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REPORT OF WORK IN AGROCLIMATOLOGY

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Petrolina, 20 January, 1984

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1.- DUTIES AND RESPONSABILITIES

1. Participate in the research activities of CPATSA relating to the areas of meteorology, climatology, agroclimatology, and bioclimatology, collaborating specifically in the elaboration of models and simulation.
2. Collaborate in the agroecological classification of the semi-arid tropics in relation to the principal production systems of Northeastern Brazil.
3. Collaborate in the comparison of characterization methods of the space-time standards of rainfall distribution in the semi-arid tropics.
4. Participate in the activities concerning spacial tele-detection to construct models to predict the phenological states of the principal crops of the region using environmental parameters and satellite images.
5. Give seminars to the CPATSA staff on methodologies of modelization applied particularly to agroclimatology.
6. Advise the center on obtaining and processing meteorological and climatological data of the semi-arid tropics.
7. To prepare technical reports according to the requirements of the IICA/EMBRAPA-World Bank Contract and the needs of the CPATSA Head.

However, on joining at CPATSA (Petrolina) I was asked by the Chief (Dr. Antone José Simões) to develop a system of crops/cropping pattern along with their associated risk levels to suggest the Banks to provide loans to the farmers to improve the agricultural production over the Northeast Brazil under rainfed condition. In order to achieve this goal I was asked to prepare necessary projects and submit to EMBRAPA for approval for necessary funds. Accordingly first I divided this aspect into three broad areas of work, namely:

1. Development of data Bank

2. Field experimentation
3. Computer based simulations

These are presented in five projects¹, namely:

1. Agrometeorological data collection
2. Agroclimatological data collection
3. Agroclimatic classification studies
4. Soil water balance modelling studies
5. Crop-weather modelling studies

1 & 2 cover the "Development of data Bank"; part of 4 & 5 cover "Field experimentation" and 3 and part of 4 & 5 cover computer based simulations. These also cover most of the points under 'duties and responsibilities' except the 4th item. However, this item is not of much relevance to the Northeast Brazil at this stage. The broad area under computer based simulation is scheduled under four phases, namely:

Phase-I : Sub-division of the Northeast Brazil into broad zones of different production systems that have different mechanisms and limiting factors like arid, semi-arid, sub-humid and humid zones. The semi-arid zone constitute the target region of my further study as it represents the main rainfed dryland agriculture belt (Reddy 1983a) (Project 3 cover this aspect);

Phase-II : Characterization of the broad zones using monthly precipitation for a period of 15-years or more for wide net work of stations (Project 3 cover this aspect);

¹ : These numbers refer to number under 'List of publications' indicated in section 5.

Phase-III: Defining the cropping patterns and water & land management practices along with the risk levels of each system in each of the homogeneous zones identified in phase-II using selected stations daily precipitation data for a period of 52-years or more. As the handling of daily precipitation for all the locations is too time consuming, phase-II is introduced to reduce this task (Project 3 cover this aspect);

Phase-IV : Identification of crops and varieties and define their productive levels under each of the homogeneous zones identified in phase-II using the same data set that is being used in phase-III through simulation of "crop-weather-soil" models (Projects 4 & 5 cover this aspect).

A document¹ on these projects is prepared and submitted to the Technical Chief of CPATSA for approval, who suggested in turn to present these before a committee. Accordingly on 7 January 1983 these projects were presented and were approved. The first four projects were included under PNP-027 and the fifth project was included under PNP-030. Next few pages present the progress made in the above mentioned activities during 10 October 1982 to 26 January 1984. The assistance or cooperation received from different persons are acknowledged at appropriate places in the text.

2.- DEVELOPMENT OF DATA BANK

The most important parameters that are of importance for the agroclimatic study are:

- . Precipitation
- . Potential evapotranspiration/open pan evaporation
- . Global solar radiation
- . Temperature (maximum & minimum)
- . Relative humidity.

Precipitation and potential evapotranspiration/open pan evaporation are the two primary inputs into the water budgeting, as the former represents the available water and the latter represents the atmospheric water need. Temperature and relative humidity affect both crop growth and development while radiation affects the crop growth. The former is being recorded at many locations over the Northeast Brazil while the others are available for sparse net work of stations and hence need to be estimated through indirect means.

Since the validity of agroclimatological research will largely depend on the quality and standardization of information, it is important to check and correct the data series before they are actually used in the analysis. The development of data bank for the above five parameters involve the following steps:

1. Acquisition of data from meteorological Institutions;
2. Checking for the quality and standardization of meteorological data particularly precipitation
3. Identification and/or development of suitable methods for the generation of data, both in time and space.

2.1- Acquisition of data from meteorological Institutions:

SUDENE (Recife) provided the monthly precipitation data* for individual years for all the available locations (991 - Fig. 1) over the northeast Brazil². Figure 2 depicts the spatial distribution of mean annual rainfall over northeast Brazil². In drawing the isolines 991 locations (Fig. 1) data were used. The monthly open pan evaporation data were available through a publication (Brasil. SUDENE, 1974) for about 24 locations over the northeast Brazil and the monthly average global solar radiation data were available through a publication (Vieira et al. 1981) for about 45 locations over the northeast Brazil. Daily meteorological data were available for Bebedouro and Mandacaru the two

* Malaquias da Silva Amorim Neto (Agrometeorologist) helped in acquiring this data from SUDENE (Recife).

Fig. 1 : List of precipitation net work over northeast Brazil.

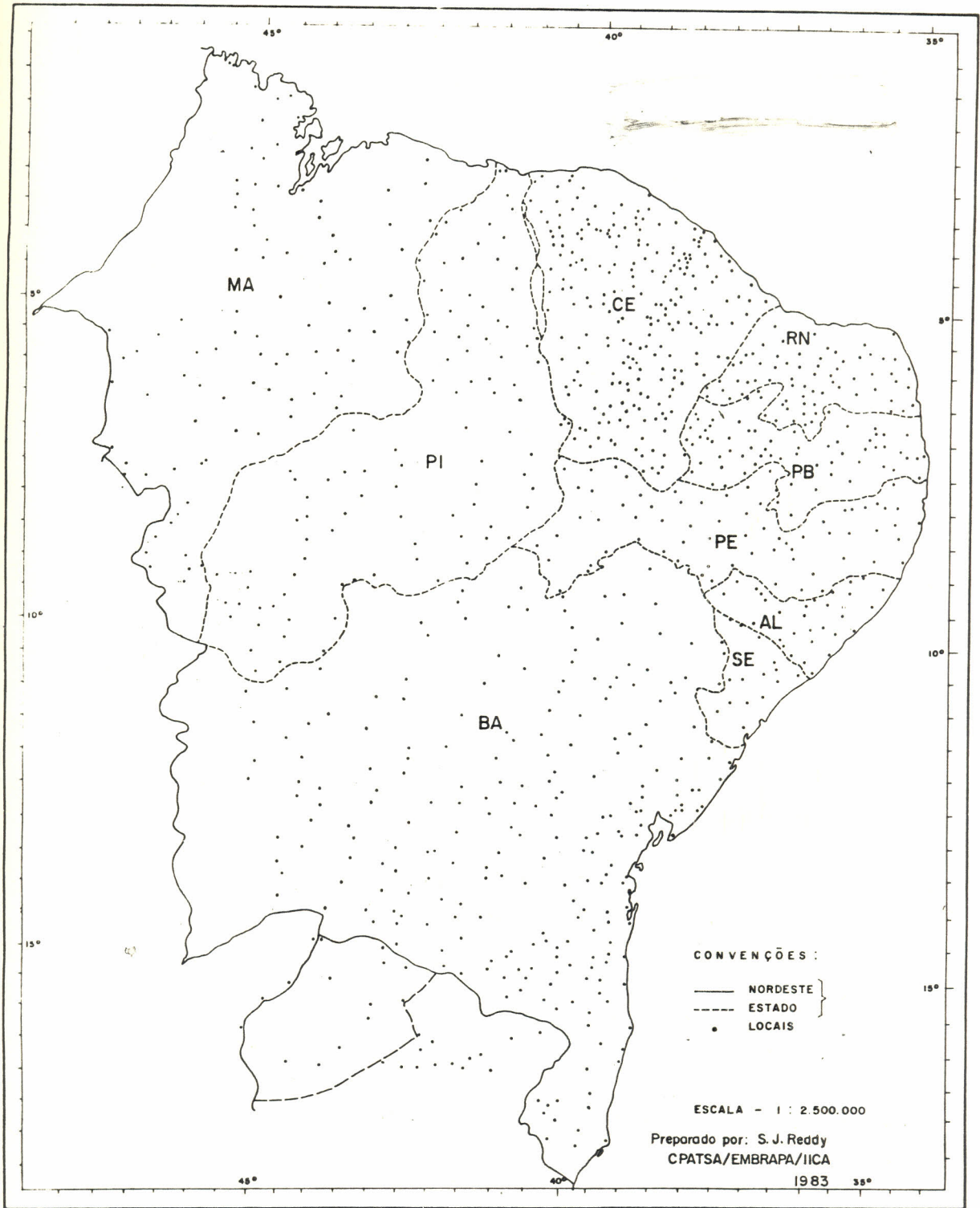
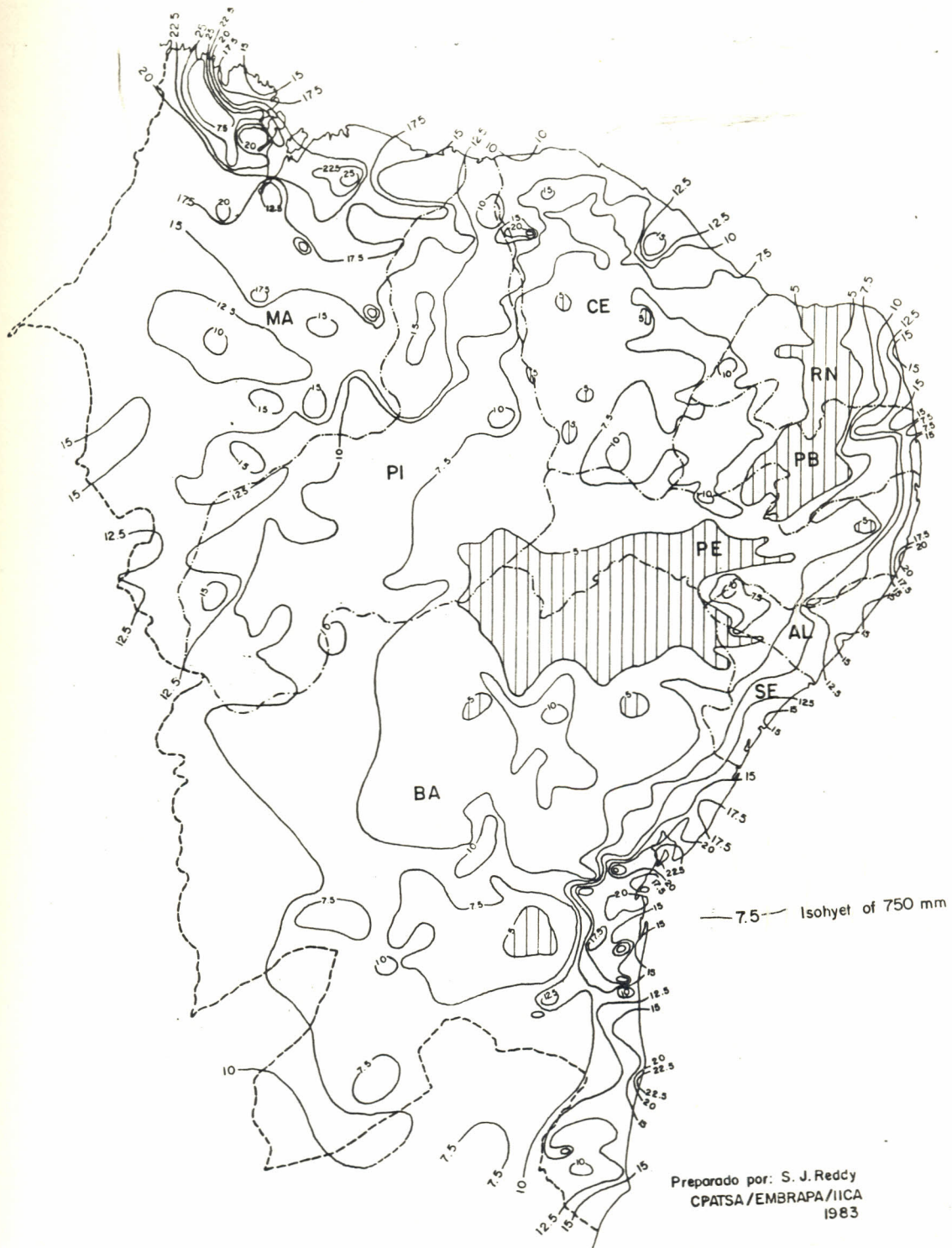


Fig. 2 : Mean annual precipitation distribution over northeast Brazil.



research centers of CPATSA (Petrolina).

2.2- Checking for the quality and standardization of precipitation data:

Before the precipitation data are being used in the actual analysis it is important to check the data series for homogeneity and for trend or cyclic variation. The latter is very important for the long-term planning or for the development of suitable agricultural systems for different climatic zones. The former is more associated with change of observation site or measuring glass or observational errors during a particular period. Preliminary study indicated such possibilities. This study was attempted using the data of 70-years for 105 locations³.

In order to assess the cyclic variations in the precipitation series and to homogenize the precipitation regimes of the Northeast Brazil 70-years annual precipitation data of 105 locations were subjected to power spectrum analysis*. According to the cycles that are present in the annual precipitation data, the Northeast Brazil (excluding Maranhão & Piauí) could be divided into three homogeneous zones, namely:

- | | |
|------------|---|
| Region-I | Comprises of regions north of $4-5^{\circ}\text{S}$ lat.; |
| Region-II | Comprises of regions between $4-5^{\circ}\text{S}$ to $8-10^{\circ}\text{S}$;
and |
| Region-III | Comprises of regions south of $8-10^{\circ}\text{S}$ lat. |

It is evident from the auto-regression analysis (Figs. 3 & 4) in Region-I, the dry period (below average precipitation) commenced in 1979 may continue upto 1995 with a break for three years in 1988-1990. The wet period (above average precipitation) may commence in 1996 and terminate in 2003. Similar patterns are

* The necessary program was prepared and analysis was carried out on EMBRAPA (Brasília) computer system.

Fig. 3 : Time series of Fortaleza (Ceará) precipitation

Lat: $3^{\circ}46'$ Long: $38^{\circ}34'$ 30 m

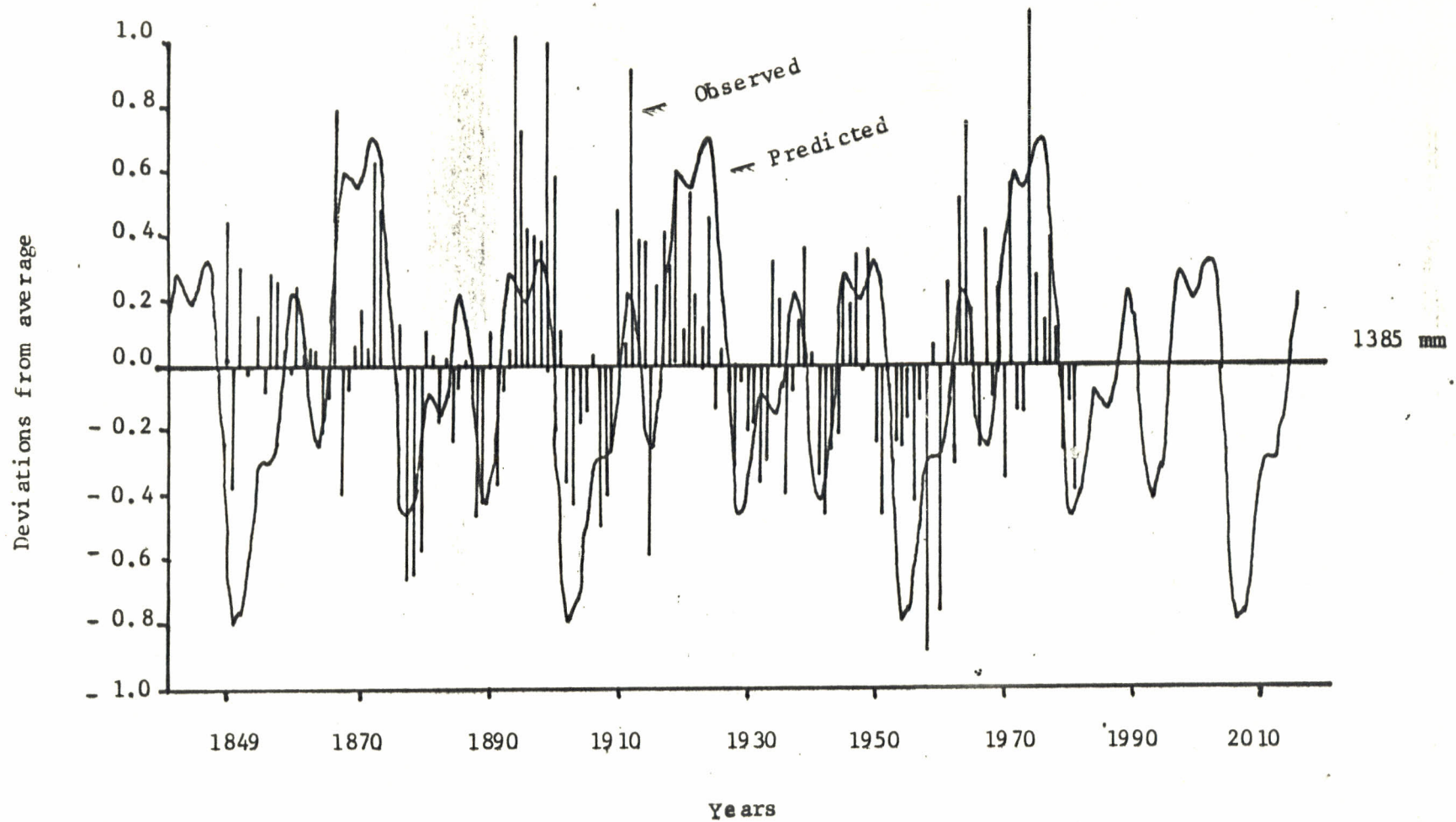
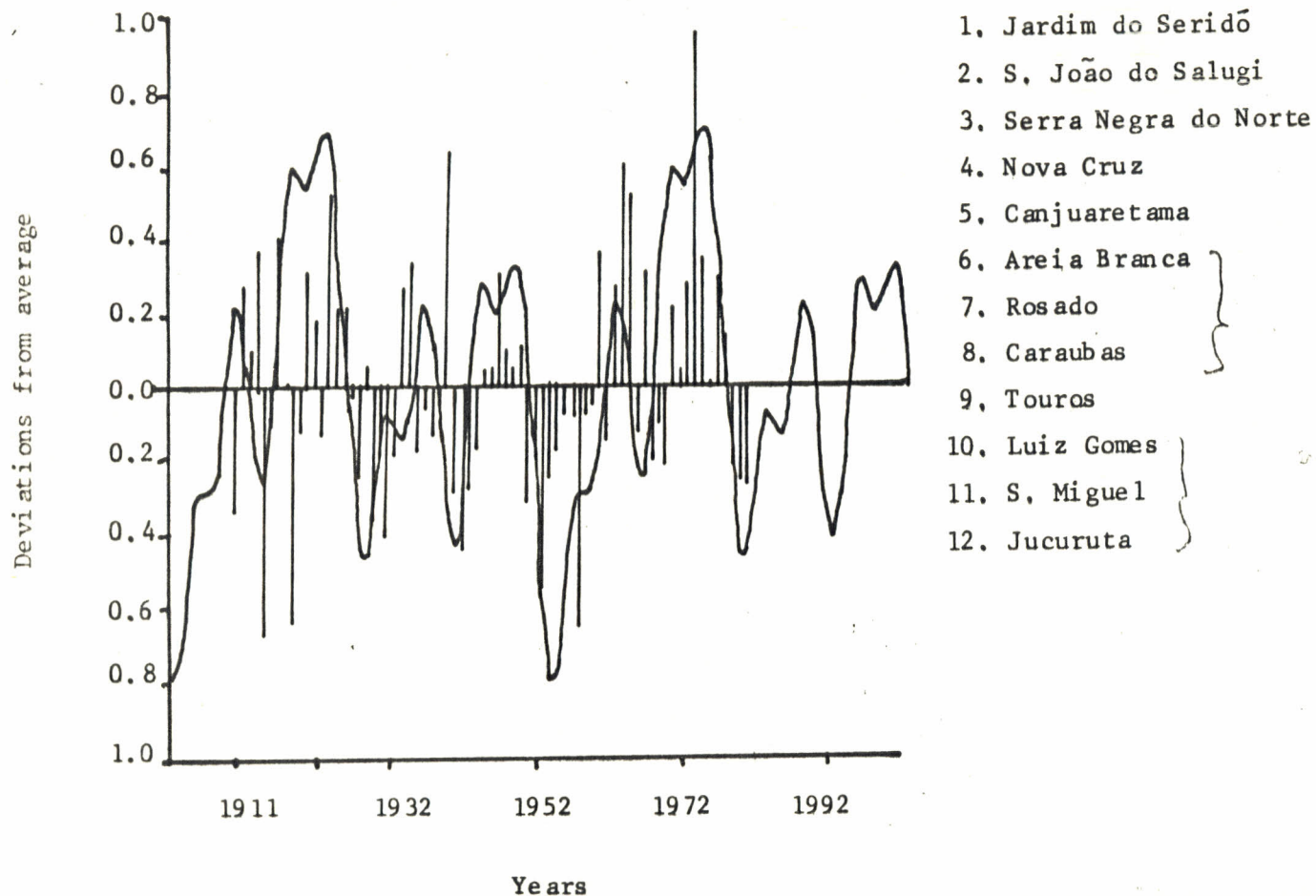


Fig. 4 : Time series of average precipitation of 12 locations from Rio Grande do Norte.

Lat.: $4^{\circ}57'$ to $6^{\circ}43'$

Long.: $35^{\circ}7'$ to $38^{\circ}30'$

Alt.: 05 to 605 m



not evident clearly in Regions-II and III, even though Region-II presenting similar to Region-I. A later study⁴ suggests that Region-III has a different cyclic variation (Fig. 5) i.e. 35-years above average followed by 35-years below average pattern with each period having for few years opposite variation. The above average pattern ended by 1927-29 and commenced the below average pattern and ended by 1961; and the above average pattern commenced in 1962 may terminate in 1996. In the below average pattern during 1937-51 present near average or above average pattern. Similarly in the above average pattern during 1977-1990 present near average or below average pattern. The reasons for such differences in Region-I and III may probably be due to the mechanisms that give rise the precipitation over these regions. In the former Region the precipitation is caused mainly due to local convective activity and/or movement of ITCZ (Inter-tropical convergence zone) more of a tropical phenomena while in the case of latter region the precipitation is caused mainly due to movement of frontal systems from south-west to north-east (more of middle latitude phenomena).

These two studies clearly demonstrate the non-homogeneity in the data series of few locations which need to be either corrected for homogeneity or to be eliminated from the analysis.

