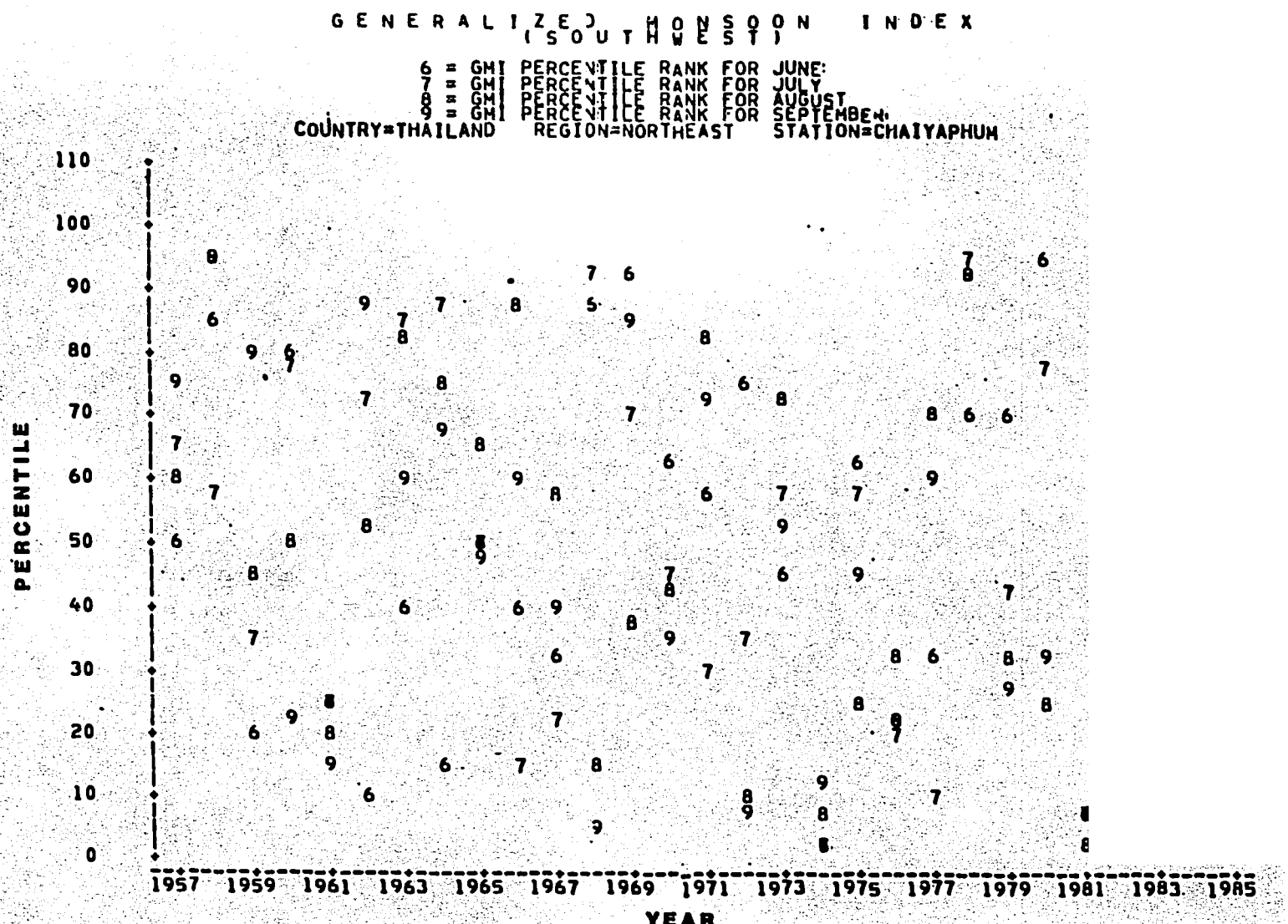

FIGURE 5.1 Historical GMI (Southwest) Percentile Rankings by Month for Chaiyaphum.

in the 0-20th percentile range there could be severe drought impact and maybe crop failure.

The GMI was defined for southwest monsoon conditions in Northeast Thailand. The index could also be defined for peninsular regions of Thailand where the Northeast monsoon provides substantial rainfall.

2. Yield Moisture Index (YMI)

The YMI was determined for main season maize and rice using crop calendar information, estimated crop coefficients for Northeast Thailand and monthly rainfall data at the same stations used in the GMI analysis. Although maize and rice were chosen, the YMI for other crops that are susceptible to drought could have also been used. AISC uses the YMI to assess short-cycle crops such as rice, maize, beans, sorghum, millet, etc., that are vulnerable to drought. Long-cycle, drought resistant crops such as cassava, cow peas, etc., are not easily assessed by this index technique.

The YMI is directly analogous to the GMI; however, the YMI is crop specific and the GMI pertains to general crop conditions for crops planted during June. The following tables and figures are directly comparable to those discussed under the GMI.

<u>YMI/MAIZE</u>

The YMI for maize was defined for planting in May, vegetative stage in June and flowering/reproductive stage in July. The preliminary crop coefficients for each of these crop stages are 0.35 for planting, 0.50 for vegetative and 1.05 for flowering. The YMI is accumulated at the end of each stage. The index value and its relationship to potential drought impact on the crop becomes most reliable at the end of flowering.

Table 5.4 and 5.5 show the YMI for maize at the stations in Northeast Thailand and during 1979 and at Chaiyaphum (1957-1981), respectively. The index is expressed in millimeters at the end of planting (YMI_P), vegetative (YMI_V) and flowering (YMI_F). "Normal" (or sample mean) values of the YMI determined from the period of record at each station are indicated, e.g., NYMI_P at planting, etc. The percent normal values (PNYMI_P at the end of the planting, etc.) are indicated. The percentile values for each crop stage are provided (e.g., PLYMI_P for planting).

Figure 5.2 shows the historic plot of the YMI/Maize (in percentiles) at Chaiyaphum. The use of the YMI in assessments and the interpretation of the YMI is directly analogous to the discussion in the GMI, except the YMI is specifically designed for maize.

The percentiles indicated in Figure 5.2 can be interpreted as follows. The YMI at the end of planting ("P" in Figure 5.2) and end of vegetative crop stage ("V") and flowering ("F") suggest crop conditions during the growing season. The percentile value at the end of flowering also suggests relative maize yield, i.e., the maize yield relative to yields in other years. This type of index information can be converted into an estimate of absolute crop yield; however, this requires assumptions that are usually are very subjective. Therefore, crop condition assessments should be confined to statements based on relative information (i.e., percentiles, percent of normal index, etc.). It should be noted that percent normal YMI does not equate to percent normal yield.

YMI/RICE

Tables 5.6 and 5.7 plus Figure 5.3 exemplify the development of the YMI/Rice at individual stations in Northeast Thailand. The analysis is essentially the same as for the YMI/Maize except for the crop calendar and crop coefficients.

YIELD MOISTURE INDEX

CROP COEFFICIENTS: KC5 = .35/ PLANTING / MAY
KC6 = .50/ VEGETATION / JUNE
KC7 =1.05/ FLOWERING / JULY

---------- YEAR=1979 COUNTRY=THAILAND REGION=NORTHEAST CROP=MAIZE SEASON=MAIN ----------

STATION	YMI F	NYMI P	PNYMI P	PLYMI P	YMI V	NYMI V	PNYMI V	PLYMI V	YMI F	NYMI F	PNYMI F	PLYMI F
BURI RAM		58				145				308		
CHAIYAPHUM	62	57	110	53	155	128	121	73	253	287	88	42
CHATTURAT	70	60	116	68	146	120	122	80	205	249	83	24
CHOK CHAI	67	56	118	73	153	111	138	83	269	236	114	65
KALASIN	71	68	104	62	173	185	94	55	385	423	91	28
KHAM KUAN KAEO	146	72	202	89	347	177	196	96	449	451	100	48
KHON KAEN	85	61	140	81	227	151	150	87	311	318	98	50
KOSUM PHISAI	87	56	155	92	163	139	118	73	242	291	83	26
LOEI	95	68	140	79	317	154	205	96	444	322	138	86
MAHA SARAKHAM	115	66	175	86	215	161	133	89	318	349	91	27
MUKDAHAN	70	65	108	56	281	205	137	87	411	461	89	37
N RATCHASIMA	35	55	63	25	78	112	70	18	139	251	55	6
NAKHON PHANOM	101	83	123	79	349	325	107	62	805	776	104	62
NANG RONG	38	57	67	26	141	132	106	69	381	294	129	88
NONG KHAI	97	87	112	55	234	234	100	55	342	507	68	17
PHUTTHAISONG		68				144				313		
ROI ET	119	67	177	90	213	162	131	84	307	382	80	21
SAKHON NAKHON	160	81	198	96	392	213	184	96	494	434	114	68
SI SA KET												
SURIN	85	63	134	75	196	143	137	87	340	349	97	46
THA TUM	71	55	129	72	217	144	151	87	391	344	114	62
U RATCHATHANI	81	72	113	71	312	199	157	93	417	493	85	34
UDON THANI	75	77	98	45	159	197	81	21	316	437	72	12
YASOTHON	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 5.4 Yield Moisture Index Analysis for the 1979 Main Maize Crop at Stations in Northeast Thailand.

YIELD MOISTURE INDEX

CROP COEFFICIENTS: KC5 = .35/ PLANTING / MAY
KC6 = .50/ VEGETATION / JUNE
KC7 =1.05/ FLOWERING / JULY

---- COUNTRY=THAILAND REGION=NORTHEAST STATION=CHAIYAPHUM CROP=MAIZE SEASON=MAIN -----

YEAR	YMI_P	NYMI_P	PNYMI_P	PLYMI_P	YMI_V	NYMI_V	PNYMI_V	PLYMI_V	YMI_F	NYMI_F	PNYMI_F	PLYMI_F
1957	47	57	83	30	117	128	91	38	324	287	113	76
1958	19	57	33	11	125	128	97	49	225	287	79	30
1959	84	57	149	84	124	128	96	42	322	287	112	73
1960	50	57	88	38	152	128	119	69	311	287	108	65
1961	63	57	111	57	112	128	88	30	236	287	82	34
1962	87	57	154	92	116	128	91	34	424	287	148	88
1963	16	57	28	7	75	128	58	11	346	287	121	80
1964	78	57	138	76	112	128	87	26	441	287	154	92
1965	77	57	136	73	148	128	115	65	307	287	107	57
1966	85	57	149	88	144	128	112	61	209	287	73	23
1967	31	57	55	19	85	128	67	15	193	287	67	15
1968	75	57	133	69	190	128	149	96	402	287	140	84
1969	55	57	97	42	174	128	136	84	285	287	100	53
1970	69	57	121	61	158	128	123	76	269	287	94	49
1971	60	57	107	46	138	128	108	57	248	287	86	38
1972	3	57	5	3	102	128	80	23	172	287	60	11
1973	61	57	109	49	124	128	97	46	314	287	109	69
1974	28	57	50	15	43	128	34	3	128	287	45	3
1975	90	57	159	96	178	128	139	88	310	287	108	61
1976	49	57	87	34	95	128	74	19	211	287	74	26
1977	71	57	126	65	129	128	100	53	195	287	68	19
1978	80	57	141	80	173	128	135	80	623	287	218	96
1979	62	57	110	53	155	128	121	73	253	287	88	42
1980	41	57	73	26	179	128	139	92	264	287	92	46
1981	34	57	60	23	57	128	44	7	150	287	52	7
1982												
1983	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 5.5 Historical Yield Moisture Index Analysis for the Main Maize Crop at Chaiyaphum.

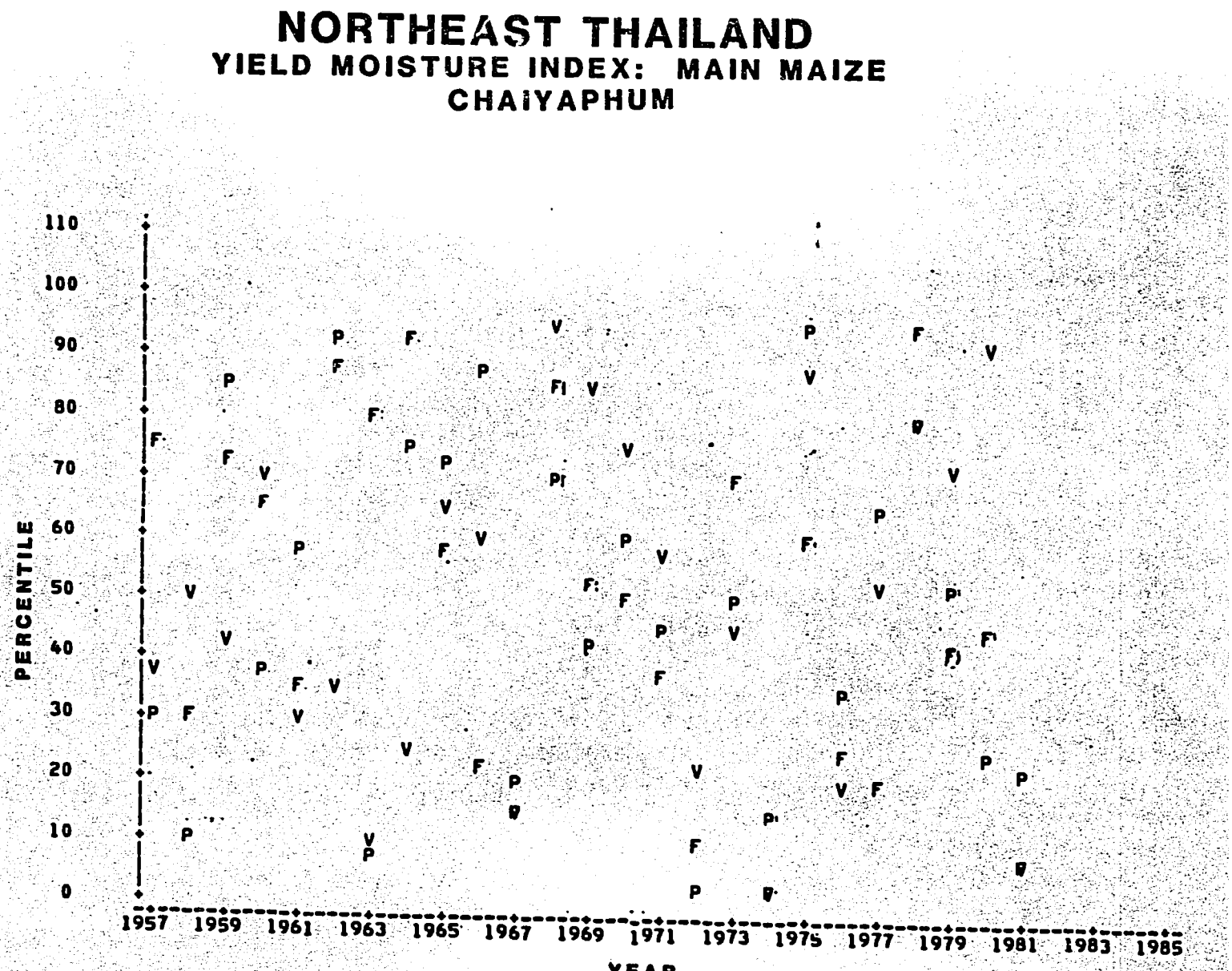

FIGURE 5.2 Percentile Rankings of the Yield Moisture Index for Main Maize at Chaiyaphum by Crop Stage (P=Planting, V=Vegetation and F=Flowering).

