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CLIMATE VARIABILITY AND AGRICULTURE
— THE HUMID TROPICS —

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September, 1978

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I. Climatic Input Required for Assessing the Impact of Climatic Changes on Agriculture

Among various climatic parameters, rainfall is of greatest concern to farmers in the humid tropics as a whole.[1] It will be through change in rainfall that changes in a climate regime have impact on agriculture in the humid tropics. Lower than average temperature may affect agricultural production in the tropical highlands and winter-season cropping in the sub-tropical zone. But this speaker will touch upon only the probable impact of changes in rainfall on agriculture in the humid tropics.

Long-term changes in different climatic parameters in various parts of the world have been examined in connection with climate changes. However, studies on rainfall in the humid tropics appear to be much fewer than those on temperature and those on rainfall in the other parts of the world.

In studies on long-term trends and periodicity of climatic parameters observed since the instrumental era, various statistical methods have been used in order to smooth out year-to-year fluctuations. Let us look at an example of this kind of study, in which the trend and periodicity of rainfall in India from 1901 to 1960 were analysed /1/. It was found that the rainfall trend was upward in 13 out of a total of 31 climatic sub-divisions during the period, and the differences between the former and latter 30 years' mean annual precipitation in those 13 sub-divisions ranged from 4 to 19 per cent. Some periodicity was also recognized; 8.5 to 12.0 years in several and 2.0 to 3.5 years in more sub-divisions.

In place of rainfall data, the water level of lakes is sometimes used to study rainfall variability. In a study of Lake Victoria, possible periodicity with a period of over half a century is discussed /2/. It becomes increasingly difficult to make use of statistical methods for analysis of such a long-term periodicity because of the limited length of available time series data.

The two examples mentioned above and many other studies, particularly those on the climatic history of the pre-instrumental era, demonstrate that the annual fluctuation of rainfall is not randomly distributed around a constant normal value, but the climate, in fact, changes. Therefore it may not necessarily be adequate to make any agricultural projections based on the means of climatic parameters of the last 30 years, or so-called "normals." It might be difficult, for example, to base determination of the premium and indemnity for crop insurance on the normals.

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1) Since agriculture will be discussed at this conference by three speakers, who will treat, respectively, the temperate, semi-arid and humid tropical zones, this final paper should cover the entire region that is warmer and/or wetter than the first two regions. This means that my discussion will not be restricted to the equatorial zone, where rainfall is plentiful throughout the year, but the main emphasis will be on the climatic zone with a distinct dry period. Actually the latter is the area of greatest population concentration while the former is still only sparsely populated.

Existence of periodicity implies that wet and dry years may recur with a certain regularity. If short cycle periodicity such as the Quasi Biennial Oscillation (QBO) could be recognized with sufficiently high accuracy, it might in the future help us forecast agriculturally relevant climatic parameters a year ahead of time. Periodicity with a longer period implies that wet or dry years tend to persist for a few years, or sometimes for decades. The damage of two consecutive drought years will be more than the arithmetic sum of that of two single years of drought which occurred separately. If periodicity with still a longer period, e.g. over half a century as suggested by the level of Lake Victoria, is proven to be really the case, "The climatic statistics of times before 1895 may .... be more relevant to the present day and for some decades ahead than the statistics of any period between 1900 and 1950" /2/.

As mentioned earlier, the trend and long-term periodicity of rainfall become discernible only after we smoothe out the year-to-year fluctuations, and the result is shown in terms of a shift of the normal; for instance, 'the mean annual rainfall was 1200 mm for 30 years since 19xx but it shifted down to 1100 mm for the following 30 years'. This is the usual manner in which information on climatic change is handed over from meteorologists to agriculturists. In order to evaluate this climatic change from an agricultural point of view, however, it is not adequate to present it merely as a shift of normals from 1200 to 1100 mm.

Year-to-year fluctuation is an inherent characteristic of climate. Therefore, adaptation of an agricultural system to a given climate is, more precisely, adaptation to a certain range of climatic parameters. In years or seasons during which climatic parameters remain within a tolerable range, agriculture is not seriously affected, while it will suffer serious setbacks in other years of anomalous climate. In other words, in a locality where the normal of the annual rainfall amount is 1200 mm, agriculture there may not be affected seriously in any years with the annual total between 1000 and 1400 mm, which is expected at a certain probability, say, in 90 out of 100 years, for example. If so, it is more desirable for evaluating the impact of climatic change on agriculture to express the change not only in terms of the shift of normal from 1200 to 1100 mm but also in terms of the change in the expected range of rainfall in 90 out of each 100 years; for example, the range might change from that between 1000 and 1400 mm to that between 900 and 1300 mm.

What was stated above can further be elaborated as follows. First, let us assume that the annual rainfall amount has the Gaussian or normal distribution with mean, $\overline{x}$, and variance, σ^2.[2] Second, it is also assumed that agriculture is not adversely affected so long as the rainfall amount of any particular year is within the range of $(\overline{x} \pm k)$. (Fig. 1a) Now, climatic

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[2] Actually, rainfall distribution is often far from the normal distribution, particularly in the arid zone or when rainfall amounts during intervals shorter than one year or season are examined. However, here the distribution is supposed to be normal or to be normalized.

changes mean the changes in either $\overline{x}$, σ^2 or both. Therefore three types of climatic change are conceivable. In the first type, $\overline{x}$ changes but σ^2 remains as before. (Fig. 1b) Since the agricultural system is well adapted to the climate before the change and it usually takes many years, decades or perhaps centuries to adapt itself to the new climatic regime, the tolerable range, $(\overline{x} \pm k)$, does not change, at least immediately. The concomitant changes in probability that the agricultural system may suffer from anomalously deficient or excessive rainfall are shown by the areas marked with plus or minus signs in Fig. 1. In the second type of climatic change, σ^2 changes but $\overline{x}$ does not (Fig. 1c). If σ^2 becomes larger than before, the increased risk of both deficient and excessive rainfall will result. Both $\overline{x}$ and σ^2 change in the third type (Fig. 1d).

Thus, from the agricultural point of view, climatic changes should preferably be presented not only in terms of the shift of normals but also in terms of the changes in frequency distribution, that is, the changes in probability of occurrence of anomalies or of climatic parameters within a certain tolerable range. If only the shift of normals is indicated, its impact on agriculture could be assessed only when a certain relationship between the shift of normals and the changes in frequency distribution is assumed. Furthermore, the second type of climatic change in which only σ^2 changes but $\overline{x}$ remain as before might not be detected if one pays attention only to the trend and periodicity of normals, although this type of climatic change might be of greater significance to agriculture than one with a small shift of $\overline{x}$ without a change in σ^2.

Studies of the long-term changes in frequency of anomalous rainfall in the humid tropics are very scarce. Three examples are introduced below.

Fig. 2 shows occurrences of anomalously small and large amounts of seasonal rainfall in India based on the data of 22 stations with long time records. The figure reveals that "the period between 1890 and 1919 was rich in both extremes, while the period 1920-1942 was quiet ...... In the 1950's a high frequency of floods was accompanied by a low frequency of droughts; the reverse was true in the 1850's" /3/. Variance, σ^2, appears to have become larger in the period 1890-1919 and smaller in 1920-1942 (the second type of climate change), while $\overline{x}$ may have shifted to one direction in the 1950's and the other in the 1850's with or without change in σ^2 (the first or third type).

Yearly changes in the drought-affected acreage in India are shown in Fig. 3. The authors concluded that "the country appears to be passing through a phase of great irregularities in the behaviour of the summer monsoon" /4/. Might this imply an increase of σ^2, a shift of $\overline{x}$ to the left hand side in Fig. 1, or a change in both ?

The third example takes up all of monsoon Asia, including the temperate and semi-arid zones. Based on the monthly rainfall data of 33 stations for the period 1931-1974, the months with the amount of rainfall above or below the upper or lower quintile first were designated as anomalously wet or dry months, respectively. Second, the years during which four months or more were anomalously wet or dry were counted as anomalously wet or dry years. In Fig. 4, the year-to-year changes in the number of stations which recorded anomalously wet or dry years are shown. One of the conclusions of this study is that "the occurrence of both anomalously wet and dry years tends to be more frequent since the 1960's than before. We are now in the period of great variability of climate" /5/.

All of the examples referred to so far deal with the trend, the periodicity or the changes in frequency of anomalies which are supposed to relate to some not yet well known natural phenomena. Apart from these climatic changes of natural origin, the possibility of climatic changes due to human activities are being seriously considered. There is even the possibility that the amplitude of man-made climatic change might exceed that of climatic changes due to natural causes which occurred during the historical past. Whatever the causes of climatic changes, projection of the future is not yet at hand. This appears to be particularly so when we consider probable changes in the rainfall regime in the humid tropics.

Certainly it is impossible to make an accurate assessment of the impact of future climatic changes until more reliable projections are made. However, the uncertainty of future climatic changes does not necessarily preclude the possible role of agricultural scientists in assessing their impact. As a first step to this end and, at the same time, as the first conclusion of this paper, I, an agronomist, want to emphasize the need for agricultural purposes, to present climatic changes in terms of the shift of normals as well as changes in frequency distribution. Once this climatic input becomes available, climatic changes can be expressed in changes in various secondary or derived parameters which have been proven to be of significant importance to agriculture.

II. The Vulnerability of Agriculture in the Humid Tropics to Variable Climate

II-1 Spatial and Time Variations in the Vulnerability of Agriculture to Climatic Changes

Once information on climatic changes is brought to agriculturists in terms of the shift of normals and changes in frequency distribution, it is the task of agricultural scientists to assess their impact on agriculture. The most powerful tool we can use to make this assessment is our knowledge of year-to-year fluctuations in agricultural production, which are caused mainly by year-to-year fluctuations in climate. What happened in anomalous years in the past will tell us what will occur if a similar anomalous year recurs in the future, and what should be done in order to minimize its adverse effects. It is more difficult to imagine the impact of climatic anomalies that have never been experienced in the past.

However, it is not an easy matter to use past experience to assess probable future impact, primarily because agricultural systems vary widely according to region and to the time period studied. In other words, the k value in Fig. 1 is not a constant. For instance, where crops are grown in the climatically marginal region (small k), even a minor climatic change may affect them seriously, while the effect may not be so serious in a more favorably situated region (large k). To make things more complex, k changes from time to time. Changes in production technology, land use, farm economic status, etc. contribute toward the increase or decrease of the tolerable range of climatic variability. If we define the agricultural system in such a way as to include storage, transportation, marketing, processing etc., changes in the whole economic system of a society may affect the vulnerability of agriculture to climatic changes.

In the foregoing section, three examples related to long-term changes in the frequency of anomalous rainfall were mentioned. In these studies, the criteria for anomaly appear to be more or less arbitrary: upper and lower deciles in the first example (Fig. 2), equal to or less than 80 per cent of normal rainfall in the second (Fig. 3), and upper and lower quintiles in the third example (Fig. 4). Although these criteria might be meaningful from the meteorological point of view, their usefulness for agriculture must be examined carefully. In any case, even if a criterion were proven to be meaningful to agriculture, it should always be kept in mind that its usefulness might be restricted to an agricultural system in a certain region at a certain time.

Thus, in order to assess the impact of climatic changes on agriculture, we require on the one hand, climatic input in adequate terms, and on the other hand, information on spatial and time variations in vulnerability of different agricultural systems to climatic variability. In other words, we need the expected values of all of $\overline{x}$, σ^2, and k in Fig. 1. If the expected change in k, ($k \rightarrow k''$), is relatively small, the impact of climatic changes may be governed largely by their magnitude. However, if k' is expected to be substantially different from k, we must pay greater attention to such a change in k value rather than to the climatic changes.

II-2 Rainfall Variability in the Humid Tropics

At least 1000 mm of annual precipitation is common in the humid tropics. Areas of such high rainfall are not so extensive in the temperate zone. Yet it is the annual fluctuation of rainfall that is the primary cause of year-to-year fluctuations in agricultural production in the humid tropics, too. It is often pointed out that the precipitation in the tropics is unreliable and that this is the reason for large annual fluctuations in agricultural production. But it is not a simple matter to compare rainfall variability in different regions because there seems to be no adequate measure of the relative variability of rainfall.

Biel's chart, "the world rainfall variability" /6/, is referred to very often even today. In this chart, variability is presented in terms of percentage departures from normal. The contrast between the arid and humid zones is sharply shown but the difference between the humid tropics and the humid temperate zone is not impressive. It may be interesting to compare the ways that two text books on climatology interpret this chart. In one, it is stated that:

> "... in spite of much lower annual-rainfall totals, wide territories (of high latitudes) enjoy reliable precipitation, ... Certainly the rainfall of low latitudes is not more reliable on a per cent bases than that outside the tropics" /7/.

The other says that:

> "the humid tropics stand out as regions with a very low variability of rainfall. However, this picture is somewhat misleading, because the units of measurements, 1 per cent of the annual mean, are much larger in the humid areas than in dry zones" /8/.

A commonly used measure of relative variability is the coefficient of variation or CV. But this is not always an adequate measure either, because CV is meaningful only when the frequency distribution is not far different from the Gaussian distribution. Furthermore, when we discuss the vulnerability of agriculture to climatic anomaly, the usefulness of both the CV and of percentage departures from normals becomes questionable. This is because, as has been shown above, we cannot understand the real reliability of rainfall for agriculture by simply considering these factors, but must take into account their relationship to the mean as well. Nevertheless, CV is commonly used, partly because there seems to be no good alternative and, perhaps, partly because it can easily be computed.

An attempt was made to compare CV relative to mean values of monthly rainfall in the humid temperate and humid tropical zones. Data from 68 stations in the agriculturally important regions of the world for the period 1941-1970 were used. Only those months of over 50 mm mean monthly precipitation and not lower than 10°C mean monthly temperature were selected, which brought the total to 483 station-months. Fig. 5a shows the relation between CV and means when all the data are considered while the data from 287 station-months in the humid tropics and 196 staiton-months in higher latitudes are shown in Fig. 5b and 5c, respectively. The exponential curves are identical in all three figures. If rainfall variability in low latitudes differed significantly from that in high latitudes, the dots in the last two figures would be scattered on either side of the exponential curve. But, as we see, this is not the case at all. Therefore, rainfall variability does not seem to be greater in the humid tropics than in the temperate zone.3)

When one deals with annual rainfall records of sufficiently long time span which usually show the Gaussian pattern, the curves of the cummulative probability diagram can be straightened by scaling the abscissa properly. The slopes of lines obtained in this fashion indicate variability of rainfall; flat slopes mean more reliable and steep ones less reliable rainfall. Fig. 6 is an example. The author's comment on this figure is that "Particularly notable is the fact that the monsoonal zones have the greatest slope — a typical feast to famine pattern. It clearly shows the wisdom of the ancient hydraulic civilization of the region with water impoundment and irrigation" /9/. Perhaps it may be more meaningful to compare rainfall variability for each of the different climatic regions than to compare the whole region of the humid tropics with the whole region of temperate climate.