2.3- Identification and/or Development of suitable methods for the generation of data, both in time and space:

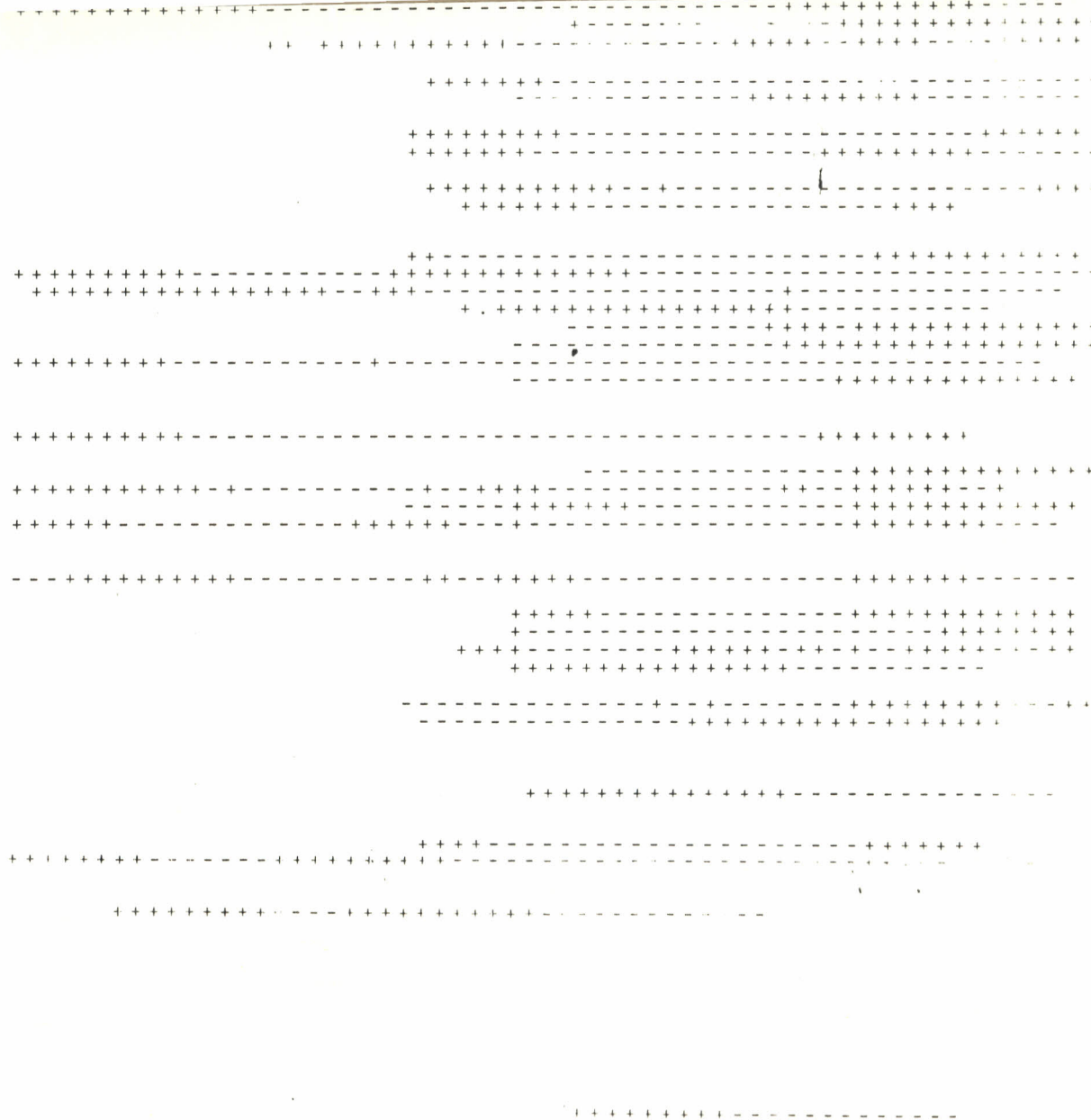
2.3.1- Potential evapotranspiration/open pan evaporation:

In the literature there are a number of models that are derived and tested over different parts of the world. However, there is one big problem in adopting these models as some of the meteorological parameters such as temperature and relative humidity need to be standardized as the mode of recording these parameters present slightly different conditions from those of other parts of the world. Open pan evaporation (U.S. Class 'A' - without mesh cover) relates directly to potential

	A	N	O	S
Chorrocho				
Curaçá	+	-	+	+
Glória				+
Casa Nova	+	+	+	+
Patamute	+	+	+	+
Juazeiro	+	+	+	+
Barra Vermelha				
Várzea da Ema				+
Sento Sé				
São Pedro				
Remanso	+	-	-	+
Juremal				
Uauã	+	+	+	+
Favel				
Canudos	+	+	+	+
Barrinha				
Salininha				
Pedro Alexandria				
Jeremoabo				
Santa Rosa				
Pilão Arcado	+	+	+	+
Cipó de Leite				
Jaguarari				
Campo Largo				+
Monte Santo	-	-	-	-
Senhor do Bonfim	-	-	+	+
Euclides da Cunha	-	-	-	-
Cícero Dantas	-	-	+	-
Mirandela				
Cancanção				
Parapiranga	+	+	+	+
Itiuba				
Landsidão				
Pindobacu				
Quijingue				
Monteiro				
Ribeiro do Pombal				
Xique-xique	-	-	+	+
Jaguaraci	+	+	+	+
Saúde				
Queimadas	-	-	-	-
Tucano				
Formoso do Rio Preto				
Barra	+	+	+	+
Jacobina	+	+	+	+
Rio do Peixe				
Itapicuru				
Santo Inácio				
Iracê				
Araci	+	+	+	+
Boqueirão				
Rio Real				
Salgadalia				
Morro do Chapéu	+	+	+	+
Caripare				
França				
Valente				
Morpara				
Serrinha	+	.	+	+
Ventura				
Mt. Alegre da Bahia				
Tagua	-	-	-	-

Formoso do Rio Preto
Barra
Jacobina
Rio do Peixe
Itapicuru
Santo Inácio
Irecê
Araci
Boqueirão
Rio Real
Salgadalia
Morro do Chapéu
Caripare
França
Valente
Morpara
Serrinha
Ventura
Mt. Alegre da Bahia
Tagua
Esplanada
Inambuê
Riacho do Jacuipê
Ipupiara
Barra do Mendes
Mundo Novo
Bonito
Brotas de Macaúbas
Irara
Cotegipe
Palame
Alagoinhas
Macajuba
Ipirá
Barreiras
Ibotirama
Bom Sossego
Araçás
Feira de Santana
kui Barbosa
Wagner
Catu
Lajedinho
Mariquita
Scabra
S.G. dos Campos
Sítio Grande
São João
Brijolândia
Paulista
Conde
Itaberaba
Açu da Torre
Lençóis
Dias d'Ávila
S.F. de Conde
S. Felix
Ibiquira
Muritiba
Boa Vista do Tupim
Bonival
Paratinga
Castro Alves
Santa Terezina
João Amaro
Serra Durada
Andaraí
St. Ant. do Jesus
St. Ant. do Jesus
Itaeté
Santana
Macaúbas
Salvador
Nazaré
Amargosa
Brejões
Sítio do Mato
Machado Portela
Santa Inês
Bom Jesus da Lapa
União

Lagoa Clara
 Novo Acre
 Água quente
 Maracão
 Batalha
 Buriata de Sincora
 Contendas
 Riacho da Santana
 Nilo Peçanha
 Barra da Estiva
 Caribe
 Cabeceira do Itiuba
 Gandu
 Igapora
 Rio de Contas
 Ituaçu
 S. Sebastião dos Gatos
 Porto Alegre
 S. Timóteo
 Jequiê
 Parateca
 Itajuru
 Lagoa dos Cochos
 Caetité
 Ipiáu
 Cocos
 Brumado
 Gamambi
 Palma de Monte Alto
 Itajiba
 Careima
 Carinhanha
 Ubaitaba
 Milha da Pedra
 Guarapa
 Aracatu
 Mandiroba
 Caculé
 Pindai
 Poções
 Ponte Chique
 Morrinhos
 Planalto Baiano
 Pres. Jânio Quadros
 Urandi
 Itabuna
 Vitória da Conquista
 Condeuba
 Itajai
 Buerarema
 Jacaré
 Campo Formoso
 Cordeiros
 Itororô
 Lagoa Preta
 Liberdade
 Itambê
 Itapetinga
 Macaramui
 Mascote
 Itaretim
 Itapebe
 Porto Seguro
 Itamaraju
 Itanhém



+ above average humid period;
 - below average humid period.

evapotranspiration* is recorded at few locations only. This presents less than 5% of the precipitation net work.

Hargreaves (1974) presented potential evapotranspiration values for about 700 locations over northeast Brazil (monthly averages only). For 154 locations these were estimated using temperature and relative humidity and for the rest estimated through extrapolation using 154 locations data. However, on comparison with observed open pan data over the Northeast Brazil suggest that these present over estimates during rainy season and under estimates during dry period. These values can be corrected to match with the open pan evaporation data using the following equation:

$$PE = PE' \times K_i \quad \dots (1)$$

$$\text{where } K_i = 1 + 0.15 \cos \left(\frac{2\pi i}{12} - 300 \right)$$

PE' = Hargreaves potential evapotranspiration estimates

PE = Potential evapotranspiration

i = 1 to 12 for January to December respectively.

This difference may be due to the errors in the input data sets (temperature & relative humidity) and also these data sets are available for few locations and for few recent years. For the agroclimatic analysis PE values are needed for as many locations and years as precipitation data are available. Therefore, to achieve this goal the following strategy was tried and found very good agreement for the entire Brazil⁵. For this analysis the data of 31 locations (Fig. 6) presented by Hargreaves (1979) were used. The two equations that were suggested for computation of PE are:

$$PE' = a + b_1 (la) + b_2 (lo) + b_3 (l) + b_4 (R^{0.25}) + b_5 (R_{-1}^{0.25})$$

$$\text{or } PE' = a + b_1 (la) + b_2 (R') \quad \dots (3) \quad \dots (2)$$

$$\text{with } R' = (R + R_{-1}/3)^{1/3}$$

* Potential evapotranspiration = 0.75 x open pan evaporation
(without mesh cover)
= 0.85 x open pan evaporation
(with mesh cover)



Fig. 6 : Distribution of locations used in the analysis of potential evapotranspiration over Brazil.

where: $a, b_1, b_2, b_3, b_4, b_5$ are regression coefficients (See Tables 1 and 2 for eqs. 2 & 3 respectively)

λa is the latitude in degrees

λo is the longitude in degrees

ℓ is the altitude in meters

R is the precipitation of that month in mm

R_{-1} is the precipitation of the previous month, mm

($PE = PE' \times K_1 \dots$ see eq. 1)

Figure 7 presents the comparison between observed and estimated values for January to December using the data of entire Brazil. They present a very close agreement. This study indicates that PE is highly correlated with precipitation during summer months and with latitude during winter months.

When elivation is not an important factor eq. 3 or when elivation is also an important factor eq. 2 could be used for the estimation of average PE. For the estimation of individual yearly values eq. 3 could be used or average values could be estimated using eq. 2 and corrected using the approach of Reddy (1979) for individual years as:

$$PE_y = PE_n (1 \pm 0.06 |Z_n|^{1/3}) \quad \dots (4)$$

where $Z_n = c' (\Delta R_n + 1/3 \Delta R_{n(-1)})$

$c' = 1$ for weekly data; 7 for daily data; 7/30 for monthly data;

PE_n = average potential evapotranspiration

PE_y = potential evapotranspiration of year y

$\Delta R_n = R_n - R'_n$

R_n = rainfall in year y

R'_n = average rainfall

+0.06 if Z_n is positive

-0.06 if Z_n is negative

$R_{n(-1)}$ = rainfall for the preceeding period (month or week or day).

TABLE 1. Regression parameters and their significance (using five independent variables). Eq. 2

Meses	\$	Regression Parameters #						
		a	b ₁	b ₂	b ₃	b ₄	b ₅	R ²
Janeiro	1	271.1	0.886*	-.295	-.014	-29.823*	-	0.757
	2		.28	.35	.009	5.83	-	
Fevereiro	1	278.0	-	-	-.008	-38.307*	-	0.828
	2		-	-	.006	3.39	-	
Março	1	353.2	-1.297*	-.338	-.006	-26.257**	-21.771**	0.816
	2		.29	.30	.008	11.20	9.90	
Abril	1	370.6	-2.690*	-.694*	-.031*	-33.175*	-13.238***	0.842
	2		.27	.20	.009	6.69	6.57	
Maio	1	296.0	-3.246*	-.623*	-.028*	-7.946**	-20.345*	0.893
	2		.25	.20	.008	3.91	6.84	
Junho	1	209.8	-3.175*	-.533*	-.014**	-10.655*	-	0.922
	2		.20	.19	.007	2.17	-	
Julho	1	219.6	-3.465*	-.385***	-.017**	-	-11.823*	0.926
	2		.20	.20	.007	-	2.30	
Agosto	1	239.9	-3.108*	-.281	-.018*	-17.859*	-	0.931
	2		.21	.19	.007	2.65	-	
Setembro	1	257.6	-2.503*	-.214	-.019**	-16.680**	-7.855***	0.916
	2		.24	.27	.007	6.41	4.02	
Outubro	1	265.0	-1.179*	-	-.026**	-10.867	-18.684**	0.739
	2		.34	-	.010	6.63	8.02	
Novembro	1	240.1	-	-	-.027*	-	-25.245*	0.668
	2		-	-	.008	-	3.88	
Dezembro	1	256.6	0.662***	-	-.012	-29.738*	-	0.651
	2		.32	-	.010	4.97	-	

\$: 1 = regression parameters; 2 = standard errors of regression

* = significant at > 99% parameters

** = significant at > 95%

*** = significant at > 90%

TABLE 2 . Regression parameters and their significance (using two independent variables). Eq. 3

Meses	\$	Regression Parameters [#]			
		a	b ₁	b ₂	R ²
Janeiro	1	237.1*	0.621**	-14.286*	0.625*
	2	15.1	.32	2.28	
Fevereiro	1	244.9*	- .202	-16.853*	0.715*
	2	14.2	.26	2.07	
Março	1	332.0*	-1.873*	-26.033*	0.761*
	2	20.1	.29	2.77	
Abril	1	253.6*	-2.519*	-15.382*	0.650*
	2	21.9	.35	3.05	
Maio	1	192.8*	-2.954*	- 6.576*	0.804*
	2	11.9	.28	1.81	
Junho	1	173.6*	-3.273*	- 4.756*	0.889*
	2	6.9	.22	1.21	
Julho	1	182.6*	-3.471*	- 4.588*	0.898*
	2	6.0	.23	1.17	
Agosto	1	207.5*	-3.274*	- 7.327*	0.902*
	2	6.0	.22	1.34	
Setembro	1	227.8*	-2.651*	-11.627*	0.891*
	2	7.9	.22	1.89	
Outubro	1	237.1*	-1.590*	-11.716*	0.670*
	2	12.6	.33	2.58	
Novembro	1	220.0*	- .467	-10.758*	0.462*
	2	13.4	.35	2.39	
Dezembro	1	232.7*	.383	-13.420*	0.550*
	2	14.4	.35	2.33	

\$: 1 = regression parameters; 2 = standard errors of regression

* = significant at > 99% parameters

** = significant at > 95%

*** = significant at > 90%

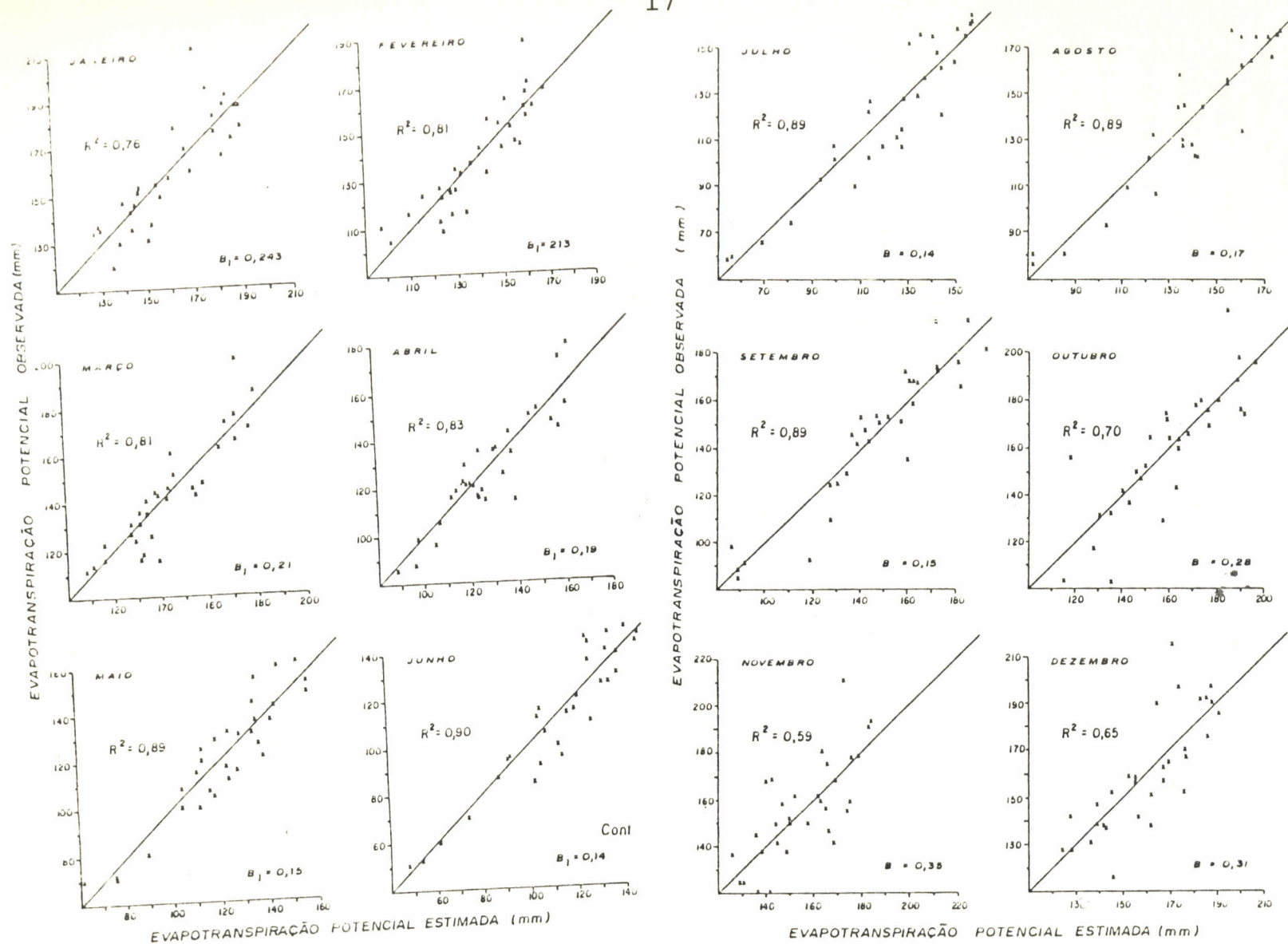


Fig. 7 : Comparison of observed (Hargreaves estimates) and estimated (using eq. 2) potential evapotranspiration over Brazil using the data of 31 locations (monthly data).

These equations could be extended to weekly data sets by simple extrapolation of the coefficients presented in Tables 1 & 2. A correction is applied based on number of days in a week and month.

This technique was applied and computed for individual weeks for about 290 data points each for Bebedouro and Mandacaru. The comparison is presented in Fig. 8. This figure indicates that the estimates for Bebedouro and Mandacaru respectively present slightly over and underestimates. This is primarily because wet advection at Bebedouro and dry advection at Mandacaru (evident from relative humidity and wind speed and direction).

Some of the draw backs of this approach are:

(1) With an overcast sky without rain evaporation will be higher and (2) on a rainy day evaporation will be low. These are not regular phenomenae. However, the major advantage of this procedure is it estimates PE as accurately as other sophisticated methods that exist in the literature using easily available other climatic parameters; and thereby it over comes the major hurdle of non-availability of data for agroclimatic analysis.

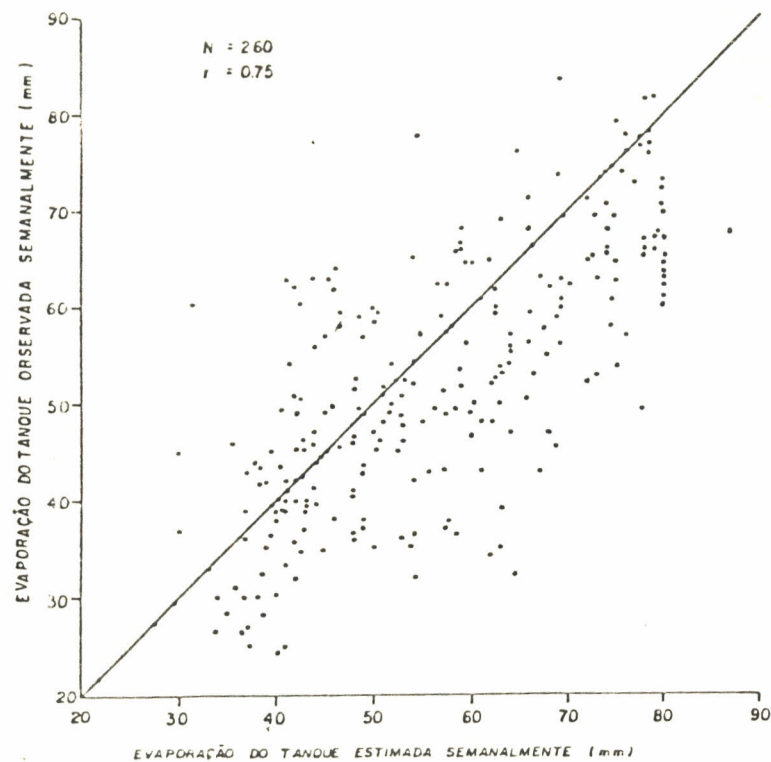
Using the eq. 2 monthly potential evapotranspiration values* were computed for 991 locations (Fig. 1) of northeast Brazil². Fig. 9 depicts the spatial distribution of mean annual PE over northeast Brazil.

2.3.2- Global solar radiation:

Over the northeast Brazil it is being measured at about 45 locations (Vieira et al. 1981). This net work constitute less than 5% of precipitation stations. These records are available only for few recent years also, instrumental differences are considerable. Because of these constraints in the past several scientists used simple empirical models to derive global solar radiation for a wide net work of stations from other meteorological paremeters (Angstrom 1924, Reddy 1971, Reddy & Rao 1973, Reddy et al. 1977).

*A Program in basic language was prepared and adopted to CPATSA computer system.

BEBEDOURO



MANDACARU

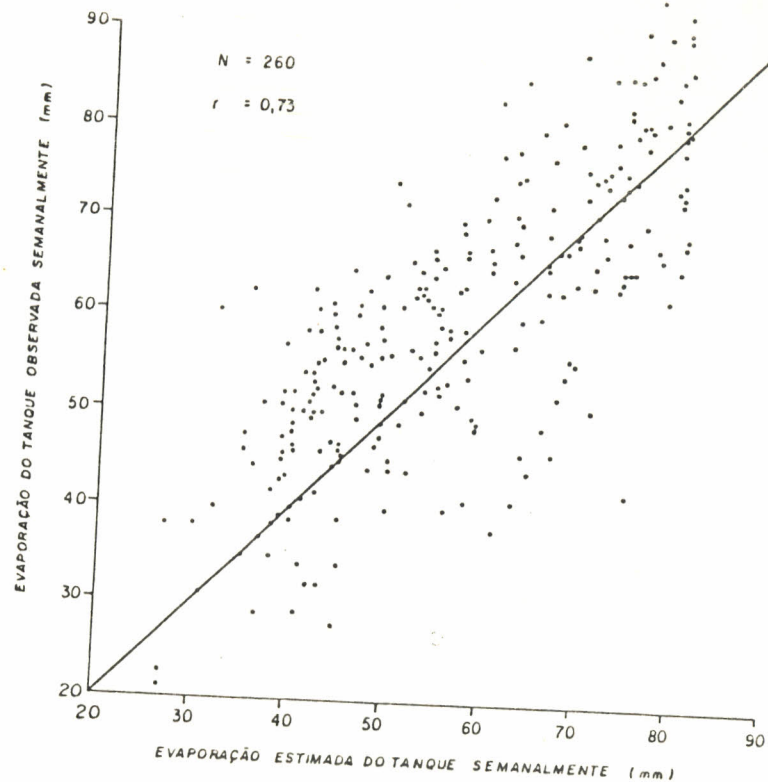
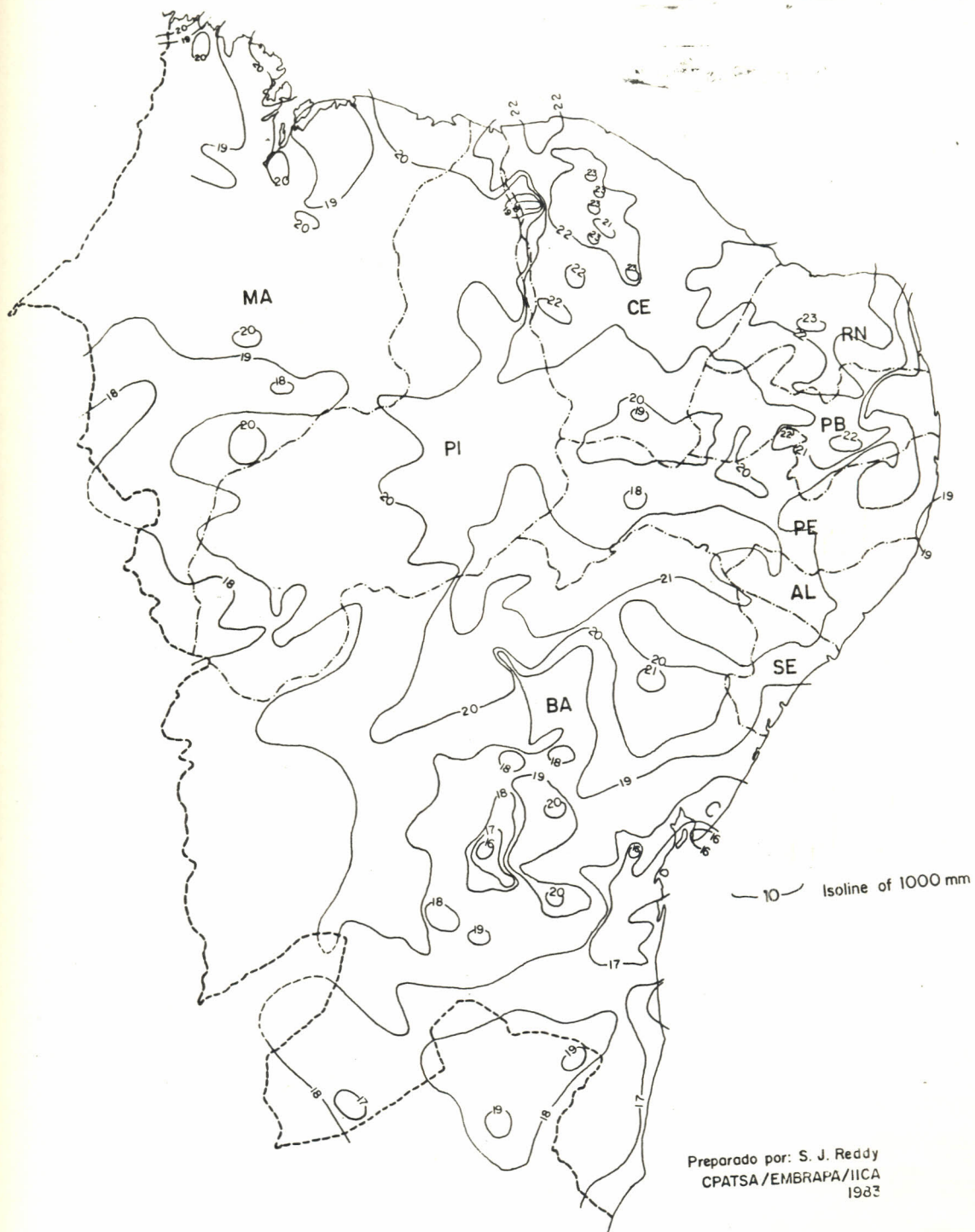


Fig. 8 : Comparison of observed and estimated (using eq. 3) open pan evaporation for Bebedouro and Mandacaru using 260 data points (weekly data of 1968, 1971, 1976, 1978 & 1982).

Fig. 9 : Mean annual potential evapotranspiration distribution over northeast Brazil.



The basic weakness of empirical formulae is that they don't account for the localized factors that contribute significantly to the level of turbidity that increases or decreases the proportionate radiation per unit cloud cover. Therefore, it is very important to test the models before they are actually applied to any new region. Three models, namely Reddy (1971); Reddy et al. (1977); Angstrom (1924) were tested to understand their suitability for the northeast Brazil using the data of 15 locations. In all the three methods the estimated values exceeded observed values by 5% in more than 70% of occasions⁶. Also, the basic input data for these models are available for few locations that too for few recent years. Hence, a simple regression equation that relates global solar radiation to precipitation and latitude is established. In the derivation of the equation data of 15 locations were used and for testing the model the data of 23 locations were used (Fig. 10). The equation is written as:

$$R_t = a + b_1 (\ell a) + b_2 (R^{1/3}) \quad \dots (5)$$

where R_t = global solar radiation, ly/day

ℓa = latitude, degrees

R = precipitation, mm

a, b_1, b_2 = constants (see Table 3).