YIELD MOISTURE INDEX

CROP COEFFICIENTS:
KC7 = .65/ TRANSPLANTING / JULY
KC8 = .85/ VEGETATION I / AUGUST
KC9 = .95/ VEGETATION II / SEPTEMBER
KC10=1.05/ FLOWERING / OCTOBER
KC11= .95/ MATURATION / NOVEMBER

-------- YEAR=1979 COUNTRY=THAILAND REGION=NORTHEAST CROP=RICE SEASON=MAIN -------

STATION	YMIT P	NYMI T P	PNYMI T P	PLYMI T P	YMI T 1	NYMI T 1	PNYMI T 1	PLYMI T 1	YMI T 2	NYMI T 2	PNYMI T 2	PLYMI T 2	YMI T F1	NYMI T F	PNYMI T F	PLYMI T F	YMI T M	NYMI T M	PNYMI T M	PLYMI T M
BURI RAM		101				252				541				679				702		
CHAIYAPHUM	61	98	62	26	149	219	65	19	417	514	81	32	427	642	67	8	427	657	65	8
CHATTURAT	37	80	46	12	107	193	55	8	413	439	94	40	413	550	75	16	413	571	72	16
CHOK CHAI	72	77	93	53	145	182	80	38	442	422	105	53	509	583	87	34	509	609	84	26
KALASIN	131	147	89	37	262	359	73	24	503	629	80	24	503	596	72	13	503	700	72	13
KHAM KUAN KAEO	63	170	37	6	249	414	60	6	664	714	93	44	664	805	82	27	664	819	81	24
KHON KAEN	52	104	51	12	233	263	83	34	470	526	89	32	470	617	76	12	470	629	75	12
KOSUM PHISAI	48	94	52	23	183	242	75	26	415	486	86	30	415	565	74	23	415	572	73	19
LOEI	79	104	76	41	200	268	75	13	357	502	71	7	362	502	60	7	362	613	59	7
MAHA SARAKHAM	64	116	55	17	189	296	64	10	507	574	88	39	507	648	78	28	507	654	78	28
MUKDAHAN	80	158	51	12	296	421	70	21	573	701	82	16	573	768	75	13	573	771	74	9
N RATCHASIMA	38	86	44	6	90	192	47	9	308	442	70	9	359	508	59	3	360	636	57	3
NAKHON PHANOM	262	279	101	55	727	781	93	48	917	1080	85	17	917	1135	81	10	917	1140	80	10
NANG RONG	149	100	148	88	228	247	92	49	476	517	92	34	480	597	69	7	480	722	66	7
NONG KHAI	67	169	40	5	242	450	54	5	425	736	58	6	427	790	54	6	427	797	54	6
PHUTTHAISONG		105				280				513				729				748		
ROI ET	58	136	43	3	263	353	75	15	534	662	81	19	534	754	71	12	534	763	70	12
SAKHON NAKHON	64	137	46	9	289	409	71	18	415	557	63	3	415	722	57	3	415	727	57	3
SI SA KET																				
SURIN	89	127	70	25	241	299	81	21	445	565	78	12	445	705	63	6	445	726	61	6
THA TUM	108	124	87	37	296	299	99	41	524	582	90	41	524	696	75	16	524	708	74	12
U RATCHATHANI	65	192	35	3	500	454	110	58	777	719	108	58	780	815	96	35	781	834	94	23
UDON THANI	97	149	65	15	289	393	74	21	390	561	59	6	390	745	52	3	390	752	52	3
YASOTHON	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 5.6 Yield Moisture Index Analysis for the 1979 Main Rice Crop at Stations in Northeast Thailand.

YIELD MOISTURE INDEX

CROP COEFFICIENTS:

KC7 = .65/	TRANSPLANTING	/ JULY	
KC8 = .85/	VEGETATION I	/ AUGUST	
KC9 = .95/	VEGETATION II	/ SEPTEMBER	
KC10=1.05/	FLOWERING	/ OCTOBER	
KC11= .95/	MATURATION	/ NOVEMBER	

COUNTRY=THAILAND REGION=NORTHEAST STATION=CHAIYAPHUM CROP=RICE SEASON=MAIN

YEAR	YMI TP	NYMI TP	PNYMI TP	PLYMI TP	YMI TV1	NYMI TV1	PNYMI TV1	PLYMI TV1	YMI TV2	NYMI TV2	PNYMI TV2	PLYMI TV2	YMI F	NYMI F	PNYMI F	PLYMI F	YMI M̄	NYMI M̄	PNYMI M̄	PLYMI M̄
1957	128	98	131	76	258	219	118	69	653	514	127	76	749	642	117	72	754	657	115	72
1958	62	98	63	30	302	219	137	84	680	514	132	80	716	642	111	64	716	657	109	64
1959	123	98	125	73	235	219	107	57	749	514	146	88	769	642	120	80	769	657	117	76
1960	98	98	100	61	197	219	90	46	343	514	67	12	577	642	90	44	583	657	89	44
1961	77	98	78	53	170	219	78	30	346	514	67	16	534	642	83	28	534	657	81	24
1962	190	98	194	88	295	219	135	80	884	514	172	96	1091	642	170	96	1093	657	166	96
1963	168	98	171	84	327	219	149	88	559	514	109	68	751	642	117	76	854	657	130	80
1964	204	98	208	92	344	219	157	92	645	514	126	72	1029	642	160	92	1060	657	161	92
1965	99	98	101	65	239	219	109	61	518	514	101	52	568	642	88	40	578	657	88	40
1966	40	98	41	3	275	219	125	76	433	514	84	40	650	642	101	56	682	657	104	60
1967	66	98	68	34	211	219	96	49	422	514	82	36	483	642	75	20	540	657	82	25
1968	131	98	134	80	170	219	78	34	259	514	52	4	402	642	63	4	402	657	61	4
1969	69	98	70	46	158	219	72	23	744	514	145	84	843	642	131	84	866	657	132	88
1970	69	98	70	42	174	219	79	38	436	514	85	44	517	642	81	24	517	657	79	20
1971	68	98	69	38	253	219	115	65	541	514	105	64	609	642	95	52	609	657	93	52
1972	43	98	44	11	103	219	47	3	270	514	52	8	437	642	68	12	442	657	67	12
1973	118	98	120	69	264	219	120	73	529	514	103	60	545	642	85	32	546	657	83	32
1974	53	98	54	15	139	219	63	15	346	514	67	20	437	642	68	16	467	657	71	16
1975	81	98	83	57	158	219	72	26	520	514	101	56	669	642	104	60	677	657	103	56
1976	72	98	73	49	177	219	81	42	353	514	75	24	716	642	112	68	750	657	114	68
1977	41	98	42	7	212	219	97	53	513	514	100	48	557	642	87	36	557	657	85	36
1978	280	98	286	96	447	219	204	96	839	514	163	92	851	642	133	88	859	657	131	84
1979	61	98	62	26	149	219	68	19	417	514	81	32	427	642	67	8	427	657	65	8
1980	53	98	54	19	119	219	54	11	404	514	79	28	586	642	91	48	586	657	89	48
1981	58	98	59	23	109	219	50	7	–	514	–	–	–	642	–	–	–	657	–	–
1982	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1983	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1984	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1985	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

TABLE 5.7 Historical Yield Moisture Index Analysis for the Main Rice Crop at Chaiyaphum.

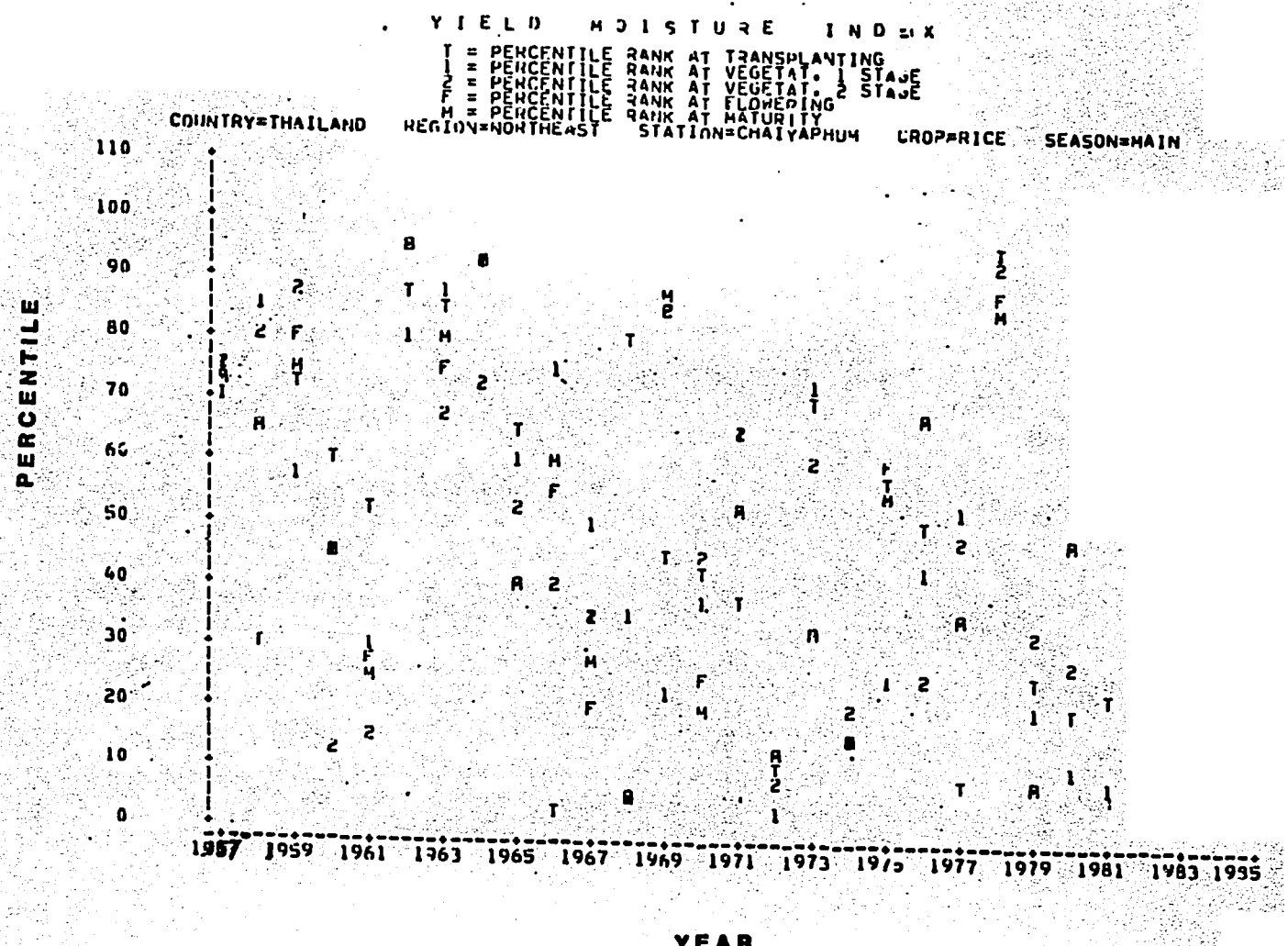

FIGURE 5.3 Percentile Rankings of the Yield Moisture Index for Main Rice at Chaiyaphum by Crop Stage (T=Transplanting, 1=Vegetative I, 2= Vegetative II, F=Flowering, M=Maturity).

These include: 1) planting in June with a crop coefficient of 0.85, 2) vegetation in July with KC of 1.05, 3) flowering in August with KC of 1.05 and 4) maturation in September with KC of 0.95.

D. Soil Moisture Assessments

The Palmer two-layer soil moisture budget model was used to estimate soil moisture at the agrometeorological stations (Figure 3.2). The Penman PET method was used in estimating the monthly soil moisture budget. The Appendix also contains the results of this analysis.

The soil moisture budget was similarly estimated at the twelve synoptic stations (Figure 3.1), except that "normal" PET was used (Table 5.8).

The R-Index (AET/PET), Soil Moisture Index (SMI) and the Palmer Drought Index (PDI) were also calcuated at the agrometeorological and synoptic stations in Northeast Thailand. These indices are by-products of the soil moisture budgeting process as outlined above (Figure 5.4).

The soil moisture estimates can be incorporated into the assessments. The derived indices may also be useful in crop conditions analysis. However, test and evaulation must be performed. Specifically, the analysis is based on an assumed maximum available water capacity (AWC) of 100.4 mm in the soil profile. This generally results in a full profile particularly during August. The implications must be carefully evaluated.

E. Statistical Climate/Crop Yield Forecast Models for Northeast Thailand

Statistical climate/crop yield models were developed for maize and main rice in Northeast Thailand. Although these preliminary models require thorough test and evaluation, they are promising. Testing should include evaluation of independent predictions for years not in the data base. The predictor variable in the models should be validated to ensure that they are biologicall related to

NORTHEAST THAILAND
SOIL MOISTURE BUDGET: PALMER 2 - LAYER MODEL
SURIN

STARTING BUDGET VALUE SS WITH	0.0000
STARTING BUDGET VALUE SU WITH	50.0000
STARTING BUDGET VALUE S WITH	50.0000
STARTING BUDGET VALUE AWCS WITH	25.4000
STARTING BUDGET VALUE AWCU WITH	75.0000
STARTING BUDGET VALUE AWC WITH	100.4000

SOIL MOISTURE BUDGET FOR OBSERVATION # 25

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SS	0.0000	0.0000	0.0000	0.0000	25.4000	25.4000	25.4000	25.4000	25.4000	25.4000	0.0000	0.0000
SU	1.2966	0.2376	0.0293	0.0036	12.6036	75.0000	75.0000	75.0000	75.0000	75.0000	49.1534	9.9873
S	1.2966	0.2376	0.0293	0.0036	38.0036	100.4000	100.4000	100.4000	100.4000	100.4000	49.1534	9.9873
PCP	0.0000	30.0000	52.0000	55.0000	175.0000	222.0000	218.0000	230.0000	529.0000	271.0000	33.0000	1.0000
PET	77.0000	112.0000	140.0000	143.0000	137.0000	138.0000	125.0000	127.0000	106.0000	103.0000	93.0000	81.0000
ET	4.2667	31.0590	52.2083	55.0257	137.0000	138.0000	125.0000	127.0000	106.0000	103.0000	84.2466	40.1660
PR	94.8367	99.1034	100.1624	100.3707	100.3964	62.3954	0.0000	0.0000	0.0000	0.0000	0.0000	51.2466
R	0.0000	0.0000	0.0000	0.0000	38.0000	62.3954	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
PL	4.2667	1.4464	0.3314	0.0418	0.0049	39.5351	99.8024	101.2964	85.6092	83.3681	75.8980	39.6556
L	4.2667	1.0590	0.2083	0.0257	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	51.2466	39.1660
PRO	5.5633	1.2966	0.2376	0.0293	0.0036	38.0036	100.4000	100.4000	100.4000	100.4000	100.4000	49.1534
RO	0.0000	0.0000	0.0000	0.0000	0.0000	21.6036	93.0000	103.0000	423.0000	168.0000	0.0000	0.0000

SOIL MOISTURE BUDGET FOR OBSERVATION # 26

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SS	0.0000	0.0000	0.0000	0.0000	25.4000	6.4000	25.4000	25.4000	25.4000	0.0000	0.0000	0.0000
SU	1.5319	0.0000	0.0000	0.0000	17.6000	17.6000	18.6000	75.0000	75.0000	40.1892	1.7613	0.3754
S	1.5319	0.0000	0.0000	0.0000	43.0000	24.0000	44.0000	100.4000	100.4000	40.1892	1.7613	0.3754
PCP	0.0000	0.0000	49.0000	33.0000	186.0000	133.0000	149.0000	276.0000	165.0000	36.0000	1.0000	2.0000
PET	85.0000	101.0000	137.0000	132.0000	143.0000	152.0000	129.0000	126.0000	108.0000	108.0000	97.0000	81.0000
ET	8.4554	1.5411	49.0000	33.0000	143.0000	152.0000	129.0000	126.0000	108.0000	96.2108	39.4280	3.3859
PR	90.4127	98.8681	100.4000	100.4000	100.4000	57.4000	76.4000	56.4000	0.0000	0.0000	60.2108	98.6387
R	0.0000	0.0000	0.0000	0.0000	43.0000	0.0000	20.0000	56.4000	0.0000	0.0000	0.0000	0.0000
PL	8.4554	1.5411	0.0000	0.0000	0.0000	47.5928	27.8916	44.0371	87.1032	87.1032	38.8283	1.4210
L	8.4554	1.5411	0.0000	0.0000	0.0000	19.0000	0.0000	0.0000	0.0000	60.2108	38.4280	1.3859
PRO	9.9873	1.5319	0.0000	0.0000	0.0000	43.0000	24.0000	44.0000	100.4000	100.4000	40.1892	1.7613
RO	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	93.6000	57.0000	0.0000	0.0000	0.0000

SOIL MOISTURE BUDGET FOR OBSERVATION # 27

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
SS	0.0000	0.0000	0.0000	25.4000	25.4000	0.0000	25.4000	25.4000	25.4000	9.4000	0.0000	0.0000
SU	0.1211	0.0000	0.0000	41.6000	75.0000	64.0936	75.0000	75.0000	75.0000	75.0000	29.7311	0.0000
S	0.1211	0.0000	0.0000	67.0000	100.4000	64.0936	100.4000	100.4000	100.4000	84.4000	29.7311	0.0000
PCP	37.0000	2.0000	80.0000	204.0000	326.0000	99.0000	303.0000	309.0000	310.0000	102.0000	28.0000	0.0000
PET	105.0000	111.0000	134.0000	137.0000	150.0000	139.0000	129.0000	128.0000	104.0000	118.0000	98.0000	106.0000
ET	37.2543	2.1315	80.0000	137.0000	150.0000	135.3064	129.0000	128.0000	104.0000	118.0000	82.6689	31.3894
PR	100.0246	100.2789	100.4000	100.4000	33.4000	0.0000	36.3064	0.0000	0.0000	0.0000	16.0000	70.6689
R	0.0000	0.0000	0.0000	67.0000	33.4000	0.0000	36.3064	0.0000	0.0000	0.0000	0.0000	0.0000
PL	0.3926	0.1339	0.0000	0.0000	77.0271	110.2606	82.3514	102.0434	84.1151	94.5733	75.5803	31.3894
L	0.2543	0.1315	0.0000	0.0000	0.0000	36.3064	0.0000	0.0000	0.0000	16.0000	54.6689	31.3894
PRO	0.3754	0.1211	0.0000	0.0000	67.0000	100.4000	64.0936	100.4000	100.4000	84.4000	29.7311	0.0000
RO	0.0000	0.0000	0.0000	0.0000	142.6000	0.0000	137.6936	181.0000	206.0000	0.0000	0.0000	0.0000

TABLE 5.8 Soil Moisture Budget for Surin Using the Palmer 2-Layer Model.