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3) But we should note that the frequency distribution of monthly rainfall is usually quite far from the normal distribution, and it may be so even when months with over 50 mm rainfall are selected.

Differences between the amount of rainfall and the amount of water required are more directly related to agriculture than rainfall amount alone, since drought is a "supply and demand phenomenon" /10/. So far we have discussed only variability of the supply. The requirement for water varies widely according to kinds of crops, cultivation methods, soil conditions and many other factors. In dry lands, less moisture consuming crops are grown, while more demanding ones are grown in the humid areas. However, the moisture balance assuming the most demanding crop could be an index of the agricultural potential of regions in terms of moisture availability. Or it will affect the range of choice of crops as far as moisture is concerned. The amount of water required by the most demanding crop could be estimated by the amount of potential evapotranspiration (PET).

In view of this, differences between precipitation (P) and potential evapotranspiration, (P-PET), were calculated on monthly basis for 20 stations, ten each in the humid tropics and temperate zone, for each year during the period 1941-1970. PET was estimated by Thornthwaite's formulae but soil moisture retention, moisture carried over from preceeding months, run-off etc. were not taken into account. Fig. 7 shows the means and lower quintiles of P and P-PET. Note that except for the three stations in the equatorial climate, the apparently great advantage of the humid tropics over the temperate zone when judged only from rainfall amounts (Fig. 7a) nearly completely disappears when we look at the balance (Fig. 7b).

In the temperate region, some stations have rather dry or wet winters, but in comparison to the tropics, the precipitation is rather evenly distributed over 12 months, except for Salisbury where winter has virtually no rain. Regardless whether the winters were wet or dry, however, the moisture balance was positive in this season, even in the sixth driest year during 30 years. Even if there is no crop in the fields, or growth is retarded during winter, water stored in the soil during this period makes a substantial contribution to the vigorous growth of crops at later stages. In spring and early summer, it becomes progressively drier but the balance remains not less than -50 mm until the driest period when it falls below that level for two to three months at most. This picture looks ideal for the growth and maturation of annual grain crops.

In the humid tropics, the seasonal variation of rainfall is immense. Some examples show the uni-modal and the others the bi-modal pattern. Except for the equatorial climate region, the dry period is long and severe, especially in the monsoon climate. The growing season of annual crops is restricted to the rainy period. Unlike the situation in the temperate zone, the pre-season storage of soil moisture is negligible. Therefore, annual crops must depend totally on the rainfall during the growing season. In many places, there are only a few months with positive moisture balance. On average, in one out of every five years, there are no or one such months.

It is often said that the daily and hourly maximum of the tropical rainfall is great, and this characteristic reduces the ratio of that part of rainfall which is actually absorbed by crops to the total rainfall amount. Tropical soils, particularly those coarsely grained ones derived from old terrace and plateau materials, are very poor in water-holding capacity. These and other factors will make the water balance in the humid tropics even less advantageous than that shown in Fig. 7b.

From the discussion above, it can be concluded that:

(1) rainfall reliability is not necessarily less in the humid tropics as a whole than in the humid temperate zone, though it may be so in areas of monsoon climate;

(2) it may not be correct, therefore, to say that large year-to-year fluctuations in agricultural production in the humid tropics in spite of much greater mean rainfall amounts is primarily due to greater variability of rainfall;

(3) in terms of water balance, the humid tropics have no advantage over higher latitudes, and the major part of the humid tropics, i.e. regions with a distinct dry season, is hydrologically marginal when the seasonal pattern of rainfall is considered in relation to suitability for annual crops, and

(4) thus, unstable agricultural production, especially of annual crops in some parts of the humid tropics, is considered to be due basically to hydrological marginality of the region rather than to large but unstable rainfall.

II-3 Vulnerability of Different Crops to Rainfall Variability

In Fig. 8, the delimitation of the humid tropics is approximated to international boundaries, or state borders in the case of Brazil and India, because in these two countries there are substantial areas which are not really in the humid tropical climate zone. By such an approximation it is possible to enumerate agricultural statistics. In Table 1, the composition of the crops on arable land in the humid tropics is compared with that in the rest of the world. As we see, cultivation of annual crops other than rice, particularly of upland grain crops, is the norm of agriculture outside of the humid tropics, while other types of agriculture are also of great significance in the humid tropics. This is especially so in the Asian and Oceanic humid tropics, which contain about two thirds of the total arable land area in this climatic zone.

The relative significance of annuals other than rice in the humid tropics is further reduced when one takes account of the following points:

(a) A substantial area within the humid tropics as approximated and shown in Fig. 8 is not actually in the typical humid tropical climate zone, e.g. the dry zone of Upper Burma, part of the Deccan Plateau of India, part of Sahel of West Africa, etc.

(b) The relative importance of the crop groups is compared in terms of harvested acreage in Table 1, but significance of annuals other than rice in the humid tropics is much less in terms of production because they are grown by the shifting cultivation method in a large area and, hence, the average yields per unit area are low.

(c) Tree crops (not included in Table 1) are planted in 44 million ha or two per cent of the total land area in the humid tropics, including the whole territories of Brazil and India, while the corresponding figures for zones outside the humid tropics are 35 million ha or 0.3 per cent. (FAO Production Yearbook 1975)

It is well known that due attention should be paid to the fast leaching of nutrients and the great risk of erosion in humid tropical agriculture. This is especially so when a short-term upland crop is cultivated, since the cultivation of these crops leaves soil temporarily uncovered every year. Not only the risks of land deterioration but also the direct influence of climatic conditions on these crops' physiology make their cultivation in the humid tropics unfavorable. For instance, temperatures may be too high for some crops, or severe damage or even total failure of annual crops may occur when certain critical growth stages such as flowering and fertilizing periods coincide with very strong rain in a very short period or with the strong winds of typhoons, cyclones or hurricanes. Hydrological marginality and the accompanying high risk of water deficiency as discussed in the foregoing subsection are also factors discouraging the cultivation of these crops. On the contrary, lowland rice and vegetative crops are, in general, better adapted to the soil and climatic conditions of the humid tropics.

Although various risks and uncertainties appear to discourage the cultivation of annual crops other than rice in the humid tropics, Table 1 shows that in 1974, more than half of the total arable land was actually planted in them. Furthermore, changes in crop composition between the years 1954 and 1976 indicate that the relative importance of upland annuals tended to increase (Table 2). Does this imply that the vulnerability to climatic variability of humid tropical agriculture as a whole is increasing, that is, that the k value is becoming smaller ?

As mentioned earlier, a substantial portion of the acreage planted in annual crops other than rice is under the shifting or slash-and-burn cultivation system. This system is one of the examples of adaptation of indigenous agriculture to environment, because the risk of land deterioration can be minimized by this method. However, it is very important to note that this risk is minimized only when population density falls below a certain level. If density exceeds that level, the fallow period becomes shorter, lowering the yield per unit area. The poorer yield necessitates the burning of a larger area, which, in turn, results in a still shorter fallow period. This vicious cycle ultimately results in infertile land which cannot be used anymore. It is said that the core area of the ancient Maya civilization was relocated because of this problem. There are many similar examples in the present day humid tropics. The vast expansion of infertile land, often covered with Imperata spp., suggests the extent of this man-made disaster.

The primary cause of overpopulation in the region of shifting cultivation is the explosive population increase in the last few decades. Besides that, however, population concentration in a certain area for other reasons aggravates the situation.

If shifting cultivation is to be practiced without causing irreversible deterioration of land, a long fallow period must be guaranteed, which means that a small group of cultivators must command a large territory and, hence, groups have to live sparsely scattered over a large area. Such a settlement pattern is detrimental to national unity and modernization. Therefore, various schemes for resettling shifting cultivators have been initiated, but many of them simply resulted in land deterioration and an eventual shift on even a larger scale after some time, as long as the basic method of cultivation was unchanged.

Apart from these forced or planned resettlement schemes, the spontaneous movement of population sometimes causes overpopulation in a certain area. Such movements are often motivated by better chances for education, medical care and use of other modern facilities, as well as opportunities to get additional cash income. In some places, better political security may be a strong motivation. Thus, the development and modernization of the countries in the humid tropics seem to make the life of the shifting cultivators in remote areas less and less attractive than before. It seems to me that these socio-economic and political factors are more important reasons for overpopulation than are changes in the population-land ratio of a whole country.

The above discussion leads me to the following conclusions:

(a) Only if we accept the condition in which a large proportion of a country's population remains scattered in remote areas and can neither benefit from nor participate in the nation's development and modernization, can shifting cultivation be practiced without irreversible deterioration of land assets.

(b) However, this is not a realistic long run policy. Therefore, the method of cultivation should be altered, since the shifting cultivation method seems to be incompatible with the concentration of population in a limited area, an apparently necessary condition for modernization.

Then, what sort of cultivation system or systems should replace the shifting cultivation method ? Could sedentary cultivation of upland grain crops be an adequate form of agriculture ? The fact that increasingly shorter fallow periods eventually force farmers to abandon their land suggests great difficulty for sedentary agriculture in the humid tropics. However, modern fertilizer and soil conservation technologies might be able to overcome this difficulty. Although such technologies certainly exist, a more important consideration is whether they, together with the necessary inputs, could be used by the majority of poor peasants.

It is said that shifting cultivation was practiced widely in the now developed countries in the temperate zone some time ago, when there was no shortage of cultivable land. But population increase and concomitant land scarcity necessitated the utilization of advancing technology to develop methods to use the land more intensively. To some extend, this could be applied to the humid tropics. But it should be noted that so far, the sedentary cultivation of upland grain crops in the humid tropics has not supported any big concentrations of population. The course of agricultural evolution in the temperate zone may not be repeated in the humid tropics. There are ample reasons for this from the agro-environmental point of view, as I have discussed already.

The second type of cultivation of annual crops other than rice in the humid tropics is the continuing cultivation of these crops on the same plot of land year after year; much of the produce is simply eaten by the cultivators. In Asia, rice is almost always preferred as a staple food, but where land suitable for lowland rice cultivation is unavailable, maize, sorghum, upland rice, cassava, peas and beans, etc. are grown primarily for direct consumption. In those Asian countries where per capita consumption of rice is low (less than 100 to 150 kg per person per annum), these crops are major sources of food for a substantial proportion of the total population.

In these countries, the villages depending on upland crops for subsistence are normally newer than the rice growing villages in the lowlands. This means that the scarcity of suitable land for lowland rice cultivation pushed less fortunate peasants from fertile valley bottoms to dry uplands. Their dietary habits are not necessarily due to their preference for upland crops. Therefore, their consumption of rice increases when either its price becomes lower or their income increases. It is said that the sudden drop in rice exports from Burma was partly due to the Government's policy of distributing cheap rice to hitherto non rice eaters in remote mountain areas.

Thus, the second type of upland crop cultivation will not persist if enough rice is produced to feed the whole population, or if extra income from other sources enables the cultivators of these crops to purchase rice. But unfortunately it is unlikely that this will happen in the near future. Instead, this type of cultivation will most probably continue to increase, and thus more and more marginal areas will be used by this type of agriculture. And I believe that this will be the form of humid tropical agriculture most sensitive to climatic variability.

The third type of upland crop cultivation in the humid tropics is the cultivation of feed crops primarily for the export market. This is a recent development and should be examined carefully. The most notable examples are soybeans in Brazil (Fig. 9) and maize and sorghum in Thailand (Fig. 10). These crops are grown commercially. Though Thai maize is grown by small farmers, their staple food is rice. The demand for these crops is and will continue to be great because of increasing consumption of animal rather than vegetable food and the concomitant increase in calorie intake on the basis of original calories in higher income countries. As long as these crops can be exported at a price level equal to or lower than the Chicago quotation, there will be no difficulty in finding buyers.

The traditional agricultural commodities exported from the humid tropical countries are coffee, cocoa, tea, coconuts, bananas, sugar, jute, rubber etc., and more recently oil palm. All of these are either perennial crops or vegetative crops. The demand for these crops can not be expected to increase dramatically in the near future. It will be very difficult for newcomers to compete against traditional exporters of these products. Conversely, the export of feed crops is quite a new affair. It opened a new way to earn foreign currencies, which are badly needed by developing countries. Thailand and Brazil are the forerunners who first realized this possibility. But can this be called a success story ?

The production of maize in Thailand was very much affected by the notorious 1972 weather. Let us examine the monthly rainfall at three stations in the major maize growing areas. (Fig. 10) Maize is grown during the early part of the monsoon season, i.e. April to August. In 1972, rain was very scanty in May but normal in June. In July and August it was also less than normal in some places. Cassava is another Thai export crop; its acreage has been increasing at a great rate in the last decade. The cassava growing area is not so far from the maize area and some section overlap. At three stations in the cassava area, rainfall was as scanty as in the maize area in May, July and August of 1972. But the cassava production seems to have hardly been affected. (Fig. 11) As the above example demonstrates very well, annuals are very susceptible to short term water stress, while root crops are quite resistant to it.

In the shifting cultivation various crops are planted after burning, and the cultivation may continue thereafter for one or more years. In the first year, the most demanding crops are grown, and less demanding ones are planted in the following years. Often the last crop planted is cassava. In West Africa, it is reported that the gradual deterioration of the soil under sedentary agriculture makes it difficult to grow maize and yams, and, in their place, cassava is planted in large areas. In Thailand, maize planters are exploiting new lands, while old and less fertile maize fields are now either planted in less demanding crops such as sorghum and cassava, or sometimes totally abandoned.

One of the characteristics of the genesis of residual soils in the humid tropics is that differences in parent material are very strongly reflected in soil formation. Most of the residual soils of reasonable fertility and resistance to erosion in the humid tropics are formed in areas of neutral to basic rocks such as limestone, basalt and basic volcanic ejecta. The sedentary cultivation of upland crops in the humid tropics is mainly distributed in these soil areas. It may be feasible to maintain the fertility level and prevent erosion of these kinds of soils, and the sedentary cultivation of upland grain crops might be possible on sustained basis.