Table 4 presents the percent occasions the deviations are (observed - estimated using eq. 5) in different ranges for 15 (used in the development of eq. 5), 23 (used to test the model) and total 38 locations (monthly values). In about 78% of occasions the deviations are less than 10%. The seven locations that contributed significantly to large deviations are Petrolina, Macei , Acarau, Macau, S o Gon alo, Carolina, Monte Santo. This appears that these large deviations are primarily due to differences in the instruments (uncalibrated) used to record the data. This can be clearly seen from Petrolina data (Fig. 11) on comparison with two nearby locations (Mandacaru & Bebedouro), Petrolina present about 10% higher than those at Mandacaru & Bebedouro. Table 5 presents the percent

Fig. 10 : List of locations used in the analysis of global solar radiation over northeast Brazil.

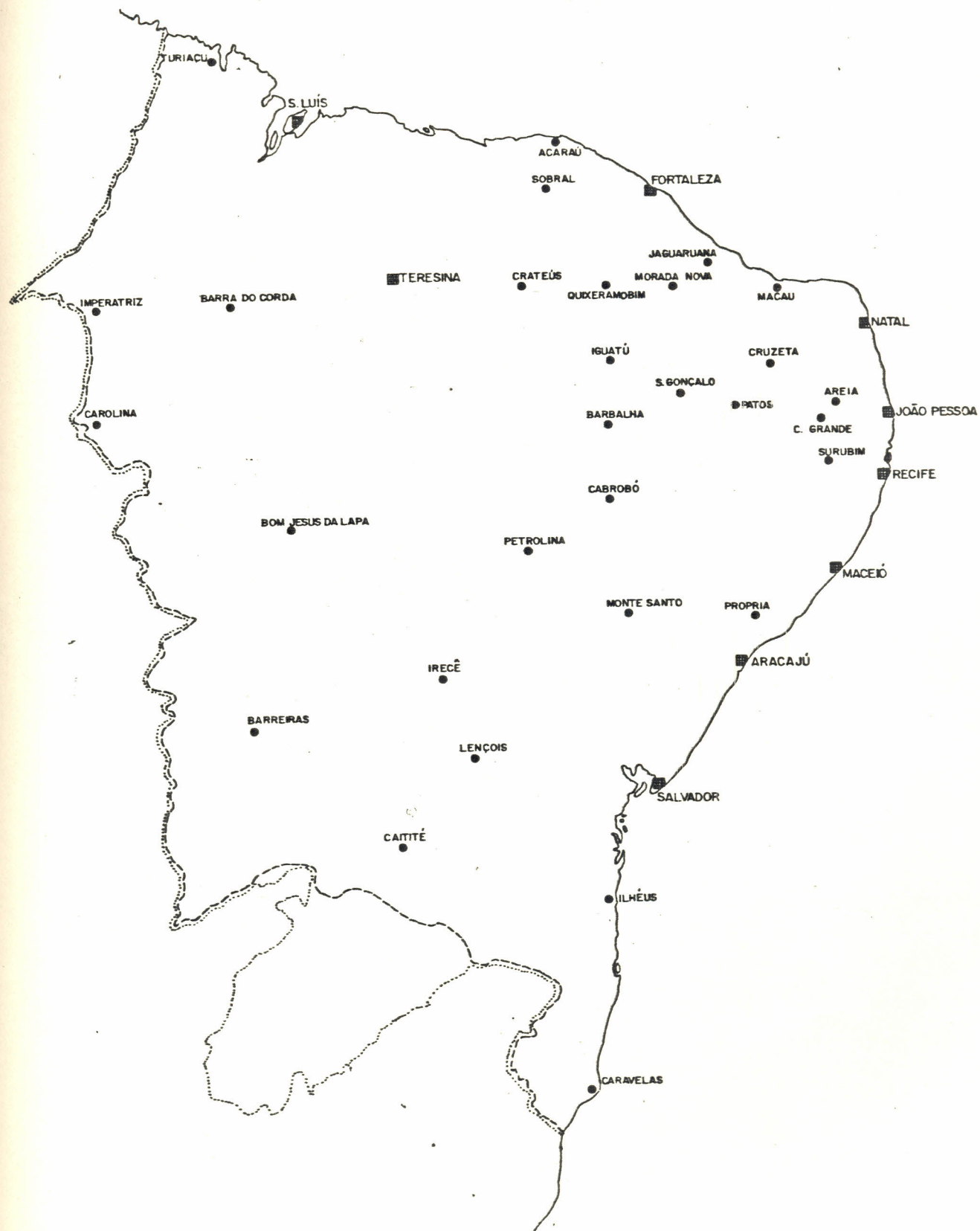


Table 3.- Regression parameters and their significance. Eq. 5.

Months	Regression parameters			R^2
	a	b_1	b_2	
January	532	15.17	-40.80	0.92
February	608	8.50	-44.44	0.76
March	685	3.70	-44.80	0.92
April	551	0.50	-23.70	0.54
May	477	- 1.50	-16.91	0.51
June	442	- 2.00	-14.00	0.73
July	444	- 2.00	-12.07	0.61
August	501	- 1.00	-13.20	0.16
September	523	0.70	-15.00	0.06
October	517	4.70	-20.20	0.34
November	543	10.66	-35.79	0.39
December	510	10.59	-30.07	0.52

Table 4.- Percent occasions the deviations under different minimum specified limits using different models.

Model	Percent occasions the deviations (D*) in the limits			
	≤ 5	5 - 10	$\geq 10 - 20$	≥ 20
Angstrom (1924)	28.3	31.7	32.8	7.2
Reddy (1971)	22.8	12.8	16.6	47.8
Reddy et al. (1977)	20.8	14.9	33.3	31.0
Eq. 5	60.0	21.7	17.8	0.6
Eq. 5	51.3	24.2	18.3	6.2
Eq. 5	54.7	23.2	18.1	4.0

*

$$D = \frac{R_{tc} - R_{t0}}{R_{t0}} \times 100, \%, \text{ Where } R_{tc} = \text{computed}$$

$$R_{t0} = \text{observed}$$

**

$$D \leq 5\%, \quad 5\% < D < 10\%, \quad 10\% \leq D < 20\%, \quad D \geq 20\%$$

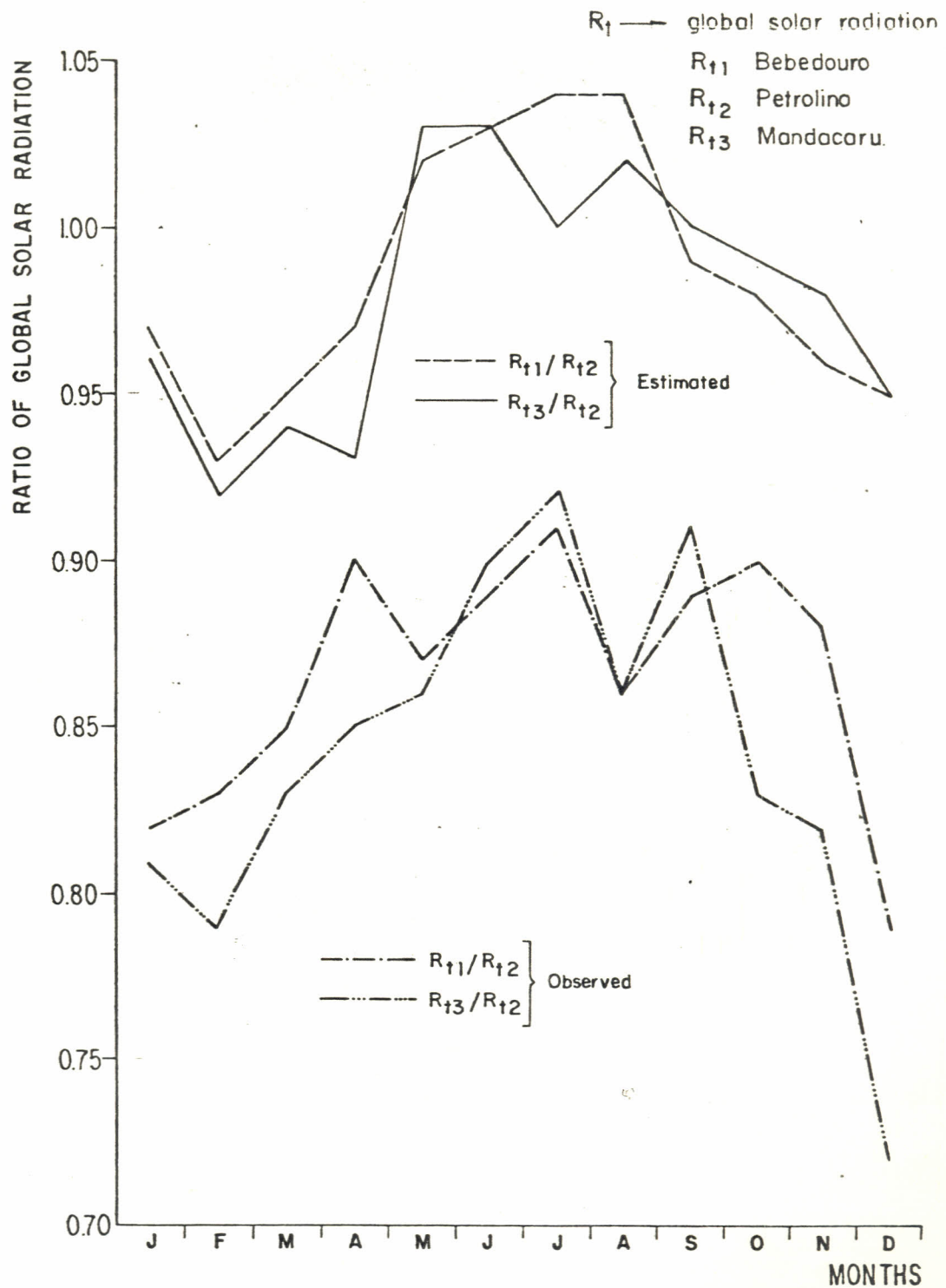


FIG. 1 Comparison of ratio of global solar radiation recorded at Bebedouro, Mandacarú to Petrolino (observed and estimated)

Table 5.- Percent occasions the deviations are in different ranges for different months (Based on 38 locations)

Range (%)	Percent occasions											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
≤ 5	64.9	54.1	55.3	57.9	57.9	57.9	63.2	57.9	55.3	50.0	47.9	44.7
5 - 10	18.9	27.0	23.7	13.2	21.1	28.9	18.4	23.7	21.1	21.1	18.4	26.3
≥ 10	16.2	18.9	21.1	28.9	21.1	13.2	18.4	18.4	23.7	35.1	28.9	28.9
R^2	.92	.76	.92	.54	.51	.73	.61	.16	.06	.34	.39	.52

occasions the deviations under different ranges for January to December. Except in October to December the deviations are $\leq 5\%$ in more than 50% of occasions. The deviations exceed 10% in more than 30% occasions in October while they are less than 20% in March to May & September to December. R^2 (square of correlation coefficient) values are not truly reflecting these deviations. See for example January to August where $R^2 = 0.92$ & 0.16 respectively with similar deviations. The R^2 values appear to be more related to the range of values over which this analysis is made (in August the range is very small while it is very large in January).

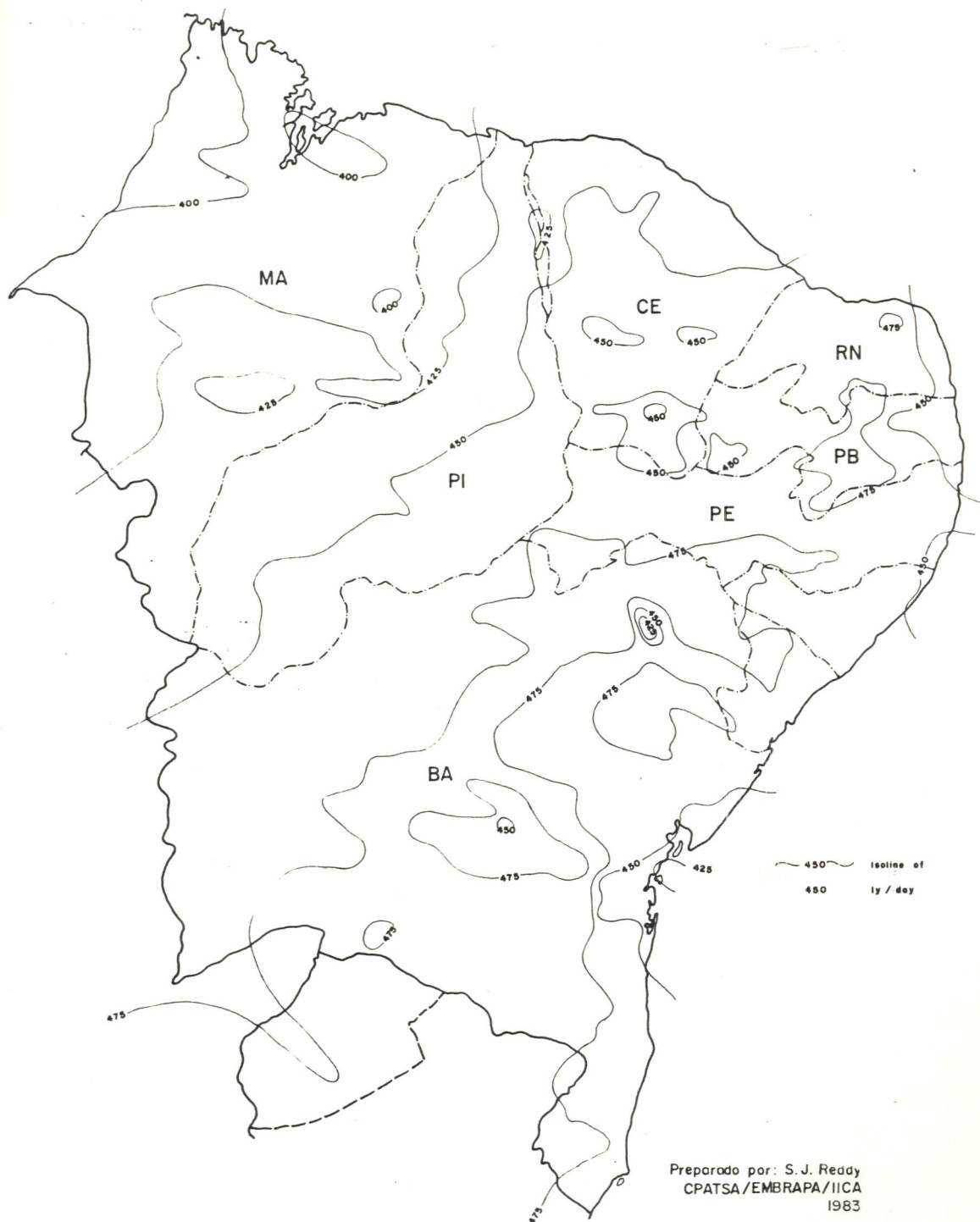
Therefore, in terms of these deviations, this method can reasonably be adopted to estimate global solar radiation over northeast Brazil. By extrapolating the regression coefficients in Table 3, this model can be extended to weekly data. Using this model monthly R_t values were computed for 991 locations (Fig. 1) of northeast Brazil². Fig. 12 depicts the spatial distribution of annual global solar radiation over northeast Brazil*.

2.3.3- Temperature & Relative humidity:

Over the northeast Brazil these parameters are being measured at about 150 locations. This net work constitute less than 10% of precipitation stations. The standard procedure of recording temperature and relative humidity are to keep the four thermometers (maximum, minimum, wet & dry bulb) in a single Stevenson's screen and thermograph & hair hygograph in a double (in size) Stevenson's screen. However, over northeast Brazil, these six instruments along with piche evaporimeter (which should be kept in a separate screen) were housed in one big screen and in turn this screen is housed inside an another big screen. Thereby, the temperature and relative humidity do not represent the true air temperature and relative humidity as free ventilation is restricted and increased humidity in the screen. Therefore, it is very important to test by simultaneous

* A program in basic-language was prepared and adopted to CPATSA computer system.

Fig. 12 : Mean annual global solar radiation distribution over northeast Brazil.



measurements using a standard screen and develop a correction factor. The simultaneous measurements need to be carried out at least 4-5 locations over northeast Brazil under different climatic regimes. This aspect is proposed in project 2. No progress has been made to date on this and hence it was not attempted to develop a method to extrapolate this information for other locations.

To appraise the scientists of northeast Brazil the above discussed material is being published in a scientific Journal of EMBRAPA. Also a seminar was presented to CPATSA Scientists on these aspects.

3.- SIMULATION

3.1- Division of northeast Brazil into broad zones:

It is seen from Fig. 2 that over northeast Brazil the precipitation varies between 300 to 2000 mm indicating high variation in climatic regimes. Over different parts the mechanisms and limiting factors for crop productivity are widely different. It is very important to isolate such distinctive regions, because the mode of research emphasis one should make are different in different regions. Therefore, before attempting to classify the northeast Brazil into agronomically relevant homogeneous zones, it is essential to divide the northeast Brazil into broad zones such as arid, semi-arid, sub-humid, humid. Such a study present a first approximation of the regions that are highly suitable respectively for grasslands, dryland agriculture, wet-land agriculture, forests (Reddy 1983a). Literature is replete with such models. The following three approaches were tested² to identify their suitability for the northeast Brazil (see for details on these methods-Reddy 1983a).

- . Hargreaves dependable moist period (Hargreaves approach)
- . Troll's humid period (Revised Troll's approach)
- . Modified Thornthwaite's annual moisture index (Modified Thornthwaite's approach).

Figures 13-15 depict the classification of northeast Brazil respectively according to Hargreaves, Revised Troll and modified Thornthwaite approaches. In drawing Fig. 13 Hargreaves (1974) used data of about 700 locations while in drawing Figs. 14 & 15 the data of 991 locations (Fig. 1) were used. According to Hargreaves map (Fig. 13) only about ~~25.6~~ 25.6% of the area of northeast Brazil is suitable for dryland agriculture, while this is 40.4% according to Revised Troll and 75% according to modified Thornthwaite approach. On comparison with the productivity statistics over northeast Brazil, it appears that the first two maps are unrealistic. The arid regions in Fig. 15 follow more or less the orographical features (Fig. 16).

Figure 13:

In drawing this map two basic parameters were used, namely dependable precipitation and potential evapotranspiration. Dependable precipitation values were estimated using incomplete gamma analysis. In the literature there are several models of incomplete gamma in use. It may be possible that the model used by Hargreaves (1974) may present underestimates in the case of northeast Brazil. Also the Hargreaves potential evapotranspiration values present over estimates during rainy period⁵.

Figure 14:

Average monthly precipitation and potential evapotranspiration were the two inputs used in computing humid period and in drawing this map. However, over the northeast Brazil the occurrence of humid period over years show high variation⁴ and therefore the average monthly data may not be reflecting true humid period over northeast Brazil. Even the commencement of humid period is unrealistic (Fig. 17).

Therefore, Fig. 15 can reasonably be used to divide the northeast Brazil into broad zones. The arid regions in this map

Fig. 13 : Classification of climate of northeast Brazil—Hargreaves approach.

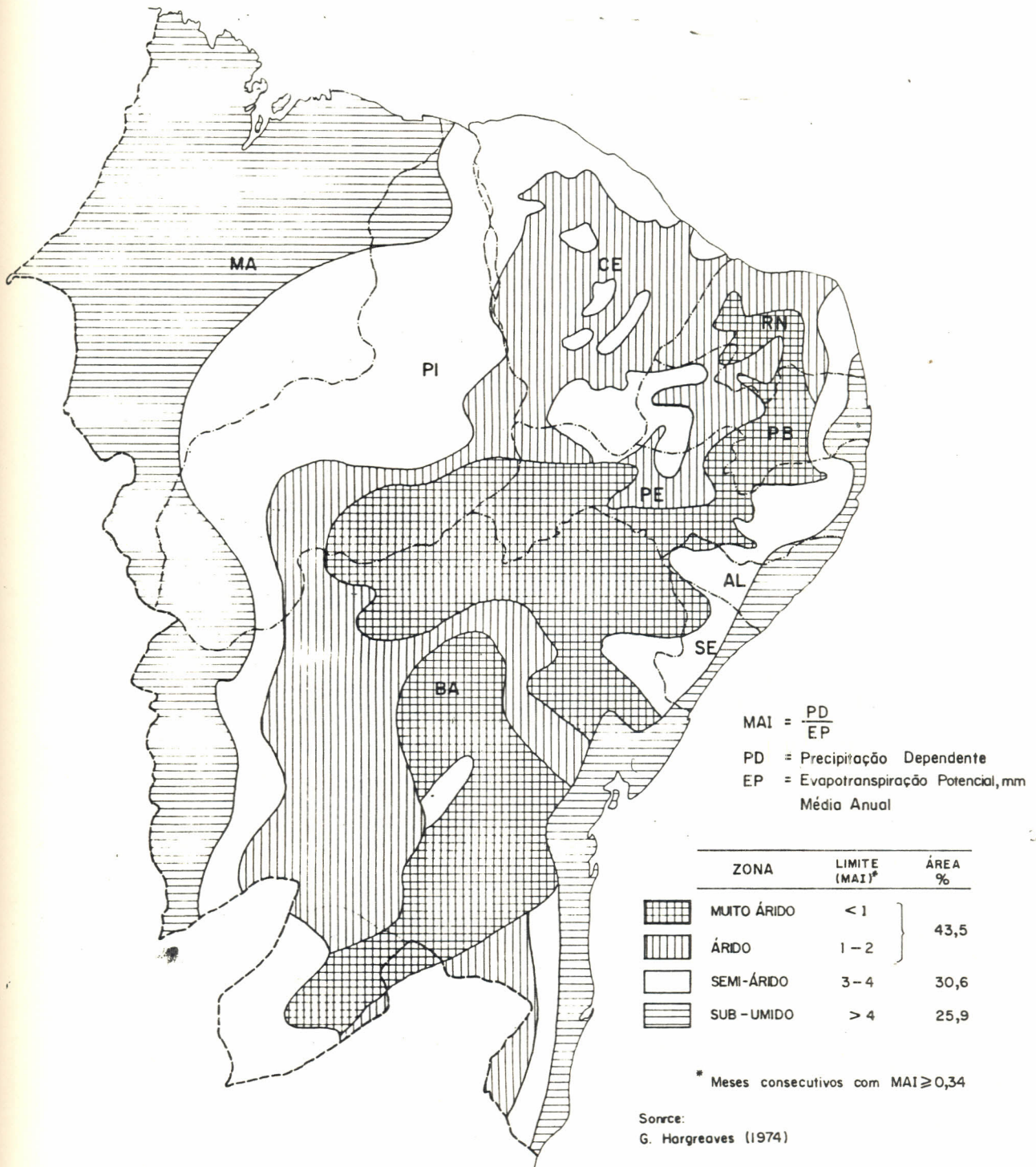


Fig. 14 : Classification of climate of northeast Brazil - Revised Troll's approach.

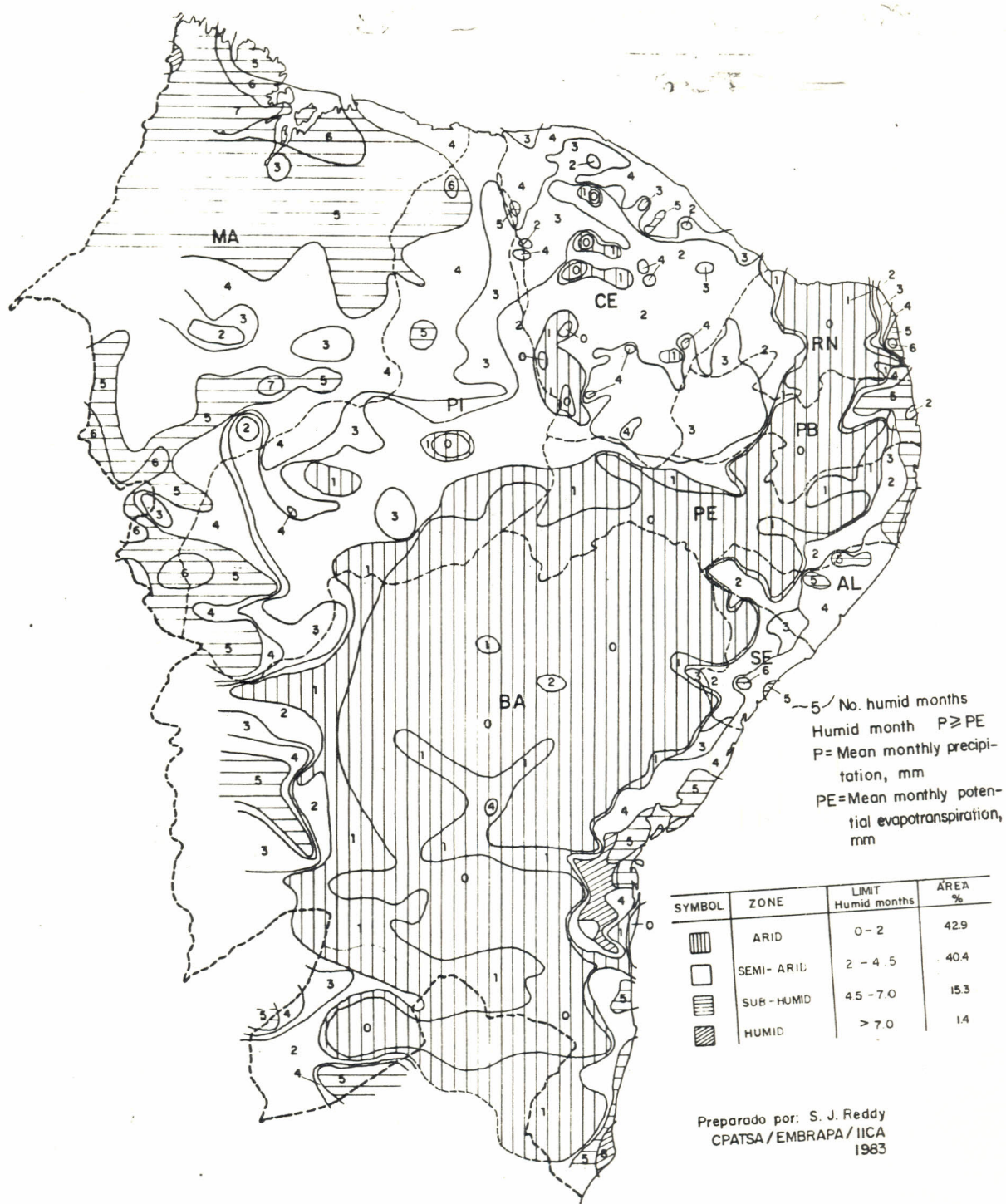


Fig. 15 : Classification of climate of northeast Brazil—modified Thornthwaite's approach.