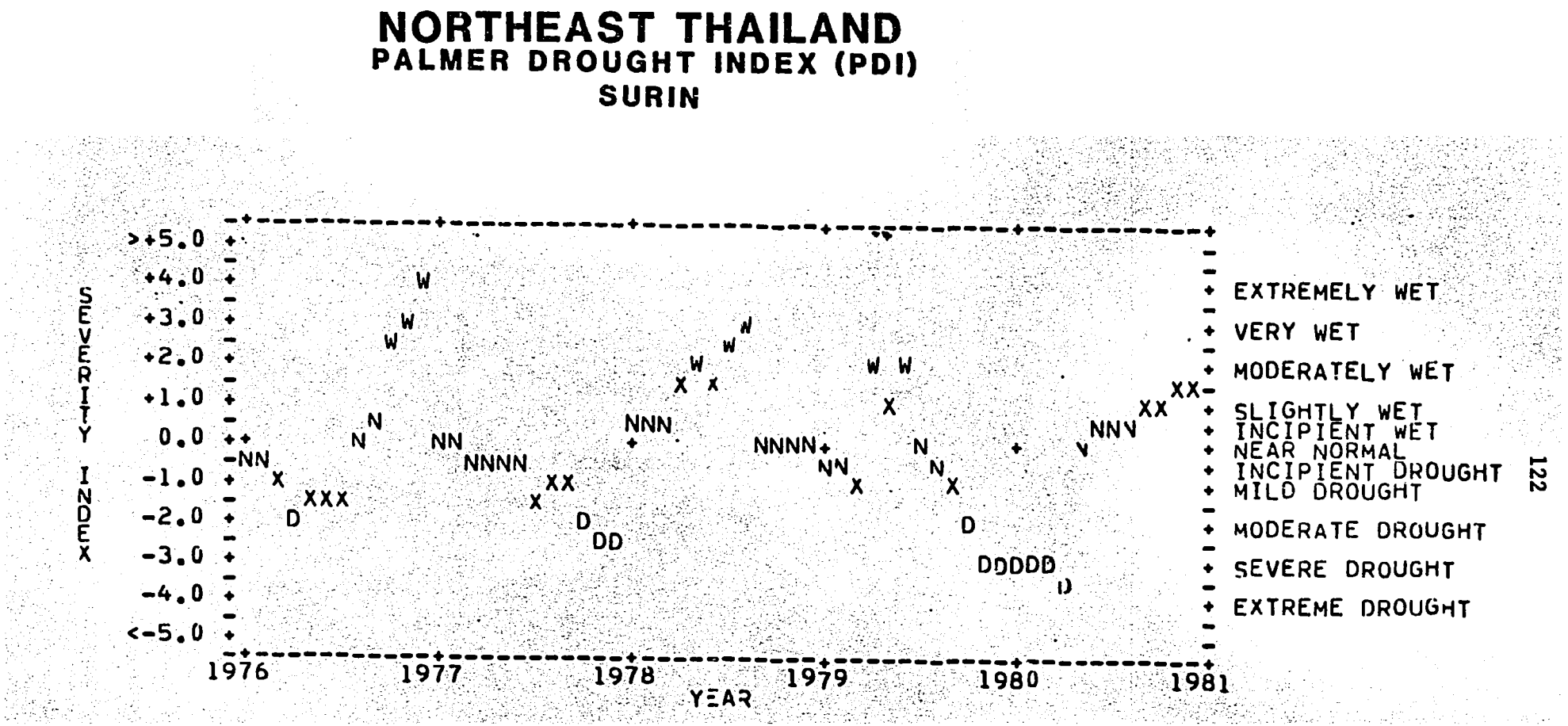

FIGURE 5.4 Palmer Drought Index Analysis for Surin

the crop and reflect vulnerability of the crop to climate anomalies which lead to yield losses.

Monthly precipitation and temperature were used as predictor variabiles in developing the linear regression models for maize and rice.

The linear regression models have the form:

$$\hat{Y} = a_o + \sum_{i=1}^{N} a_i x_i$$

where:

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

a_o is the regression constant (i.e., intercept), and

a_i is the ith estimated regression coefficient for the Nth meteorological variable x_i.

Maize Models

Maize data on area, production and yield for Northeast Thailand is provided in Table 5.9. The standardized plot of the data (Figure 5.5) indicates no significant trend in the yield. This may be due to: 1) an expansion of the crop into marginal areas and/or 2) the low level of technological inputs to maize provided by most farmers.

The input data for modeling maize are shown in Table 5.10. Linear correlations between yield and weather variables or detrended yield and weather variables are shown in Table 5.11. Maize in Northeast Thailand is generally planted in May and harvested during late August through September.

Time-series plots of P5_8 (May-August rainfall), P5_9 (May-September rainfall) and T8 (August temperatures) overlayed with yield are shown in Figures 5.6-5.8. The year 1968 was deleted from the analysis due to the incidence of pests and disease.

OBS	COUNTRY	REGION	CROP	YEAR	AREA	PROD	YIELD
1	THAILAND	NORTHEAST	MAIZE	1967	524020	122775	0.234294
2	THAILAND	NORTHEAST	MAIZE	1968	647295	129440	0.199971
3	THAILAND	NORTHEAST	MAIZE	1969	500900	165000	0.329407
4	THAILAND	NORTHEAST	MAIZE	1970	689100	280000	0.406327
5	THAILAND	NORTHEAST	MAIZE	1971	1006000	401500	0.399105
6	THAILAND	NORTHEAST	MAIZE	1972	1100000	215600	0.196000
7	THAILAND	NORTHEAST	MAIZE	1973	1536000	456000	0.296875
8	THAILAND	NORTHEAST	MAIZE	1974	1874000	553000	0.295091
9	THAILAND	NORTHEAST	MAIZE	1975	2143022	704062	0.328537
10	THAILAND	NORTHEAST	MAIZE	1976	2586700	744208	0.287706
11	THAILAND	NORTHEAST	MAIZE	1977	1859746	394433	0.212090
12	THAILAND	NORTHEAST	MAIZE	1978	2047943	566909	0.276819
13	THAILAND	NORTHEAST	MAIZE	1979	2437036	673542	0.276378
14	THAILAND	NORTHEAST	MAIZE	1980	2267002	730408	0.322191
15	THAILAND	NORTHEAST	MAIZE	1981	3043753	970842	0.318962

TABLE 5.9 Area (Rai), Production (Metric Tons) and Yield (MT/Rai) Data for Maize in Northeast Thailand.

NORTHEAST THAILAND
MAIZE: AREA, PRODUCTION, AND YIELD

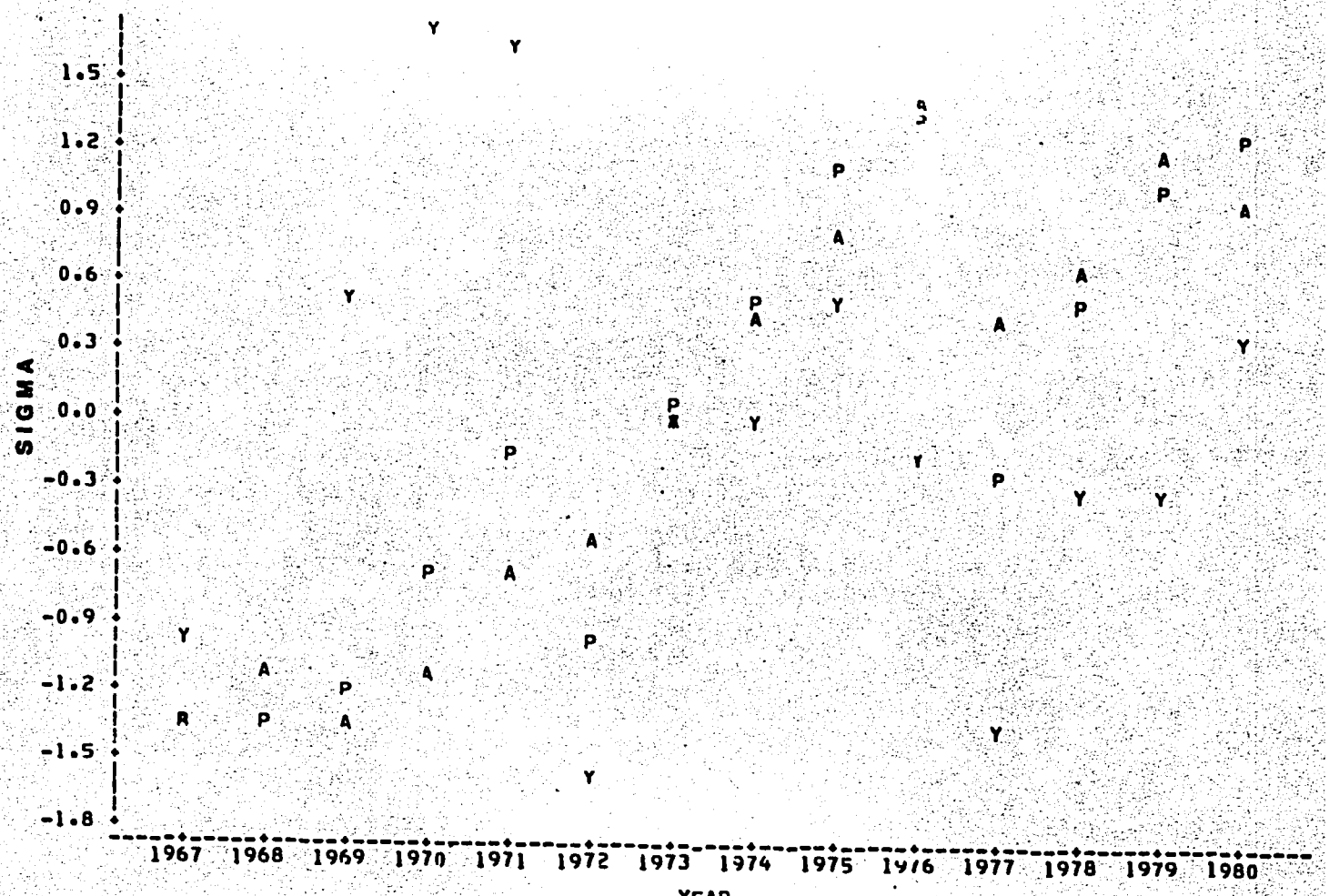

FIGURE 5.5 Standardized Plot of Area (A), Production (P) and Yield (Y) for Maize in Northeast Thailand.

NORTHEAST THAILAND: INPUT DATA FOR CROP MODELING 5

---------- COUNTRY=THAILAND REGION=NORTHEAST CROP=MAIZE ----------

OBS	YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	T1	T2	T3	T4	T5	T6
19	1967	1	25	23	68	182	152	148	160	294	37	30	10	22.0	23.8	27.7	29.0	29.2	28.6
20	1968	9	21	32	124	192	191	223	150	275	54	8	0	23.0	24.0	28.3	28.0	28.1	28.0
21	1969	38	1	53	79	160	249	190	127	341	100	22	0	25.1	26.1	28.8	29.6	29.5	28.2
22	1970	9	1	43	84	217	374	132	200	362	65	14	5	23.0	25.4	29.3	28.6	28.6	27.4
23	1971	1	17	22	105	211	198	171	274	253	70	4	22	21.4	23.9	27.3	29.1	28.2	27.4
24	1972	0	6	60	75	63	211	96	168	159	140	18	14	21.2	25.5	25.2	28.0	30.6	28.3
25	1973	0	7	10	54	134	144	171	220	266	55	6	8	23.3	27.3	29.2	31.5	29.0	28.8
26	1974	11	8	51	119	97	71	174	286	215	72	50	0	22.5	23.7	25.7	28.6	28.5	28.9
27	1975	15	38	45	41	289	219	192	188	357	111	4	1	23.1	25.8	28.6	30.8	20.0	27.9
28	1976	1	19	51	114	136	98	173	215	256	187	23	0	20.3	24.8	25.9	28.9	27.5	28.5
29	1977	13	8	27	91	207	137	112	172	303	51	2	13	22.6	22.4	25.9	28.5	28.2	29.8
30	1978	1	20	35	55	214	149	347	266	296	67	5	0	23.6	24.8	29.1	29.2	28.1	28.2
31	1979	4	36	11	95	203	228	124	173	194	20	1	0	23.9	25.4	28.8	29.2	28.4	27.5
32	1980	1	9	47	68	255	287	236	180	305	94	1	0	22.3	24.5	28.5	29.5	28.7	27.3

OBS	T7	T8	T9	T10	T11	T12	AREA	PROD	YIELD	P5_6	P5_7	P5_8	P5_9	P5_10
19	28.2	29.0	26.4	26.0	25.1	21.7	524020	122775	0.23	334	482	542	936	974
20	28.2	27.8	27.1	26.0	26.3	25.0	647295	129440	.	383	606	756	1031	1085
21	27.5	27.3	26.9	27.1	23.8	21.2	500900	165000	0.33	409	599	726	1066	1166
22	27.7	25.9	26.6	26.4	24.5	24.2	689100	280000	0.41	591	722	923	1285	1350
23	27.0	25.7	27.1	25.2	22.6	22.4	1006000	401500	0.40	409	580	854	1108	1178
24	28.2	27.5	27.3	27.3	26.1	23.9	1100000	215600	0.20	274	371	539	698	837
25	28.0	27.4	26.9	26.3	23.9	20.8	1536000	455000	0.30	278	449	569	935	991
26	28.2	27.4	27.4	26.9	25.0	24.1	1874000	553000	0.30	168	342	528	843	914
27	27.6	27.2	26.7	26.4	23.8	19.8	2143022	704062	0.33	508	700	887	1244	1355
28	27.5	25.3	26.7	26.5	23.0	22.4	2586700	744208	0.29	234	407	522	877	1064
29	27.8	27.5	26.6	26.9	23.6	23.1	1859746	394433	0.21	345	456	528	931	983
30	26.9	27.0	26.3	26.0	24.2	22.6	2047943	566909	0.28	362	710	976	1272	1339
31	28.3	27.4	26.9	25.6	23.2	22.0	2437036	573542	0.28	432	555	728	922	942
32	27.8	27.6	26.4	26.5	24.7	22.8	2267002	730408	0.32	542	778	958	1263	1357

OBS	P6_7	P6_8	P6_9	P6_10	L1P5_10	L2P5_10	P7_8	P7_9	P7_10	P8_9	P8_10	P9_10	YMT
19	300	460	754	792	1045	2253	307	602	639	454	491	332	295
20	414	564	839	894	974	2019	373	648	702	425	480	329	396
21	439	566	907	1007	1085	2059	317	658	758	468	568	441	380
22	505	706	1068	1133	1166	2252	372	694	759	552	627	427	401
23	369	644	897	967	1350	2516	445	699	769	528	598	324	352
24	308	476	635	774	1178	2528	264	423	563	327	467	298	229
25	316	535	802	857	837	2015	391	657	713	486	542	322	299
26	245	531	746	817	991	1828	460	675	746	500	572	286	252
27	411	598	955	1066	914	1905	379	736	847	544	656	468	412
28	271	486	742	929	1355	2270	388	643	830	470	657	443	278
29	249	421	724	775	1064	2420	284	587	638	475	527	354	258
30	496	762	1058	1125	983	2047	614	909	977	562	629	363	514
31	352	525	719	739	1339	2322	296	490	510	366	387	214	315
32	523	703	1008	1102	942	2291	416	721	815	485	579	399	490

TABLE 5.10 Input Data for Modeling Maize in Northeast Thailand.