The Mekong Committee has proposed a long-term land use plan for the Lower Mekong Basin. (Fig. 12) As we see, areas suitable for three major kinds of land use are delineated on the map. The first are the areas principally suitable for paddy fields, where different kinds of water control devices enable the mono-culture of rice or rice-based multicropping systems. The second mainly in the mountains, are the areas designated as nature reserves. The third areas are those in which rain-fed upland crop agriculture should be feasible. The third areas are regions whose soils are derived from neutral or basic rocks and riverine levee material. The remaining vast area for which no land use designation has been proposed may be topographically suited to agriculture, but either inferior soil conditions make it infeasible to cultivate upland crops on a sustained basis, or poor hydrological conditions make cultivation of lowland rice difficult. At present, these inferior areas are being exploited either by planters of kenaf or cassava, or by rice growers, and the rest is covered with very poor stands of deciduous forest. Rice cultivation in such areas is extremely unstable: in some places farmers are fortunate if they can plant rice in one out of five years.

Three types of cultivation of short-term upland crops in the humid tropics have been discussed above. In all cases, there are strong reasons to continue or even to expand such risky types of cultivation. On the other hand, technology to prevent land from deterioration may be known, but various social, economic and cultural factors make its application difficult. Therefore, these types of cultivation are likely to expand to more marginal regions without proper measures to prevent land deterioration. This implies that vulnerability to climatic variation will not diminish but, rather, it will probably increase in the foreseeable future.

What can be done to prevent land deterioration ? It is evident that greater efforts should be directed toward research in and dissemination of technology that would achieve such an end. However, I personally feel that it might be unrealistic to expect the development of prosperous rural communities based on the sustained cultivation of short-term upland crops and taking adequate measures to prevent land deterioration, and, hence, that any efforts to make such a condition possible might not be rewarded except in rather limited areas of suitable soils. Rather, I feel that this kind of agriculture should be totally replaced by other systems of agriculture which have already been proven to be better adapted to the humid tropics, i.e. cultivation of lowland rice and other crops on paddy lands and/or perennial crops on upland.

In the present in the Mediterranean region, only extensive forms of agriculture, e.g. cultivation of olive and vines, are found on uplands, while highly intensive forms are seen on the alluvial plains. The uplands might have been the granary of ancient Roman Empire, while the lowlands were uninhabitable at that time, due to poor drainage and malaria. It occurs to me that the landscape of the humid tropics in the far future may be such that vast upland areas are covered with _Imperata_ spp. or extremely poor stands of trees with small pockets of cassava fields, while in the alluvial valley, a very intensive rice-based multicropping system is practiced in an area surrounded by hills covered with tropical trees.

The cultivation of cassava and other root crops has been well adapted to the humid tropics, and, hence, these crops are less vulnerable to climatic variability. However, root crops have other difficulties. Among other things, they are bulky, and perishable unless processed. This may be no drawback in a subsistence economy, but it will become a great disadvantage if these crops are to be staple food for an urbanized society. In the case of the commercial production of cassava for industrial purposes, first, dry tips are prepared and, next, they are processed into tapioca flour. Proper methods for processing, storage, marketing and cooking of cassava and other root crops for direct consumption as food by city dwellers are yet to be discovered. If root crops such as cassava cannot become staple food for urbanized society, farmers will turn to other, more acceptable crops which may not be so suited to humid tropical conditions, and thus the vulnerability of this agricultural area to climatic variation will increase.

Trees are also considered to be less vulnerable to climatic variation. However, that does not mean that trees are not at all affected. The following citation may be interesting.

> "During one growing season a tree normally stores photosynthates in excess of that year's growth needs. This provides a reserve which is drawn on the following year and makes it possible for the tree to survive a single severe year ..... Those integrative mechanisms mean that the variance spectrum of tree response to climate should show suppressed response to high-frequency climatic variations, but accumulated response to small systematic changes in climate, and such spectra do ..... It is not realistic to say that, because trees survive the large interannual variation, climatic mean changes are unimportant." /11/

The above citation refers to those trees, such as timber and rubber trees, that are not grown for their flowers or fruit. Flower and fruit formation is more sensitive to climatic variation than vegetative growth of trees because stress at a certain phenological stage is critical.

Oil palm plantations in Peninsular Malaysia are presently expanding at quite a high rate as a good replacement for rubber plantation agriculture. Malaysia's share in the world's total production of oil palm is 44 per cent. In the case of this crop, the period between the initiation of primordia and the harvest of bunches is from 33 to 36 months, and during this period there are several growth stages which are highly sensitive to rainfall deficiency. A severe drought affected the oil palm area for much of the years 1976-1977. At the end of 1977 the effect of the drought on production was already estimated at a loss of some 50,000 tons. (In 1976, figures for the total production of palm oil and palm kernel were 1,250,000 and 275,000 tons, respectively.) In view of the long development cycle of the palm bunch, the effect of the 1976-77 drought will certainly still be felt by plantations until mid-1979, although the present steeply ascending trend of oil production in Malaysia will make this loss insignificant. /12/

Serious frost damage to the Brazilian coffee crop followed by the price jump in 1975 is still fresh in many memories. It is known that a period of six hours below -2°C is sufficient to kill the leaves and that further exposure to cold could cause serious damage in the stem of coffee plants. /13/ Although frost may cause some damage to coffee on an average of once every three years, the impact of the frost that occurred on 17 July 1975 was very serious. (Table 3) But the damage was serious only in two out of the four major coffee-growing states of Brazil, those in the cooler southern area. Fig. 13, showing the absolute minimum temperature for July at -2°C, explains the severe damage in Parana and Sao Paulo.

In the major coffee-growing area of Brazil, the mean temperature for the month of July may drop to as low as 16°C, and representative average minimum temperatures are on the order of 7 - 8°C. Though most of the area is north of the Tropic of Capricon, it may hardly be called the humid tropics climatologically. Frost damage to coffee in Brazil is an example of damage that may affect tropical crops planted in thermally marginal regions.

During the colonial period, a few big political powers commanded vast undeveloped territories in the humid tropics. It was possible to introduce large-scale plantation agriculture anywhere within their territories where environmental conditions were suitable. Thus, the most suitable areas were developed while the less suitable ones were left unused. Under such political and economic conditions, one major role of agro-environmental research was to find the most suitable area for a particular plantation crop. Research in agro-climatology was no exception.

After many of the tropical countries gained their independence and their populations increased explosively, the emphasis in such research shifted from a search for the best agricultural conditions to an attempt to make the best possible use of available resources. In most newly independent countries, development of only the most suitable areas is an impermissible luxury. This means that many crops, including tree crops, are now being planted in less than favorable environments in terms of soil, topography and climate. Though trees are in general less vulnerable to climatic variability than other short-term crops, particularly the annual grain crops, it is anticipated that the propagation of tree crops to marginal areas will adversely affect their production stability, too.

III Vulnerability of Lowland Rice Cultivation to Climatic Variability

Lowland rice cultivation differs in various ways from rain-fed upland crop agriculture as well as from irrigated agriculture in the arid zone. The difference is particularly notable in the mode of the supply of water to plant roots. Therefore, the vulnerability of rice agriculture to rainfall variation is expected to differ substantially from that of other types of cultivation.

In the humid tropics, the population density in the rice-growing region is surprisingly higher than that outside of it. /14/ Historically, lowland rice cultivation is the only agricultural system that ever supported great concentrations of population on a sustained basis in the humid tropics. The reason for this is probably the high and stable productivity of lowland rice.

It has been repeatedly mentioned that the eventual degradation of land makes upland crop cultivation highly risky in the humid tropics. Rice cultivation is almost completely free from such land deterioration. First, the depletion of plant nutrients in the soil is compensated by the extra supply of nutrients through peculiarities of paddy cultivation; that is, very active non symbiotic nitrogen fixation, the release of nutrients by strong reduction of soil under submerged contitions, and supply by irrigation water.4) Second, the levelled paddy plots surrounded with bunds are nearly immune to water erosion. Thus, rice agriculture lacks both fallowing and rotation practices, and yet a certain level of yield can be maintained by planting rice on the same plot year after year.

It ia not so simple to compare the productivity of rice with that of other cereals. One to two tons of paddy rice per hectare is the most common level attained without chemical fertilizer in contemporary tropical Asia. This level is no lower than that of wheat in medieval Europe. In terms of the ratio of the number of grains sown to the number harvested, the superiority of rice is more evident. However, the best terms in which productivity can be compared are the yields per unit land managed by a farmer rather than the yields per unit area harvested. In Europe during the pre-fertilizer period, the portion of one's farm that could be cropped in a particular single year depended on the delicate balance among soil fertility, number of cattle and number of mouths to be fed. How to improve cropping intensity was the central theme of technological progress there. Every plot of one's farm could be cropped year after year, that is, the intensity approached unit, only after the development of chemical fertilizer. On the contrary, the cropping intensity is almost always unit in rice-growing Asia no matter how primitive the cultivation techniques. Continuous cropping of lowland rice does not diminish the yield to such an extent that it is no longer worthwhile to cultivate the land.

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4) The contribution of irrigation or flood water may not be so great as many believe, because, first, not such an extensive rice area is flooded with river water every year or at least every few years, and, second, the nutrients are supplied to an extensive area by such anomalous floods as may occur once in several decades or centuries and may be disastrous in the year they occur.

The stability of rice production can be explained by the following two factors.

(1) Water ponded by bunding would otherwise be lost as run-off. Therefore, the bunds increase the amount of water available to the plant over that retained by the water-holding capacity of soil. This effect is especially significant when one takes account of the timing and intensity of rainfall in tropical Asia.

(2) A substantial portion of rice land is irrigated. It is said that about 20 per cent of rice land in south and southeast Asia is presently irrigated.

Thus, rice agriculture, in general, can be characterized by high and stable productivity. However, this may not always be the case when one looks into the actual situation of rice production. For instance, the difference in productivity between European and Asian agriculture became less pronounced since the land use intensity of the former increased to unit. Yet, in comparison with shifting cultivation, as well as with even the sedentary cultivation of upland crops in the humid tropics, higher productivity of rice agriculture will be maintained in many years to come or will even become more significant.

The supposedly greater stability of rice production compared with other forms of agriculture is not always reflected in actual production statistics. (Table 4) Certainly rice production in such countries as the U.S.S.R. and U.S.A., where all rice is irrigated, is much more stable than the production of any other crop. But it is not the case in tropical Asian countries where irrigated rice is only a small portion of all the rice produced.

In Japan, nearly all rice lands are irrigated. Drought affecting lowland rice is now a story of once-upon-a-time. Under such circumstances, therefore, various crop-weather analyses of rice reveal the relationship betweeen rice yield and climatic parameters other than rainfall. An example of such a time-series analysis indicates the significance of solar radiation and temperature during the maturation period of rice as the determinants of rice yield. The negative correlation between yield and rainfall is merely the reflection of the negative correlation between rainfall and sunshine hours. (Table 5) A cross-section analysis in which yields of different provinces in Japan were studied also indicates the significance of the same two climatic parameters. (Fig. 14) A similar result is obtained in experiments under controlled conditions in tropical Asia. /17/

It is natural that variations in rainfall do not directly affect variations in yield when water is controlled. This can be seen not only in rice cultivation but also in any other type of irrigated agriculture. What is important to rice agriculture's vulnerability to rainfall variability is the extent and the rate at which irrigation facilities are implemented.

Irrigation of rice in the traditional Asian rice zone and that in the arid zone may be basically quite different. Some peculiar features of the irrigation for rice are listed below.

Fig. 15 shows the percentage of irrigated and rice acreage of 76 countries with more than one million hectares of arable land. Group I in the figure consists of 46 countries where less than ten per cent of the arable land is irrigated and less than ten per cent is planted in rice. These countries are found in non-Mediterranean Europe, the Americas and Africa south of the Sahara, where rain-fed upland crop agriculture is dominant. Group II comprises 14 non rice-growing countries, in which irrigated lands exceed ten per cent of the total arable land area. These countries are in the Mediterranean region, North Africa, the Middle East and parts of South America, where irrigated agriculture is practiced in a substantial portion of the countries' arable land.

The countries with more than ten per cent rice area are shown in the wide space at the right hand side of the figure. Four countries among them, i.e. Egypt, China, India and Pakistan, differ from the other rice-growing countries in that irrigated agriculture as seen in the arid zone of the Group II countries is dominant in large areas. Therefore, the relatively high percentage of irrigated area in these four countries does not necessarily indicate a high percentage of irrigated rice area. In the rice-growing countries other than these four, most of the irrigated area is devoted to rice. In the ten countries forming this group, the percentage of irrigated rice land ranges from eight in Khmer to 56 per cent in Japan. This wide variance is not related to rainfall, while rainfall is the decisive element determining the percentage of irrigated area in the group I and II countries. It is not the case at all that in the rice-growing countries plotted close to the diagonal line in Fig. 15, such as Japan, Madagascar and Indonesia, irrigation for rice is required due to scarce rainfall, and in those countries with a low percentage of irrigated area, it is not required thanks to favorable rainfall.

Assuming that there is no irrigation, the water balance of rice fields can be estimated by some conventional method such as Thornthwaite's. An example of such a calculation applied to tropical Asia is introduced here. /18/ Since rice fields are surrounded by bunds to pond water, Thornthwaite's method was slightly modified: a maximum of 200 mm of water can be retained by bunds as the surface water layer in addition to 100 mm in soil solum. Among 125 stations' data from South and Southeast Asia, the number of months during which rice fields can be inundated was found to be less than two months at 50, three months at 14, four to six months at 39 and more than seven months at 22 localities. Fig. 16 shows the water balance at some representative locations. The author concluded that "the greater part of the rice lands in Pakistan, India, Thailand and Cambodia are either prohibitive or marginal for rice cultivation unless the land is artificially irrigated or naturally inundated due to physiographic conditions." It is these countries (except for Pakistan) rather than those in more humid insular Southeast Asia that form the core region of the Asian rice zone, and yet the irrigation ratio is not particularly higher in the former than the latter.

Two characteristic features of the rice-water relationship were mentioned above, that is,

(1) the irrigation ratio is not related to the amount of rainfall in rice-growing Asia, and

(2) assuming no irrigation, the water balance is very unfavorable or even prohibitive for rice cultivation in the very core region of the traditional Asian rice zone.