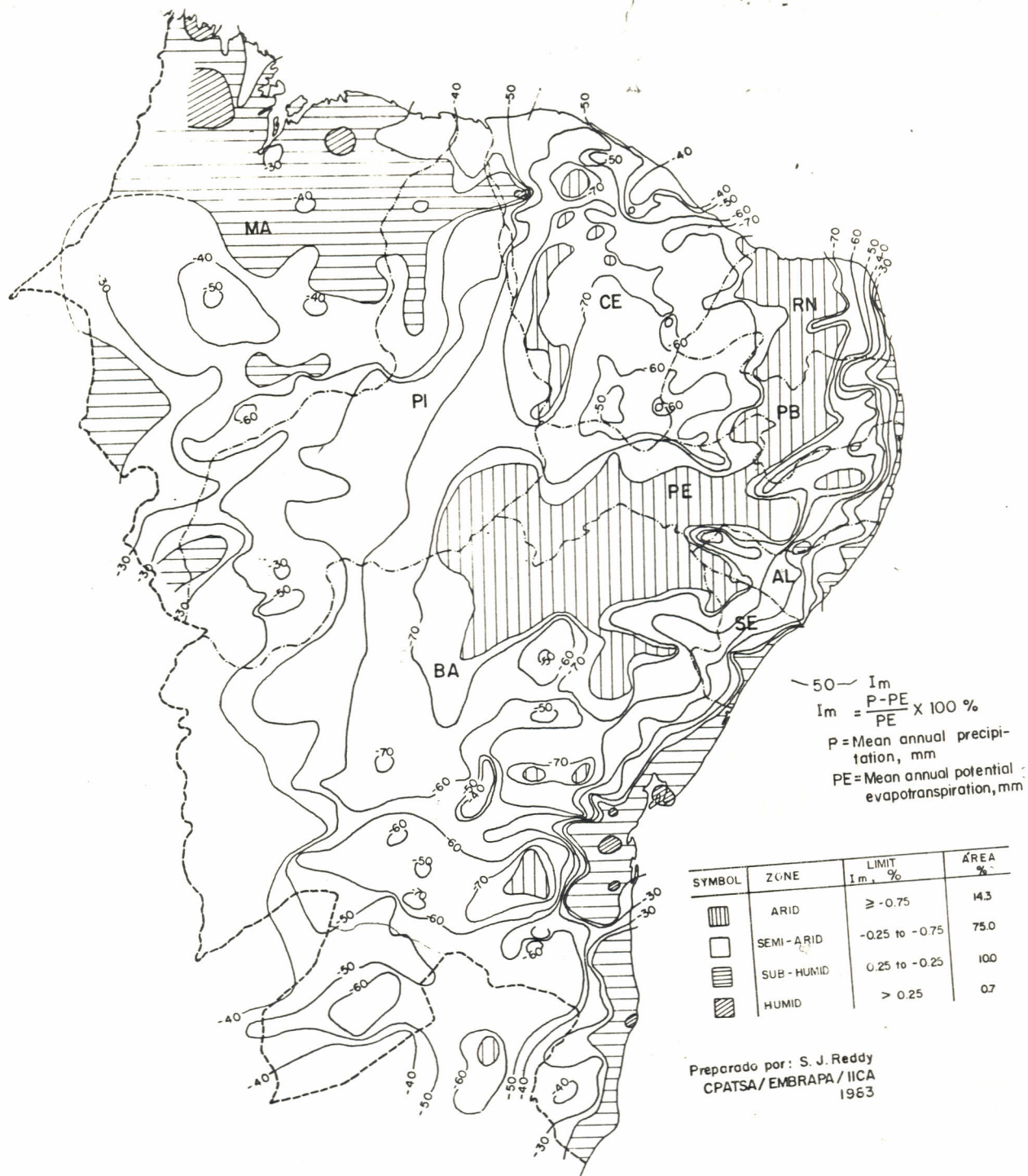
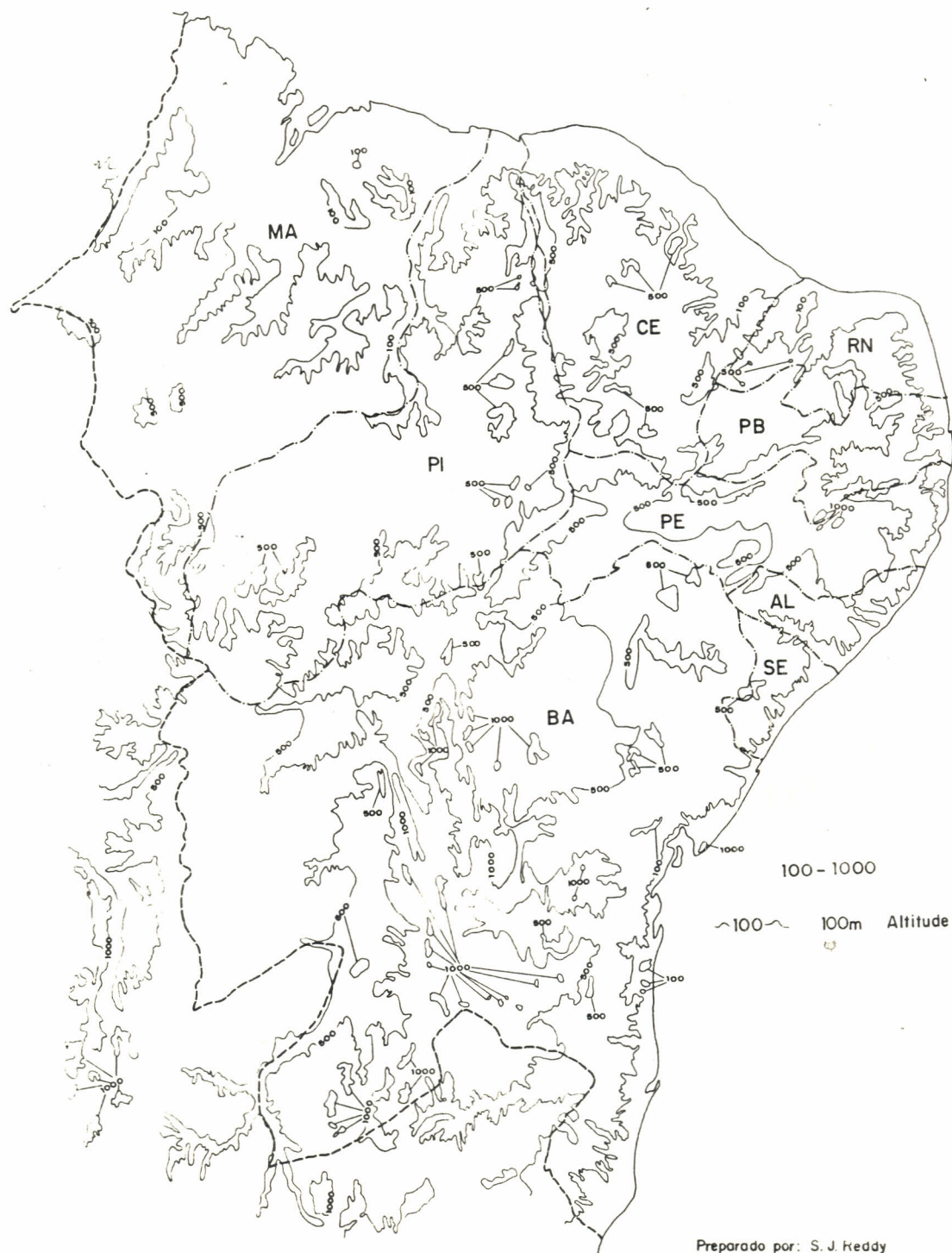
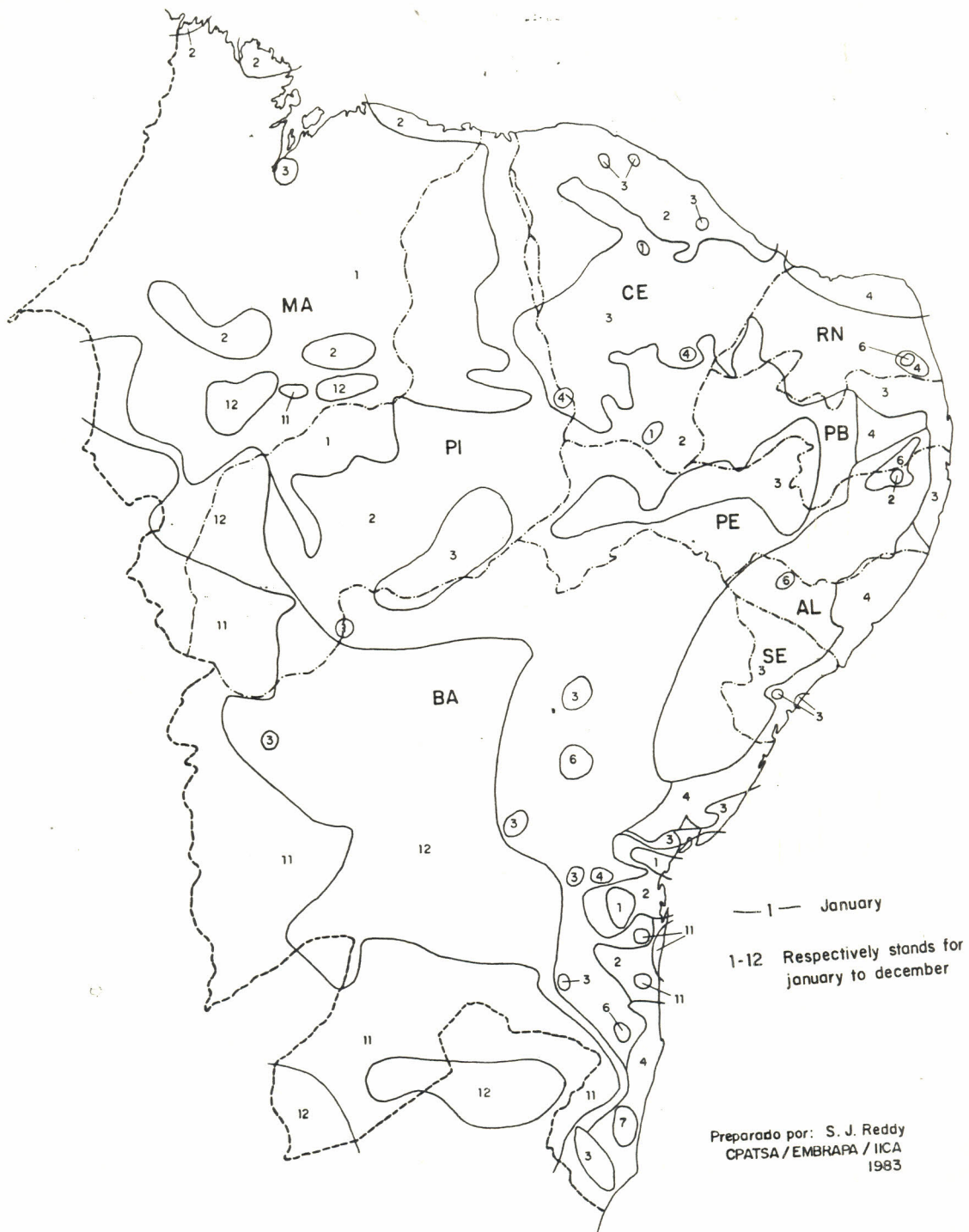


Fig. 16 : Altitude variation over northeast Brazil.



Preparado por: S. J. Keddy
CPATSA/EMBRAPA/IICA
1983

Fig. 17 : Commencement of average humid period over northeast Brazil.



are not suitable for dryland agriculture and hence it is not worth venturing dryland agriculture in these areas as a first approximation. More details could be worked out later.

A seminar was presented to appraise the CPATSA scientists on these findings.

3.2- Characterization of broad zones:

In order to sub-divide the broad zones identified in the previous section into agronomically relevant homogeneous zones it is very important to use daily or weekly data sets. Month is too long a period when compared to dryland crops of few days. However, handling such data sets for all the locations is an enormous effort which needs good computer facility and other technical assistance. The computer facility at CPATSA-Petrolina is very small polymax system. Therefore, to overcome this hurdle it was proposed an intermediate step-characterize the broad zones using monthly data sets of individual years. As a first step this analysis is initiated for Bahia state⁴ in the northeast Brazil. The intermediate analysis facilitate to divide the broad zones using climatic variables derived from the monthly data sets. The details of this are presented below.

3.2.1- Data and analysis:

The primary data consists of monthly precipitation and potential evapotranspiration for 196 locations of Bahia state (Fig. 18). The period of data varies between 15 and 70 years. The potential evapotranspiration values for individual years were computed following eqs. 3 & 4 presented in section 2.

Following the water budgeting technique of Thornthwaite & Mather (1955 & 1957) with few modifications the water balance parameters such as actual evapotranspiration, deficit and runoff using average monthly data and individual yearly monthly data sets for 196 locations* were computed. Table 6 presents an example of water budgeting using average monthly data. Table 7 presents an example of probability of deficit/potential evapotranspiration and runoff under different ranges estimated from individual

* A program in basic-language was prepared and adopted to CPATSA computer system.

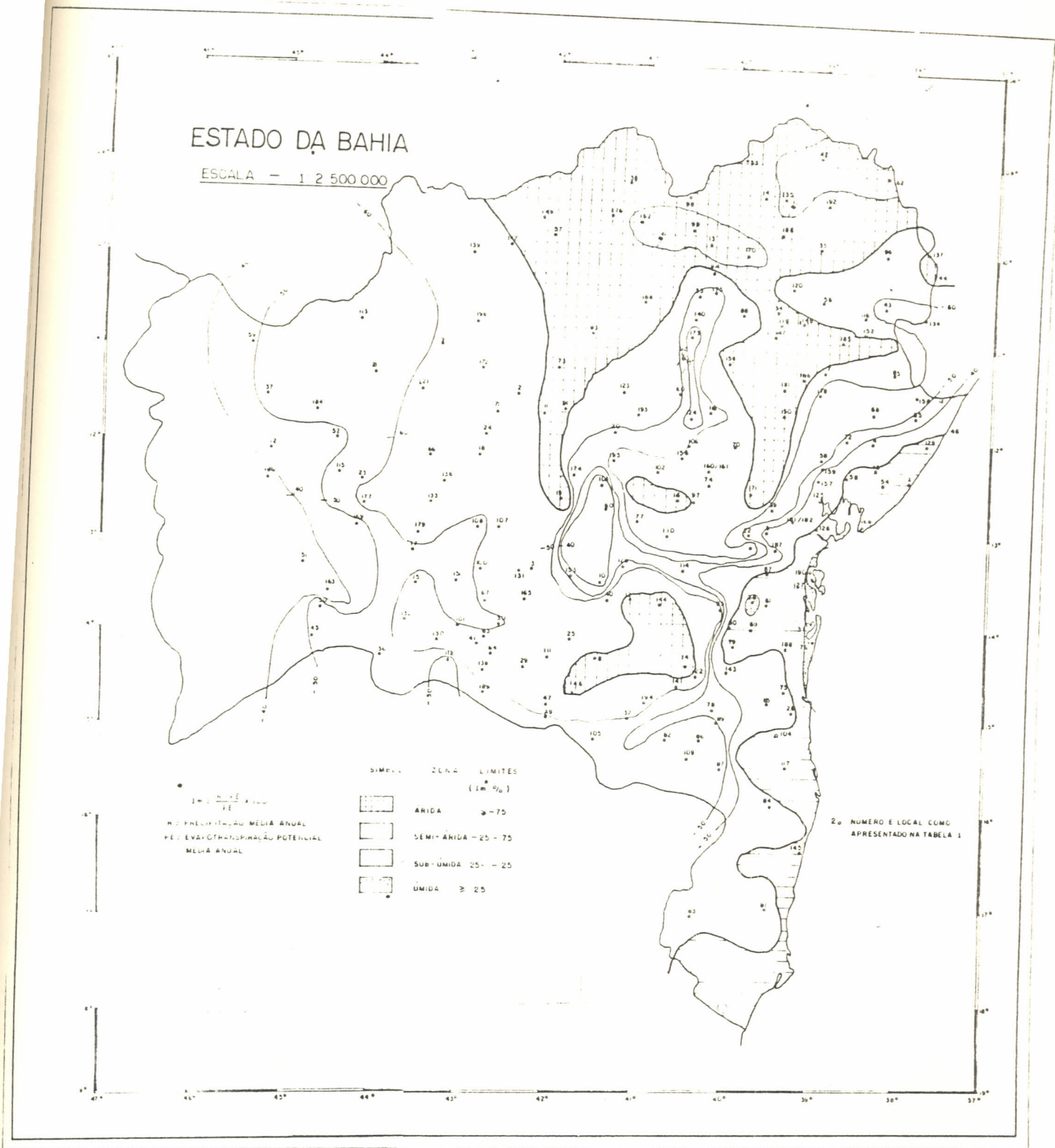


FIG. 18. Distribution of locations and climatic classification (modified Thornthwaite) - Bahia.

yearly values. From the individual yearly values the averages, standard deviations* and the probable occurrences in different ranges were computed for humid period, moderately-humid(or-dry period), dry period, commencement of humid period & moderately humid period. The spatial distribution of these parameters are depicted in Figs.19-27. For comparison of these maps in Fig. 28 the altitude variation is depicted. Fig. 29 presents the water holding capacities of the soil, which were used in the estimation of water balance parameters.

3.2.2- Discussion of results:

3.2.2.1- Interpretation of results for individual locations as an example:

Let us consider the location Açú da Torre: This has got the data for 17-years, mainly representing above average rainfall period. The soil type present a water holding capacity of 75-mm. According to Table 6 this location has about six humid months and ten moderately humid months with January and November being dry months. The humid period commences in March while moderately humid period commences in February. The average humid period obtained using individual years water balance is 4.8 ± 3.3 months with no consecutive dry period (0.2 ± 1.1 months) and moderately-humid period of 8.4 ± 2.0 months. The commencement of average humid and moderately humid periods are month no 3.3 ± 2.5 weeks and month no 2.2 ± 2.5 months (3 = March and 2 = February). This clearly demonstrates that the humid period is highly variable, therefore, the pattern obtained from average monthly data is highly misleading. This can be seen more clearly from Table 7. This table indicates that May and June are the only two stable months meeting potential demand in about 90% of years. In April and July this satisfied in about 65% of years only. In February and August this satisfied only in 47% of years. However, in between February and April, March presents a dry month in many years. Rest of the months present high deficit in 75% of years. This suggests that rainfed paddy can be transplanted

* In the computation of some of these parameters I received partial help from Malaquias da Silva Amorim Neto.

Table 6 : Average water balance for Açu da Torre.

Location: Açu da Torre State: Bahia Lat: 12°56 Long: 38°00 Alt: 12 M

Water holding capacity of the soil: 75 mm Data: Normal

Month	Water balance parameters*										
	P	PE	P'	P'-PE	APW	ST	BST	AE	D	S	RO
Jan.	81.0	181.4	81.0	-100.4	-471.1	0.1	-0.3	81.3	100.1	0.0	0.0
Feb.	108.7	142.7	101.2	- 41.5	-515.6	0.1	-0.1	101.3	41.4	0.0	7.5
Mar.	151.7	140.6	135.4	- 5.2	-520.8	0.1	-0.0	135.4	5.2	0.0	16.3
Apr.	249.2	112.0	210.6	78.5		75.0	74.9	112.0	0.0	23.6	56.3
May	309.5	101.8	257.8	155.9		75.0	0.0	101.8	0.0	155.9	174.6
Jun.	200.8	101.2	170.8	69.6		75.0	0.0	101.2	0.0	69.6	121.2
Jul.	146.2	116.7	128.6	11.9		75.0	0.0	116.7	0.0	11.9	43.9
Aug.	107.4	142.4	100.2	- 42.2	- 42.2	42.2	-32.8	132.9	9.5	0.0	10.2
Sept.	78.0	161.5	78.0	- 83.5	-125.8	13.6	-28.7	106.7	54.9	0.0	0.0
Oct.	102.8	183.7	100.6	- 83.1	-208.9	4.4	-9.2	109.8	73.9	0.0	2.2
Nov.	74.7	180.1	74.7	-105.4	-314.3	1.0	-3.3	78.0	102.1	0.0	0.0
Dec.	125.5	177.6	118.2	- 59.5	-373.7	0.5	-0.6	118.7	58.9	0.0	7.3
Annual	1735.5	1741.8	1557.0	-184.8				1296.0	445.8	261.0	439.5

* P = average monthly precipitation, mm

PE = average monthly potential evapotranspiration, mm

P' = average monthly effective precipitation, mm

$[P - (P - 0.5 PE) \times 0.2]$

APW = average monthly accumulated potential water loss or gain, mm

ST = average monthly storage, mm

BST = average monthly change in storage, mm

AE = average actual evapotranspiration, mm

D = average monthly water deficit (PE - AE), mm

S = average monthly water surplus, mm

RO = average monthly runoff, mm.

Table 7 : Probabilities of relative deficit and runoff under different ranges for Açú da Torre

Name: Açú da Torre State: Bahia Lat: 12°56 Long: 38°00 Alt: 12 M
 Water holding capacity of the soil: 75 m No of years: 17

Limit	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
D/PE	Deficit (D/PE) * probabilities											
< 0.1	23.5	47.1	29.4	64.7	94.1	88.2	64.7	47.1	23.5	23.5	29.4	17.6
0.1 - 0.2	5.9	0.0	17.6	5.9	0.0	5.9	11.8	17.6	0.0	5.9	0.0	5.9
0.2 - 0.3	5.9	5.9	0.0	5.9	0.0	5.9	5.9	11.8	5.9	0.0	0.0	0.0
0.3 - 0.4	5.9	11.8	0.0	5.9	0.0		11.8	5.9	5.9	5.9	11.8	11.8
0.4 - 0.5	5.9	5.9	17.6	11.8	0.0		0.0	5.9	17.6	0.0	5.9	5.9
0.5 - 0.6	11.8	0.0	17.6	5.9	0.0		0.0	5.9	11.8	11.8	0.0	5.9
0.6 - 0.7	0.0	5.9	0.0		5.9		5.9	5.9	17.6	17.6	0.0	11.8
0.7 - 0.8	17.6	11.8	5.9						5.9	0.0	29.4	17.6
0.8 - 0.9	17.6	0.0	11.8						11.8	29.4	11.8	17.6
0.9 - 1.0	5.9	11.8	0.0						5.9	5.9	11.8	5.9
RQ, mm	Runoff (RO) probabilities											
< 20	88.2	76.5	70.6	35.3	17.6	23.5	47.1	70.6	82.4	88.2	76.5	82.4
20 - 40	5.9	11.8	11.8	11.8	5.9	5.9	11.8	11.8	5.9	0.0	17.6	5.9
40 - 60	5.9	5.9	0.0	11.8	5.9	5.9	5.9	5.9	0.0	0.0	0.0	0.0
60 - 80		0.0	0.0	0.0	0.0	5.9	0.0	5.9	5.9	0.0	5.9	0.0
80 - 100		0.0	0.0	5.9	0.0	0.0	5.9	0.0	5.9	0.0		0.0
100 - 120		5.9	5.9	0.0	5.9	0.0	5.9	0.0		0.0		5.9
120 - 140			0.0	0.0	0.0	11.8	5.9	5.9		5.9		0.0
140 - 160			5.9	0.0	11.8	17.6	0.0					5.9
160 - 180				0.0	0.0	5.9	0.0					
180 - 200				5.9	0.0	5.9	11.8					
200 - 220				11.8	5.9	5.9	0.0					
220 - 240				0.0	0.0	5.9	5.9					
240 - 260				0.0	11.8							
260 - 280				0.0	5.9							
280 - 300				0.0	5.9							
300 - 320				0.0	0.0							
320 - 340				11.8	0.0							
340 - 360				0.0	5.9							
360 - 380				0.0	5.9							
380 - 400				5.9	5.9							

* D = deficit (PE - AE)
 PE = potential evapotranspiration
 AE = actual evapotranspiration.

in April and harvested in August but there will be some problems at the time of harvest. Probably because of this problem this region is mainly used for cultivation of coconuts (Mata de São João Município). Finger millet, paddy, groundnut, maize, casava could be grown as intercrop with coconut. This practice is seen in some of the Asian countries. It is seen from Table 6 about 439.5 mm of precipitation (i.e. 25%) goes as runoff primarily in May and June. It is seen from Table 7 in more than 40% of years the runoff is > 100 mm during April to July and from August to March the runoff is ≤ 20 mm in 70% of years.

3.2.2.2- Comparison of agroclimatic parameters with crop productivity area:

The average humid period and its standard deviations on comparison with the average area under cultivation and its coefficient of variation (C.V.) for paddy, sugarcane, cowpea/beans, casava, maize, cotton, castor suggests that:

- . where the humid period is longer the C.V. of the area under cultivation over different years is low ($< 35\%$);
- . where the humid period is shorter the C.V. of the area under cultivation over different areas is high ($> 50\%$);
- . where the humid period is longer with low C.V. paddy and sugarcane are also grown in addition to maize and casava indicating preference to sole cropping;
- . where humid period is longer with high C.V. cowpea/beans and castor are also grown in addition to maize and casava, indicating preference to intercropping;
- . where the humid period is shorter cotton is also grown in addition to cowpea/beans and castor.