NORTHEAST THAILAND

YIELD-WEATHER CORRELATIONS FOR MAIZE

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

YIELD

P6_9	P6_10	P6_8	P5_9	P5_10	P5_8	P8_9	T6	P5_7	P6_7
0.70422	0.67960	0.67039	0.67001	0.66385	0.66290	0.64907	-0.64609	0.57372	0.56775
0.0072	0.0106	0.0122	0.0122	0.0124	0.0136	0.0164	0.0170	0.0404	0.0430
13	13	13	13	13	13	13	13	13	13
P5_6	P8_10	T8	P6	YMI	P7_9	T7	P9	T3	P7_10
0.56636	0.55146	-0.52930	0.52074	0.50271	0.49259	-0.48515	0.48398	0.46854	0.45426
0.0436	0.0507	0.0629	0.0681	0.0900	0.0872	0.0929	0.0938	0.1063	0.1189
13	13	13	13	13	13	13	13	13	13
P5	T11	T10	P9_10	T5	P8	P7_8	T4	T2	P7
0.43584	-0.43560	-0.40762	0.38580	-0.34576	0.31440	0.30007	0.29485	0.24161	0.20710
0.1366	0.1368	0.1668	0.1929	0.2457	0.2955	0.3192	0.3455	0.4265	0.4972
13	13	13	13	13	13	13	13	13	13
P1	AREA	T1	L2P5_10	P11	L1P5_10	P2	T12	P4	P12
0.19241	-0.18314	0.18195	-0.18023	-0.14242	0.12635	-0.10555	-0.09370	0.08197	-0.05969
0.5288	0.5493	0.5519	0.5557	0.6426	0.6808	0.7315	0.7857	0.7901	0.8464
13	13	13	13	13	13	13	13	13	13
P10	P3	T9							
-0.03206	-0.00335	0.00171							
0.9172	0.9913	0.9956							
13	13	13							

DTYLD

P6_9	P5_8	P6_8	P5_10	P5_9	P6_10	T6	P8_9	P5_7	P6_7
0.72815	0.72221	0.71662	0.70921	0.70339	0.70510	-0.66560	0.65365	0.62219	0.59937
0.0048	0.0053	0.0058	0.0066	0.0067	0.0071	0.0130	0.0154	0.0232	0.0304
13	13	13	13	13	13	13	13	13	13
P5_6	YMI	T8	P8_10	P7_9	P6	T7	P5	P7_10	T3
0.58885	0.56179	-0.55984	0.55933	0.53120	0.50671	-0.50657	0.49828	0.49318	0.48783
0.0342	0.0457	0.0466	0.0469	0.0518	0.0772	0.0773	0.0831	0.0868	0.0908
13	13	13	13	13	13	13	13	13	13
T11	P9	T5	T10	P9_10	P7_8	P8	T4	P7	P11
-0.48586	0.46021	-0.44040	-0.42524	0.37002	0.35377	0.35146	0.29913	0.27332	-0.22934
0.0923	0.1136	0.1320	0.1475	0.2133	0.2218	0.2390	0.3208	0.3662	0.4510
13	13	13	13	13	13	13	13	13	13
T2	L2P5_10	T1	P1	P12	L1P5_10	P4	T12	P2	T9
0.22202	-0.19170	0.18469	0.14528	-0.13467	0.11840	0.08402	-0.07654	-0.05355	-0.04619
0.4660	0.5304	0.5458	0.6358	0.6609	0.7001	0.7849	0.8037	0.8621	0.8809
13	13	13	13	13	13	13	13	13	13

TABLE 5.11 Correlation Analysis for Maize in Northeast Thailand.

CORRELATION COEFFICIENTS / PROB > IRI UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

DTYLD

P10	AREA	P3
-0.02525	-0.02073	-0.01456
0.9347	0.9464	0.9623
13	13	13

YEAR

AREA	P11	T11	T5	T9	P7_8	P12	P1	P5	P8
0.92615	-0.39284	-0.38878	-0.36731	-0.33536	0.30598	-0.28951	-0.26926	0.26806	0.26578
0.0001	0.1647	0.1695	0.1964	0.2396	0.2874	0.3154	0.3519	0.3541	0.3594
14	14	14	14	14	14	14	14	14	14

P5_8	P7	T8	P2	YMI	P7_10	P6_8	T4	T7	P4
0.24740	0.23842	-0.23693	0.22508	0.19549	0.18970	0.18758	0.17624	-0.17620	-0.16805
0.3938	0.4117	0.4147	0.4391	0.5008	0.5160	0.5208	0.5467	0.5468	0.5658
14	14	14	14	14	14	14	14	14	14

P5_10	P7_9	P5_7	P9	T12	P5_9	P6	P10	P6_10	P8_10
0.16618	0.16273	0.16007	-0.15862	-0.14553	0.14050	-0.11205	0.10189	0.10011	0.09947
0.5702	0.5795	0.5846	0.5881	0.6196	0.6316	0.7029	0.7289	0.7335	0.7351
14	14	14	14	14	14	14	14	14	14

P6_9	P9_10	P6_7	P5_6	P4_9	T2	L2P5_10	T1	T3	L1P5_10
0.07026	-0.06978	0.06552	0.06235	0.05026	-0.04806	0.04515	-0.02900	0.02882	0.02334
0.8154	0.8126	0.8239	0.8323	0.8645	0.8704	0.8782	0.9216	0.9221	0.9369
14	14	14	14	14	14	14	14	14	14

P3	T10	T6
-0.02334	0.02127	-0.01870
0.9369	0.9425	0.9494
14	14	14

TABLE 5.11 Correlation Analysis for Maize in Northeast Thailand (continued).

NORTHEAST THAILAND
MAIZE: TIME - SERIES OF YIELD AND P5-8

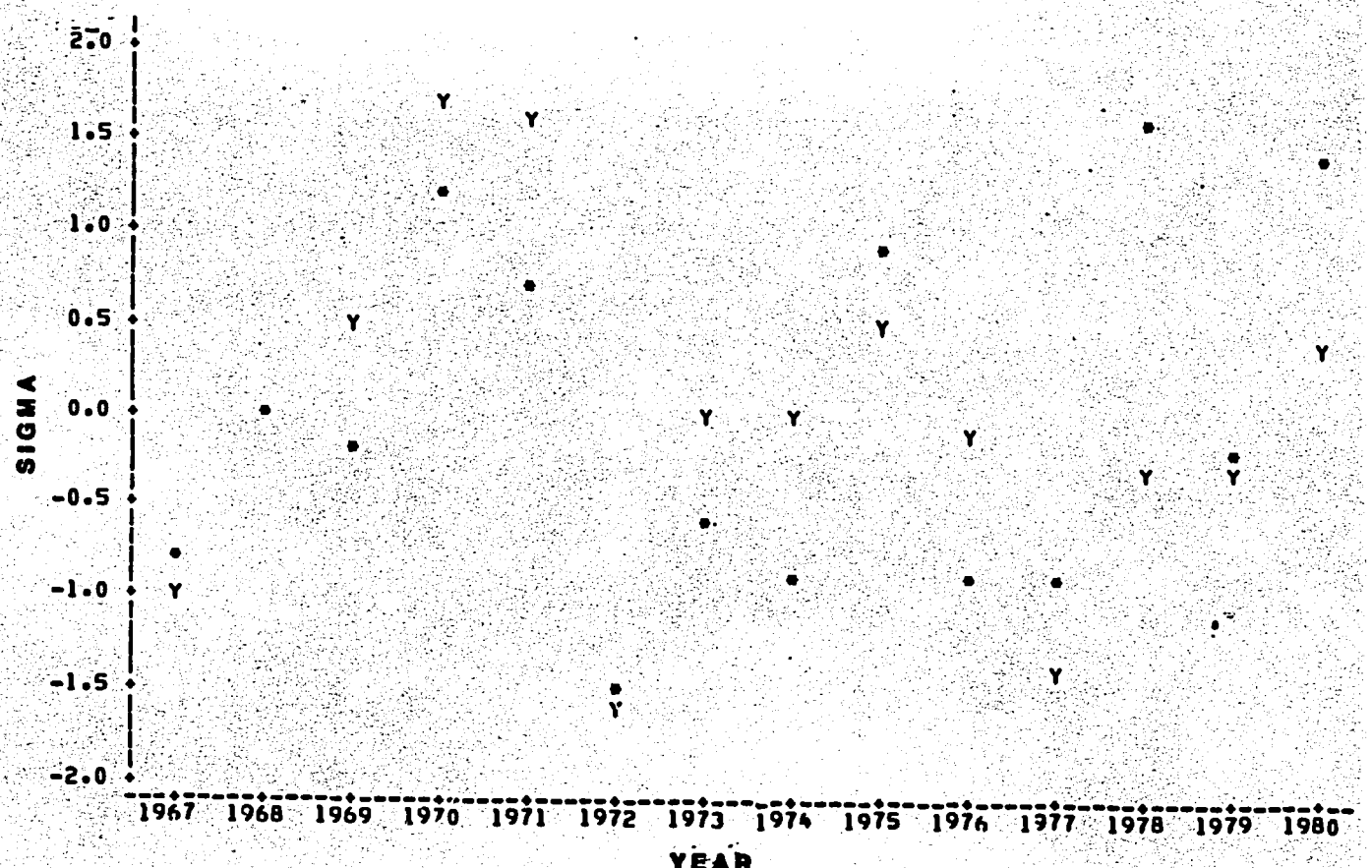

FIGURE 5.6 Time Series of Standardized Maize Yield (Y) and May through August Rainfall (P5_8) for Northeast Thailand.

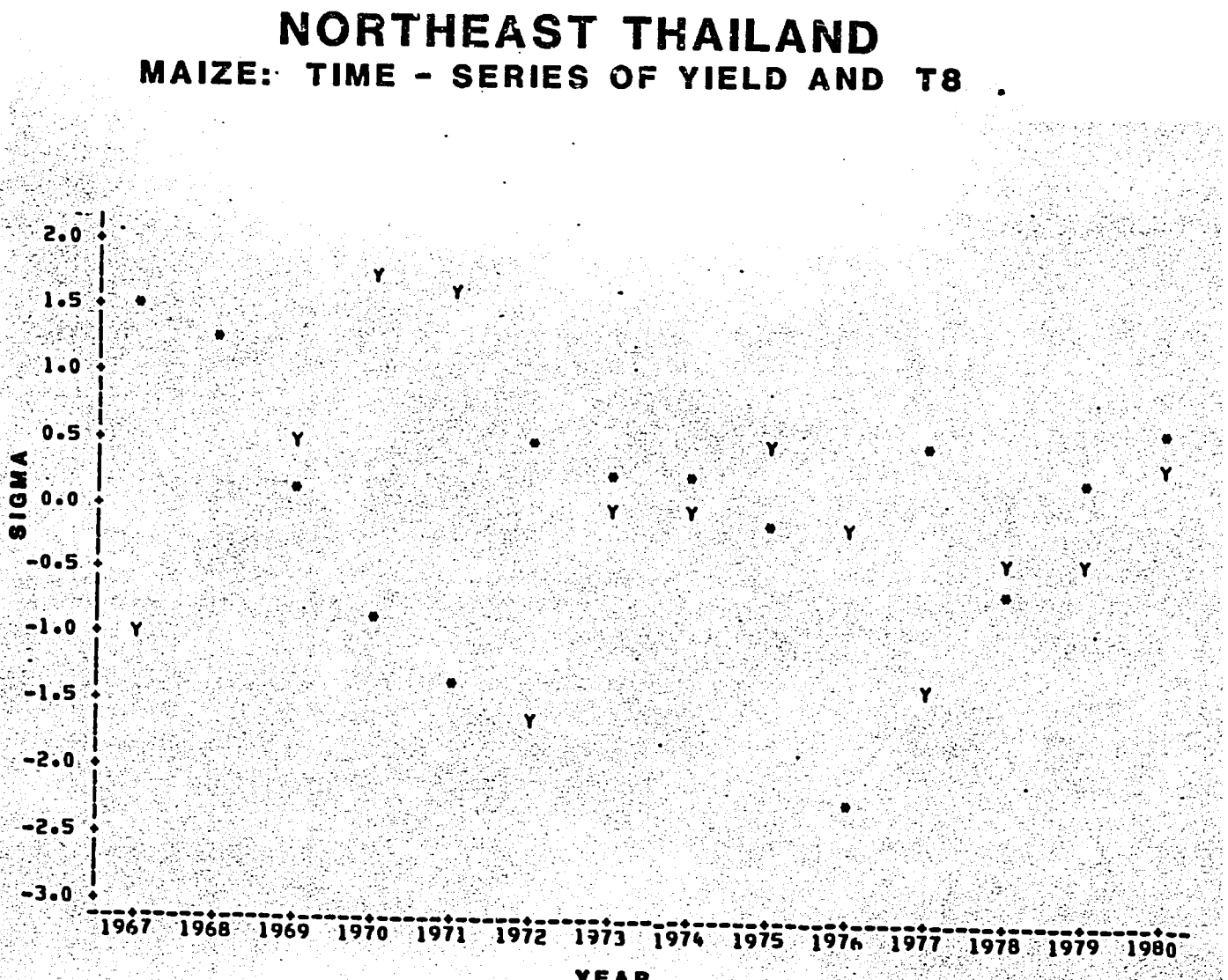

FIGURE 5.7 Time Series of Standardized Maize Yield (Y) and August Temperatures (T8) for Northeast Thailand.