To understand these seemingly contradictory features and other peculiarities of rice cultivation, a comparison with other types of agriculture will be useful. In terms of water use, three types of agriculture can be distinguished. The first type is rain-fed upland crop agriculture, the most dominant form of agriculture on the earth. In this type, water supplied to crops is derived solely from rain water falling precisely on each patch of the fields, in other words, direct rainfall. Water supply by irrigation or use of groundwater is unusual. Therefore, apart from rainfall itself, the dominant factors governing the supply of water to plant roots are evaporation, water-holding capacity and permeability of the soil etc.

The second type is irrigated agriculture in the arid zone, in which direct rainfall has no significance. Most, if not all, of the water supplied to crops is carried from distance places where precipitation is abundant. Therefore, the dominant factors determining water supply are primarily of an engineering nature, and involve some agronomic qualities of soil.

The third type is rice agriculture, in which the crop depends on both direct rainfall and the rain water which falls on the catchment area and eventually flows to where the crop grows. The catchment area could be a village compound a few meters away or mountains hundreds of kilometers away. The flow of water from the catchment could be natural or artificial. Careful observation reveals that there seldom exists so-called 'rain-fed' paddy land in the strict sense of the term.

In the non rice-growing countries, crops depend either nearly exclusively on direct rainfall or nearly exclusively on irrigation water. Where the former is dependable, the latter is unnecessary. Where it is not, irrigation becomes indispensable. Therefore, it is a natural consequence that percentages of the irrigated area are closely related to climate in the non rice-growing countries. In these countries, agriculture practiced in the irrigated tracts is completely different from that of the unirrigated land, if there exists any agriculture there. The demarcation between the irrigated land and the unirrigated land is very distinct, no matter what type of irrigation devices are used.

In the rice-growing countries, on the contrary, the crop always depends partly on direct rain and partly on the inflow of water. The degree to which artifacts control the latter source of water varies widely. Some paddy fields appear to be nearly purely rain-fed while some others may be equipped with a complete water control system. The dependability of direct rainfall certainly is one of the determinants affecting the degree to which artifacts are used to supply water inflow; this degree varies between the two extremes mentioned above. However, many other factors than rainfall affect the use of water control devices. One of the most important factors is the level of technology required, which is primarily determined by the inherent physical conditions of the land. Apart from these natural factors, various socio-economic and cultural factors are closely related to the degree of water control. The historical interrelationship between development of irrigation systems and political structure is a well-known example. The fact that there is no relationship between rainfall and the irrigation ratio in the rice-growing Asia can be explained by the above factors.

As long as the sources of water for rice lands are not only direct rainfall but also rain water falling on catchment areas, it is quite understandable that the ratio of the catchment to the rice area would be of prime importance. This ratio together with rainfall itself roughly determines potential rice acreage and stability of production.

As Koide has pointed out, the rice-growing areas are found mainly in the Alpine orogenic belt. /19/ Most of the high mountains in the world today are in this geologic zone, which is characterized by an abundance of steep slopes. Where this zone overlaps that of a warm and humid climate, rapid weathering and transportation and sedimentation of weathered materials result in the development of alluvial plains. As shown in Table 6, a large area of alluvial plains is found in the Asian humid zone, and they make up a high percentage of the total land area. The Asian rice zone is situated in that part of the Alpine orogenic belt that has a warm and humid climate.

As a natural consequence of the alluvia-forming processes, the alluvial plains are always surrounded by steep mountains. The landform of the Asian rice zone is characterized by a pattern consisting of a large area of steep mountains and a small area of alluvial valleys. Rice agriculture in Asia as a whole very much owes its existence to the large ratio of the catchment area (mountains) to rice land (alluvial plains). Contrary to this, the landform of the rain-fed agricultural zone is characterized by vast plains with gentle slopes developed on tectonically stable land masses.

This difference in the basic landform of the rice agriculture and rain-fed agriculture zones can be well demonstrated by comparing the percentages of agricultural land to total land area among the countries belonging to the three groups illustrated in Fig. 15. In the rice-growing countries, these percentages are always low in spite of a generally warm and humid climate and very great population pressure. These low percentages in the rice-growing countries are attributable to a large area of steep mountains which serve as the catchment area.

Two studies of rice production in Thailand also illustrate the significance of landform as a determinant of the hydrological condition of paddy lands.

In one, the interregional variation of rice production in Thailand was studied. /20/ /21/ Traditional methods of cultivation, productivity, holding area per farm family, kind of water control devices etc vary substantially from one place to another within the Chao Phraya river basin. First, these variations in aspects of production were examined. Second, all the paddy land within the basin was divided according to different environmental conditions such as topographical, hydrological, and soil conditions into six physiographic regions. As the hydrological and soil conditions are strongly governed by the topography, the resulting physiographic regional division was found to be mainly determined by landform rather than rainfall and soil. Third, such a physiographic regional division was correlated to the interegional variations of rice production, and it was found that these variations could be very well explained by the physiographic conditions. (Table 7) This study discussed the potential dissemination of high-yielding varieties of rice based on such regional divisions.

Another study on rice production in Thailand is more directly related to the vulnerability of rice cultivation to rainfall variation. First, the coefficient of variation of rice production was calculated for each of the 28 provinces which are major rice-producing provinces in Thailand, and whose rainfall and production data have been sufficiently reliable and consistent for at least 15 years. The water balance for the period of four rice-growing months was calculated by Thonthwaite's method assuming the extra 200 mm of ponded water. The topographical characteristics of each province are more difficult to quantify than the other elements. In this study, an attempt was made to quantify them in terms of the ratio of recent alluvial soil area to the total paddy land area.

Fig. 17 shows the year-to-year fluctuation of rice production and the seasonal rainfall in some representative provinces. When both the rainfall and the ratio of alluvial soil area are high, production is stable (Fig. 17a), while it is highly unstable when both are low. (Fig. 17b) In Chieng Mai, production is relatively stable although the amount of the four months' rainfall is less than 1000 mm in most years. (Fig. 17c) This can be attributed partly to the high ratio of alluvial soil area in this province. Where the rainfall and the ratio are neither particularly high nor low, the production variability is somewhat between the two extremes. (Fig. 17d and e)

The simple correlation coefficients (r) between CV of production and either the seasonal water balance or the ratio of alluvial soil area alone were found to be rather small. But the multiple correlation was more significant when both were correlated to production variability. (Table 8)

Opening of new land in rain-fed upland crop agriculture is nothing but the replacement of the original vegetation by crops. The moisture regime remains basically unchanged before and after reclamation. Once land is reclaimed, man's efforts are directed toward preserving the original land condition as well as possible. All he can do to improve the land is to modify the original nutrient-supplying capacity of the soil, that is, manuring. In order to maintain good land conditions, various methods such as fallowing, crop rotation, the combination of crops and animals, contour cultivation and so on are employed. All of these practices characteristic to upland crop agriculture are absent in rice agriculture.

As long as land conservation rather than land improvement is man's main work in a given environment, the discovery and improvement of crop species and varieties become very important as a means of mitigating the restrictions imposed by physical conditions. Therefore, the general direction of technological progress in rain-fed upland crop agriculture is toward better conservation of land and adaptation to a given environment rather than amelioration of it. As a result, in this type of agriculture, no single crop occupies such a predominant position as rice in rice agriculture, and, on the contrary, different crops are chosen according to local agro-environmental conditions in the same way that the type of natural vegetation is determined by these conditions.

When a tract of land is opened for rice cultivation, the land is levelled and surrounded with bunds to impound water from direct rain as well as local run-off, streams and/or rivers. In the case of rice agriculture, reclamation is not merely the replacement of original vegetation for rice, but it is also the creation of a new environment which does not exist in nature. The resulting hydrological condition of such a man-made environment is a function of both a given physical setting and the degree of the artifacts used to modify it.

Since such measures for improving the hydrological condition of paddy fields always progress steadily, the terms 'irrigated' and 'unirrigated' are not always adequate for designating the actual hydrological condition of the land tract. It can be said that man's efforts in rice agriculture are directed mainly toward amelioration of the conditions of the land and water, rather than toward land conservation. In other words, the cumulative toil of past generation has created the land and water conditions of the paddy fields.

In the traditional rice-growing countries, land used for rice and land used for other field crops are commonly called by different terms, and all of the arable land is considered to consist of these two kinds of land which usually cannot be converted into each other. For example, these fields are called 'ta' and 'hata' in Japanese, 'na' and'rai' in Thai, and 'sawah' and 'ladang' in Malay and Indonesian. These expressions reflect not only differences between the two in their inherent physical conditions but also the great amount of labor expended for generations on the rice land.

The above discussion indicates that the control of water for rice cultivation is basically of a different nature from so-called 'irrigation' in other types of agriculture. In the former, at the very beginning of land reclamation, water is already controlled by some measure, and the hydrological condition is gradually improved thereafter, until water is so completely controlled that rice production is no longer affected by rainfall variability. In the latter case, irrigation is an all-or-nothing matter. It drastically changes the whole system of agriculture. In rice agriculture, water control is a built-in characteristic of the system, though the degree it is used varies widely. Water control can be likened to a road system which begins with foot paths and is improved to make cart roads, then single lane roads, double lane roads and finally, highways. Thus, such a system can be called an infrastructure rather than of the inputs needed for production.

Everywhere in the traditional rice zone in Asia, farmers are doing their best to improve hydrological conditions; moreover, water is nearly completely controlled in some advanced countries in the Far East as well as some localities in the tropical Asia. These fasts make one think that the hydrological conditions of all the paddy lands in Asia should and will eventually be perfected and production will become free from the erratic rainfall regime.

Fig. 18 and Fig. 19 can be considered to be an example which reflects this idea. In the first figure, the estimated yield increase of rice in Japan since the sixth century is shown, and on this curve, the present yield levels of Asian countries are plotted. In the second figure, the national paddy yield of these countries is related to the percentage of irrigated area. These two figures appear to suggest that rice agriculture evolves from the low yield level with poor water control to the high yield level with better water control, and the countries with lower yield and poorer water control can be located at certain stages of this evolutionary sequence which the better-off countries have passed some time in the past.

The fact that the actual water condition of rice lands is so diverse and complex that it is not adequate to classify these lands simply as 'irrigated' and 'rainfed' is becoming known to a greater number of people. For instance, there is an attempt to classify the world's rice land according to the depth to which fields are inundated. (Table 9) The much heralded high-yielding varieties of rice bypassed the rice grown in areas with less favorable physical (mainly hydrological) conditions. It is said that such a classification is relevant to the development of a technology of production adapted to variable hydrological conditions.

To devide rice lands into 'rainfed', 'inadequately irrigated' and 'adequately irrigated' lands is the first step in the program for doubling rice production in Asia in 1990. /23/ The criterion for judging the adequacy of this classification is whether the length of the irrigation canal is longer or shorter than 50 meters per hectare of rice land.

In Table 10, the present, projected, and potential irrigation areas of the tropical Asian countries are compared with the 'adequately irrigated rice area' and 'rainfed rice area' which are targeted for doubling rice production in 1990. /23/ The potentially irrigable area was estimated based on existing data, and where such data are unavailable, by simply multiplying the present irrigated area by 2.5 or the projected area by 2.0 or 1.5. /24/ Therefore, the potential area is grossly underestimated for most underdeveloped countries, such as Laos and Cambodia. Except in India, most of the potentially irrigable land will be used for rice cultivation. Taking these points into consideration, the table indicates that the eventual completion of water control for most, if not all, of rice lands in Asia is not too unrealistic.

In rainfed upland crop agriculture, it is unavoidable that production is substantially affected by the year-to-year variation of rainfall. Even where production technology is most advanced, such as in the developed countries in the temperate zone, the coefficient of variation of grain production in a large area such as the whole U.S. or U.S.S.R., ranges from eitht to 20 per cent. This figure becomes still larger when the production of smaller regions is considered. Progress in technology, mainly in genetic improvement, soil conservation, and, perhaps, weather forecasting, might further stabilize production, but to a limited extent.

On the contrary, rice production could be stabilized to a much greater extent by improvement of the hydrological condition. However, whether or not this potential stability can actually be realized depends on:

(1) the rate of implementation of water control facilities, and
(2) the rate of expansion of the rice area to increasingly marginal lands.

The rate of expansion of rice land as well as that of lands under other agricultural system will depend very much on the increase of productivity per unit area on the land now in use.

According to Grigg /25/, "Between 1870 and 1930 most of the new arable land (in the world) came in the mid-latitude temperate grasslands .... However, in the 1930s the expansion of this frontier came to a halt," first because "the attraction for migrants was no longer the land but the cities" and, secondly because of "a major agricultural revolution in western countries .... Since then (the 1940s) the increase in population ... has led to a remarkable increase in the arable area" in China, India, Africa and Latin America. This was because "the need for extra food was naturally met by reclaiming new land

.... To what extent the rapid expansion of the arable area ... will continue, it is difficult to say. Continued population increase and the expansion of a landless rural proletariat favour further increases in arable land. On the other hand, the first sign of intensification in Asian agriculture — the Green Revolution — and the steady drift to the towns suggest that the new frontier of the underdeveloped world may well close before the end of the century, and before the supply of cultivable land runs out."

As long as agricultural land is expanding at a great rate, the vulnerability of agriculture to rainfall variation will remain great or tend to increase no matter what crops are cultivated. Only when people begin to divert their efforts toward intensification of cultivation, will production be stabilized. But the sustained production of upland crops appears to be much more difficult in the humid tropics than in the temperate zone. Perhaps intensive rice cropping will be the only alternative in larger parts of the humid tropics, including those countries where rice cultivation is not common at present.

IV Conclusions

(1) In order to assess the impact of climatic changes on agriculture, data concerning not only the changes in means of climatic parameters but also the changes in their distribution pattern are required.

(2) The impact of climatic changes on agriculture depends on both the amplitude of such changes and agriculture's vulnerability to climatic variability. This vulnerability varies according to the region where cultivation is practiced, and also changes over time; such variations might sometimes be more relevant than climatic changes themselves. Agricultural scientists should play a major role in assessing the impact of climatic changes on agriculture by analyzing the spatial and time variations of the vulnerability of different agricultural systems to climatic variations.

(3) Agricultural production in the humid tropics is affected by the year-to-year variations of rainfall, though the zone receives a great amount of rainfall. The reason for this is not necessarily the great variability of annual rainfall there. Rather, it is primarily because of hydrological marginality due to the great amount of evapotranspiration in the economically most active parts of the humid tropics.