3.2.2.3- Discussion-general:

- Irrespective of whether the location is in arid or semi-arid or sub-humid the humid period presents a clear cyclic variation of 35-years below average and 35-years above average (Fig. 5). The above average pattern (+) ended by 1926-'29 and there onwards the below average pattern (-) commenced and continued upto 1961-'62. With 1937-1951 showing a tendency of near or above average pattern. The above average pattern commenced in 1962 and may extended upto 1996 with 1977-'91 presenting below average or near average tendency. This clearly suggests that crops/cropping pattern suitable under years of above average pattern are different from those years with below average pattern.
- Arid regions are characterized by:
 - . average humid period $\leq$ 1.0 month
 - . probability of occurrence of '0' and $\leq$ 1 humid months are respectively > 25 and $> 50\%$ of years
 - . probability of occurrence of ≥ 3 humid months is only about 10-15% of years.

This clearly demonstrates that the arid regions are not suitable for dryland agriculture but only useful for grasslands. The risk of venturing dryland agriculture in these areas is very high. Cowpea and/or Pearl millet of 70-80 days are possible only in some years when the rainfall cycle presents above average pattern. Also, the success of these crops primarily depends upon identifying the appropriate time of sowing. The important time for this is between the average month of commencement of moderately-humid and humid periods.

- Eventhough the sub-humid regions are characterized by long humid period, the variation with years is very high except over few regions with rainfall occurring more or less throughout the year. The probability of occurrence of '0' and ≤ 1 humid months are respectively 00 and $\leq 40\%$ years. This definitely indicates they are not suitable for dryland agriculture.

ESTADO DA BAHIA

ESCALA — 1:2 500 000



FIG. 19. Spatial distribution of average humid period and its standard deviation over Bahia.

ESTADO DA BAHIA

ESCALA — 1:2 500 000



FIG. 20. Spatial distribution of average moderately - humid period and its standard deviation over Bahia.

ESTADO DA BAHIA

ESCALA — 1:2 500 000



FIG. 21. Spatial distribution of average consecutive dry period and its standard deviation over Bahia.

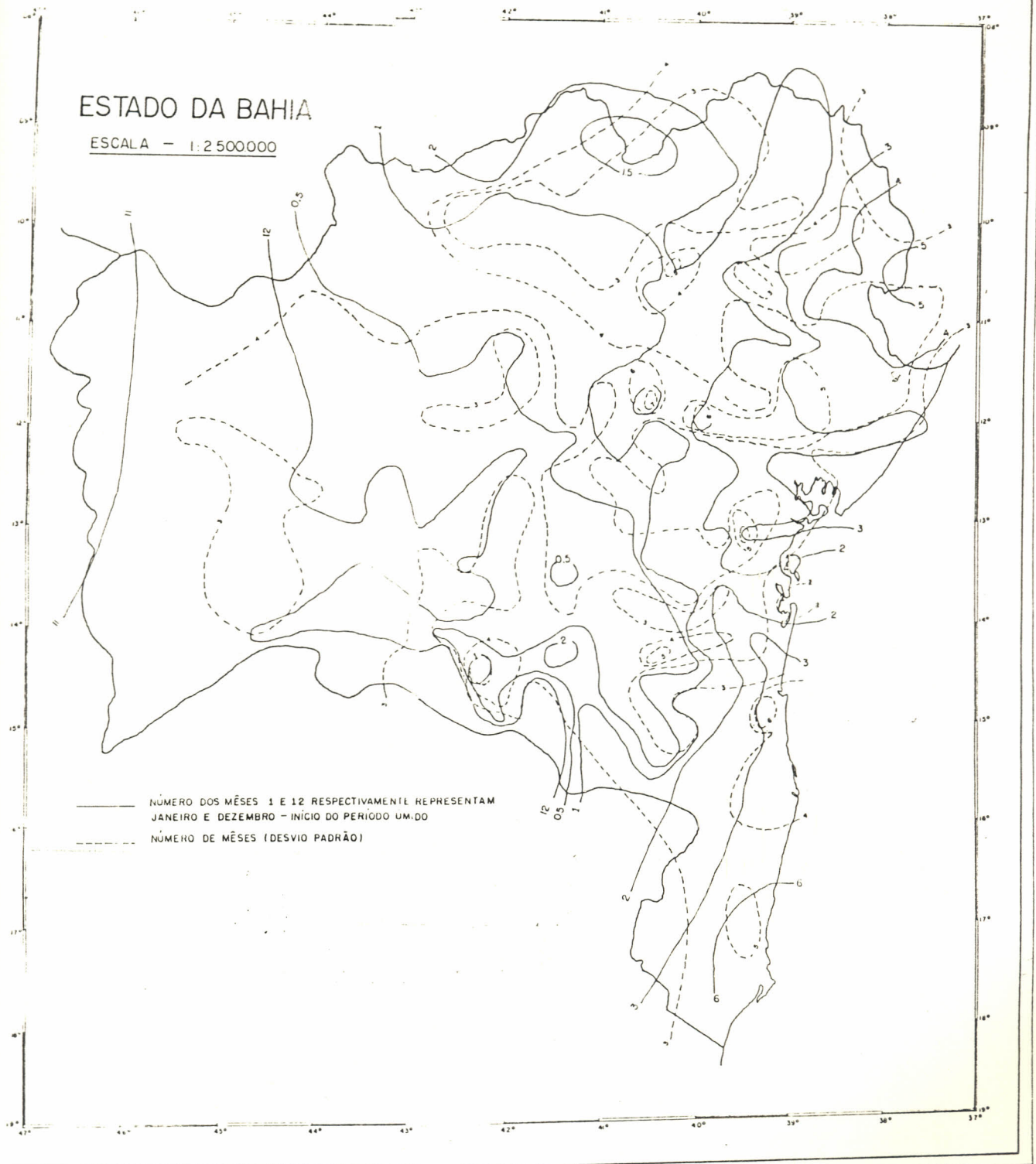


FIG. 22. Spatial distribution of average commencement of humid period and its standard deviation over Bahia.

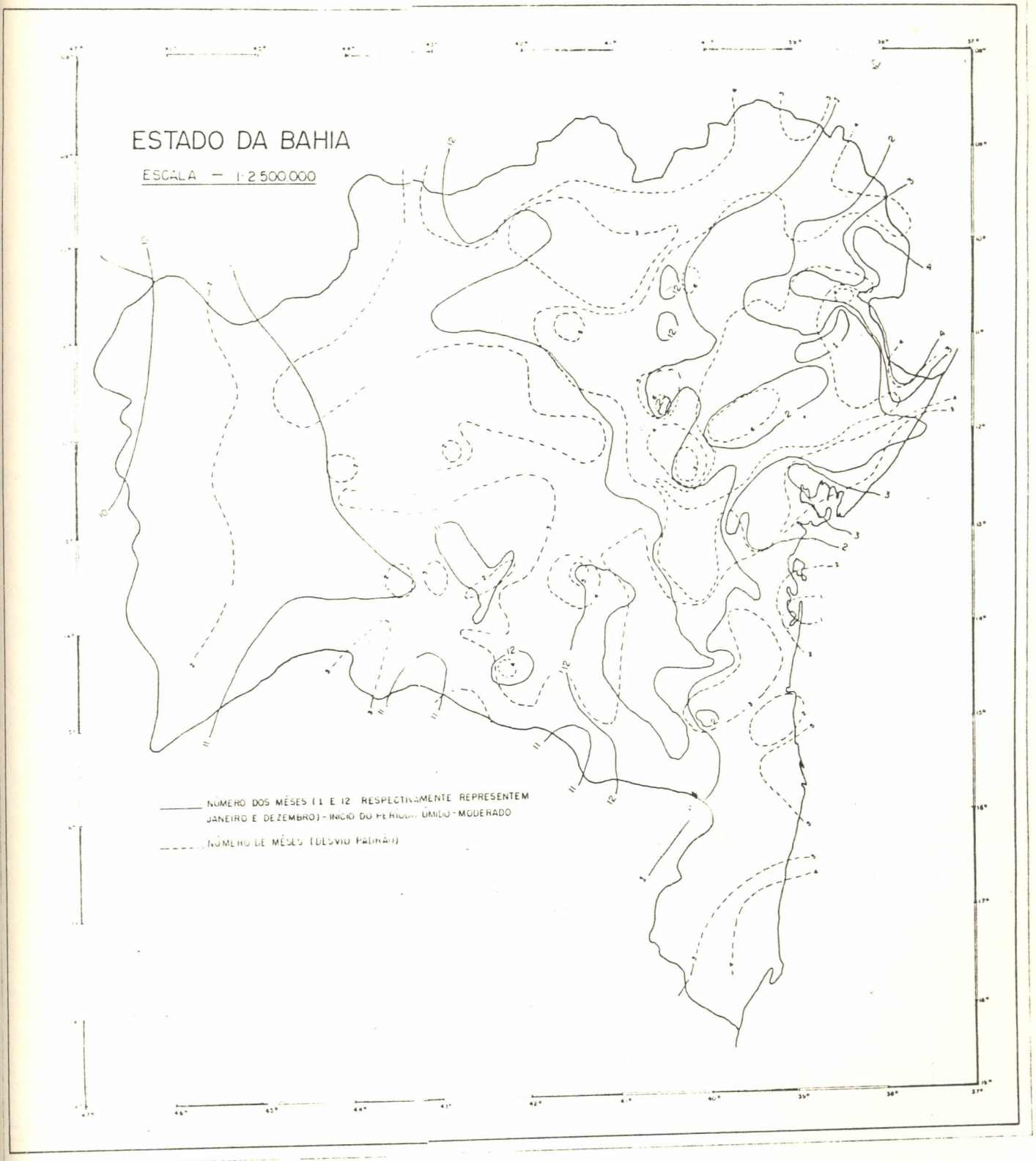


FIG. 23. Spatial distribution of average commencement of moderately - humid period and its standard deviation over Bahia.

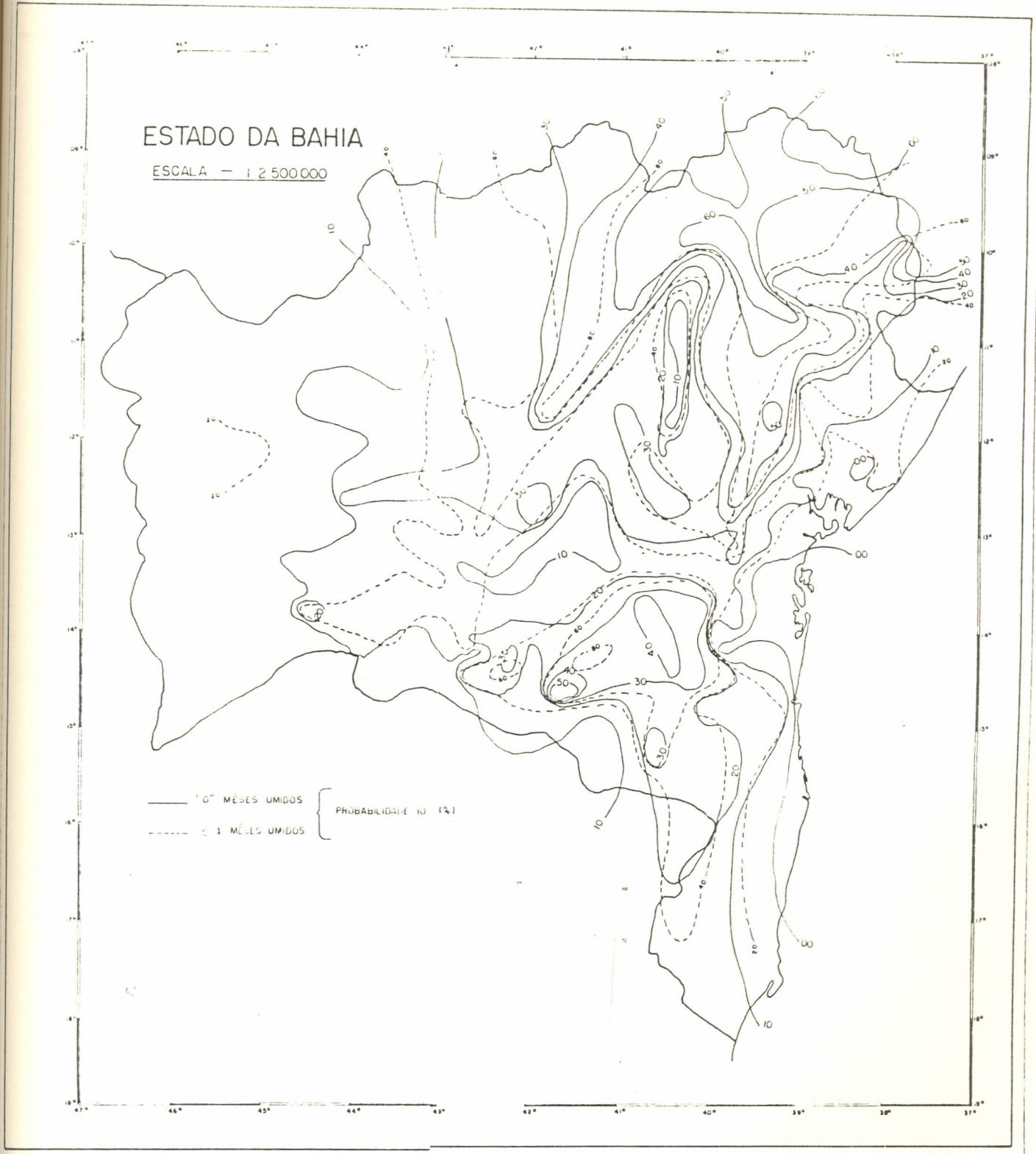


FIG. 24. Spatial distribution of percentage occurrence of '0' and ≤ 1 humid months over Bahia.

ESTADO DA BAHIA²

ESCALA — 1:2.500.000

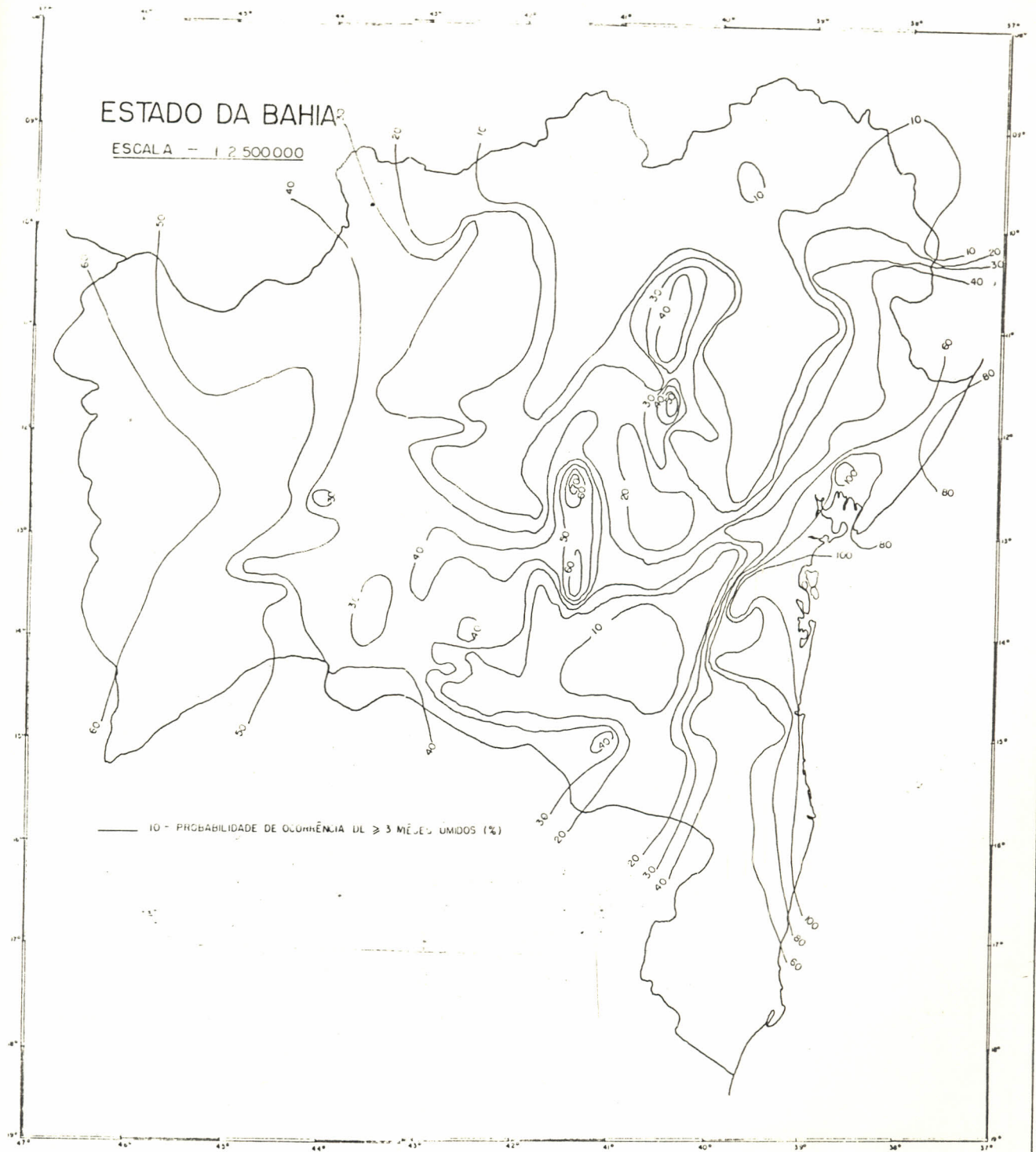


FIG. 25. Spatial distribution of percentage occurrence of > 3 humid months over Bahia.

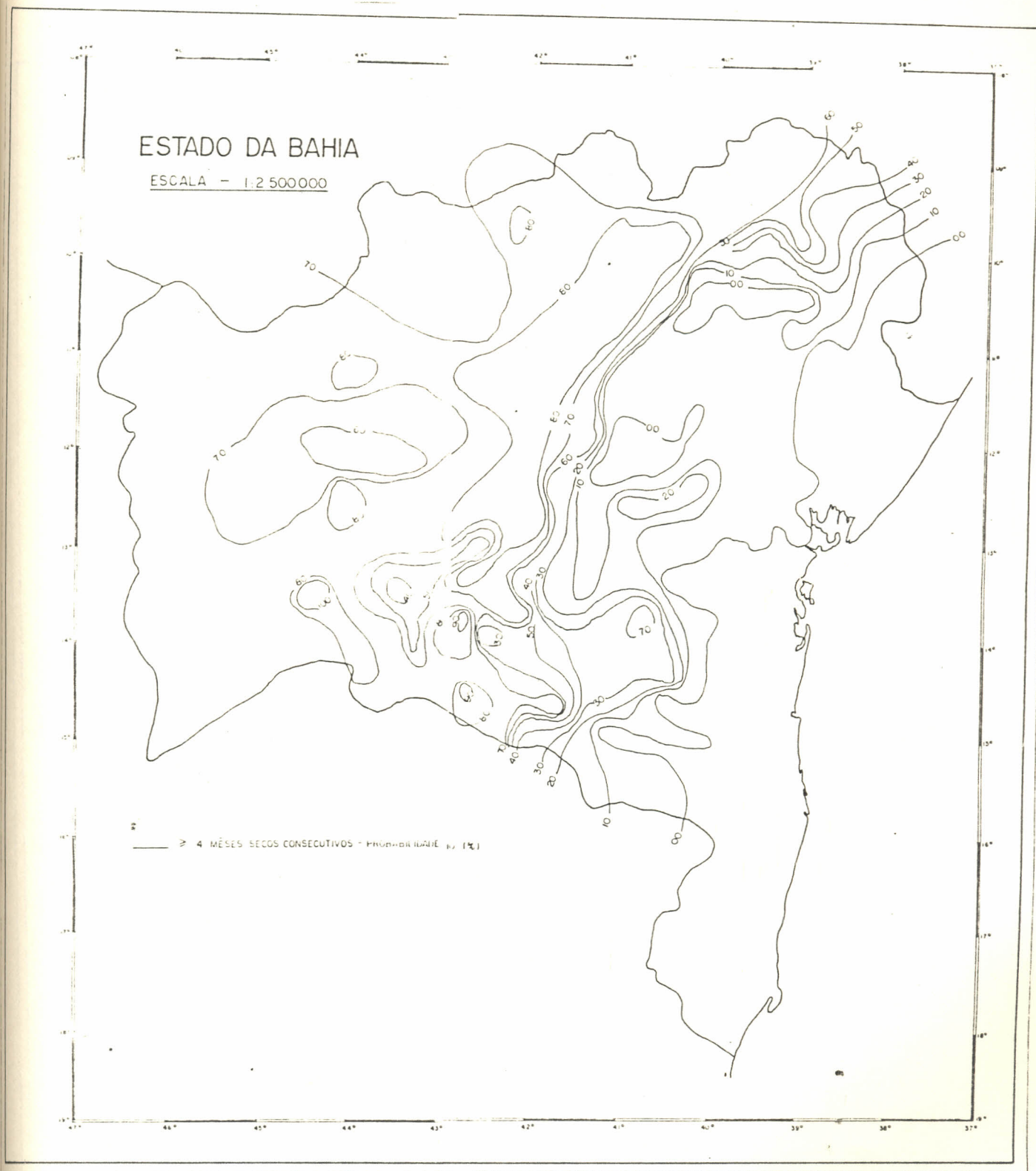


FIG. 26. Spatial distribution of percentage occurrence of dry period ≥ 4 consecutive months over Bahia.

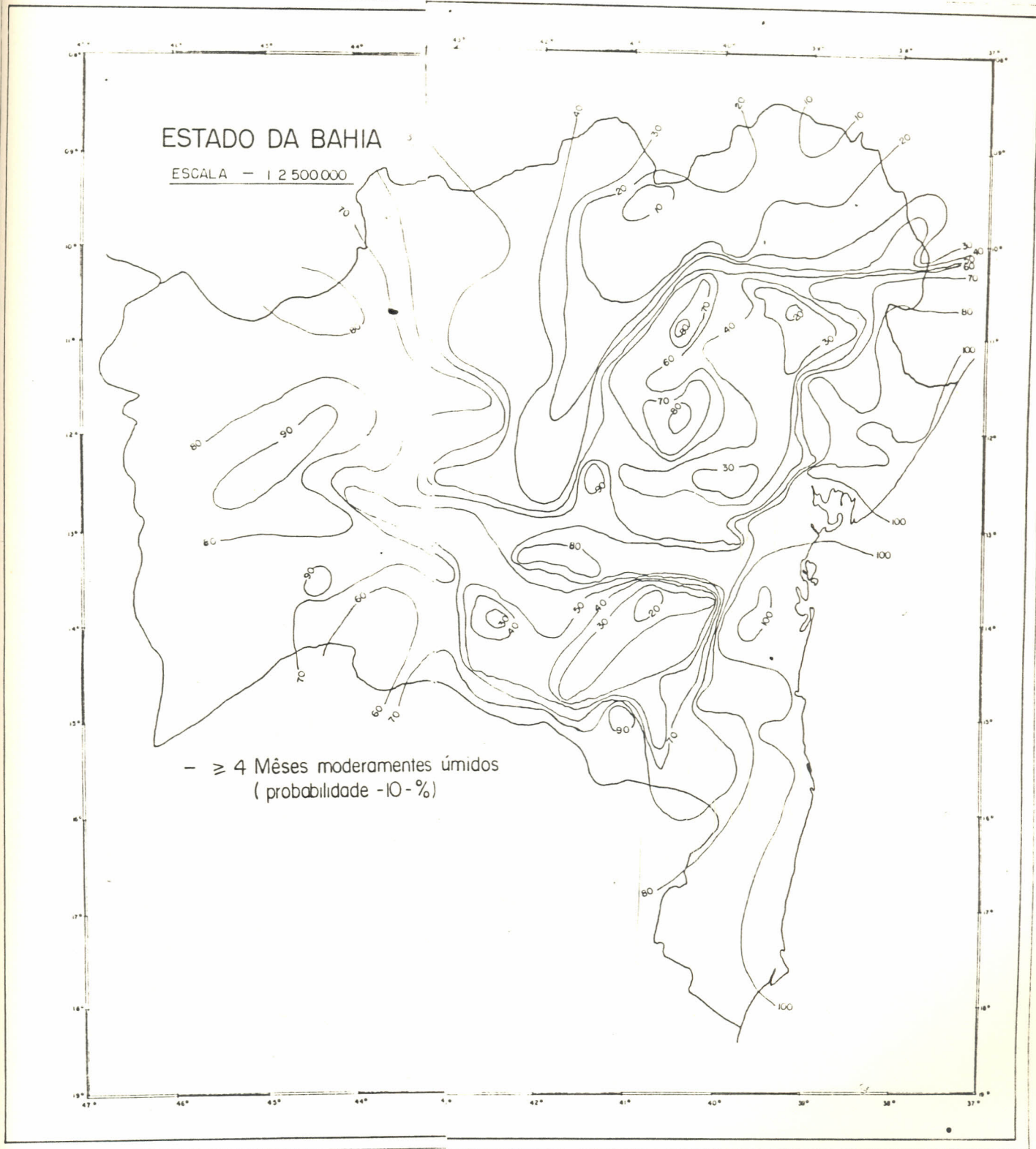


FIG. 27. Spatial distribution of percentage occurrences of moderately - humid period ≥ 4 months over Bahia.