NORTHEAST THAILAND
MAIZE: TIME - SERIES OF YIELD AND P5-9

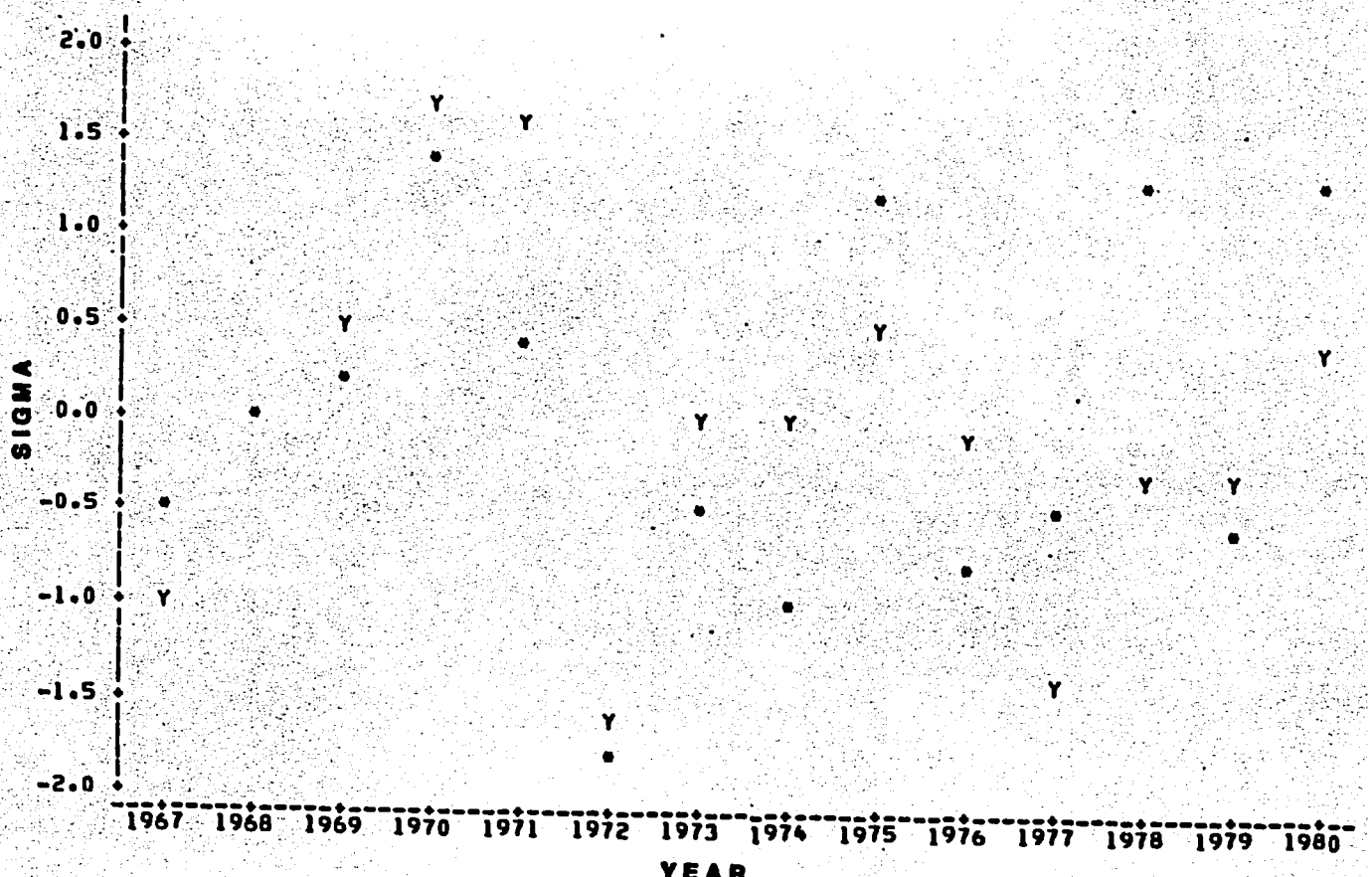

FIGURE 5.8 Time Series of Standardized Maize Yield (Y) and May through September Rainfall (P5_9) for Northeast Thailand.

Two models were developed for maize in Northeast Thailand. The first model (Table 5.12) includes P5_8 and T8. The model explains 58 percent of the variability in yield and has a standard error of 0.04 mt/rai. The model fit is shown in Figure 5.9. This is the primary model recommended for test and evaluation.

The second model for maize includes P5_9 and T8 as predictor variables (Table 5.13). This model explains 60 percent of the yield variability and has a standard error of 0.04 mt/rai. The model fit is shown in Figure 5.10.

Rice Model

Rice data on area, production and yield for Northeast Thailand is provided in Table 5.14. The standardized plot of the data is shown in Figure 5.11. No significant trend in the yield was observed possibly due to an expansion of the acreage under rice and also due to limited usage of fertilizers.

The input data for modeling main rice are shown in Table 5.15. Correlations between yield versus weather variables and detrended yield versus weather variables are shwon in Table 5.16. Rice in Northeast Thailand is generally transplanted in July and harvested during December-January.

Time series plots of P6-7 (June-July rainfall) and T8 (August temperature) are shown in Figures 5.12 and 5.13. The model was developed on 1960-1976 data.

The main rice model is shown in Table 5.17 and includes P6-7, T8 as predictor variables. The model explains 64 percent of the variability in yield due to weather and has a standard error of .11 mt/rai. The model fit is shown in Figure 5.14. The rice model looks promising and it has to be tested extensively prior to operational use.

NORTHEAST THAILAND
MAIZE YIELD MODEL (1)

MODEL:	MODEL01	SSE	0.019960	F RATIO	6.85
		DFE	10	PROB>F	0.0133
DEP VAR:	YIELD	MSE	0.001995972	R-SQUARE	0.5782

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	1.693978	0.888529	1.9063	0.0857
P5_8	1	0.0002391305	0.0000899542	2.6584	0.0240
T8	1	-0.057825	0.031862	-1.8148	0.0996

TABLE 5.12 Maize Yield Model(1) for Northeast Thailand Using August Temperature (T8) and May through August Rainfall (P5_8).

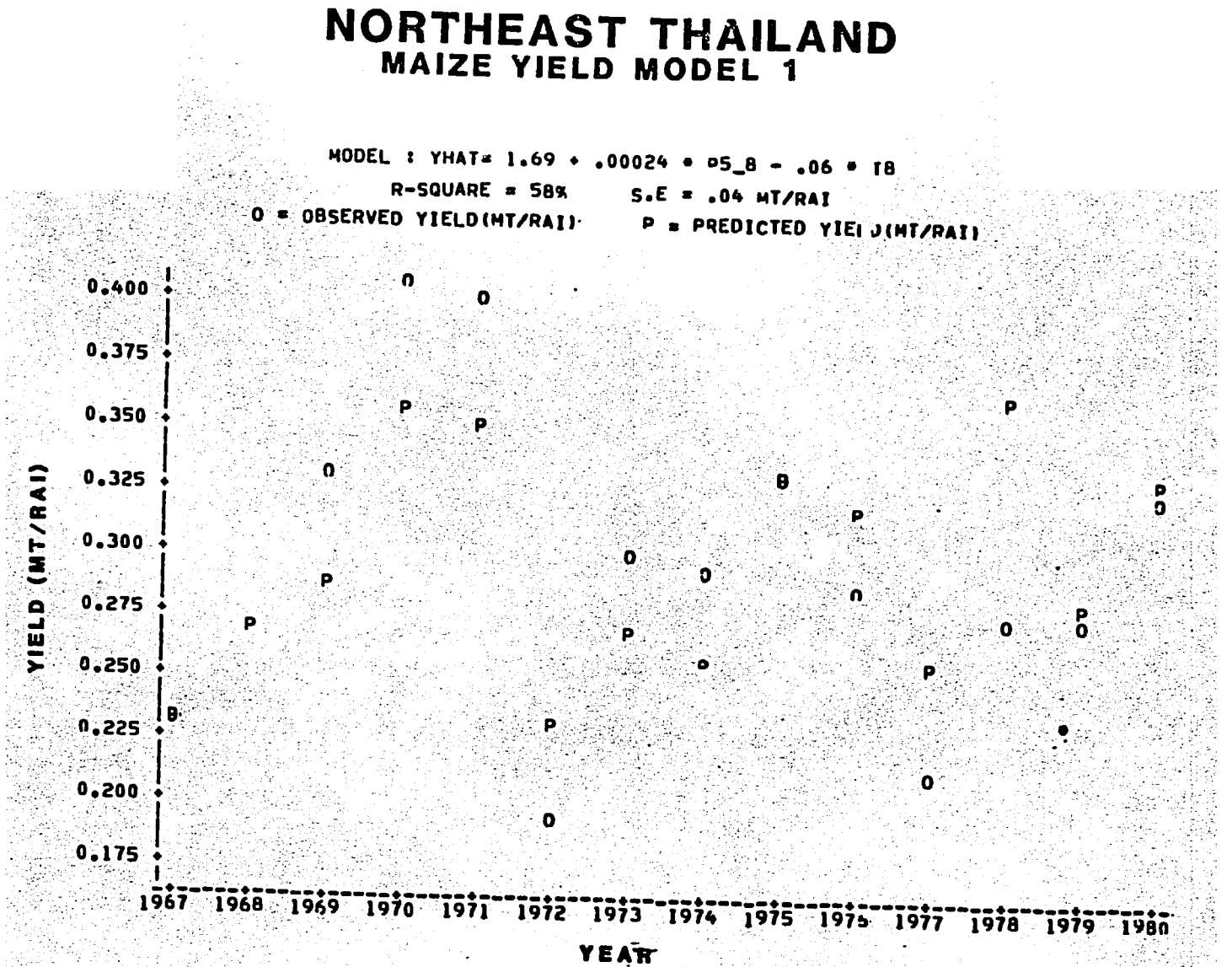

FIGURE 5.9 Northeast Thailand: Maize Yield Model(1) Using August Temperature (T8) and May through August Rainfall (P5_8).

COUNTRY=THAILAND REGION=NORTHEAST CROP=MAIZE

MODEL: MODEL01	SSE	0.019018	F RATIO	7.44
	DFE	10	PROB>F	0.0105
DEP VAR: YIELD	MSE	0.001901781	R-SQUARE	0.5981

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	1.724619	0.861150	2.0027	0.0731
P5_9	1	0.0001901932	.00006761572	2.8129	0.0184
T8	1	-0.059530	0.030894	-1.9269	0.0829

TABLE 5.13 Maize Yield Model (2) for Northeast Thailand Using August Temperature (T8) and May through September Rainfall (P5_9).

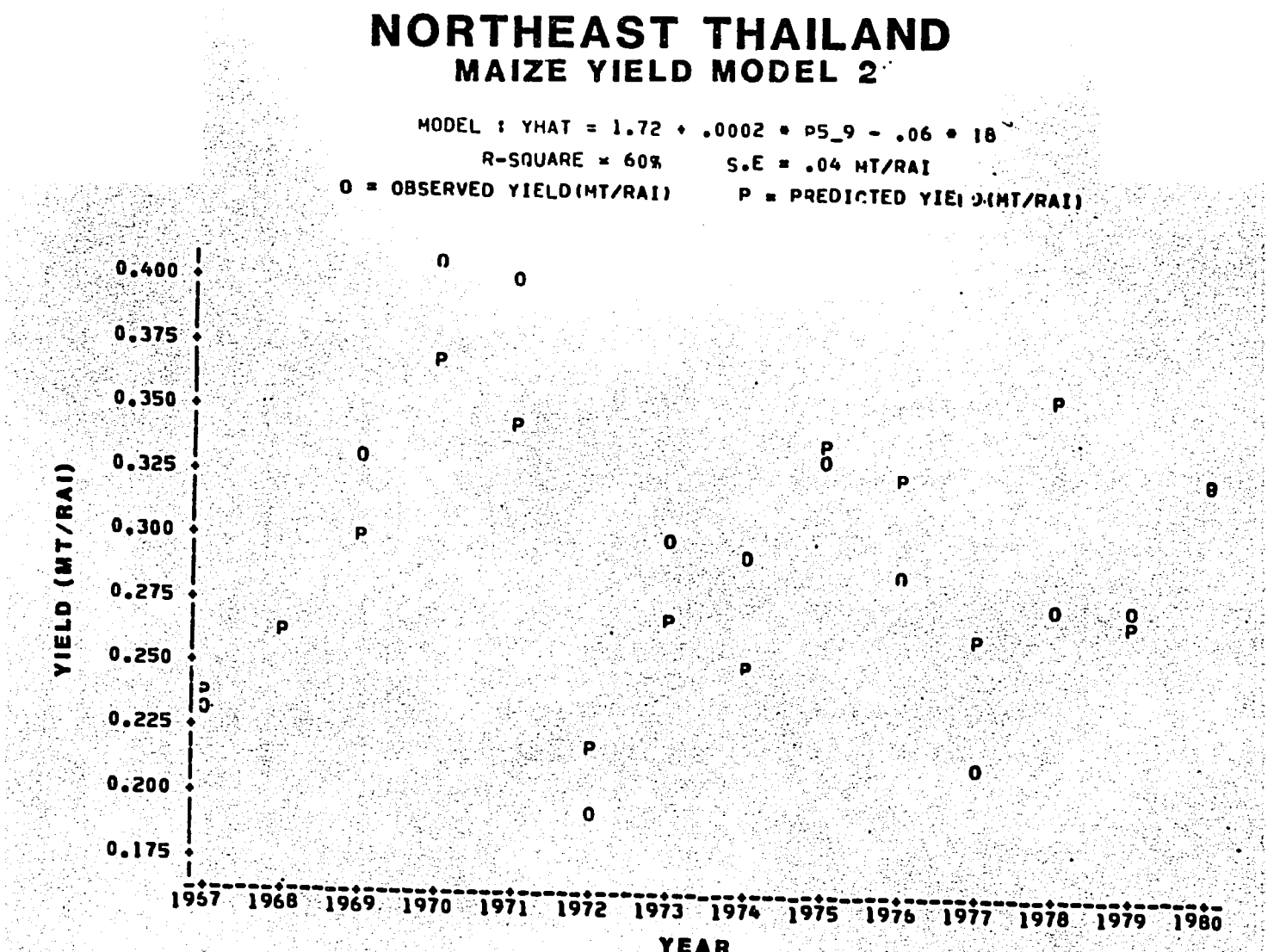

FIGURE 5.10 Northeast Thailand: Maize Yield Model Using August Temperature (T8) and May through September Rainfall (P5_9).

OBS	COUNTRY	REGION	CROP	YEAR	AREA	PROD	YIELD
1	THAILAND	NORTHEAST	MAIN RICE	1960	14729462	2774844	1.17742
2	THAILAND	NORTHEAST	MAIN RICE	1961	15587306	2807072	1.12554
3	THAILAND	NORTHEAST	MAIN RICE	1962	18031194	3665952	1.27070
4	THAILAND	NORTHEAST	MAIN RICE	1963	17169669	3515532	1.27970
5	THAILAND	NORTHEAST	MAIN RICE	1964	15652300	3301117	1.31814
6	THAILAND	NORTHEAST	MAIN RICE	1965	15513181	2733932	1.10146
7	THAILAND	NORTHEAST	MAIN RICE	1966	19841444	3792227	1.19454
8	THAILAND	NORTHEAST	MAIN RICE	1967	15333356	2349250	0.95757
9	THAILAND	NORTHEAST	MAIN RICE	1968	18066856	3189930	1.10352
10	THAILAND	NORTHEAST	MAIN RICE	1969	20480350	4580000	1.39768
11	THAILAND	NORTHEAST	MAIN RICE	1970	20702962	4920000	1.48529
12	THAILAND	NORTHEAST	MAIN RICE	1971	21725969	5434000	1.56322
13	THAILAND	NORTHEAST	MAIN RICE	1972	18439275	4188460	1.41968
14	THAILAND	NORTHEAST	MAIN RICE	1973	22401900	4610340	1.28626
15	THAILAND	NORTHEAST	MAIN RICE	1974	20880044	3773000	1.12937
16	THAILAND	NORTHEAST	MAIN RICE	1975	25287319	5321329	1.31522
17	THAILAND	NORTHEAST	MAIN RICE	1976	24017037	4671025	1.21555
18	THAILAND	NORTHEAST	MAIN RICE	1977	25039662	3537747	0.88304

TABLE 5.14 Area (Rai), Production (Metric Tons) and Yield (Mt/Rai) for Northeast Thailand.