(4) Cultivation of annual grain crops is highly risky in the humid tropics because of the great risk of eventual land deterioration and susceptibility to rainfall variability. Cultivation of these crops under the shifting cultivation system does not necessarily cause land deterioration as long as the land-people ratio is above a certain level. However, a sparsely scattered population in remote areas is detrimental to the nation's development and modernization. Therefore, the shifting cultivators tend to concentrate in a certain areas either spontaneously or under some resettlement scheme, and, this makes their agricultural production riskier. Sedentary cultivation of upland field crops by peasants is always expanding to marginal regions because of the scarcity of land suitable for cultivation of crops which are better adapted to the humid tropical environment. The recent development of feed crop cultivation for the export market is similarly risky. The technology needed to grow these crops on a sustained basis may be known, but it does not seem that the majority of peasants will utilize it in the near future. Nonetheless, it is necessary to

continue to grow these crops in regions under any of the three systems of cultivation mentioned above. Therefore, the vulnerability of agriculture in these regions to rainfall variations will remain great or even increase for many years to come.

(5) Root crops are well adapted to the humid tropics and hence, their cultivation is less vulnerable to rainfall variations than are many other crops. However, root crops are not suitable as staple food for urbanized society unless they are processed properly. The technology for processing these crops for urbanized society will affect the futuer trend of root crop agriculture.

(6) Tropical tree crops are, in general, less vulnerable to rainfall variability than are short-term crops. But in recent years, they have tended to be grown in increasingly marginal lands. Therefore, one should not be too optimistic about the vulnerability of the cultivation of these crops to rainfall variations.

(7) Lowland rice cultivation is the agricultural system best adapted to humid tropical conditions. Its vulnerability to rainfall variations could be decreased further by better water control. Water control for rice is basically different from the conventional concept of 'irrigation' in the arid zone. In rice agriculture, not only the vertical movement of water, that is, direct rainfall, evapotranspiration and percolation, but also its horizontal movement play an important role. The latter is controlled by man to a certain degree of efficiency. The degree to which artifacts control the horizontal movement of water varies widely according to physical conditions and human elements. Since human elements are significant determinants of the hydrological condition of rice land, such a condition is highly time-dependent. Rice agriculture evolves step by step from a low level of production with poor water control to a higher level with better water control. It is not too unrealistic to expect that all rice lands in Asia will eventually be equipped with adequate water control facilities and that rice production will be unaffected by rainfall variability. However, rice cultivation is also expanding to increasingly marginal areas. The vulnerability of rice agriculture as a whole to rainfall variations will be affected by the rate of expansion of the area cultivated on the one hand and, on the other hand, the rate of improvement of water control.

(8) In the whole humid tropical zone, population has been increasing at a high rate since the 1930s. The ever increasing need for food could be met by either the expansion of cultivated land area or an increase in yield per unit area by intensifying cultivation. So far, the former occurs more often than the latter. As long as this trend continues, the vulnerability of agriculture to rainfall variability will increase in the humid tropics. Therefore, the impact on future agriculture of a greater frequency of anomalously dry years due to climatic changes would be greater than that in the past and present in the humid tropics.

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TABLE 1. HARVESTED AREA OF DIFFERENT CROPS IN "THE HUMID TROPICS"[1]
(MILLION HECTARES)

	Annual flowering crops other than rice[2]	Rice	Short-term vegetative crops[3]	Total
Africa	37 (67)[4]	4 (7)[4]	14 (25)[4]	55 (100)[4]
Americas	10 (50)	5 (25)	5 (25)	20 (100)
Asia and Oceania	75 (50)	66 (44)	10 (7)	151 (100)
"Humid Tropics," total	122 (54)	74 (33)	29 (13)	226 (100)
Rest of the world	670 (86)	63 (8)	43 (6)	775 (100)

1) "Humid Tropics" as defined in the text and shown in Fig. 8.

2) Cereals other than rice, pulses, oil seeds, and cotton.

3) Roots and tubers, sugarcanes, and fibre crops.

4) Percentage of each of three crop-groups, assuming their sum to be 100 %. These crops account for approximately 80 % of the total arable land.

(Data source : FAO Production Yearbook 1974.)

TABLE 2. CHANGES IN SHORT-TERM CROPS' ACREAGE IN THE HUMID TROPICS 1) DURING 1954-1976

		Annual flowering crops other than rice 2)	Rice	Short-term vegetative crops 3)	Total
			(million hectares)		
Africa	1954	16.9 (70) 4)	1.7 (7) 4)	5.4 (23) 4)	23.9 (100) 4)
	1976	31.2 (77)	2.8 (7)	6.6 (16)	40.5 (100)
America	1954	15.5 (65)	3.0 (13)	5.5 (23)	24.0 (100)
	1976	34.8 (68)	8.0 (16)	8.6 (17)	51.4 (100)
Asia and Oceania	1954	6.6 (23)	20.4 (69)	2.4 (8)	29.5 (100)
	1976	12.5 (28)	27.3 (61)	4.8 (11)	44.6 (100)
"Humid Tropics"	1954	39.0 (50)	25.1 (32)	13.3 (17)	77.4 (100)
	1976	78.0 (57)	38.1 (28)	20.0 (15)	136.6 (100)

1) The area of "the humid tropics" is basically the same as in Table 1. But the comparable figures for 1954 and 1974 are not available for some countries and territories, particularly in Africa. In Asia, the whole of India was deleted because the state-wise crop statistics for each state for 1954 were not on hand. All of Brazil was included, though more than half of its arable land is not in the humid tropical zone.

2) Cereals other than rice, pulses, oil seeds, and cotton.

3) Roots and tubers, sugarcanes, and fibre crops.

4) Percentage of each of three crop-groups, assuming their sum to be 100 %.

(Data source : FAO Production Yearbooks)

TABLE 3. COFFEE PRODUCTION IN BRAZIL

States	1974			1975		
	Area ha	Prod. tons	Yield kg/ha	Area ha	Prod. tons	Yield kg/ha
Miras Gerais	329,300	244,000	759	375,000	330,000	880
Sao Paulo	646,000	864,000	1338	406,000	255,000	630
Espirito Santo	171,520	98,000	571	229,000	155,000	678
Parana	839,000	477,000	568	3,724	264	71

(Data source : Synopse Estatistica do Brasil 1975-77.)

TABLE 4. YEAR-TO-YEAR FLUCTUATION OF YIELDS OF RICE AND OTHER CROPS

Country Crop	Coefficient of variation[1] (CV %)	Total production[2] (million tons)
U.S.S.R.		
wheat	12.4	85.8
rice	3.6	1.6
U.S.A.		
wheat	7.3	42.0
rice	3.7	3.9
Philippines		
rice	6.9	4.9
maize	6.4	2.0
Indonesia		
rice	4.5	18.1
maize	4.1	2.7
Thailand		
rice	5.1	11.8
maize	18.1	1.7
India		
rice	7.1	60.5
wheat	5.4	26.5
barley	8.8	2.5
maize	9.0	5.3
millet	7.7	8.3

1) Based on the de-trended yield during the period of about ten years in the 1960's.

2) In 1970, 1971 or 1972.

(After ; Ministry of Agriculture and Forestry (Japan), 'World Climatic Change and Crop Production', 1974. mimeo. in Japanese.)

TABLE 5. CORRELATION OF YIELD OF RICE IN SHIMOINA DISTRICT WITH CLIMATIC ELEMENTS[1)]

Period	Correlation coefficient with grain yield			
	sunshine hours	mean air-temperature	air-humidity	rainfall
Sept.3 - Sept.17 (most active filling period)	0.832	0.323	-0.741	-0.602
Sept.1 - Sept.30 (filling period)	0.429	0.184	-0.811	-0.771

1) Based on 15 years data.

(After Oka 1937 /15/)

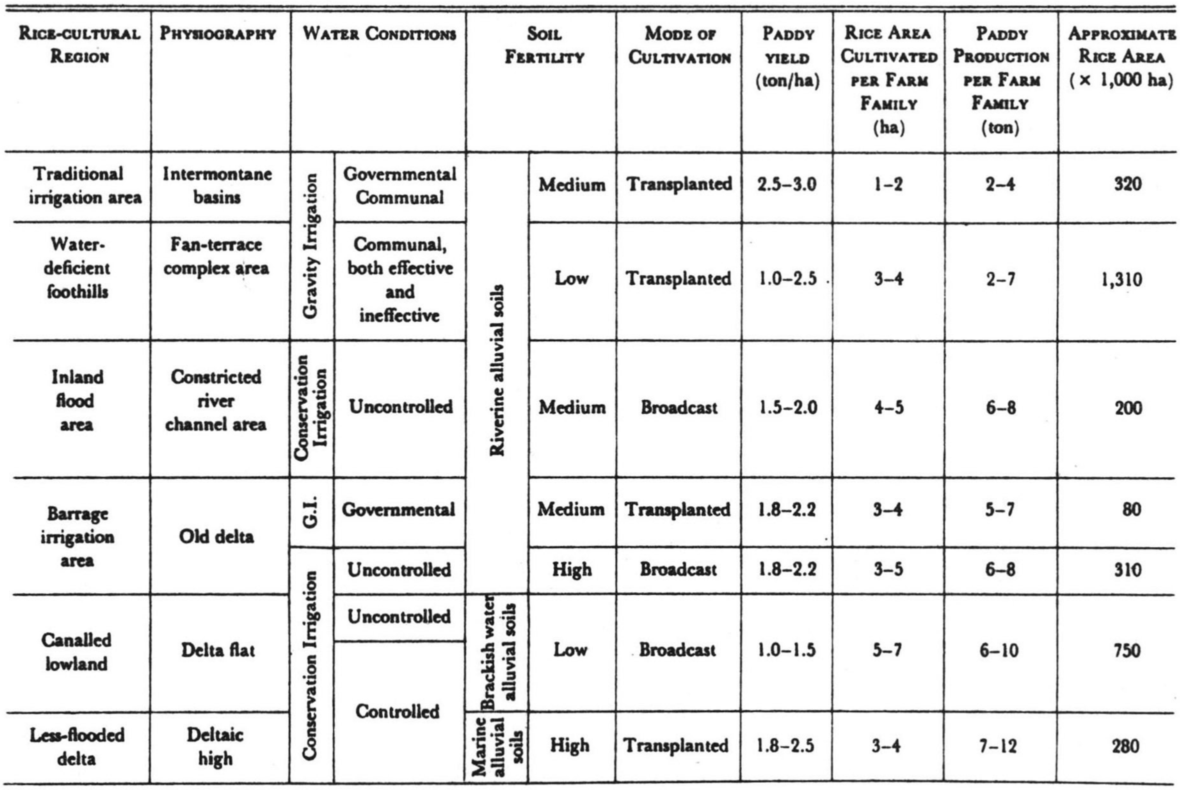
TABLE 6. IMPORTANCE OF ALLUVIAL LAND IN ASIA (IN MILLION HECTARES)

	Land Area		Alluvial Soil Area	
	Total	Potentially arable	Total	Potentially arable
World	13000	3152	588	316
Aria[1)]	2704	620	-	192
Tropical Asia	987	344	168	114

1) Excluding USSR

(Source : World Food Problem, White House, 1967)

TABLE 7. REGIONAL DIVISION OF THE CHAO PHRAYA BASIN



Rice-cultural Region	Physiography	Water Conditions		Soil Fertility		Mode of Cultivation	Paddy yield (ton/ha)	Rice Area Cultivated per Farm Family (ha)	Paddy Production per Farm Family (ton)	Approximate Rice Area (× 1,000 ha)
Traditional irrigation area	Intermontane basins	Gravity Irrigation	Governmental Communal	Riverine alluvial soils	Medium	Transplanted	2.5–3.0	1–2	2–4	320
Water-deficient foothills	Fan-terrace complex area		Communal, both effective and ineffective		Low	Transplanted	1.0–2.5	3–4	2–7	1,310
Inland flood area	Constricted river channel area	Conservation Irrigation	Uncontrolled		Medium	Broadcast	1.5–2.0	4–5	6–8	200
Barrage irrigation area	Old delta	G.I.	Governmental		Medium	Transplanted	1.8–2.2	3–4	5–7	80
		Conservation Irrigation	Uncontrolled		High	Broadcast	1.8–2.2	3–5	6–8	310
Canalled lowland	Delta flat		Uncontrolled Controlled	Brackish water alluvial soils	Low	Broadcast	1.0–1.5	5–7	6–10	750
Less-flooded delta	Deltaic high			Marine alluvial soils	High	Transplanted	1.8–2.5	3–4	7–12	280

(After ; Fukui, H. 1977 /21/)

TABLE 8. CORRELATION OF CROSS-PROVINCE VARIATION OF RICE PRODUCTION'S YEAR-TO-YEAR FLUCTUATION WITH CLIMATIC AND TOPOGRAPHIC PARAMETERS

		Simple correlation coefficient (r) between CV of production in each of 28 provinces, CV(PRO)2), and
Mean rainfall total in four rice-growing months	$4\overline{R}$	-0.284
CV of the above	CV(4R)	0.297
Mean of sum of monthly water balance in the same four months3)	$4\overline{W}$	-0.434
Median of the above	4W(M)	-0.429
Percentage of recent alluvial soil area to total paddy land area	α	-0.465
Rate of increase of paddy area	H	0.425

	Multiple correlation coefficient (R) between CV(PRO) and
4W(M) and α	0.583
4W(M), α and H	0.645

1) The period for which calculation was made varies from one province to another depending on availability of consistent data. It ranges from 15 to 30 years.

2) CV(PRO) is based on the de-trended production data.

3) Water balance was calculated according to Thornthwaite's method assuming the extra 200 mm of ponded water.

(After; Fukui, Uchida and Kobayashi. unpublished.)

TABLE 9. GENERAL ASSOCIATION OF HYDROLOGY CLASS TO LANDSCAPE POSITION

Hydrology	Water table	Landscape position
Pluvic	Deep water table	Knolls and summits of rolling and hilly topography
Perfluxic	Deep ground water table, Highly fluctuating perched water table	Upper side slopes of knolls and summits of rolling and undulating topography
Orthofluxic	Deep water table less fluctuating perched water table	Lower side slopes and water ways associated with rolling and hilly topography
Orthocumulic	Ground or perched water table fluctuate close to soil surface during wet and intermediate months	lowest paddies on the side slopes, high plains, and low plains
Percumulic	Ground or perched water table is almost consistently above ground level (GL) during wet months	High plains with high phreatic and surface enrichment and water ways associated with high plains; low plains
Orthodelugic	Water table rises more than 30 but less than 50 cm above GL and stays for more than two weeks during wet and at most one intervening intermediate rainfall months	Water ways and back swamps associated with cumulic low plains subject inundation
Perdelugic	Water table rises above 50 cm but less than 100 during wet and at most 2 intervening intermediate rainfall months	Landscape position similar to Orthodelugic

(From; Zandstra, H.G., et al. IRRI. mimeo.)