ESTADO DA BAHIA

ESCALA - 1 2 500 000

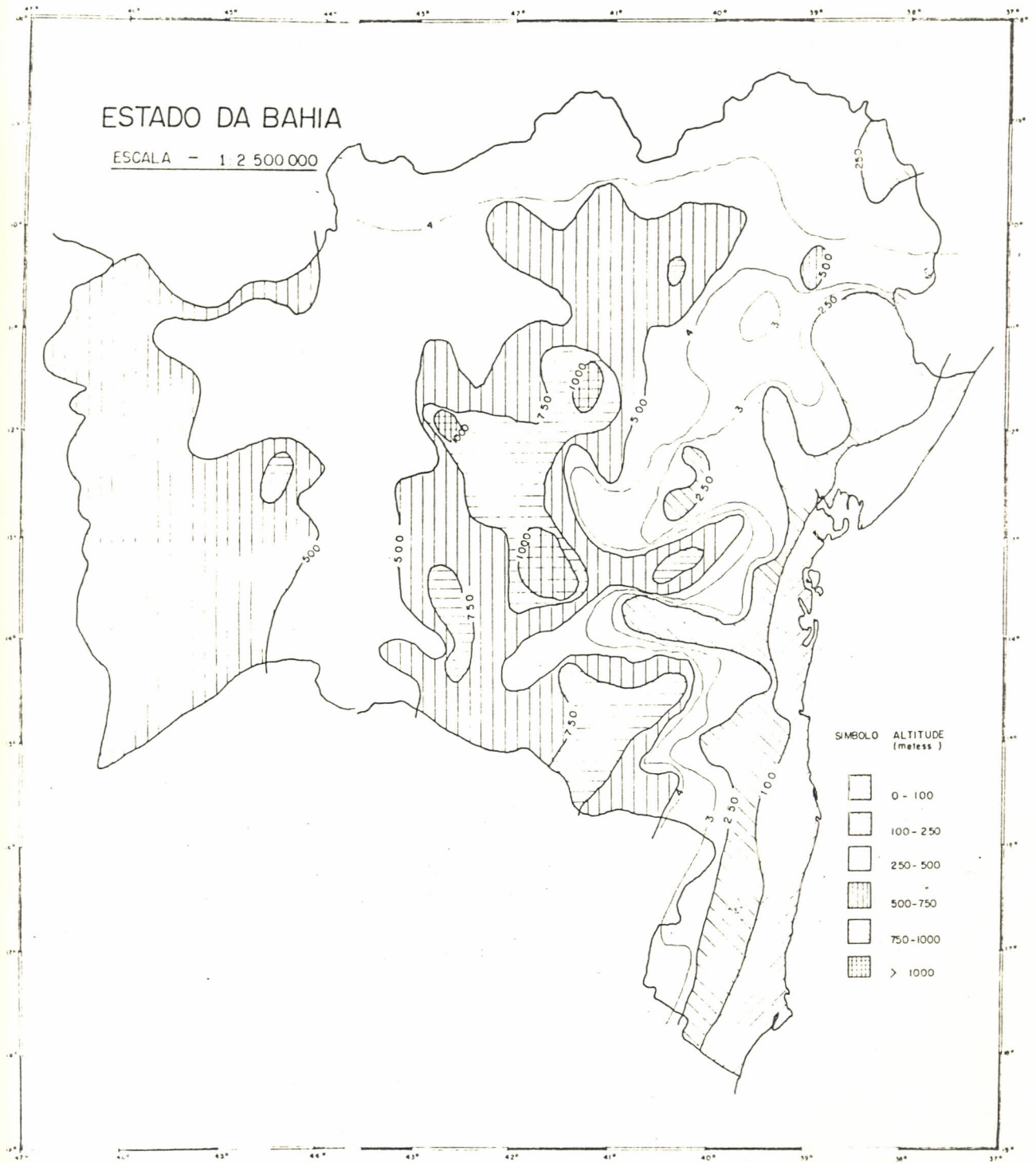


FIG. 28. Variation of altitude over Bahia.

ESTADO DA BAHIA

ESCALA — 1 2 500 000

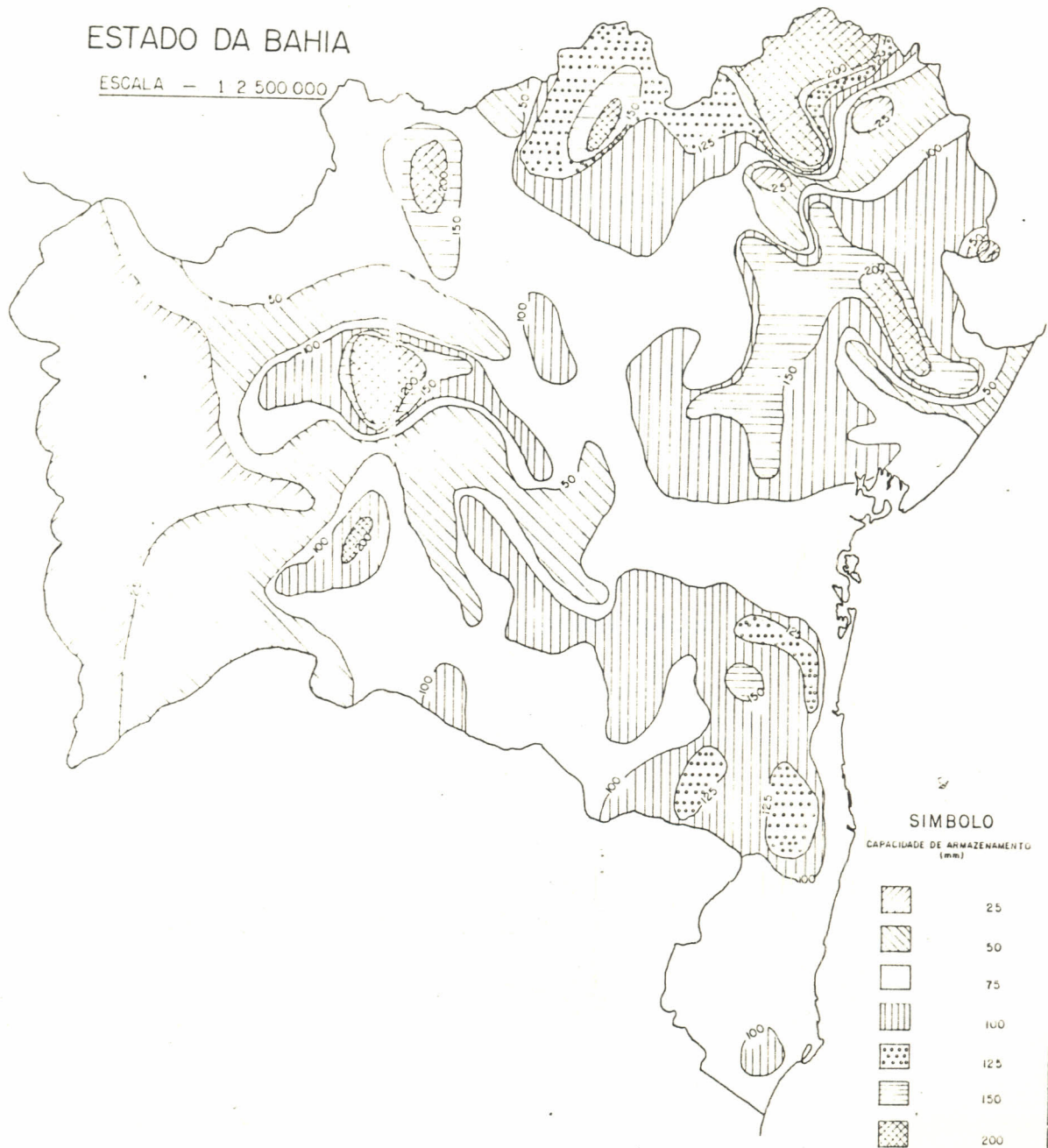


FIG. 29. Variation of soil water holding capacities over Bahia.

- The semi-arid regions could be divided into two zones, namely one on to the West of Rio San Francisco and the other on to the east of Rio San Francisco.

The regions to the West of Rio San Francisco are characterized by:

The average humid period varies between about 1.5 to 3.0 months with a standard deviation of ≤ 3 months. There is a definite dry period. The dry period with ≥ 4 consecutive months occur in 70-80% of years. In this zone the probability of occurrence of '0' and ≤ 1 humid month is $< 15-20$ and $< 20-50\%$ of years with occurrence of ≥ 3 humid months reaching as high as 40-60%. Unfortunately majority of this area is covered by very shallow soils with very low water holding capacity. In shallow soils definitely sole crop is successful while in the deeper soils it is possible to grow a second crop. There is high possibility of getting runoff which can be harvested and utilized to increase the productivity. When the rainfall follow the below average pattern it is preferable to adopt intercrop rather than double crops.

The regions to the East of Rio San Francisco are characterized by:

Due to orography these regions present high variations in agroclimatic variables. The probability of occurrence of '0' and ≤ 1 humid months are 10-40 and 30-60% respectively except a small band in between 13 to 14° latitude which present generally lower occurrences. The probability of occurrence of ≥ 3 humid months is 20-60%. The chances of occurrence of consecutive dry period ≥ 4 months is very low ($\leq 10\%$) with chances of occurrence of moderate-humid period ≥ 4 months of 60-80%. The high variations over years clearly suggest that this region is more suitable for intercropping rather than sole or double crops. However, the type of intercropping need to be adjusted according to the period (below or above average rainfall pattern). More details could be worked out after completing analysis in phase-III (see next section 3.3).

- In general the commencement of humid period and moderately-humid period show 4 to 6 months variation over Bahia state. Because of this the water demand by the atmosphere and available global solar radiation and temperature conditions are definitely different during the growing season of different parts of Bahia on similar latitudes. The crops and varieties, therefore, suitable for different parts of Bahia under similar latitudinal belts may differ, eventhough cropping pattern may be similar. Details on this could be worked out after phase-IV analysis (see section 3.4).
- The best time for planting in the semi-arid regions is in between the commencement of average moderately-humid period and humid period. However, to get better information on this it is essential to work with weekly data sets, proposed under phase-III (see section 3.3).

3.2.3- Conclusions:

- Bahia state presents cyclic variation in humid period with 35-years of below average and 35-years of above average pattern and in each of these periods for few years opposite tendency is seen.
- The arid regions are not suitable for dryland agriculture, however, in some years during the above average rainfall period it may be possible to grow a 70-80 days cowpea and/or pearl millet with proper planning of sowing time.
- The sub-humid regions present long humid period with high variation (with few exceptions along the coast) with no definite continuous dry period and moderately humid period is ≥ 10 months. This definitely suggests that these regions are not suitable for dryland agriculture.

- In the semi-arid zone with low C.V. sole cropping is more relevant under shallow soils and double cropping is more relevant under deeper soils when the precipitation presents above average pattern and intercrops in general during the below average pattern. In the semi-arid regions with high C.V. intercropping may be a better strategy. Most of this zone indicates possibility of occurring good runoff and hence re-use of this water will certainly contribute significantly to improve the productivity level in the semi-arid zone.
- The commencement of growing season show 6-months variation on similar latitudinal belts of Bahia. Hence, the climate in terms of global solar radiation and temperature may be different over different parts of Bahia during the crop growing season. Therefore, crops or varieties that fit into the cropping system may differ over different parts of Bahia under similar agroclimatic conditions.
- The best time for planting is in between the commencement of moderately-humid period and humid period with good rains.

3.2.4- Future areas of work:

- . Similar analysis can be completed for other states of northeast Brazil.
- . Climatic attributes obtained in this study for entire northeast Brazil can be used in the numerical classification techniques (see Reddy 1983b) to sub-divide different broad zones of northeast Brazil. This is very important for making detailed analysis for identifying crops/cropping patterns. (These are discussed in the next two sections).

A Seminar was presented to appraise the scientists of CPATSA on the findings of this study.

3.3- Agroclimatic classification-an example (Bebedouro & Mandacaru)

The monthly averages present the relative differences of two or more locations but of little use in agricultural planning as month is too long a period when compared to shorter duration of dryland crops. The most appropriate form for such a study are daily records. However, handling the daily data involves enormous efforts. As a compromise between these two situations one can choose the weekly data as a reasonable period for agricultural planning in tropics. There are several ways of assessing the agroclimate of a location or region using such an information. One such procedure is estimation of probabilities. There are two types of probability estimates, namely: (i) estimation of parameter at fixed probabilities and (ii) estimation of probabilities at fixed amount of parameter (here the parameter may be precipitation or derived index). In the former case the basic data sets of a parameter are fitted to a theoretical distribution (such as incomplete-gamma, log or exponential) and derive the parameter at different levels of probabilities. In this type of analysis certain amount of assumptions are involved in solving the theoretical distribution. Even in the case of incomplete-gamma there are several forms of assumptions and hence the estimates differ according to these assumptions. There is no valid test to prove which assumption is the best for that data set. The second method is, however, not biased by such assumptions. This is a simple frequency distribution study.

However, all these types of probability estimates do not present the continuous period for the same growing season, which is very important in understanding the degree of riskiness of a certain crop/cropping pattern and likely variations in the commencement and cessation of effective rainy periods. A method involving the continuous period for the same growing season is suggested by Reddy (1983c) and applied to India, west Africa (Reddy 1983d, 1984a, b) and for tropical Australia (Reddy & Williams 1984). This method is not only

useful in the agricultural planning at a place but also helps in the transfer of location-specific technology through identifying similarities with other locations in terms of agroclimate. Variations due to soil types can also be assessed using water balance simulation (Reddy 1983d, Reddy & Williams 1984) using the water balance model of Reddy (1983e).

Some of these aspects are explained with reference to Bebedouro and Mandacaru data.

3.3.1- Data and analysis:

3.3.1.1- Data: The primary data consists of daily precipitation and open pan (US Class A) evaporation (potential evapotranspiration $\sim$ 0.75 open pan evaporation) for 1963 to 1982 at Bebedouro and 1966 to 1982 at Mandacaru. The average climatic pattern is presented in Tables 8 and 9 respectively for Bebedouro & Mandacaru.

3.3.1.2- Analysis:

a. Initial and conditional probabilities

Figures 30 and 31 represent the probability distribution respectively for Bebedouro and Mandacaru for week numbers 40 to 22*. In these diagrams a, b and c respectively represent the probability estimates for three different limits of the parameter ($R/E \geq 'X'$ ($X = 0.30, 0.60, 0.90$) — where R and E respectively stand for weekly precipitation and open pan evaporation). These three limits approximately represent the water requirements at different phenological stages of a dryland crop (of sorghum or maize with about 100-days duration). In these diagrams the curve 'U' represents the probability of occurrence of $R/E \geq 'X'$ in N years (N represents the number of years for which the data R/E are available). The curve 'U/U' represents the probability of occurrence of $R/E \geq 'X'$ for two consecutive weeks in N years; while the curve 'S/U' represents the probability of occurrence of $R/E \geq 'X'$ followed by a dry

*I received the help of Malaquias da Silva Amorim Neto in the calculation of weekly totals of R and E and probabilities.

week in N years. The former is termed as initial probability while the latter two are termed as conditional probabilities. These are computed for each individual weeks based on N-years.

b. Agroclimatic variables:

Figures 32 and 33 depict the agroclimatic variables estimated following the methodology of Reddy (1983c) respectively for Bebedouro and Mandacaru. These figures not only depict the variables for individual years but also averages $\pm$ standard deviations. The terms are explained as follows:

- $\bar{G}$: The mean available effective rainy period (weeks);
- θ : Standard deviation of G (weeks);
- $\bar{S}$: The mean week of commencement of sowing rains (week n^o);
- δ : Standard deviation of S (weeks);
- $\bar{W}$ & $\bar{D}$: Are respectively the wet and dry spells with in G period (weeks);
- α & β : Standard deviations of W and D (weeks);
- A : Aridity index or riskyness (%) (% occasions $G \leq 5$ weeks).

3.3.2- Results and Discussion:

3.3.2.1- General climate:

Tables 8 and 9 present the average climatic pattern of temperature (média, máxima & mínima), sunshine hours, global solar radiation, relative humidity, precipitation, open pan (U.S Class 'A' - without mesh cover) evaporation and wind velocity respectively at Bebedouro and Mandacaru. It is seen from these tables that the average temperature show little variation with seasons ($26.5 \pm 1.3^{\circ}\text{C}$ for Bebedouro and $27.0 \pm 1.2^{\circ}\text{C}$ for Mandacaru). Similar pattern is also evident in the case of average máxima & mínima temperatures ($31.4 \pm 1.5^{\circ}\text{C}$; $20.3 \pm 1.3^{\circ}\text{C}$ for Bebedouro and $31.3 \pm 1.3^{\circ}\text{C}$; $20.6 \pm 1.3^{\circ}\text{C}$ for Mandacaru).

The sunshine hours also show little seasonal variation at both the places (6.4 - 8.5 hours for Bebedouro and 6.8 - 8.5 hours for Mandacaru). The global solar radiation present 372-545

Table 8 : Average monthly climatic data for the Bebedouro experimental station for the period 1964 to 1982.

Latitude : 09°09' S

Longitude : 40°22' W

Altitude : 365.5 M

Month	Temperature (°C)			Relative humidity (%)	Sunshine (hr/day)	Global solar radiation (ly/day)	Precipitation (mm)	Evaporation (mm/day)	Wind velocity (km/h)
	Média	Máxima	Mínima						
January	27.1	32.1	21.1	63	7.3	483.5	67.6	7.2	7.0
February	26.9	31.6	21.4	67	6.8	474.2	97.6	6.6	6.3
March	26.6	31.3	21.1	69	7.0	474.4	128.9	6.1	6.0
April	26.1	30.5	20.8	71	6.7	437.7	104.2	5.8	6.0
May	25.5	29.9	19.6	67	6.4	390.1	17.4	5.7	7.6
June	24.7	29.4	18.7	64	6.3	372.0	10.5	5.9	8.8
July	24.5	29.0	17.9	60	6.9	385.6	7.5	6.6	9.8
August	25.4	30.6	18.5	56	8.3	455.0	4.7	8.1	10.3
September	26.9	32.0	19.6	52	8.0	493.9	7.1	9.3	11.0
October	28.5	33.6	21.2	50	8.5	545.1	9.8	9.6	10.1
November	28.4	33.8	21.9	55	7.8	529.9	47.7	8.9	8.2
December	27.9	32.6	21.4	59	7.5	499.5	79.6	7.6	7.2
Annual	26.5	31.4	20.3	61	7.3	461.7	582.6	7.3	8.2

Table 9 : Average monthly climatic data for the Mandacaru experimental station for the period 1965 to 1982.

Latitude : $09^{\circ}24' S$ Longitude : $40^{\circ}26' W$ Altitude : 375.M

Month	Temperature ($^{\circ}C$)			Relative humidity (%)	Sunshine (hr/day)	Global solar radiation (ly/day)	Precipitation (mm)	Evaporation (mm/day)	Wind velocity (km/hr)
	Média	Máxima	Mínima						
January	27.5	32.0	21.5	60	7.5	469.7	69.2	8.3	9.0
February	27.4	31.5	21.4	63	7.0	473.5	93.8	7.5	8.0
March	27.3	31.2	21.4	65	7.0	468.9	121.8	7.2	7.2
April	26.7	30.7	21.0	66	7.4	431.4	65.2	6.7	7.4
May	26.0	30.0	20.2	63	6.8	408.7	18.9	6.9	9.8
June	25.2	29.5	19.0	61	6.9	364.6	8.5	7.0	11.1
July	25.0	29.3	18.2	58	7.3	388.6	3.5	7.9	11.8
August	25.7	20.5	18.5	53	8.4	457.8	0.9	9.3	12.4
September	27.2	32.0	20.1	49	8.2	498.8	9.6	10.5	13.4
October	28.8	33.4	21.6	47	8.5	510.7	13.6	11.0	12.1
November	28.8	33.4	22.2	51	8.1	498.5	61.1	9.9	10.8
December	28.1	32.6	21.9	53	7.6	469.1	87.5	8.7	9.0
Annual	27.0	31.3	20.6	57	7.5	453.3	553.6	8.4	10.2

ly/day for Bebedouro and 365 - 511 ly/day for Mandacaru. At both the places the relative humidity is $> 50\%$ throughout the year, with Bebedouro presenting slightly higher values than for Mandacaru throughout the year. The wind speeds vary between 6.0 - 11.0 km/hr for Bebedouro and 7.2 - 13.4 km/hr for Mandacaru with Mandacaru presenting slightly higher wind velocities over Bebedouro. The open pan evaporation varies between 5.7 - 9.6 mm/day for Bebedouro and 6.7 - 11.0 mm/day for Mandacaru with Mandacaru presenting slightly higher evaporation over Bebedouro. These values ~~are~~ consistent with the relative humidity and wind velocity data, where it suggests that there might be dry advection for Mandacaru while for Bebedouro wet advection (consistent with wind direction from the River San Francisco) that increases evaporation at Mandacaru and decreases evaporation at Bebedouro⁵.

The mean annual precipitation is > 500 mm at both the places. However, the longterm average for this region (Petrópolis) is about 400 mm. The high average for these two locations is because the period 1963-1982 present the above average rainfall pattern (1927-1961 being below average rainfall pattern)³. Hence, the average climatic data for these two locations present the pattern for better rainfall period. Therefore, one must be very careful in making sweeping conclusions based on this data.

3.3.2.2- Initial and conditional probabilities:

Figures 31 and 32 depict the probability of occurrence of $R/E \geq 0.30$ (a); ≥ 0.60 (b) and ≥ 0.90 (c) respectively for Bebedouro and Mandacaru. These three limits respectively represent the water requirement for dryland crops at different growth stages of a crop. For example (a) represents the limit for early and late growth stages; (b) represents the early vegetative and grain filling and (c) represents for flowering and/or reproductive stages. Based on this the crop callender is indicated in Figure 31 (b).

ESTAÇÃO EXPERIMENTAL DE BEBEDOURO (CPATSA/EMBRAPA)

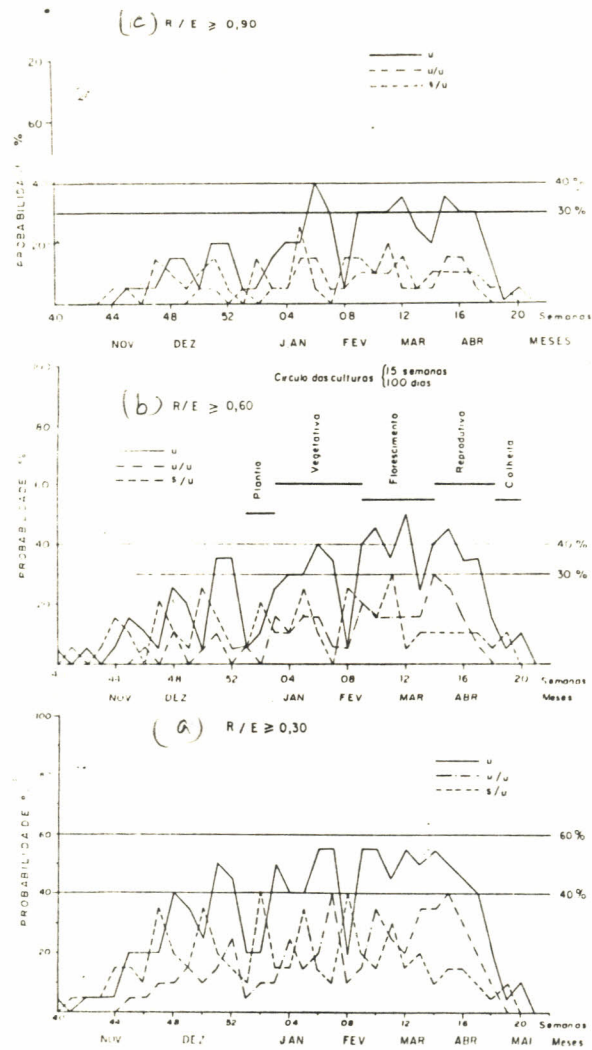
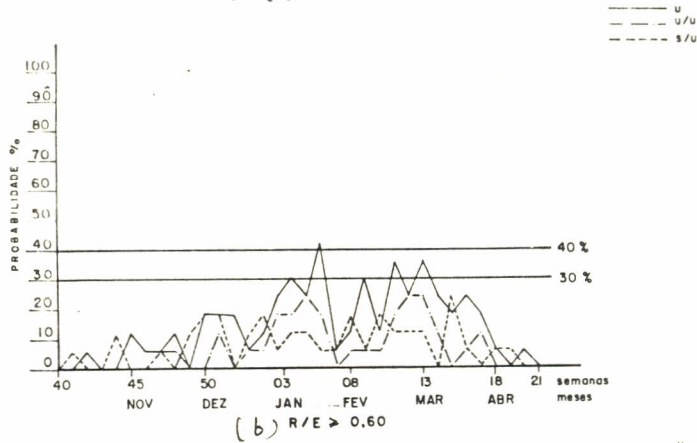


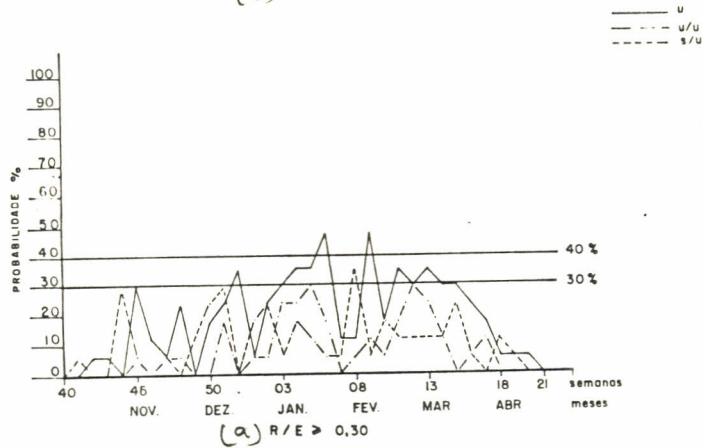
Fig. 30 : Initial and conditional probabilities of $R/E \geq 0,30$ (a), $0,60$ (b), $0,90$ (c) at Bebedouro.

ESTAÇÃO EXPERIMENTAL DE MANDACARU (CPATSA / EMBRAPA)

(c) $R/E \geq 0,90$



(b) $R/E \geq 0,60$



(a) $R/E \geq 0,30$

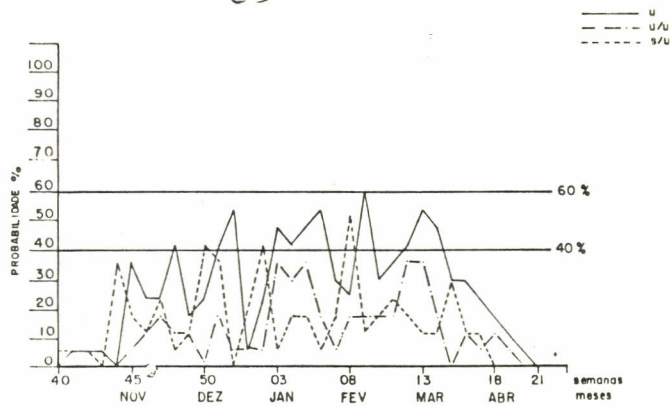


Fig. 31 : Initial and conditional probabilities of $R/E \geq 0,30$ (a), $0,60$ (b), $0,90$ (c) at Mandacaru.

Bebedouro: At Bebedouro $R/E \geq 0.30$ line crosses 40% (but less than 60%) during middle of December and continues upto April with few breaks, during early two weeks of January and last week of February (Fig. 30). The chances of occurrence of $R/E \geq 0.30$ in the succeeding week having either $R/E \geq 0.30$ or $R/E < 0.30$ is very low ($< 40\%$). This indicates sufficient water is available for initial growth and final growth periods only in about 4 out of 10 years. Mandacaru also presents the similar pattern with slightly lower reliability (Fig. 31).