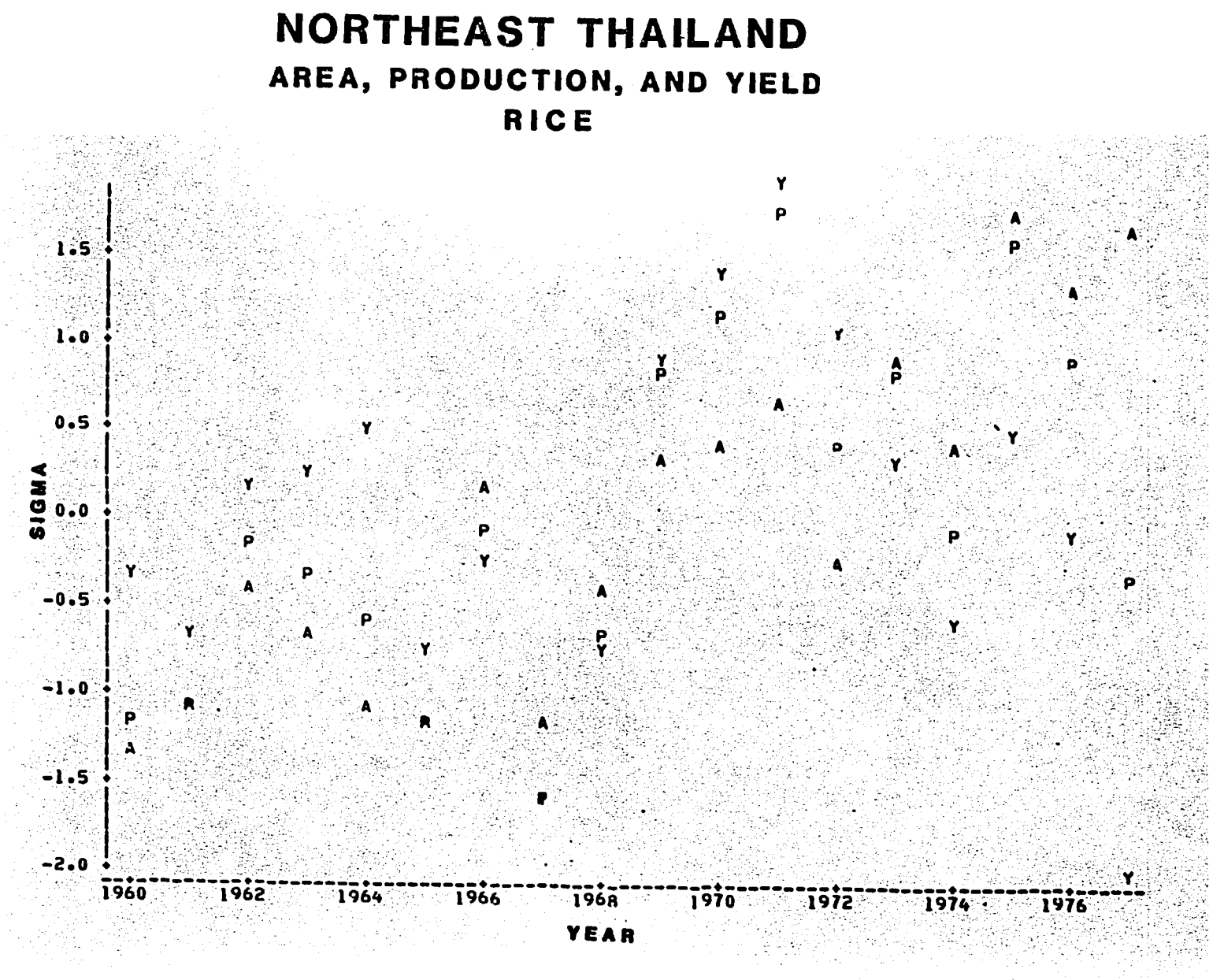

FIGURE 5.11 Standardized Plot of Area (A), Production (P) and Yield (Y) for Main Rice in Northeast Thailand.

NORTHEAST THAILAND: INPUT DATA FOR CROP MODELING

---------- COUNTRY=THAILAND REGION=NORTHEAST CROP=MAIN RICE ----------

OBS	YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	T1	T2	T3	T4	T5	T6
1	1960	1	3	57	33	161	180	209	293	246	200	15	0	23.7	24.9	29.5	30.4	29.4	28.8
2	1961	0	7	52	97	202	203	160	242	347	150	1	0	22.1	26.2	28.5	29.5	28.6	27.5
3	1962	0	8	43	97	206	175	260	252	412	119	10	1	21.2	24.1	27.6	29.5	28.9	28.1
4	1963	0	1	56	56	156	207	233	242	247	112	62	1	19.5	23.5	26.6	29.5	29.4	28.0
5	1964	0	13	40	67	282	127	146	220	321	148	32	0	24.7	24.5	27.5	29.6	27.9	28.4
6	1965	0	23	36	106	239	222	171	209	239	82	9	0	21.7	26.3	27.4	29.1	28.4	27.3
7	1966	0	26	51	78	383	159	199	356	236	91	16	.	25.0	26.5	28.9	29.5	27.8	28.4
8	1967	4	11	16	102	185	150	173	178	322	47	39	2	21.9	23.9	27.9	29.1	29.0	28.5
9	1968	7	14	33	108	164	210	157	185	345	58	5	0	23.1	23.7	29.2	28.2	28.3	28.0
10	1969	28	4	46	81	186	273	241	159	328	83	17	0	25.6	26.2	28.8	29.7	29.6	28.3
11	1970	2	6	27	89	192	260	192	280	257	54	5	7	23.4	25.9	29.5	28.9	28.9	27.6
12	1971	1	20	21	88	184	260	223	265	255	69	2	14	21.7	24.1	27.3	29.4	28.3	27.3
13	1972	2	33	55	82	100	279	187	227	255	148	27	6	21.1	25.3	26.1	27.7	30.1	28.0
14	1973	0	8	19	57	162	204	226	201	250	57	5	2	23.5	27.2	29.1	31.3	28.9	28.5

OBS	T7	T8	T9	T10	T11	T12	AREA	PROD	YIELD	P5_6	P5_7	P5_8	P5_9	P5_10
1	28.1	27.6	27.1	26.3	25.9	22.5	14729462	2774844	1.18	340	549	842	1087	1288
2	27.9	27.5	26.6	26.6	25.4	24.1	15587306	2807072	1.13	405	565	806	1153	1304
3	27.5	27.1	26.6	26.4	25.0	21.7	18031194	3665952	1.27	381	540	893	1305	1424
4	27.1	27.3	27.3	26.6	26.0	22.6	17169569	3515532	1.28	363	595	838	1085	1197
5	28.0	27.5	27.0	26.8	23.2	21.7	15652300	3301117	1.32	409	555	775	1096	1244
6	27.8	27.5	27.2	27.2	25.8	24.7	15513181	2733932	1.10	461	531	840	1079	1161
7	28.1	26.9	26.6	27.2	25.3	24.9	19841444	3792227	1.19	542	742	1098	1334	1425
8	28.1	27.8	26.4	25.8	25.2	21.7	15333356	2349250	0.96	335	508	686	1008	1055
9	28.4	27.8	27.1	26.3	26.3	25.2	18066956	3189930	1.10	374	531	715	1060	1118
10	27.5	27.6	27.2	27.2	24.1	21.6	20480350	4580000	1.40	459	700	859	1188	1271
11	27.9	27.1	27.0	26.4	24.5	24.4	20702952	4920000	1.49	451	543	923	1190	1243
12	27.1	26.9	27.3	25.3	22.7	22.3	21725969	5434000	1.56	443	566	931	1186	1255
13	27.9	27.2	27.3	27.2	25.9	23.8	18439275	4188460	1.42	378	565	793	1057	1206
14	27.8	27.3	27.0	26.1	23.7	20.8	22401900	4610340	1.29	366	592	793	1053	1110

OBS	P6_7	P6_8	P6_9	P6_10	L1P5_10	L2P5_10	P7_8	P7_9	P7_10	P8_9	P8_10	P9_10	YMI
1	388	681	927	1127	.	.	501	747	947	538	739	446	913
2	363	605	951	1102	1288	.	402	749	899	589	739	497	924
3	434	687	1099	1218	1304	2591	512	924	1044	665	784	532	1078
4	439	682	929	1041	1424	2728	475	722	834	490	602	359	909
5	273	493	814	962	1197	2621	366	687	835	541	689	469	797
6	392	601	841	922	1244	2441	380	619	700	448	530	321	814
7	358	715	951	1042	1161	2405	556	792	883	593	683	327	943
8	323	501	823	870	1425	2586	351	673	720	500	547	369	802
9	366	551	896	953	1055	2480	341	686	744	529	587	402	864
10	514	674	1002	1085	1118	2173	400	729	812	487	571	412	965
11	452	731	998	1052	1271	2389	472	738	792	546	600	321	969
12	482	747	1002	1071	1243	2514	487	742	811	519	588	324	974
13	466	693	958	1106	1255	2498	414	679	827	492	640	413	923
14	430	632	892	949	1206	2460	427	688	744	462	518	317	870

TABLE 5.15 Input Data for Modeling Main Rice in Northeast Thailand.

NORTHEAST THAILAND: INPUT DATA FOR CROP MODELING

---------- COUNTRY=THAILAND REGION=NORTHEAST CROP=MAIN RICE ----------

OBS	YEAR	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	T1	T2	T3	T4	T5	T6
15	1974	10	12	42	93	166	161	201	314	200	100	41	1	22.3	23.4	25.2	28.2	28.4	28.2
16	1975	19	23	33	46	214	248	226	258	264	119	24	2	23.2	25.6	28.5	30.5	28.0	27.7
17	1976	1	17	46	105	161	137	214	265	266	195	14	2	20.6	25.2	25.9	28.8	27.7	28.4
18	1977	4	4	19	73	162	122	156	275	273	57	8	6	22.6	22.1	26.8	28.6	28.4	29.7

OBS	T7	T8	T9	T10	T11	T12	AREA	PROD	YIELD	P5_6	P5_7	P5_8	P5_9	P5_10
15	27.9	27.1	27.3	26.6	24.6	23.5	20980044	3773000	1.13	327	528	842	1042	1142
16	27.5	27.0	27.0	26.2	23.8	19.9	25287319	5321329	1.32	462	688	946	1210	1329
17	27.4	26.5	27.0	26.9	23.0	22.7	24017037	4671025	1.22	298	512	777	1043	1238
18	27.9	27.6	26.8	27.0	23.7	23.3	25039662	3537747	0.88	284	440	715	988	1045

OBS	P6_7	P6_8	P6_9	P6_10	L1P5_10	L2P5_10	P7_8	P7_9	P7_10	P8_9	P8_10	P9_10	YMT
15	362	676	875	975	1110	2316	515	715	815	513	613	300	867
16	473	731	995	1115	1142	2232	484	747	867	522	641	383	969
17	351	616	882	1077	1329	2471	479	745	940	531	726	461	872
18	278	553	826	884	1238	2557	431	704	761	549	606	330	816

TABLE 5.15 Input Data for Modeling Main Rice in Northeast Thailand continued.

COUNTRY=THAILAND REGION=NORTHEAST CROP=MAIN RICE

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

YIELD

P6_7	P6	P6_8	P6_9	P5_7	YMI	P6_10	T6	T7	P5_8
0.74257	0.68886	0.65852	0.62925	0.61985	0.59882	0.56773	-0.53542	-0.50452	0.49653
0.0004	0.0016	0.0030	0.0051	0.0061	0.0086	0.0140	0.0220	0.0327	0.0360
18	18	18	18	18	18	18	18	18	18
P7	P5_6	T8	T9	P5_9	P5_10	P12	T2	T11	P7_8
0.49393	0.48180	-0.48140	0.47335	0.46922	0.46261	0.42837	0.38458	-0.30523	0.26647
0.0372	0.0429	0.0431	0.0472	0.0495	0.0532	0.0761	0.1151	0.2181	0.2851
18	18	18	18	18	18	18	18	18	18
T5	T12	L2P5_10	P7_9	P7_10	P2	T10	P4	T4	AREA
0.24105	-0.22475	-0.21464	0.21408	0.20820	0.20203	-0.20172	-0.18610	0.18125	0.14955
0.3353	0.3699	0.4247	0.3937	0.4071	0.4214	0.4221	0.4597	0.4717	0.5537
18	18	16	18	18	18	18	18	18	18
P3	T3	P1	P10	L1P5_10	T1	P11	P9	P8_9	P5
0.14681	0.12907	0.12130	0.10008	-0.09464	0.08782	-0.07933	-0.06050	-0.05622	-0.04454
0.5610	0.6098	0.6316	0.6928	0.7179	0.7290	0.7544	0.8115	0.8246	0.8607
18	18	18	18	17	18	18	18	18	18
P8_10	P9_10	P8							
0.02489	0.02328	0.00594							
0.9219	0.9269	0.9813							
18	18	18							

DTYLD

P6_7	P6	P6_8	P6_9	P5_7	YMI	P6_10	T6	P5_8	T7
0.74129	0.68767	0.65596	0.63434	0.62573	0.60376	0.57595	-0.54253	0.50017	-0.50012
0.0004	0.0016	0.0031	0.0047	0.0055	0.0080	0.0124	0.0200	0.0345	0.0345
18	18	18	18	18	18	18	18	18	18
P7	P5_6	P5_9	P5_10	T8	T9	P12	T2	T11	P7_8
0.49307	0.48911	0.47887	0.47470	-0.46903	0.46640	0.41919	0.38903	-0.28877	0.26422
0.0376	0.0394	0.0444	0.0465	0.0496	0.0511	0.0833	0.1106	0.2452	0.2894
18	18	18	18	18	18	18	18	18	18
T5	P7_9	T12	P7_10	L2P5_10	T10	P2	T4	P4	P3
0.24810	0.22125	-0.21998	0.21766	-0.20345	-0.20185	0.19427	0.18844	-0.18821	0.16087
0.3209	0.3776	0.3804	0.3856	0.4498	0.4218	0.4399	0.4540	0.4545	0.5237
18	18	18	18	15	18	18	18	18	18
T3	AREA	P1	P10	T1	L1P5_10	P11	P9	P8_9	P9_10
0.13813	0.12366	0.11226	0.10801	0.08891	-0.08683	-0.07696	-0.04912	-0.04676	0.03715
0.5846	0.6249	0.6574	0.6697	0.7257	0.7404	0.7615	0.8465	0.8538	0.8836
18	18	18	18	18	17	18	18	18	18

TABLE 5.16 Correlation Analysis for Main Rice in Northeast Thailand.

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

DTYLD

P8_10	P5	P8
0.03599	-0.03550	0.00369
0.8872	0.8888	0.9884
18	18	18

YEAR

AREA	T11	P3	P9_10	L2P5_10	T8	P5_10	P9	P8_10	P8_9
0.87918	-0.56194	-0.47424	-0.46938	-0.42565	-0.42606	-0.40264	-0.38647	-0.37568	-0.32151
0.0001	0.0152	0.0468	0.0494	0.0993	0.0779	0.0976	0.1131	0.1245	0.1933
18	18	18	18	16	18	18	18	18	18

P5_9	P7_10	P12	P1	P5	T3	L1P5_10	P6_10	P10	P2
-0.32013	-0.31757	0.31730	0.30812	-0.30580	-0.30515	-0.28595	-0.27016	-0.26717	0.26594
0.1953	0.1991	0.1995	0.2135	0.2156	0.2182	0.2659	0.2783	0.2838	0.2861
18	18	18	18	18	18	17	18	18	18

T9	T4	P5_6	P7_9	T5	T6	P5_7	T12	P6_9	YMT
0.24231	-0.24101	-0.24043	-0.23976	-0.23537	0.23285	-0.18985	-0.16458	-0.16319	-0.15840
0.3327	0.3353	0.3365	0.3379	0.3471	0.3525	0.4505	0.5140	0.5176	0.5301
18	18	18	18	18	18	18	18	18	18

T7	T2	P5_8	P6_8	P11	P7_8	P8	P4	P6_7	P6
-0.15652	-0.14514	-0.11258	0.09648	-0.08146	0.08013	0.07630	0.06891	0.05441	0.05033
0.5351	0.5655	0.6565	0.7033	0.7480	0.7520	0.7635	0.7858	0.8302	0.8428
18	18	18	18	18	18	18	18	18	18

P7	T1	T10
0.03642	-0.03572	0.00141
0.8859	0.8881	0.9956
18	18	18

TABLE 5.16 Correlation analysis for Main Rice in Northeast Thailand (continued).