TABLE 10. PRESENT, PROJECTED AND POTENTIAL AREA OF IRRIGATION IN ASIAN RICE-GROWING COUNTRIES

Country	Paddy area (harvested in 1974)1)	Irrigated rice area in 19741)	Potentially irrigable area2)	Rice acreage needed for doubling production in 19901)	
				'adequately irrigated'	'rainfed'
			(in thousand hectares)		
Bangla Desh	9,904	495	6,800	6,461	3,370
Burma	4,974	797	2,753	3,109	1,690
Cambodia	555	17	470	1,504	780
India	37,500	16,100	80,940	20,890	12,720
Indonesia	8,537	4,950	5,265	4,433	2,900
Laos	686	69	66	583	310
W.Malaysia	597	287	732	(382)3)	(203)3)
Philippines	3,539	1,590	3,189	1,953	1,200
Sri Lanka	680	449	1,000	341	231
Thailand	7,734	2,860	4,000	4,418	2,625
Total of 10 countries	74,706	27,614	105,215	44,074	26,029
Total excld. India	37,206	11,514	24,275	23,184	13,309

1) Okita and Takase 1976 /23/.

2) Moen and Beek 1974 /24/.

3) Total of East and West Malaysia.

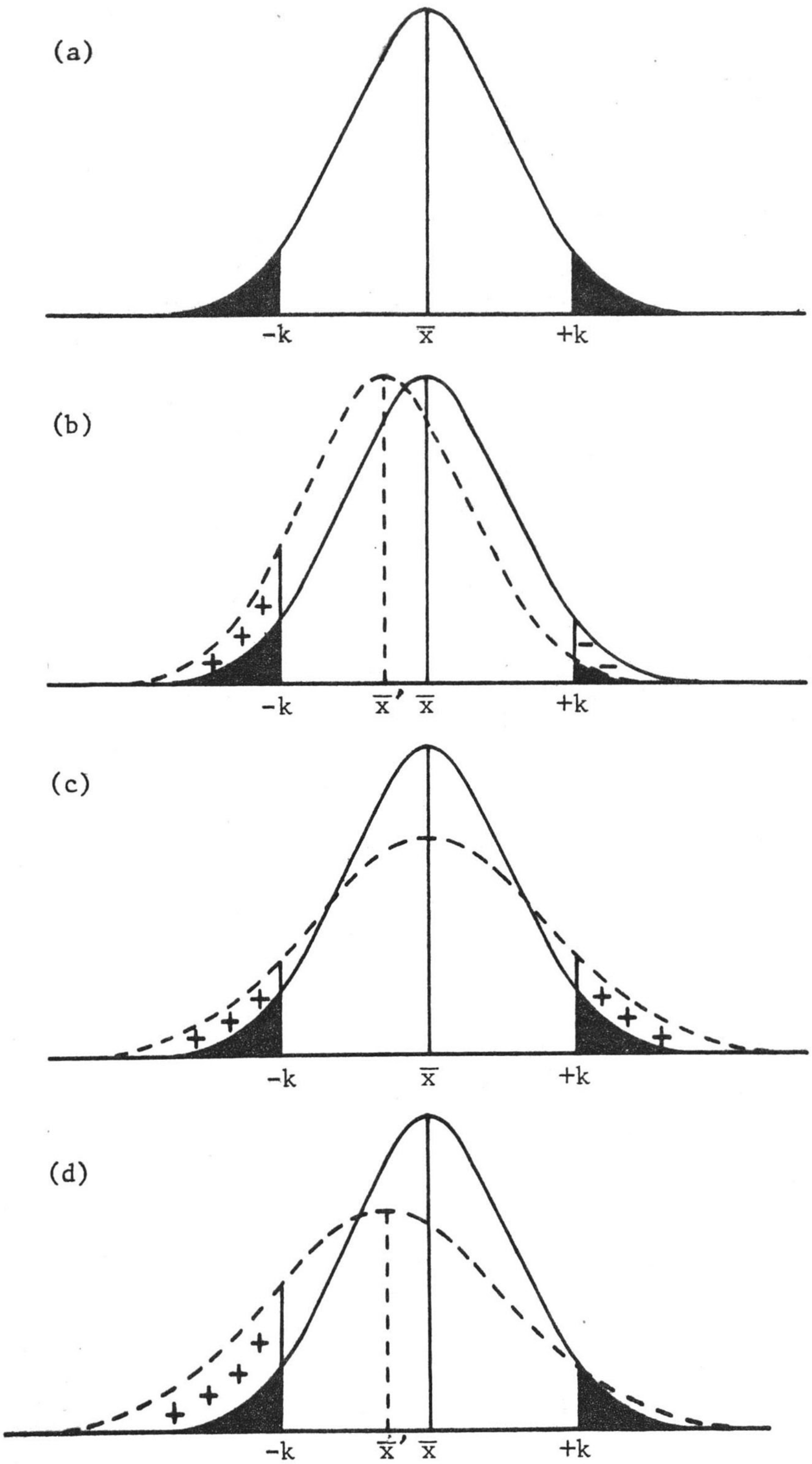


Fig. 1. A Schematic Presentation of Three Types of Climatic Changes in Relation to the Vulnerability of Agriculture

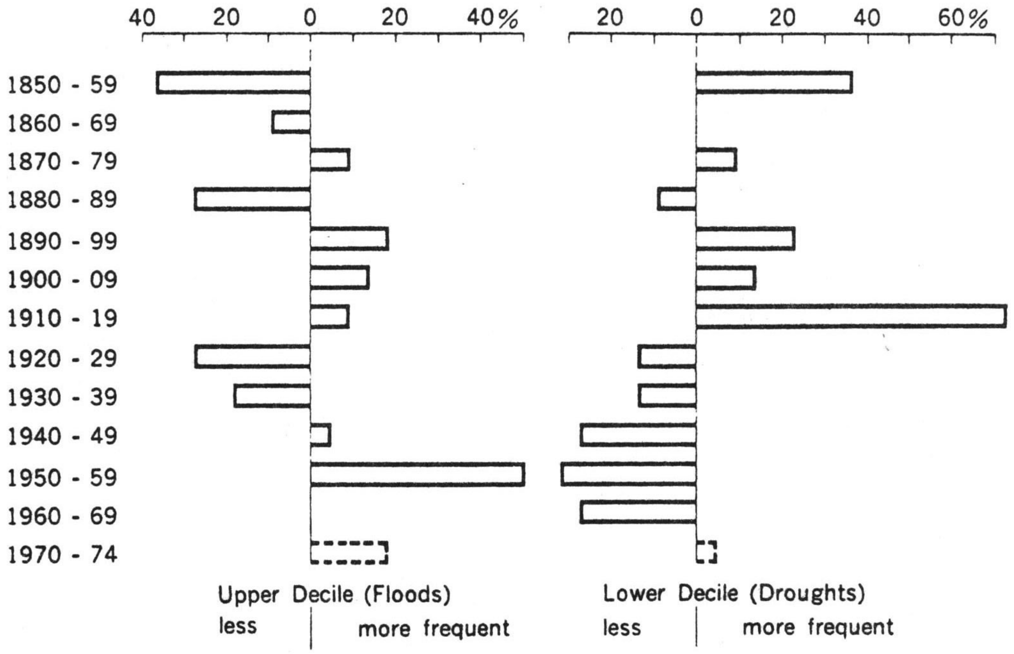


Fig. 2. Extreme Summer Monsoon Rainfall in India (22 stations), June-September

(Flohn, 1978, /3/)

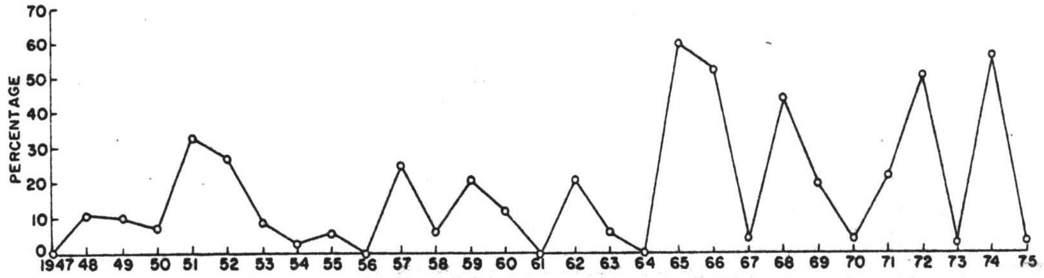


Fig. 3. Percentage Area of India over which Summer Monsoon Seasonal Rainfall is Deficient/Scanty during Each of the Years 1947-75

(Saha and Mooley, 1978, /4/)

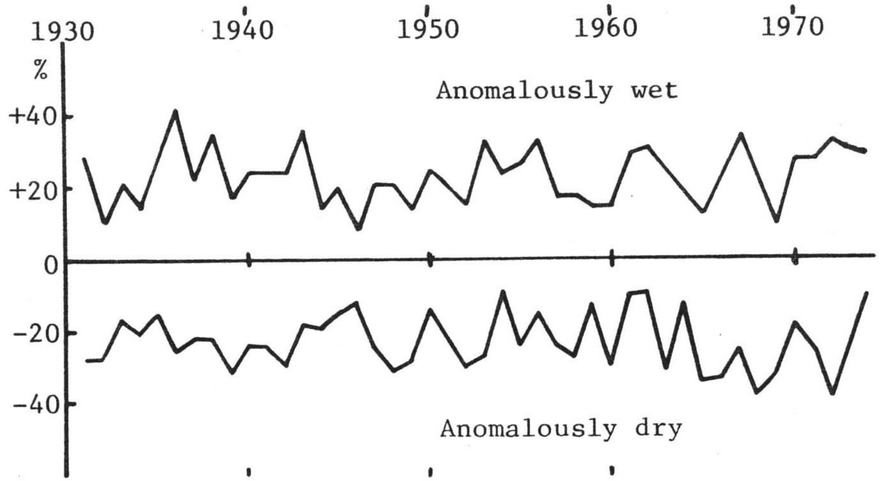


FIG. 4. YEAR-TO-YEAR CHANGES IN PERCENTAGES OF STATIONS RECORDING ANOMALOUSLY WET OR DRY YEARS IN MONSOON ASIA

(MIZUKOSHI, 1978. $\boxed{57}$)

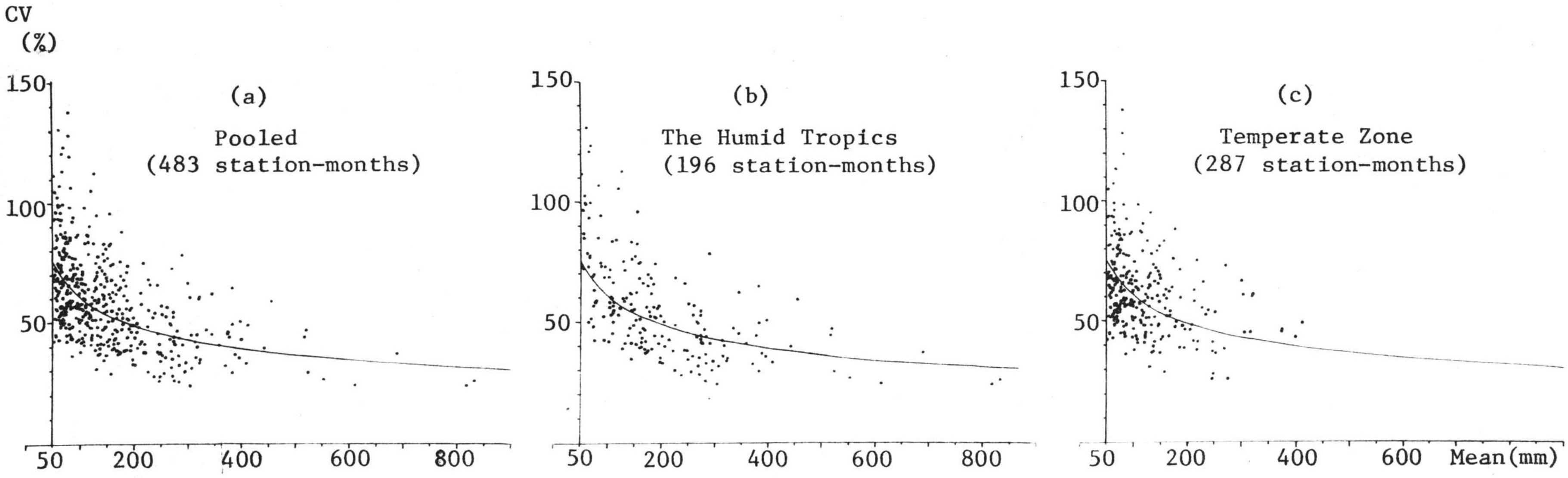


Fig. 5. Comparison of Relationship between Coefficients of Variation and Means of Monthly Precipitation in The Humid Tropics and Temperate Zone