3.3.2.3- Agroclimatic variables for Bebedouro and Mandacaru:

The above discussed probabilities do not present the continuous period of the same growing season of the year and hence they are more appropriate to assess the day to day operational problems.

The traditional crops, varieties and cropping systems often do not make full and efficient use of available soil and water resources. To improve this situation, new techniques for resource management which more effectively conserve and utilize the rainfall and the soil, and the new crop production systems which increase the productivity and minimize the instability are to be developed. By fitting certain agricultural operations to particular environment yields can be increased substantially.

The research results of any given station are relevant not only to the neighbouring areas, but to widely dispersed regions in the world having similar physical environment. This involves the establishment of guiding parameters for the transfer of location-specific technology to other regions with the least risk. Much of the environmental information is an integral part of the system where careful analysis can yield valuable information about important hazards and constraints. A logical step in this direction is, therefore, to understand the climates of different regions and to classify them into agronomically relevant homogeneous zones. Reddy (1983c) developed an analogue approach to understand the climate and applied this technique to India, West Africa and tropical Australia (Reddy 1983d, 1984a,

1984b & Reddy & Williams 1984). For such a study weekly data of individual years are required. However, this information was not available to me at this time except for the two research centers of CPATSA, namely Bebedouro & Mandacaru. The results for these two locations are depicted in Figs. 32 & 33. The period under consideration represent the above average rainfall period. Therefore, this information present the best possible situation for these two locations.

At these two locations energy is not limiting the crop productivity. The major limiting factor is precipitation relative to high evaporative demand. Even with the precipitation of high rainfall years the success of a short duration dryland crop is 60% and 41% respectively for Bebedouro & Mandacaru respectively. The difference is mainly due to evaporation (Tables 8 & 9). During 1963-1982 about 6-years present complete failure at Bebedouro. During 1966-1982 about 7-years present complete failure at Mandacaru. The average effective rainy period respectively for Bebedouro and Mandacaru are 7.9 ± 6.7 weeks and 5.1 ± 5.2 weeks and within this effective rainy periods the dry and wet spells constitute about 5.1 ± 3.0 weeks, 3.8 ± 1.4 weeks and 3.5 ± 2.0 weeks, 3.0 ± 1.5 weeks. This suggest that the growing period is highly variable, the dry spells constitute more than 50% of the growing period with wet spells less than dry spells. This demonstrate this region is only suitable for a short duration drought tollerant varieties like cowpea and pearl millet of 70-80 days. The appropriate time for sowing is week n^o 5.3 ± 4.7 weeks and week n^o 4.2 ± 5.9 weeks respectively for Bebedouro and Mandacaru. Indicating high variations in both commencement and withdrawal of effective rains. This suggests the success of a crop depends upon the time of planting primarily. The best time is late January with good rains.

If one considers the 70-years data of Petrolina that covers both high and low rainfall periods the success of crop is less than 15-20%. Therefore, this region is more suitable for grasslands during the low rainfall period and only in about 50% of years of high rainfall years short duration crops are successful.

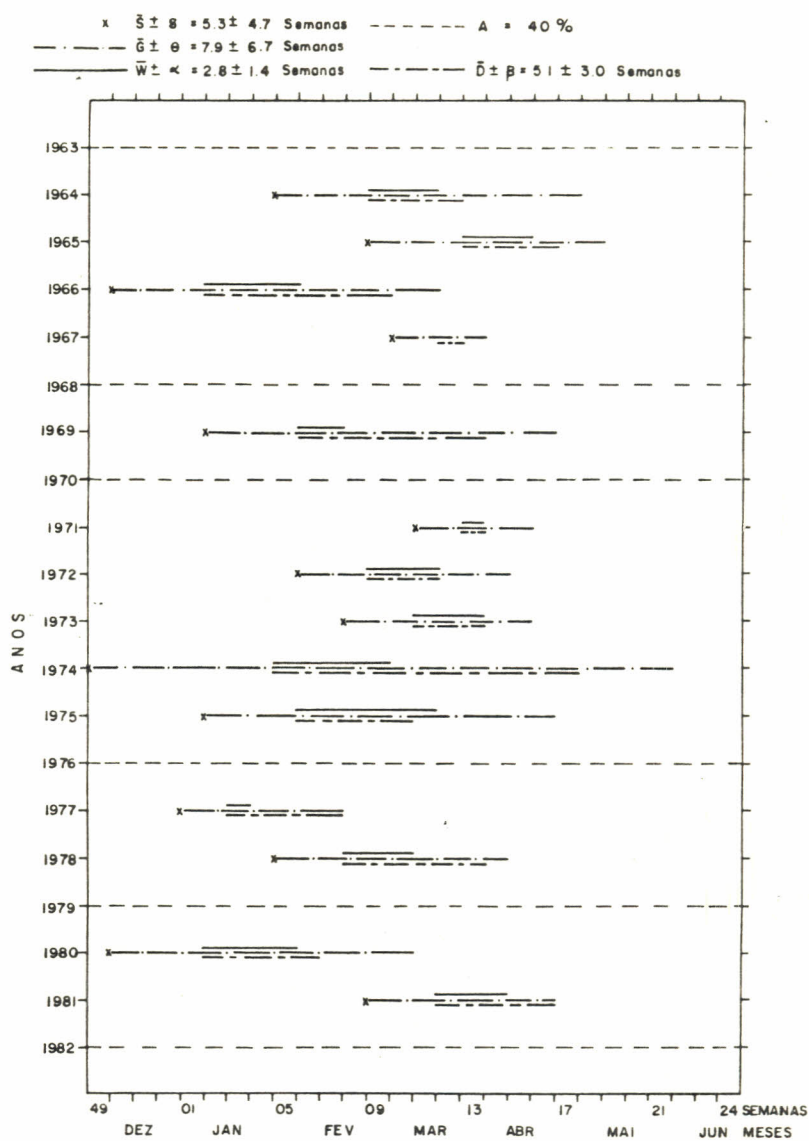


Fig. 32 : Agroclimatic characteristics for Bebedouro.

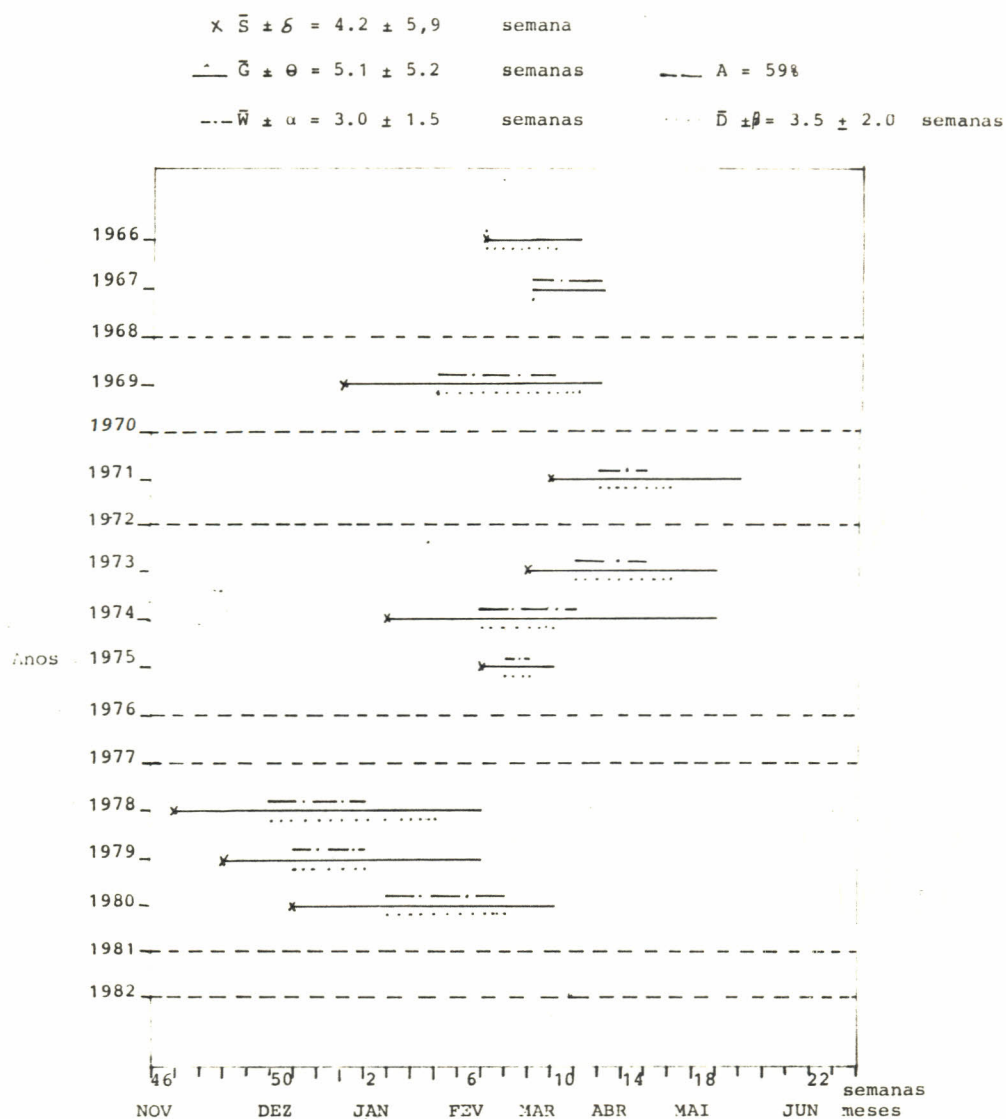


Fig. 33 : Agroclimatic characteristics for Mandacaru.

When the weekly data are available similar analysis can be carried out for few selected locations with data sets of 70-years. Utilizing some of the inferences of Reddy (1984a & b) it may be possible to characterize the northeast Brazil as relevant to cropping patterns and land & water management practices along with the associated risk levels both under low and high rainfall periods separately. By comparison of these variables with India, tropical Australia & west Africa it may be possible to extend technology for similar situations in northeast Brazil.

3.4- Crop-weather-soil models:

The natural limits of crop adoption are imposed by the important ecological factors. Primarily among these factors is the climate. The farmer is aware of crop adoption in recognizing some crops do well in his region whereas others do not. He also knows that the choice of varieties is essentially important. Better adoption may refer to higher yields of forage or seed, capacity to cope with unfavorable soil & climatic conditions, ability to resist insect or disease attack, or more favorable chemical composition. The plant environment relationships involved are many and exceedingly complex. This is amplified with new varieties that are being developed.

Relationships between climate and crop yields are difficult to calculate because of the complex interactions involved. At certain growth stages, one environmental factor may be critical, whereas at other stages of development, another factor may be limiting. Correlation studies may show that yield and certain factor of the environment vary together, but the causal effect may not be proved.

Therefore, to identify and evaluate those areas which have the greatest advantages for a particular crop or variety requires a critical analysis of all aspects of the production system. The recent computer based 'crop-weather-soil' models have been designed to evaluate the performance of any crop or variety at any location given a specified minimum set of site, crop, weather and management data. Therefore, this aspect

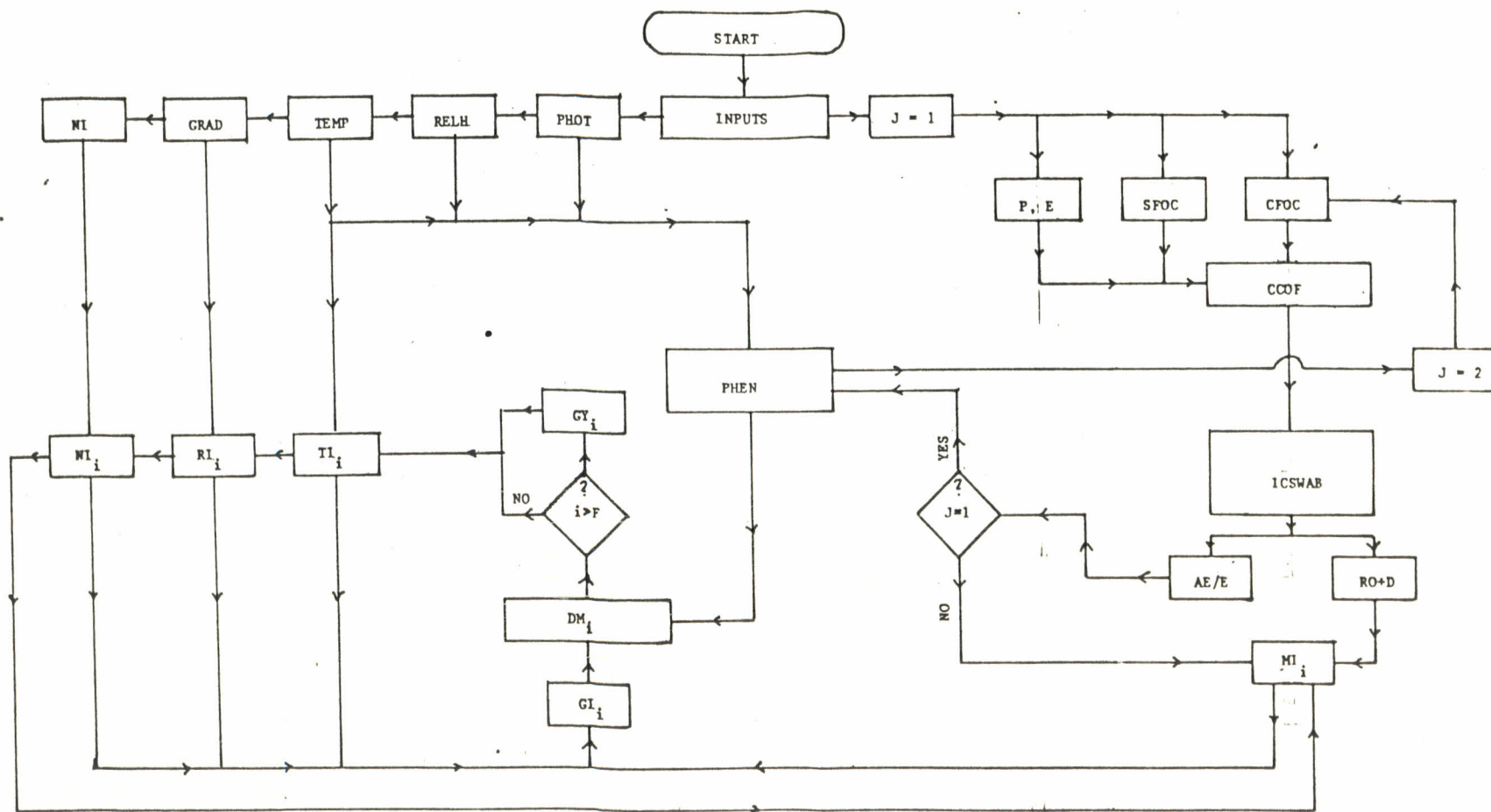
involve:

1. identification of appropriate model(s)
2. verification and/or development of appropriate coefficients through field experimentation
3. simulation using environmental data

3.4.1- Identification of appropriate model(s)⁷:

The literature is replete with different types of crop-weather-soil models. They can be arranged into three broad categories, namely climatological, water-stress and crop-growth models. In climatological models productivity is related to few randomly identified weather parameters. They are highly location specific and hence they are less suitable for regional planning. In water stress models, relative yields are related to relative evapotranspiration or relative transpiration or relative percent soil moisture. Under dryland situations the models that present relative to soil moisture are unsuitable as there are no models that predict the soil moisture accurately in different layers of the soil. In the case of other types the linear and additive models appear to be highly location and or year or season specific. The multiplicative models those that account differential effect of growth stages appear to explain more than 60% of variance in the productivity. However, yield is not only influenced by stress, but also with soil type and waterlogging. In addition temperature, relative humidity and global solar radiation also influence the productivity when one considers wider regions and years. Crop-growth models integrate complex processes of crop growth & development through climatic parameters. However, some of the models require a lot of crop information which are rarely quantified for northeast Brazil. Also, in these models weightage is given more to radiation and temperature compared to water stress. The latter is more important in dry tropics. Hence, as a compromise between water stress and crop-growth models, a simple model as applicable to northeast Brazil is suggested. Figure 34 depicts the flow chart

Fig. 34g. Flow chart of crop - growth model for tropical dryland situation



EXPLANATION OF SYMBOLS IN FIG. 34

NI = nitrogen level (fertilizer level)

GRAD = global solar radiation, ly/day

TEMP = average daily temperature, °C

RELH = average daily relative humidity, %

PHOT = photoperiod, hours

P = daily precipitation, mm

E = daily open pan (U.S. class 'A' mesh covered) evaporation, mm

SFOC = soil factors

CFOC = crop factors

CCOF = crop coefficient

AE/E = relative evapotranspiration

RO+D = runoff (surface + deep drainage), mm

NI_i = nitrogen stress index on day i

RI_i = radiation stress index on day i

TI_i = temperature stress index on day i

MI_i = moisture stress index on day i

DM_i = dry matter on day i

GY_i = grain yield on day i

F = flowering day, days

of this model. The basic inputs into this model for simulation are:

- . daily precipitation
- . daily open pan evaporation
- . daily average temperature
- . daily average relative humidity
- . daily global solar radiation
- . water holding capacity of the soil
 - entire profile in the root zone
 - top 10-cm layer
- . % clay content

This model is primarily based on the concepts developed by Fitzpatrick & Nix (1970) and Angus & Zandstra (1979). The equation for dry matter and grain yield are written as follows:

- . For dry matter (total biomass):

$$W_i = W_{i-1} + \alpha W_{i-1} \cdot GI_i \cdot AGE_i \quad \dots (6a)$$

- . For grain yield

$$G_i = G_{i-1} + (W_i - W_{i-1}) + 1/D_i [K_{13} + (1 - GI_i) (K_{12} - K_{13})] W_{\text{anthesis}} \quad \dots (6b)$$

where

- W_i = total biomass on day i
- α = inherent relative growth rate
- G_i = grain yield on day i
- $GI_i = RI_i \times TI_i \times MI_i \times NI_i \quad \dots (7)$
- RI_i = radiation index
- TI_i = temperature index
- MI_i = moisture index
- NI_i = nitrogen index
- K_{12} = maximum biomass reserve at anthesis available for translocation to grain
- K_{13} = minimum biomass reserve

$$AGE = e^{-\beta d_i}$$

β = final value of the relative growth rate

$d_i = (= 1/D_i) =$ developmental time.

3.4.1.1- Phenology model: Phenophase duration is primarily related to temperature and photoperiod (Argus et al. 1980). In addition, relative humidity (Reddy et al. 1984) and water stress (Anderson et al. 1978) particularly during the later stage of growth⁸ (Reddy 1984c) also influence the phenophase duration. This is very important in identifying the duration and time sequence to estimate the stress factors for each critical growth stages. The proposed model is presented as follows:

i) Prior to anthesis:

$$d_i = \sum_{i=1}^n \frac{1}{D_i} = \sum_{i=1}^n K_1 [1 - e^{-K_2 (t_i - t_{base})}] + \frac{K_3}{PP_e - PP_i} + K_4 h_i + K_5 (AE/E)_i \dots (9a)$$

ii) After anthesis:

$$d_i = \sum_{i=1}^n \frac{1}{D_i} = \sum_{i=1}^n K_1 [1 - e^{-K_2 (t_i - t_{base})}] + K_4 h_i + K_5 (AE/E)_i \dots (9b)$$

where K_1, K_2, K_3, K_4, K_5 are constants to be derived through field experimentation; PP_i is the photoperiod on day i ; PP_e is the critical photoperiod; t_i is the average temperature on day i ; T_{base} is the threshold temperature; h_i is the average relative humidity on day i and $(AE/E)_i$ is the relative water use on day i (AE = actual evapotranspiration and E = open pan evaporation mesh covered). $d_i = 1$ means that particular phase is complete.

3.4.1.2- Moisture index:

The appropriate terms that need to be considered to account stress are:

- . logistic form to account water deficit
- . effect of soil type on yield
- . effect of excess water on yield
- . estimation of water stress relative to potential evaporation

The logistic form: The logistic curve of Minhas et al. (1974) is more realistic for dryland situation and also mathematically sound.

Effect of soil type: It was noted by Reddy (1984c) that potential grain yield varies with soil type. This is also evident from the Bebedouro & Mandacaru (Brazil) data⁸ in addition they also show the response of fertilizer is different in different soils. This means the differential effect of water stress on relative yields are different. This may be characterized by % clay content.

Effect of excess water: Eagleman (1976) noted corn yield reduction in above normal rainfall years as much as those in below normal rainfall years in USA. Therefore, in addition to stress, a factor that defines the excess rainfall also needs to be accounted. This is particularly important in clayey soils⁸ (Vertisols & Alluvial soils) where waterlogging is a major problem. Willaimson & Keitz (1978) while reviewing the effect of water table or flooding on yield, felt the probable reason for less yields are poor aeration.

Estimation of water stress relative to potential evaporation:

This involves identification of suitable soil water balance (A seminar was presented on this aspect to CPATSA scientist).

model that takes into account all the physical process involved and which can be used under diverse soil, climate and crop conditions.

A large number of models have been developed during the past two decades that aim at predicting soil water balance parameters such as evapotranspiration, runoff, soil moisture status over time intervals of a day to one week.

In determining the soil water balance evapotranspiration is one of the complex parameters to be estimated. There are several approaches for the estimation of evapotranspiration. They can be grouped under two broad types, namely:

- . micro-meteorological methods
- . meteorological methods.

According to Baier "micrometeorological methods of modeling soil moisture distribution within the soil profile are now at a stage to be useful in research, but are not yet ready for agricultural applications which require such information over time and space". Of these, aerodynamic methods are used less often because of their input data requirements that require expensive instrumentation. Energy balance methods utilizing the Bowen ratio yield valid estimates of evapotranspiration if the basic assumptions are met, but with ratios less than - 0.5, the determinants are less reliable. These models are not particularly useful in situations for which few environmental and crop data are available unless a number of simplifying assumptions are used. In the combination methods, energy balance and aerodynamic equations are combined to produce an equation that can be used to estimate potential evapotranspiration. Again, the plant factor must be introduced to obtain actual evapotranspiration estimates.

On the other hand, meteorological water budgeting techniques have been much used both for research and for application. However, many of the models are site, or climate, or crop stage-specific.

Reddy (1983e) presented a simple method (ICSWAB) of computing daily evapotranspiration. The major inputs into this model are easily measurable weather parameters such as rainfall and open pan evaporation (U.S Class 'A' pan-mesh covered). The model successfully differentiates between fallow and cropped areas and adequately accounts for differences in the evaporative demand as well as soil and crop factors. The growth stage of a crop is represented by coefficients which are based on leaf area index and the percent light interception by the crop. Use of crop growth stage coefficients permits the model to account for variable available water at different stages of crop growth. Maximum available soil moisture in the top 10-cm soil layer and also in the total profile is an important input in the model. Available water in the top 10-cm soil layer at a given stage is used to determine the potential evaporation. Actual evapotranspiration is computed as a function of time after wetting of the soil irrespective of available soil moisture. Hence in extraction of water, the model gives preference to recent rains which wet the top layer of the soil compared to water in the deeper layers.

The daily soil balance equation is generally written in the form:

$$\Delta M_n = R_n - AE_n - RO_n - D_n$$

and AE_n is estimated according to ICSWAB model as:

$$\left(\frac{AE}{E}\right)_n = \left[1 + \frac{5 - E_n}{16} \sqrt{\frac{t_n}{E_n}}\right] \text{Exp} \{(-t_n + a)/b_n \cdot K\} \dots (10)$$

where:

n = day number (1, 2, ...)

R = rainfall or irrigation amount, mm

AE = actual evapotranspiration, mm

RO = surface runoff, mm

D = deep drainage, mm

ΔM_n = soil moisture change, mm

$$(M_n - M_{n-1})$$

M = soil moisture storage, mm

E = open pan evaporation, mm

(U.S Class 'A' pan - mesh covered)

t = time after rain or irrigation, days

(1, 2, ...)

b = crop growth stage coefficient

(varies with crop/cropping pattern)

K = water holding capacity of the soil in the root zone, mm

a = number of days for which the available water in the top 10-cm soil layer meets the potential evaporation, days

Warning: Before actually applying this model to the Northeast Brazilian situation it is very important to test the model with observed data as the crops (varieties)/cropping pattern are different. Estimates of soil water balance are useful in several ways for solving agricultural problems. For example:

- . In the development of agroclimatic models for establishing the length of crop growing season - This allows a more predictive approach to land management problems by adjusting crops to climates, and, at a given site permits assessment of different fallow crop strategies;
- . In the development of yield forecasting models - This can help in the interpretation of the considerable variability of crop yields between seasons and regions and identification of suitable crops to that environment.
- . In the monitoring of supplemental irrigation requirements and runoff modelling. This is very important for better utilization of limited water in the seasonally dry tropics. Application of this model for irrigation scheduling is presented by Reddy (1983f).

All these aspects may be important for efficient management of agricultural production at a particular site.

Now the final form of moisture index is written as:

$$MI_i = \frac{n}{\sum_{i=1}^n} \left[1 - \left(1 - \frac{AE}{E_i} \right)^2 \right]^{s_i \chi_i} + m_i r_i \quad \dots (11)$$

where m_i & s_i = soil dependent factors for growth stage i under excess rainfall and deficit rainfall situations respectively;

χ_i = stress weighting factor for growth stage i

and r_i = excess water factor for growth stage i
(related to runoff)

3.4.1.3- Temperature, radiation and nitrogen indices:

Eventhough, global solar radiation and temperature are abundant in tropics, the relative yields under different climatic conditions depend upon the actual levels of temperature and radiation, they present high relative variation under different climatic regimes.