NORTHEAST THAILAND

MAIN RICE: TIME - SERIES OF YIELD AND P6-7

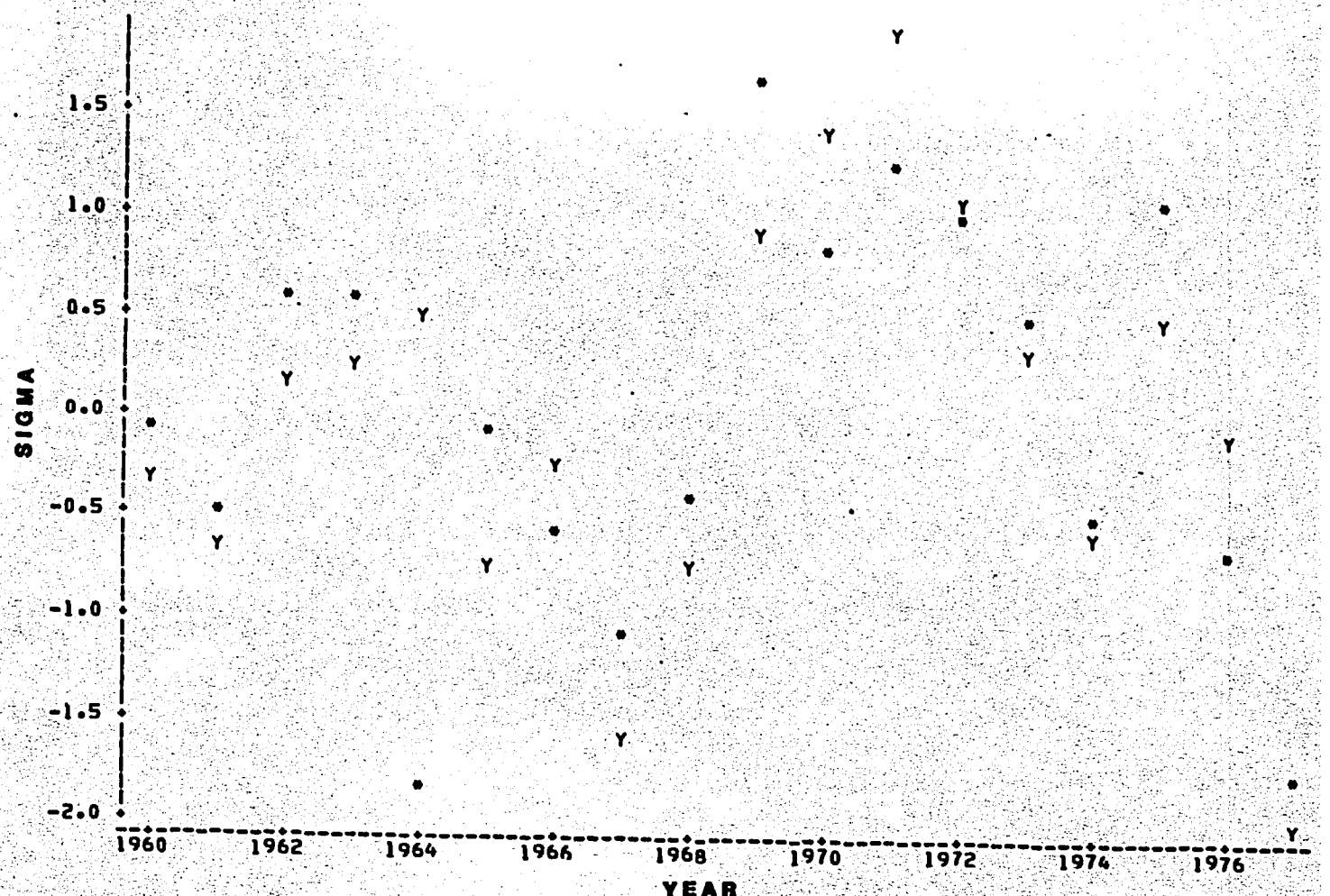

FIGURE 5.12 Time-Series of Standardized Rice Yield (Y) and June through July Rainfall (P6_7) for Northeast Thailand.

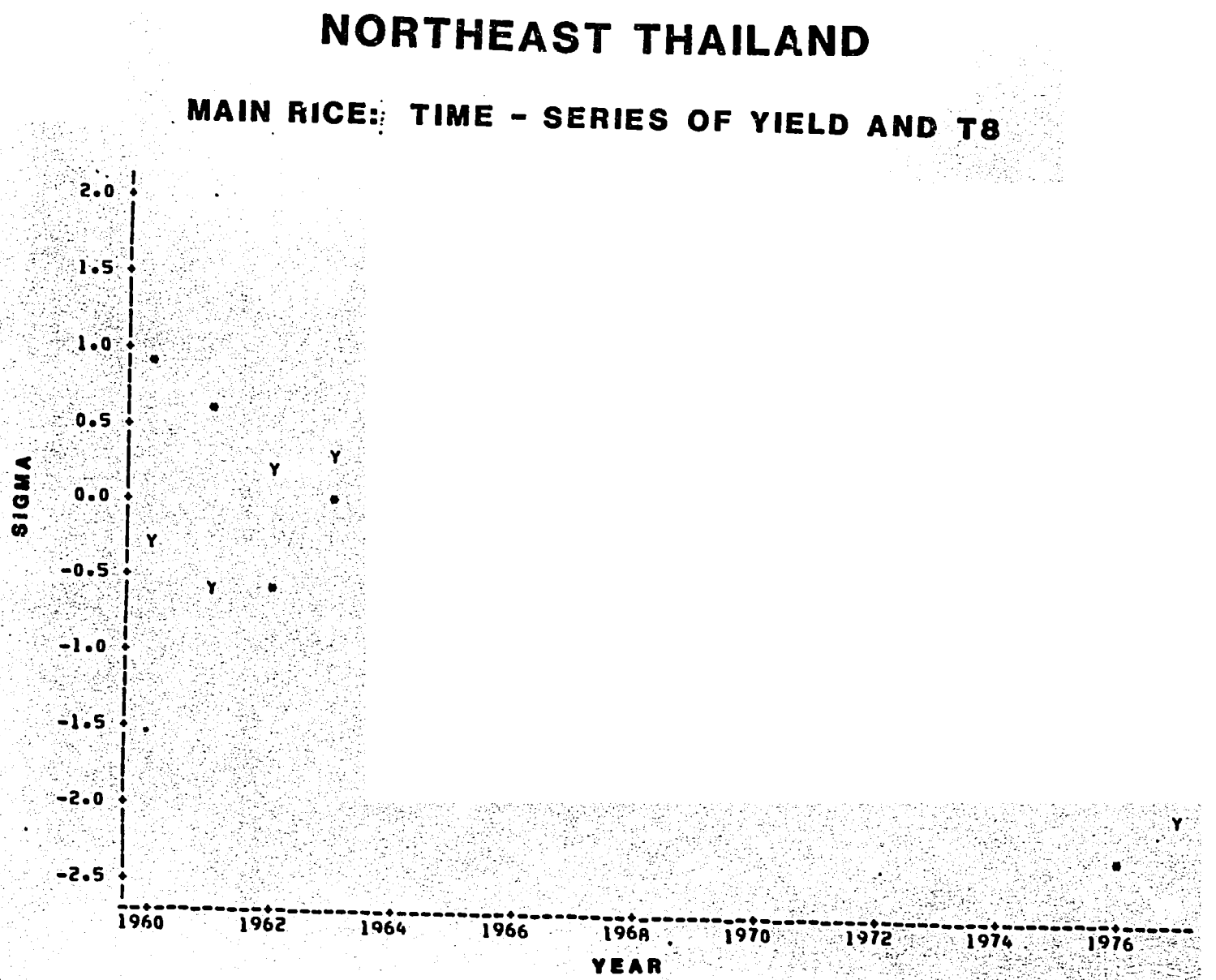

FIGURE 5.13 Time-Series of Standardized Main Rice Yield (Y) and August Temperature (T8) for Northeast Thailand.

NORTHEAST THAILAND

MAIN RICE YIELD MODEL

MODEL: MODEL01

DEP VAR: YIELD

SSE	0.187100	F RATIO 13.13
DFE	15	PROB>F 0.0005
MSE	0.012473	R-SQUARE 0.6364

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB>|T|
INTERCEPT	1	4.758468	2.283286	2.0840	0.0547
P6_7	1	0.001664107	0.0004072495	4.0862	0.0010
T8	1	-0.153374	0.081889	-1.8729	0.0807

TABLE 5.17 Main Rice Yield Model for Northeast Thailand Using August Temperature (T8) and June through July Rainfall (P6_7).

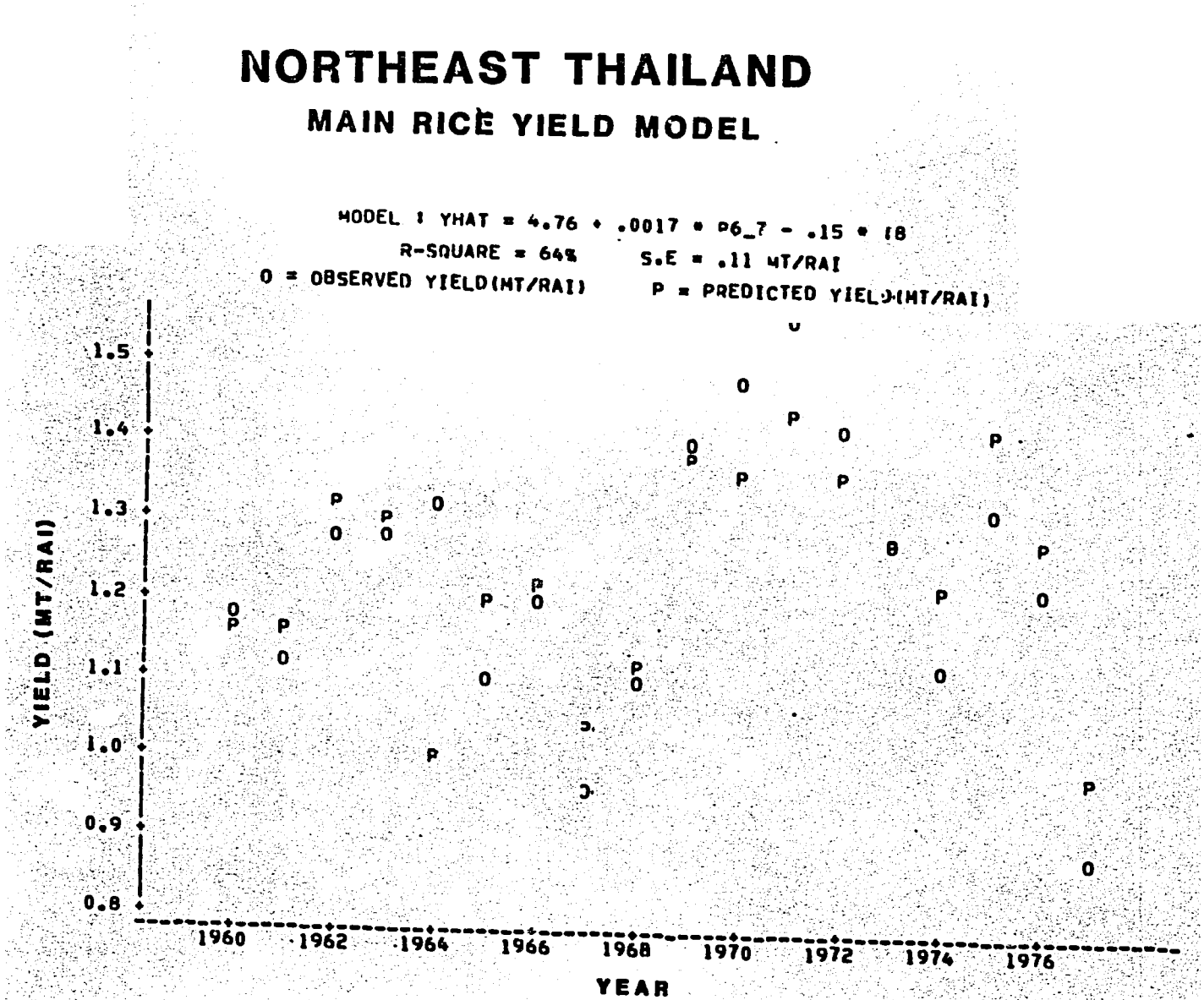

FIGURE 5.14 Main Rice Yield Model for Northeast Thailand Using August Temperature (T8) and June through July Rainfall (P6_7).

Model Simulations

Maize and rice yields for Thailand were simulated over the period 1951-1980 using the crop yield models developed earlier, 1967-1980 for maize and 1960-1977 for rice. Simulated yields for maize are shown in Figure 5.15 and those for rice in Figure 5.16. These plots are useful in studying the influence of weather on crop yield for the entire period of record, 1951-1981. This procedure can also be used to examine yield variability given fixed technology (trend specification). Finally, the approach can be used to examine the change in yield assocaited with various levels of rainfall.

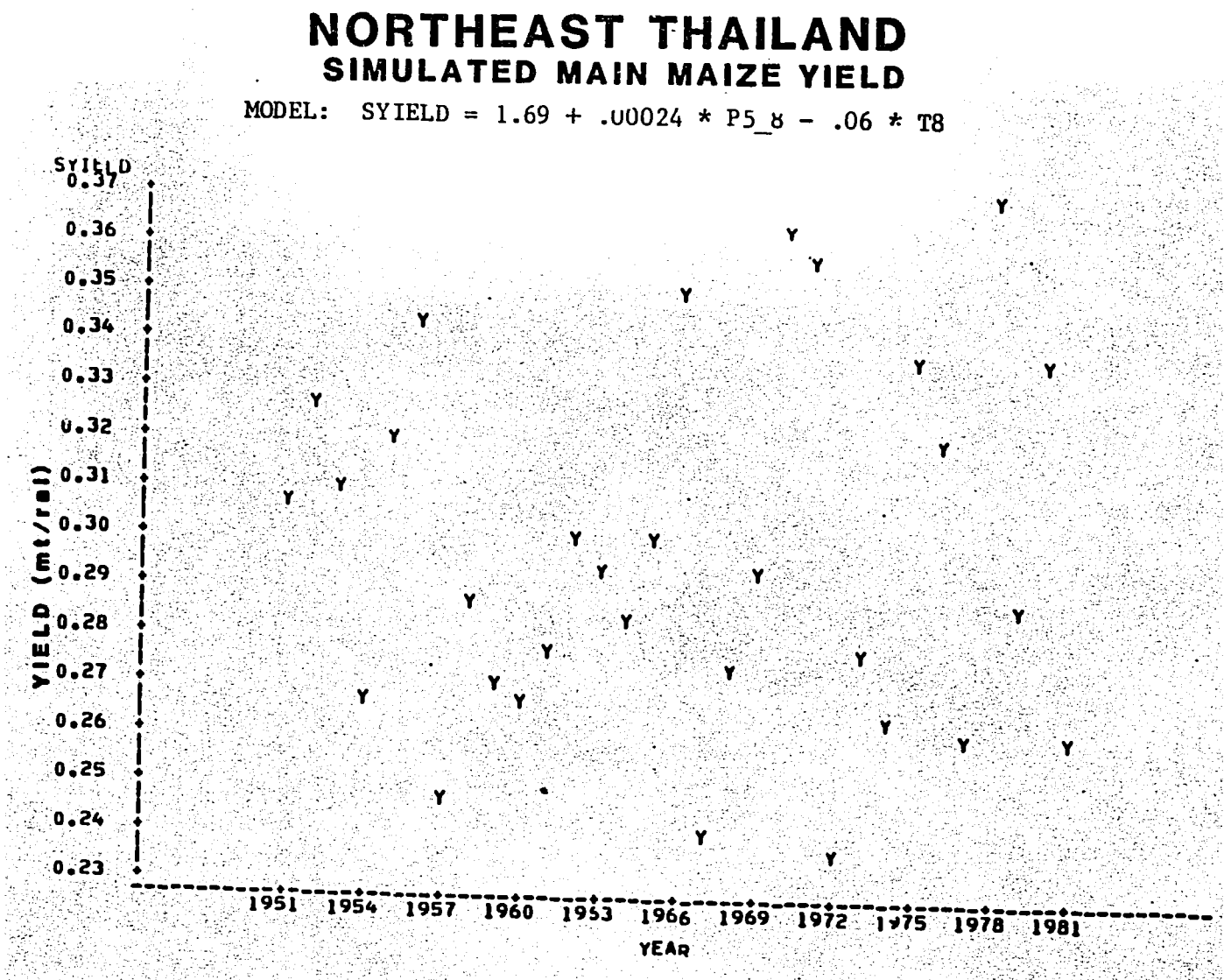

FIGURE 5.15 Simulated Time-Series of Main Maize Yield for Northeast Thailand.