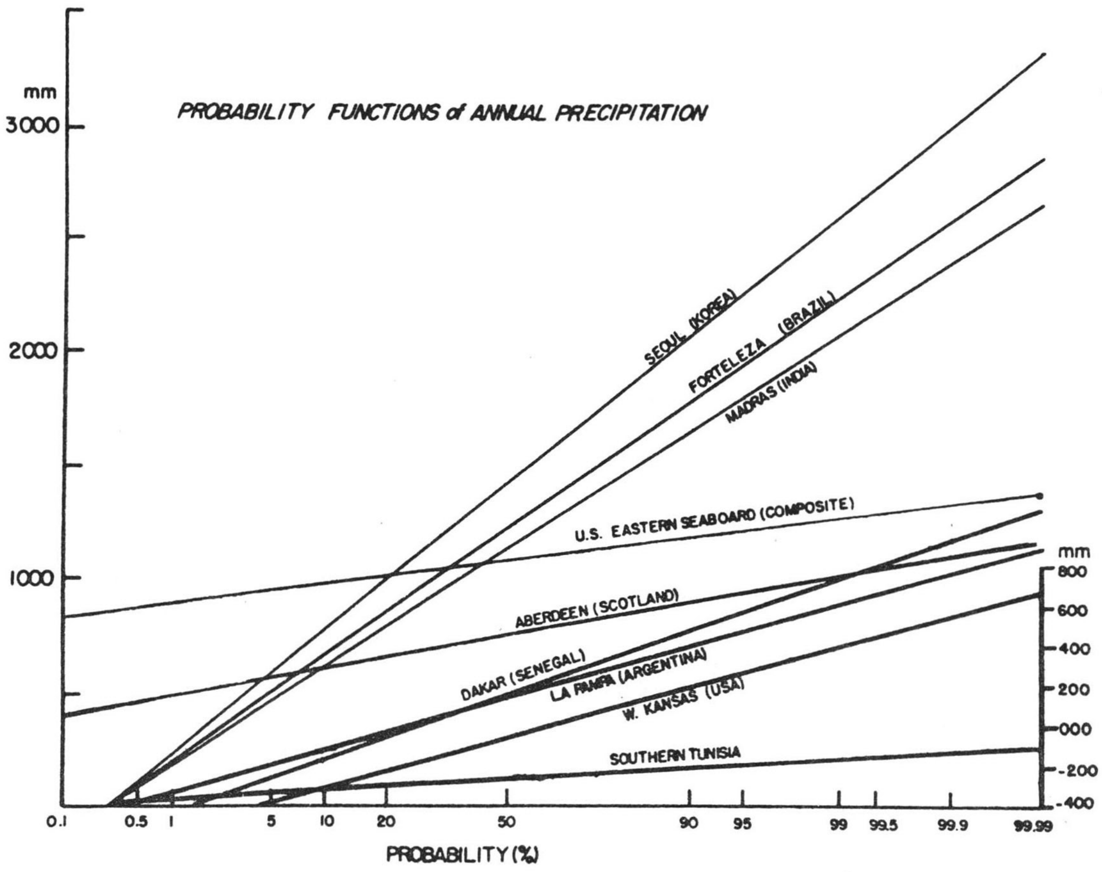


Fig. 6. Probability Function of Annual Precipitation Amounts at Selected Localities in Different Climatic Regimes (Landsberg, 1975, /9/)

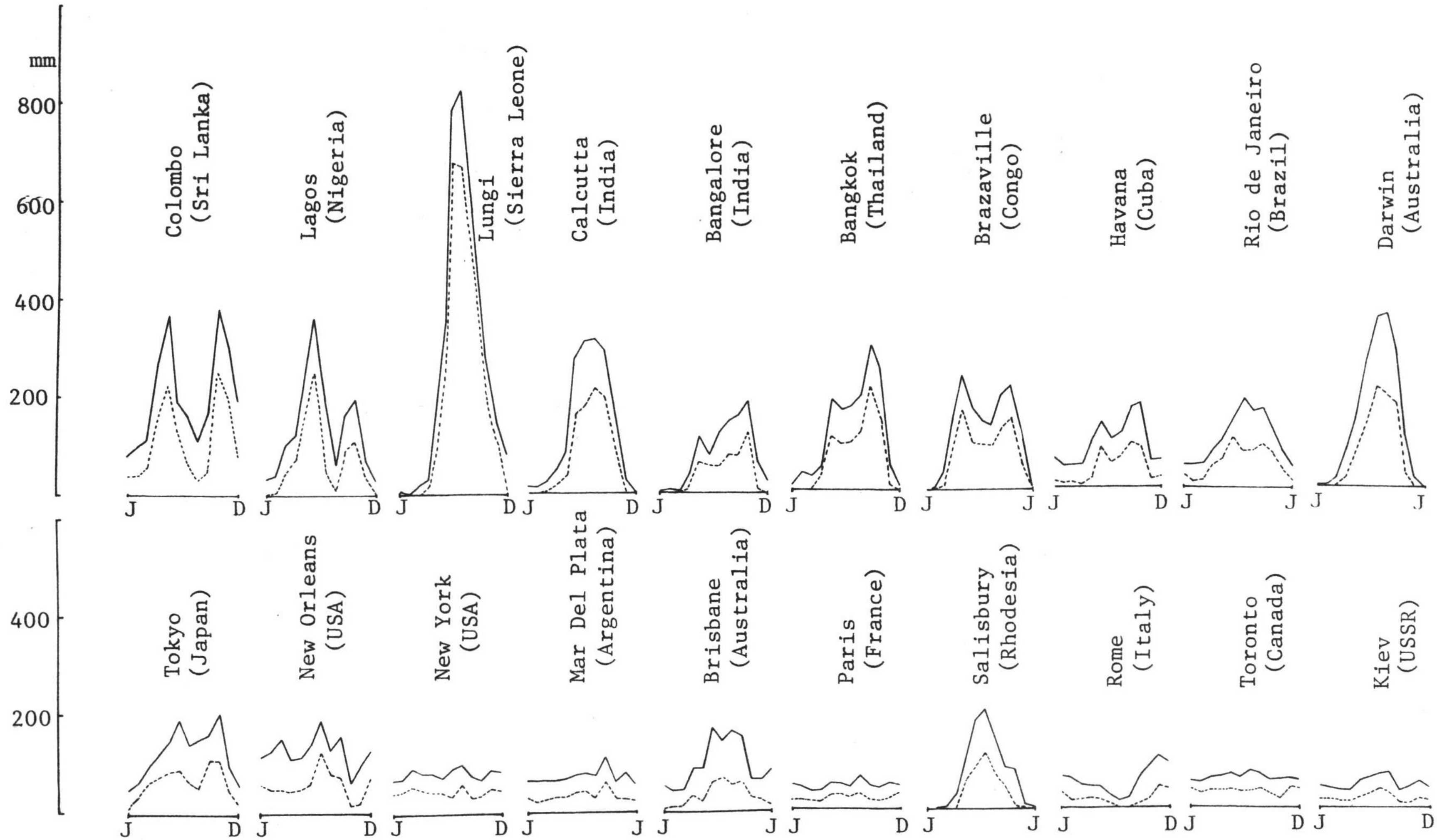


FIG. 7A. MEANS AND LOWER QUINTILES OF MONTHLY PRECIPITATION AT 20 STATIONS

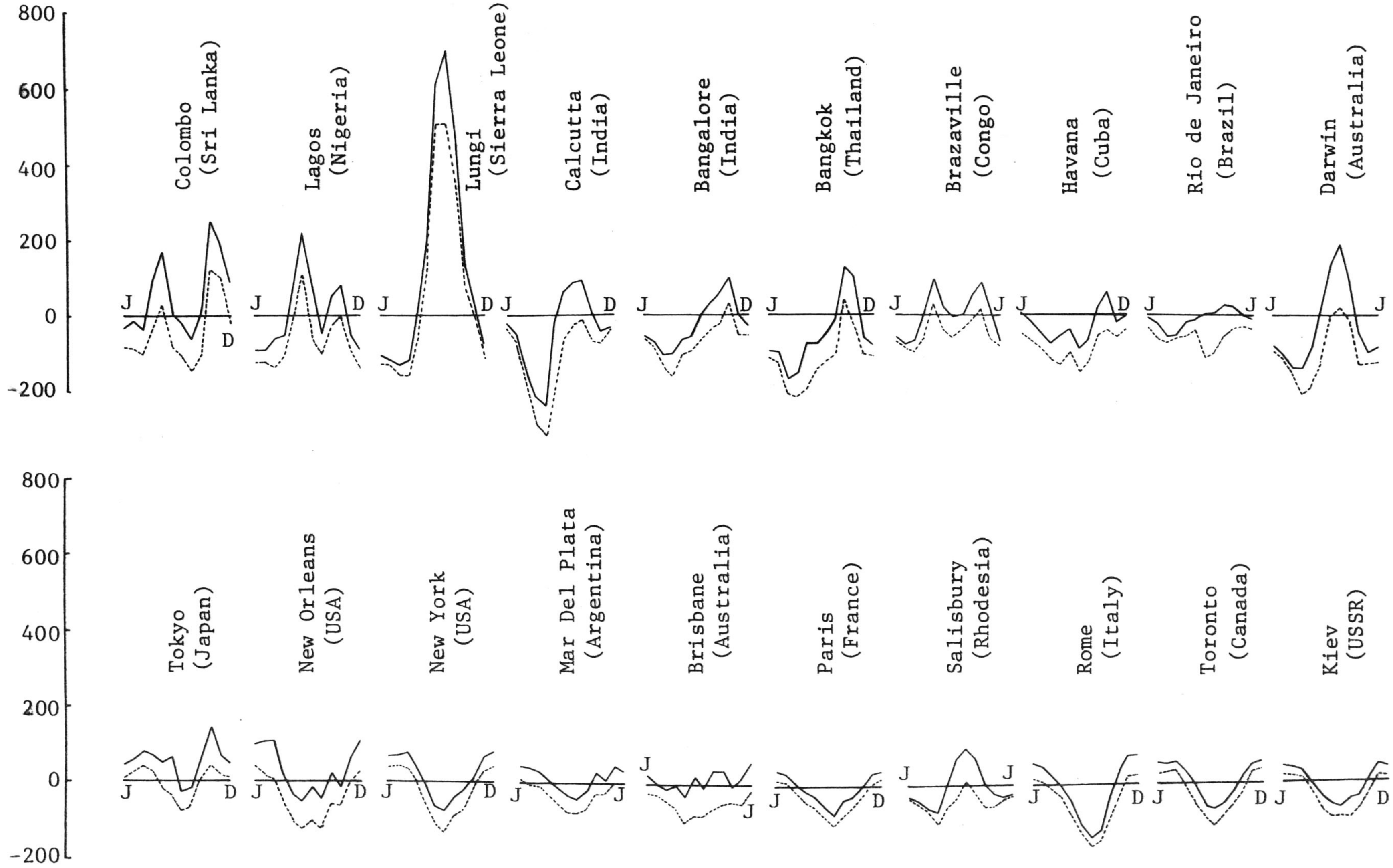


Fig. 7b. Means and Lower Quintiles of Monthly Differences Between Precipitation and Potential Evapotranspiration (P-PET) at 20 Stations

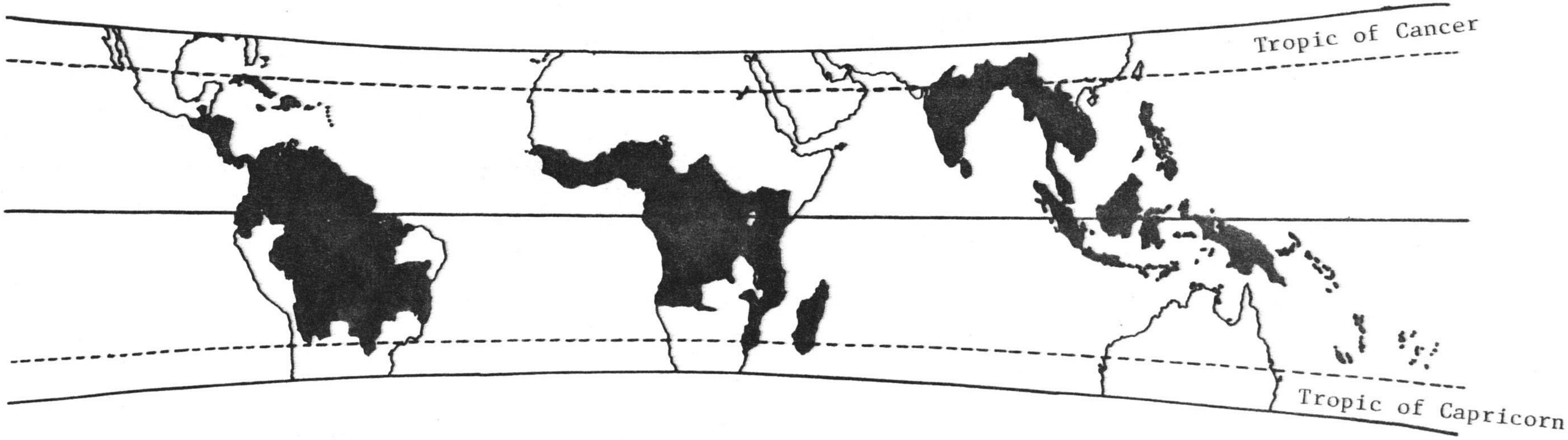


FIG. 8. MAP SHOWING THE COUNTRIES OF "THE HUMID TROPICS"

(Note : The climatic delimitation of the humid tropics is approximated by international boundaries. For Brazil and India, state boundaries are used.)

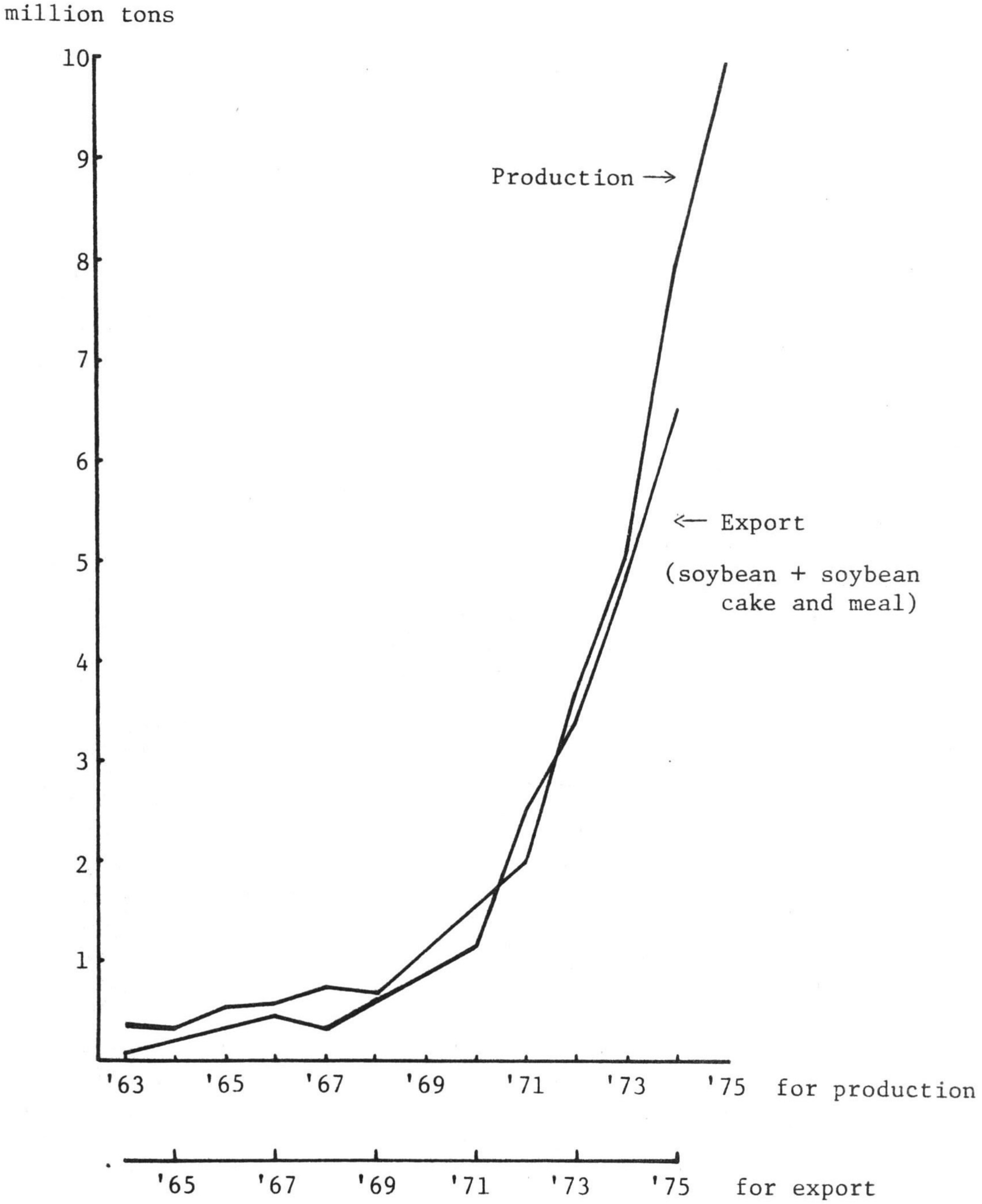


FIG. 9. BRAZIL'S PRODUCTION AND EXPORT OF SOYBEANS, 1963-1975

(SOURCE : FAO PRODUCTION YEARBOOKS AND TRADE YEARBOOKS)