Solar radiation affects many physiological processes, particularly photosynthesis. The light requirement varies with plant species. There are critical stages of plant growth when solar radiation is essentially important. For the same amount of daily solar radiation, the photosynthetic ratio increases with day length (Monteith, 1965). Crop response to fertilizer application is intimately related to the climatic environment of energy and water. At high light intensities, increasing application of nitrogen increase rice yield, whereas at low light intensities, grain yield does not respond to increased nitrogen application (Yoshida 1972). Heavy application of nitrogen at low light intensities may result in a high percentage of sterility in rice. According to Hagan & Vaadia (1981) it is wasteful from the stand point of water use efficiency to supply moisture to the field where growth is seriously retarded by nitrogen deficiency. Consequently, it is also wasteful to apply a large amount of fertilizer to a field where the growth is limited by water deficit. Therefore, growth is limited by

integrated stress index, involving temperature, radiation nitrogen & water. The later is explained above. The other terms are given as:

Radiation index: $RI_i = 1 - e^{-kR_i/R_{\max}}$ with $R_{\max} = 750 \text{ ly/day}$
and

$R_i = \text{global solar radiation on day } i, \text{ ly/day}$

Temperature index: $TI_i = T^2 + 2T$

where $T = \frac{t_i - t_{\text{base}}}{t_{\text{opt}} - t_{\text{base}}}$

$t_{\text{opt}} = \text{optimum temperature}$

Nitrogen index: $NI_i = 1 - \exp\left(\frac{\text{Crop } N_i}{W_i} \times \frac{1}{\text{MCNS}}\right)$

where MCNS = biomass at the time of anthesis

To test and develop appropriate coefficients the data sets required are presented below.

Minimum data set that need to be collected at the experimental site:

a) Crop factors:

- . planting date
- . duration of the crop, days
- . main phenological events, days
- . final grain yield, kg/ha
- . final dry matter, kg/ha
- . dry matter at main phenological events, kg/ha

b) Soil factors:

- . water holding capacity of the soil, mm
- . initial soil moisture & fertility
- . % clay content

c) Climatic factors:

- . precipitation, mm
- . open pan evaporation, mm
- . global solar radiation, ly/day
- . temperature, °C
- . relative humidity, %

} daily

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- . water holding capacity of the soil, mm
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- . % clay content

c) Climatic factors:

- . precipitation, mm
- . open pan evaporation, mm
- . global solar radiation, ly/day
- . temperature, °C
- . relative humidity, %

} daily

d) Management factors:

- . fertilizer level
- . crop/cropping pattern
- . population/spatial variation

3.4.2- Verification and development of appropriate coefficients through field experimentation:

In order to develop appropriate coefficients for the models discussed above it was proposed to conduct field experimentation over few selected areas over the northeast Brazil. However, this will commence only in 1984. Figures 35 & 36 depict the proposed field lay out for the experimentation. For this purpose visited the appropriate Institutions over the northeast Brazil and initiated on the probable collaboration with some Institutions. This venture involve multi-disciplinary team effort. At CPATSA it was also initiated a multi-disciplinary team consists of agronomist, physiologist, soil scientist, irrigation scientist and agrometeorologist. At majority of the places it is irrigated experiment during dry period of the year. However, at some places where there is no irrigation facility the water stress treatments are related to different dates of sowing during rainy season. In the case of mode of irrigation, it is felt that the most appropriate way is furrow irrigation. The line-source procedure is not suitable for many places including Petrolina (Bebedouro & Mandacaru) as the wind speeds are considerably higher (> 10 km/hr) during dry period and also horizontal movement of water is possible in many of the northeast Brazilian soils and hence it will not be possible to quantify the exact stress that need to be related to relative yields.

The trip to northeast Brazil has given me not only the opportunity to meet different scientists but acquaint with the wealth of the experimental information they had. This data can be used to derive the basic coefficients at a first approximation. It was therefore, suggested to the scientists to codify the data and collect some of the missing environmental information for

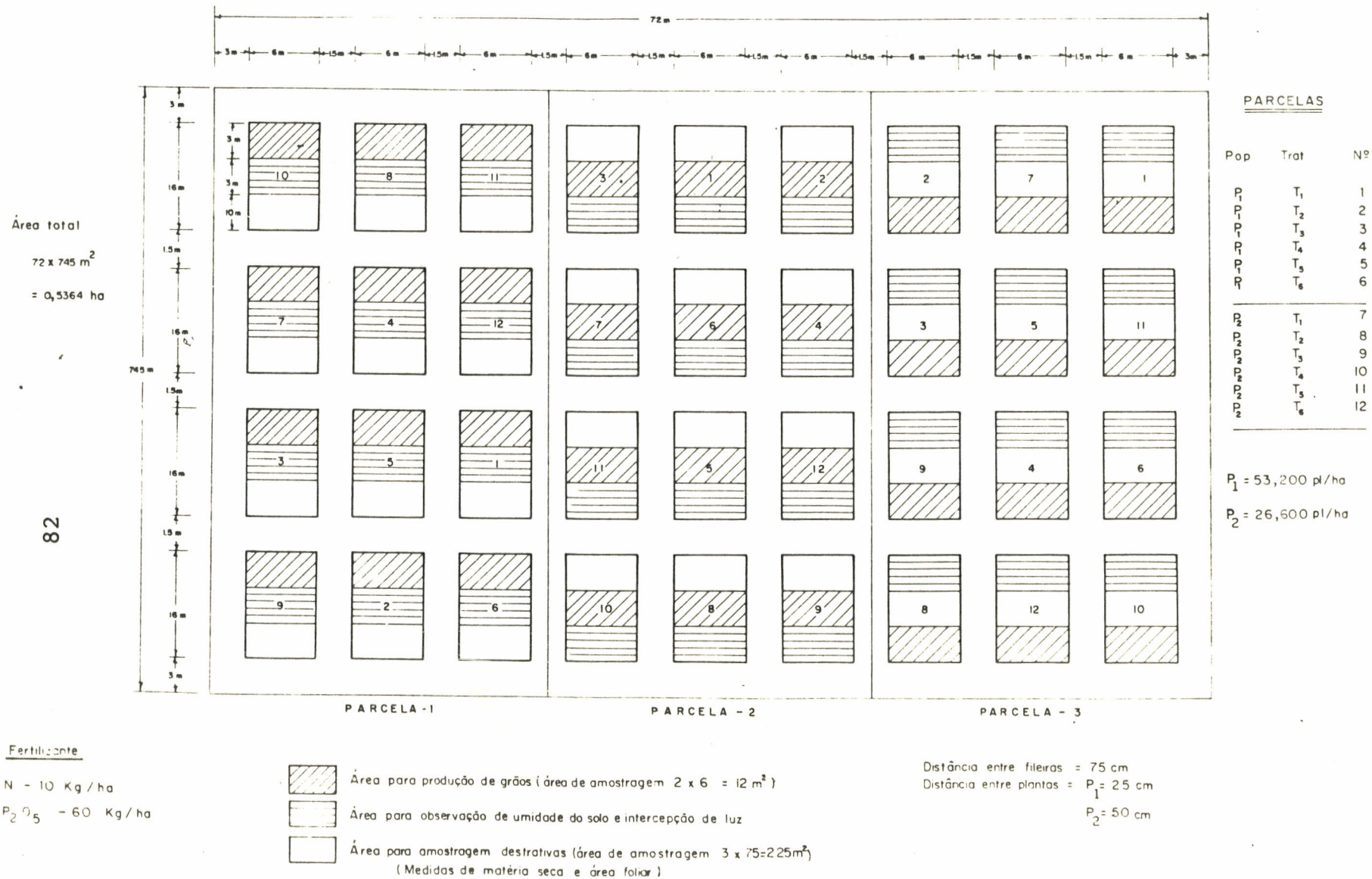


Fig. 35 : Field lay-out of crop-weather modelling experiment.

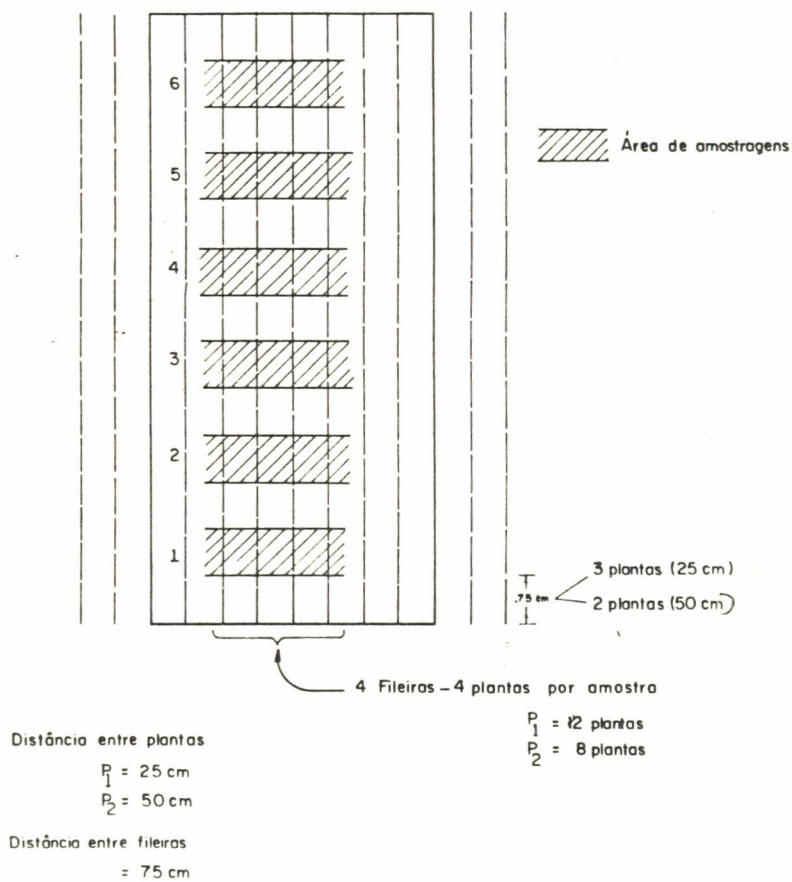


Fig. 36 : Sub-plots-field lay-out of crop-weather modelling experiment (for dry matter and grain yield).

integration of such information. To induce interest among the scientists for better utilizing their data for the transfer of technology a test calculations were made⁸ using the data of cowpea/maize intercrop results* collected at Caatinga (CPATSA) during 1981-1983. Figures 37-39 depict the water balance simulations using ICSWAB model (Reddy 1983e). Table 10 & 11 present the yield response to stress under sole and intercrops. The potential yields derived through non-linear model agree very closely with the observed potential yields. These results present only an example but not final results. The Figs. 37-39 suggest that the water use is not directly related to the soil moisture level. The phenophase durations in the three years are different for maize. These differences are associated not only with the differences in the temperature but also with the early withdrawal of water application. The yield response is different to stress at different growth stages (Table 11). Therefore, the success of this venture depends upon the careful experimentation.

3.4.3- Simulation using environmental data:

This aspect will commence only after the finalization of the model. This involves the following three stages:

1. Development of final form of the model
2. Computerization of the model
3. Development of data Bank.

So, for the progress is partial under development of data Bank only.

4.- IMPORTANT SUGGESTIONS AND/OR RECOMMENDATIONS

- . For achieving better results it is very important that the scientists and/or consultants should concentrate more in the field of their expertise.

* These experiments were conducted solely by L.B. Morgado.

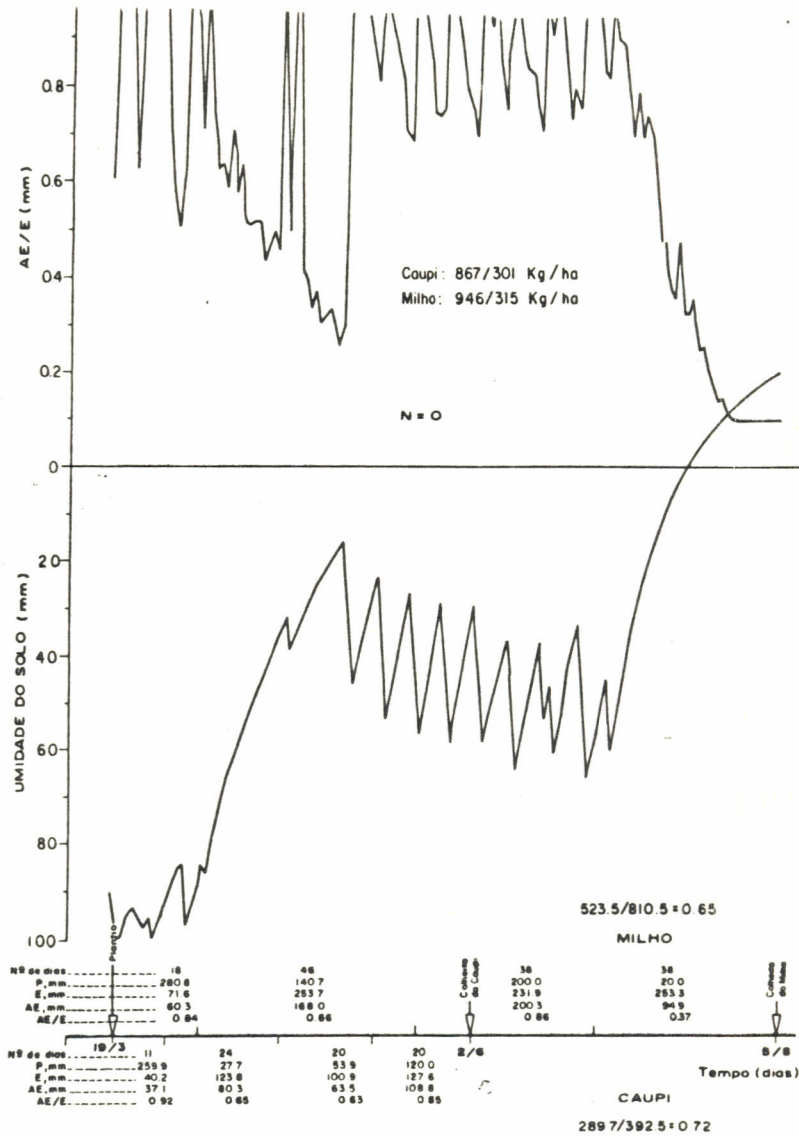


Fig. 37 : Water use by maize/cowpea intercrop in 1981 at Caatinga (Petrolina-PE).

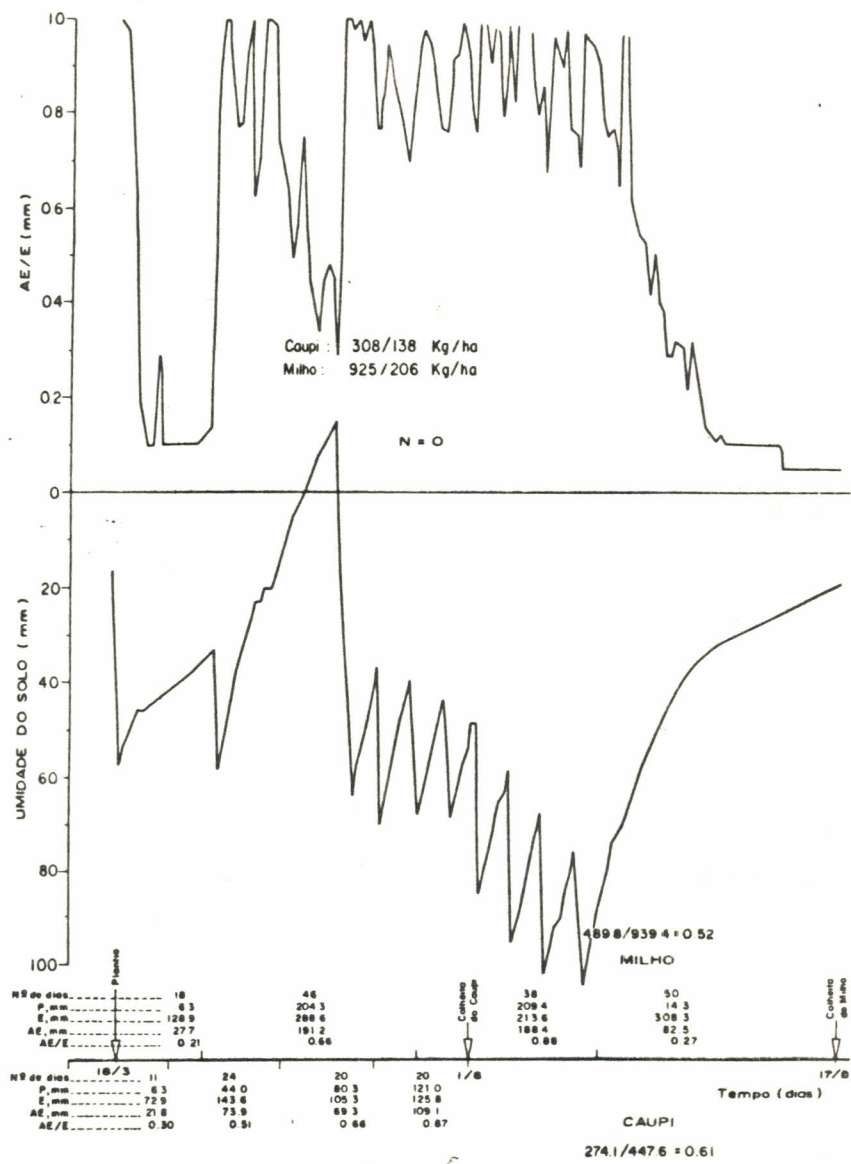


Fig. 38 : Water use pattern by maize/cowpea intercrop in 1982 at Caatinga (Petrolina-PE).

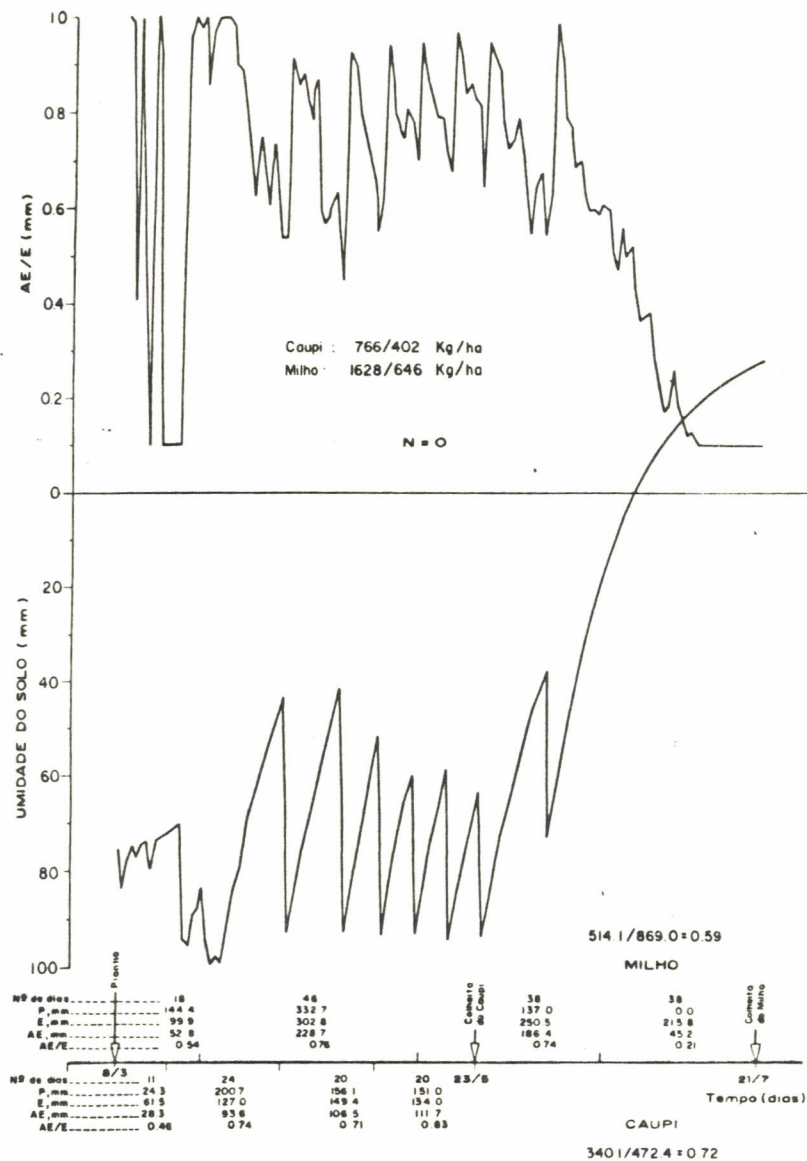


Fig. 39 : Water use pattern by maize/cowpea intercrop in 1983 at Caatinga (Petrópolis-PE).

Table 10 : Water use pattern and productivity at Caatinga during 1981-1983 under '0' kg/ha of N.

Year	Entire growth cycle		(AE/E) _i ^{**} at growth stage i				Grain yield, kg/ha		Duration [#] (days)	Average	
	AE (mm)	AE/E*	1	2	3	4	Sole	Inter-crop		Temperature (°C)	Relative humidity (%)
<u>a. Cowpea</u>											
1981	290	0.74	0.92	0.65	0.63	0.85	867	301	76		
1982	274	0.61	0.30	0.51	0.66	0.87	308	138	75		
1983	340	0.72	0.46	0.74	0.71	0.83	766	402	77		
<u>b. Maize</u>											
1981	523	0.65	0.84	0.66	0.86	0.37	946	315	141	22.9	60.7
1982	490	0.52	0.21	0.66	0.88	0.27	925	206	153	23.9	66.7
1983	514	0.59	0.54	0.76	0.74	0.21	1628	464	136	25.1	64.7

* AE/E → average of the entire growth cycle

** (AE/E)_i → average of growth stage i

sowing to harvest

Maize → growth stage 1 : planting to 18 days
 2 : 19 to 64 days
 3 : 65 to 103 days
 4 : 104 to harvest

Cowpea → growth stage 1 : planting to 11 days
 2 : 12 to 35 days
 3 : 36 to 55 days
 4 : 56 to harvest

Table 11 : Yield response to stress at two growth stages of maize and cowpea under sole and intercrop situations.

Yield	Crop	Situation	Linear model				Non-linear model		
			y_0 (kg/ha)	a	b_1	b_2	a (y_0 , kg/ha)	λ_1	λ_2
y	Cowpea	Sole crop	1476.3	-678.2	536.2	1618.3	1288	0.90	3.00
y/ y_0	Cowpea	Sole crop		-0.46	.36	1.096	1.0	0.90	3.00
y	Cowpea	Intercrop	702.0	-447.15	4.41	1144.76	588.8	0.06	5.12
y/ y_0	Cowpea	Intercrop		-.637	.006	1.63	1.0	0.06	5.12
y	Maize	Sole crop	3304.1	-3649.2	33.3	6920.0	5636	0.02	14.52
y/ y_0	Maize	Sole crop		-1.104	.01	2.094	1.0	0.02	14.52
y	Maize	Intercrop	1025.77	-1156.3	173.02	2009.05	1530.09	0.45	12.77
y/ y_0	Maize	Intercrop		1.127	.169	1.96	1.0	0.45	12.77

$$y = a [1 - (1 - (AE/E)_i)^2]^{\lambda_1} \quad - \quad \text{non-linear model}$$

$$y = a + b_1 (AE/E)_i + b_2 (AE/E)_i^2 \quad - \quad \text{linear model}$$

$$\text{If } (AE/E)_i = 1 \quad \text{then } y = y_0$$

- . Before any model is adopted to northeast Brazil it is very important to test the model at least at few selected locations under different climatic regimes.
- . To achieve better agroclimatic classification it is essential to work with daily or weekly data sets.

5.- LIST OF PUBLICATIONS

1. REDDY, S.J. 1982. Proposed areas of Research in the field of Agroclimatology as relevant to CPATSA/EMBRAPA. CPATSA/EMBRAPA/IICA, Petrolina (PE), 18.11.1983, 20p.
2. REDDY, S.J. & AMORIM NETO, M. da S. 1984. Dados climatológicos da P, PE & R_t e classificação da climática do Nordeste do Brasil. CPATSA/EMBRAPA, Documento Nº , pp.
3. REDDY, S.J. 1984. Climatic fluctuations and Homogenization of northeast Brazil using precipitation data. Pesq. Agropec. Bras. (Brasília), 19:
4. REDDY, S.J. & AMORIM NETO, M. da S. 1984. Caracterização climática do Estado da Bahia (Probabilidades do Balanço Hídrico mensal). CPATSA/EMBRAPA, Tech. Bull. , pp.
5. REDDY, S.J. & AMORIM NETO, M. da S. 1983. A method for the estimation of potential evapotranspiration and/or open pan evaporation over Brazil. Pesq. Agropec. Bras. (Brasília), 18:
6. REDDY, S.J., AMORIM NETO, M. da S. & ELPÍDIO, M. da G. da S. 1983. A simple method for the estimation of global solar radiation over northeast Brazil. Pesq. Agropec. Bras. (Brasília), 18:

7. REDDY, S.J. 1984. Crop weather modelling - a review (as applicable to northeast Brazil). Pesq. Agropec. Bras. (Brasília), 19:

8. REDDY, S.J. & MORGADO, L.M. 1984. Coleta mínima de dados do meio ambiente - Importância. Pesq. Agropec. Bras. (Brasília),

9.- REPORTS (Tour)

- . Tour report of S.J. Reddy (trip to northeast Brazil during 6-18th June 1983).
- . Tour report of S.J. Reddy (trip to Campinas-SP during 16-24th July 1983).
- . Tour report of S.J. Reddy (trip to Brasília from 20 — 23rd June 1983).
- . Tour report of S.J. Reddy (trip to Terezina from 24-28th October 1983).

6.- SEMINARS PRESENTED AT CPATSA

- . Métodos de estimativa da evapotranspiração potencial e Radiação Solar Global para o Nordeste do Brasil.
- . Delimitação do TSA.
- . Balanço de Solo-Água.
- . Probabilidade de Estimativa de Precipitação Pluviométrica.

7.- SYMPOSIA OR CONFERENCES ATTENDED AND PAPERS PRESENTED

- . Intercropping multilocation collaborative meeting at CPATSA/Petrolina.

- Meteorological elements - Their importance to crop production - S.J. Reddy.
- . III Agrometeorology congress in Campinas.
- Crop-weather modelling - a review (as applicable to northeast Brazil) - S.J. Reddy.
- Climatic fluctuations and homogenization of northeast Brazil - S.J. Reddy.
- Classification of climate of northeast Brazil - a review - S.J. Reddy.
- Numerical techniques as applicable to agroclimatic classification - a review - S.J. Reddy.
- . I Reunião sobre Culturas Consorciadas no Nordeste, Teresina (PI).
- Coleta mínima de dados do Meio Ambiente - Importância. - S.J. Reddy & L.B. Morgado.

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