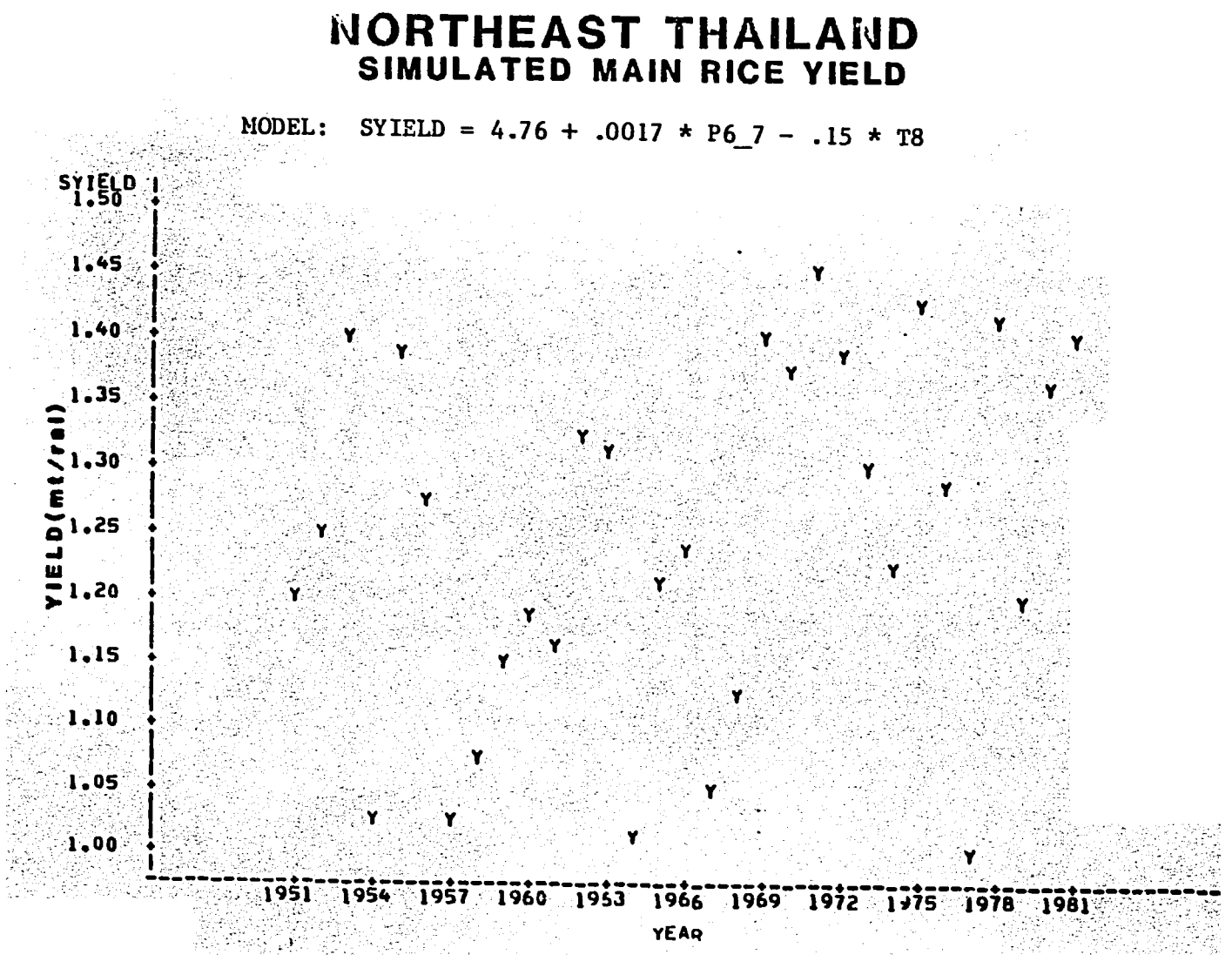

FIGURE 5.16 Simulated Time-Series of Main Rice Yield for Northeast Thailand.

CHAPTER VI

ASSESSMENT PROCEDURES

This chapter describes the structure of climatic impact assessments, the types of assessments proposed for Northeast Thailand, the agroclimatic models, display of the data, steps in making an assessment and comments on user interpretation of assessments. Test and evaluation procedures for the period May-October 1983 are discussed.

A. Definition and Assessment Format

1. Definition

The climatic impact assessment is a concise statement which provides decision makers with quantified information on the current or potential effect of climate and weather variability on some aspect of socio-economic activity. Assessments could address agriculture and food security as discussed in this study, other economic sectors (e.g., fisheries, energy, transportation, construction, recreation, health, etc.). The assessment provides decision makers with needed information on climate impact, one of the many factors which influences policy and economic planning. Assessments represent a method for converting meteorological data into economic information. This process can be viewed as a means for interdisciplinary communication and in many cases promote interagency dialogue.

The meteorologist prepares a basic assessment from agroclimatic models and real-time meteorological input data. The assessment is provided to users such as food security managers, economic policy analysts, agricultural statisticians, extension officials and others. They can use the assessment to supplement information from other sources available to them. This process can frequently benefit the user's individual products, reports and forecasts. For example,

the agricultural statistician or economist involved in the crop production and yield forecast problem can combine the assessment with analysis from area farm survey results, crop cutting reports, farmers reports and other data sources.

There are no fixed rules for preparing an assessment and it is very important to adapt the assessment to individual user needs. However, the following basic structure is recommended.

2. Format

The format for an assessment includes the following sequential statements: 1) Impact, 2) Perspective, 3) Model Results, 4) Weather Analysis and 5) Support Information. Only information and data relevant to the impact are used in statements 2 through 5. These justify the impact statement.

Impact

This is the statement which directly communicates needed information to the decision maker. The terminology is strictly associated with the user's discipline. Preparing the impact statement is the most difficult task of the assessor. It must be objective and clearly stated.

Some example statements could include: 1) there will be a crop failure in Region X due to drought, 2) crop conditions are very poor in Region X and potentially represent the worst case of crop failure in the last 10 years, 3) there is the potential for isolated food shortages in Region X due to severe drought, or 4) agricultural crops are in very good condition and the prospects for this year's harvest are exceptionally good. If abnormal rainfall was a problem in the early part of the growing season, the impact statement could be, "farmers probably could not plant" or "planting was delayed due to a delayed rainy season (heavy rains)", etc.

The impact statement does not include any technical discussion of meteorological events or data. These are described in subsequent portions of the assessment.

Perspective Statement

The perspective statement can be used to qualify the impact by describing the expected scope and magnitude of the potential problem. For example, the statement that a maize crop failure is likely in Region X could be followed by a statement which describes the favorable situation at other locations within Region X or other regions in the country. Another example is, "this is the worst drought in the past 30 years." The decision maker is provided with information on, "how large is the expected problem?".

Model Results

The perspective statement is followed by a discussion which lists the quantitative results from the assessment models. The model could be a drought or crop condition index, a statistical crop yield model or soil moisture information. The model output is presented as a percent of normal or percentile rank. For example, the statement could be, "Agroclimatic/crop condition indices are 60 percent of normal which is below the 20th percentile", or "The southwest monsoon index is at the 5th percentile which has a probability of occurrence of about one chance in 20." Decision makers frequently find it useful to know how this year's information compared to last year (e.g., as a percent of last year) or by also listing recent good (poor) years which are comparable. For example, an assessment of crop conditions made at the end of August and describing conditions as bad or worse than conditions in Thailand during 1979 would be well understood by users.

Weather Analysis

The weather analysis section describes the weather and climatic conditions which were associated with the impact. Only relevant information and data are provided. Information such as seasonal rainfall amount, monthly rainfall, tropical storm conditions, etc., are provided. Statements on the behavior of the monsoon (erratic, late arrival, early retreat, etc.,) are included. This is the classical weather description.

Support Information

The very last portion of the assessment is optional and provides reliable support statements taken from secondary sources of information. For example, reports from the field would be appropriate. News media accounts are generally not recommended.

B. Types of Assessments for Indonesia

This study developed three types of assessments including: 1) Drought Early Warning, 2) Agricultural Crop Condition and 3) Weather Advisories for the Extension Service. Depending on the user's requirements, the drought early warning and crop condition assessments can be combined into one report. The advisory assessment for the extension service should provide weather analysis in great detail and considerable information and data on soil moisture. A table providing soil moisture estimates for each month could be included. The specific requirements and format desired by users must be obtained.

C. Frequency for Making Assessments

The models developed in this study use monthly meteorological data; therefore, primary assessments are made within about 5 days after the end of each month during the growing season. However, update assessments providing current weather and other qualitative information can also be provided each week or every two weeks. These help the user maintain continuity.

Frequently, users require special assessment reports which elaborate on the potential impact problems. These could be 5-10 page reports.

Assessment models could be developed from decadal meteorological data (e.g., 10 day total rainfall) and assessments made every 10 days.

D. Assessment Models

Primary

The primary assessment models to be tested include the Generalized Monsoon Index (GMI) for the June-September rainy season, the Yield Moisture Index (YMI) defined for main rainy season maize and rice, monthly soil moisture estimates determined from the Palmer two-layer model and preliminary statistical climate/crop yield models for main rice and maize crops.

The historic indices have been summarized in computerized tables and time-series plots for each station in Northeast Thailand (see Chapter V for examples). The index is listed for each year and assessment period (GMI: Table 5.3 and Figure 5.1; YMI: Tables 5.5 and 5.7 plus Figures 5.2 and 5.3). Indices are expressed in raw numerical form as well as percent normal and percentile rank. Percentile ranks range from zero to 100. Each table can be used as a worksheet to compute real-time index values for the current year (1982, 1983, etc.). Current year index values can also be placed on the time-series plots for analysis. The tables and graphs permit the assessor to easily make comparisons with previous index years.

Each index has also been summarized in tables which provide index values for each location but for a specific year (e.g., see Table 5.2 for GMI). This is useful in performing a spatial analysis.

Soil moisture tables provide monthly moisture estimates for each layer in the soil (see Table 5.8).

Secondary models

The climatic diagram and the Palmer Drought Index (PDI) are very important secondary assessment tools. The climatic diagram can be determined from the soil moisture budget tables; however, the PDI (Figure 5.4) is usually calculated on a computer.

The climatic diagram can be presented in either table or graphic format. It is very useful as a tool to analyze conditions during the progress of the crop season.

The extension service and other users may be interested in receiving this information as a regular assessment product. Variables would include monthly rainfall, normal Potential Evapotranspiration (PET), Actual Evapotranspiration (AET), Soil Moisture (SM) and runoff. Rainfall or soil moisture normals could also be added.

It is also possible to define normal PET values for 10 day periods within each month. These can be used with real-time, decadal rainfall to provide the climatic diagram assessment every 10 days. Daily assessments can also be developed. For example, NOAA/AISC converts monthly rainfall normals into daily normals. This same process could be used with PET.

E. Display of Data

In addition to the tables and graphs discussed above for the index models and climatic diagram, there are other useful ways to display the data for enhanced analysis. For example, it is useful to prepare station location maps for the Northeast Region and to spatially analyze rainfall data and index values. Rainfall data can be plotted as a percent of normal for indivudal months or the growing season. Cumulative rainfall during the growing season can be displayed on a graph which also shows the normal cumulative rainfall.

F. Steps for Preparing Assessments

Some of the suggested procedural steps for preparation of an assessment include:

1) Obtain monthly rainfall data for the assessment stations and conduct quality control. Perform a spatial analysis.
2) Enter the rainfall data into the tables for the GMI, YMI and Soil Moisture.
3) Calculate the raw values for the GMI and YMI for the assessment period, as appropriate.
4) Calculate soil moisture, AET, etc.
5) Use the historic index tables to calculate percent of normal (YMI & GMI) and interpolate the percentile rank from the tables.
6) Plot the GMI and YMI percentile rank on the historic time-series plots.
7) Determine climatic diagrams for the current year.
8) Prepare maps which indicate the spatial variability of rainfall (percent normal) and indices (percentile rank).
9) Prepare the assessment using the above results and in the recommended format as outlined above, and
10) Obtain approval for the assessment and distribute to users in the Ministry of Agriculture and others, as appropriate.

G. Comments on Interpretation of Assessments by Users

The assessment should be viewed as an additional source of information that is available for making decisions on drought early warning, crop condition analyses and extension services. The assessment <u>only</u> provides information in potential or actual climatic impact. It does not consider the many other factors, for example, which could cause crop yield variability. These may include changes in planted area, fertilizer and pesticide applications, varieties and

other management decisions; crop losses due to pests are not assessed. The assessment is most reliable for potential drought impact, not flooding damage or other extreme weather events.

Drought impact can be reliably assessed by about 30 days before the crop harvest. This may represent as much as 3-6 months lead-time before economic impacts.

H. Comments on Test and Evaluation

It is proposed that the assessment models be tested and evaluated on the 1983 southwest monsoon season. Test assessments would be prepared at the end of May, June, July, August, September and October. These would be provided to users.

The purpose of this test period is to evaluate the models, learn how to interpret them, gain experience in preparing the assessment and to establish a dialogue with users. The users needs must be determined and their comments are very necessary.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

This program focused on rainfed agriculture in Northeast Thailand because of its drought vulnerability. The climatic impact assessment models developed during this program should be tested and evaluated before operational assessments are provided to users. Test assessments based on real-time meteorological data can be provided to interested users in government. Assessments can be evaluated and verified according to user comments and reliable field reports. The usefulness of the agroclimatic indices and models can be determined. If they are satisifactory, operational assessments can be provided. It is also desirable that similar models be developed for other regions. This can lead to a national climatic impact assessment program.

The major goal of this assessment program is to help decision makers and economists mitigate potential climatic impact on crops and the national economy by providing reliable, timely, yet inexpensive information on potential climatic impact. The assessments obtained from the models can be made 30 days in advance before harvesting of crops. This can represent a 3-6 month lead-time before national and regional economic impacts occur. This should certainly help users either in the governmental agencies or the public make economic decisions ranging from drought mitigation to land use planning.

One advantage of these agroclimatic indices and models is that they are simple. The assessments and models are purposely designed for manual operation. However, it is desirable to have computer facilities for faster and more accurate processing. In addition, more information concerning the phenological stages of the main crops at the provincial level should be obtained and analyzed together with the available climatological information. Finally, knowledge of

local practices constitute an important requirement for the modeling as well as for the testing of the model.

The Meteorological Department has agreed to be the NOAA/UMC focal point in Thailand for this technology transfer program and also to provide climatic impact assessments to appropriate agricultural and economic agencies. Thus, a staff or working group in this program should be set up. Cooperation with all other government agencies that deal with agriculture, land use and economics will help make the program worthwhile. Meetings between the staff and other governmental officers should be held to determine what other agencies need or whether they prefer to have the assessments made for some particular cases, areas or periods. Exchange of knowledge and real-time data on meteorological elements or agricultural information, soil condition, phenological data, yield, etc., should be encouraged. Local knowledge is also important. It can be provided either from other government agencies or through field surveys. The models and assessments will be of higher efficiency and more accurate if both the meteorological and agricultural experiment stations are linked together, i.e., the agricultural stations should have weather instruments installed within the area so meteorological elements there can be observed. As a result, the models obtained will be well represented in that region and greater efficiency in assessments can be provided.

The models developed will be tested and evaluated in 1983. Thus, the first trial assessments will be made and their usefulness can be estimated. Some adjustments will probably be made to imporve the models in various areas.

It is hoped that this technology transfer to Northeast Thailand will help the government mitigate potential drought impact on the region as well as the country. Early warning and preparedness for severe weather impacts on both agriculture and the economy can be made.

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