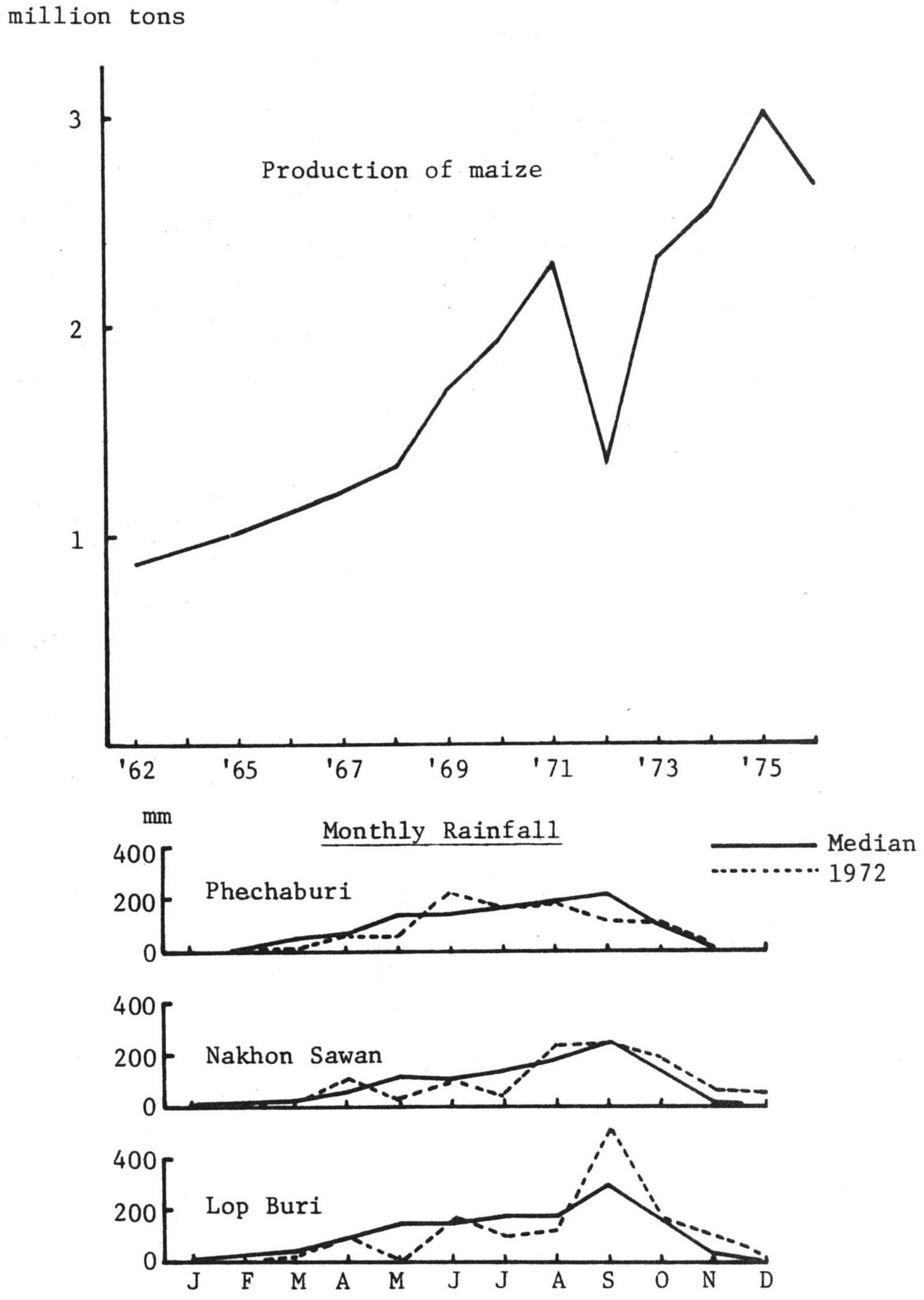


Fig. 10. Rainfall and Production of Maize in Thailand in 1972

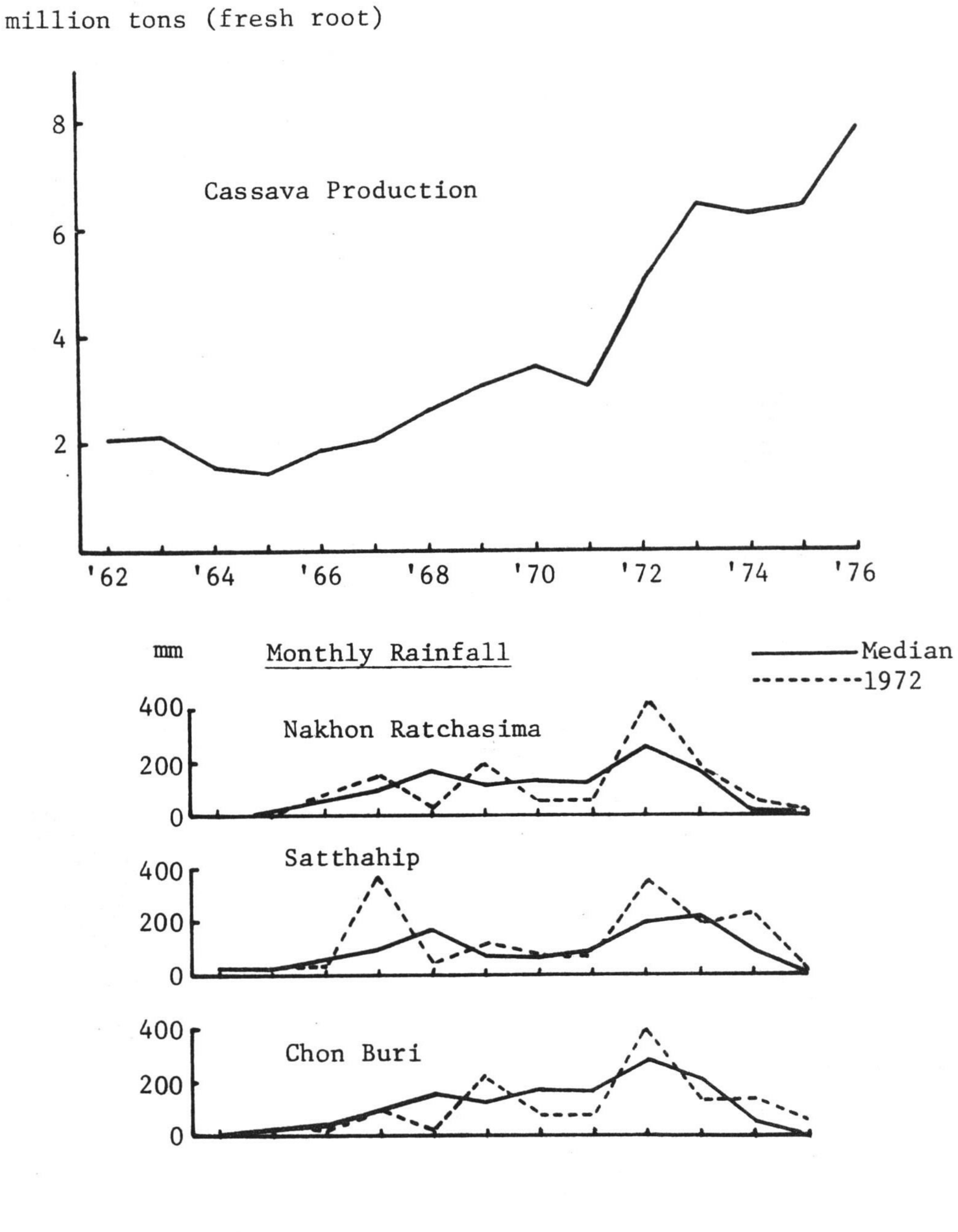


Fig. 11. Rainfall and Cassava Production in Thailand in 1972

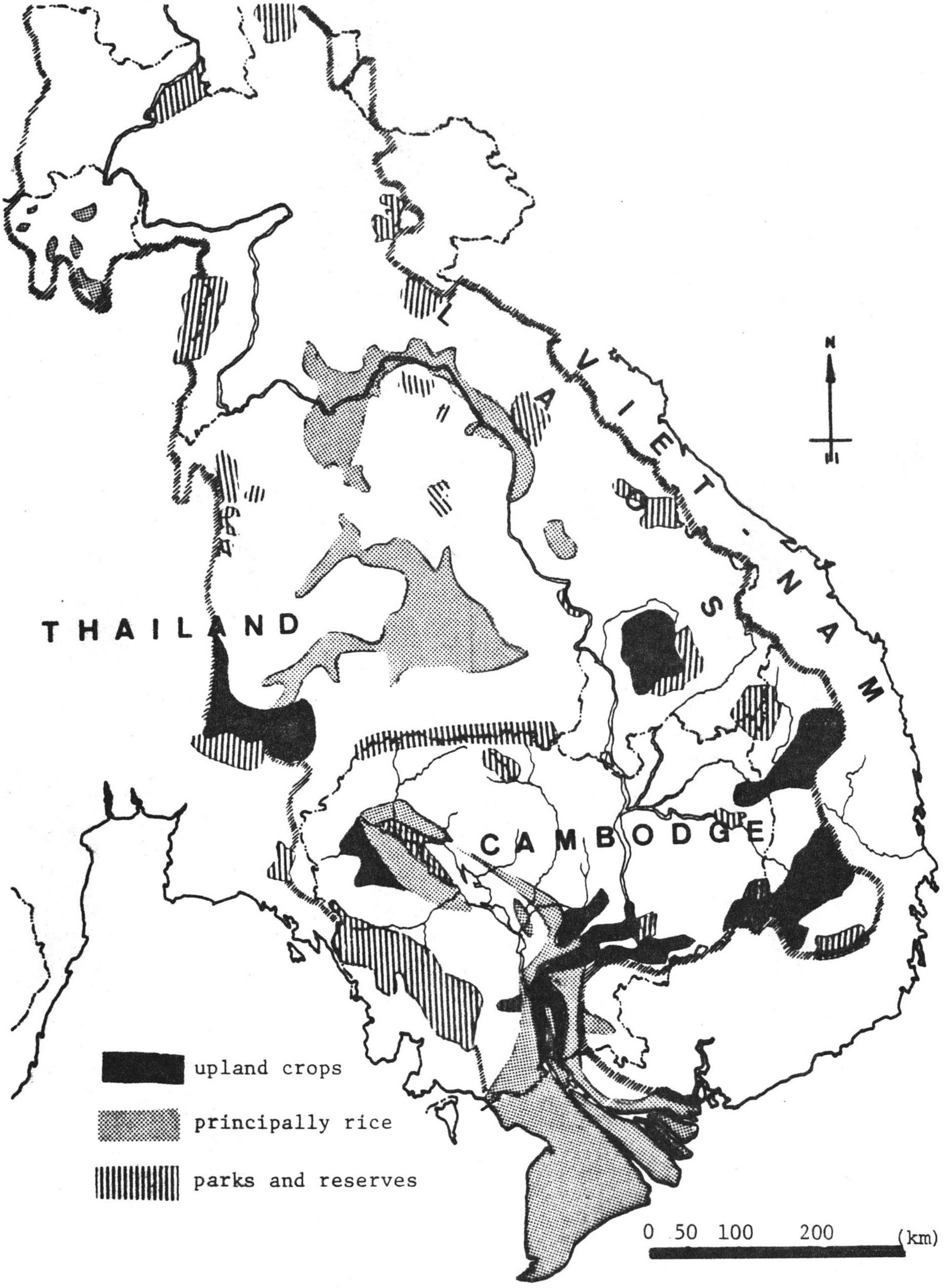


Fig. 12. Tentative Land Use Model for the Lower Mekong Basin (Simplified)
(Source : Mekong Committee, 1976)

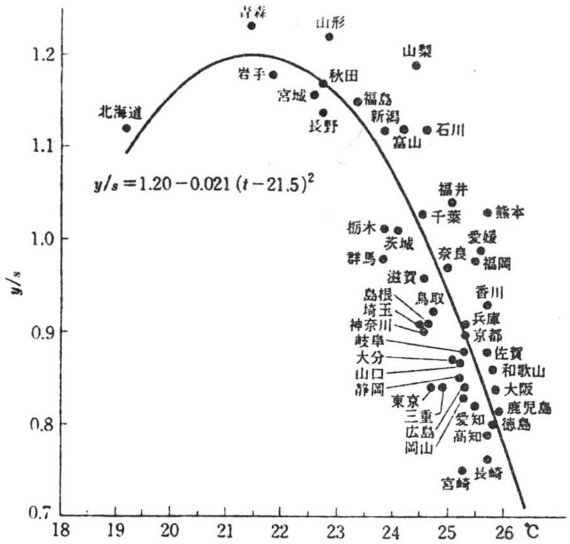


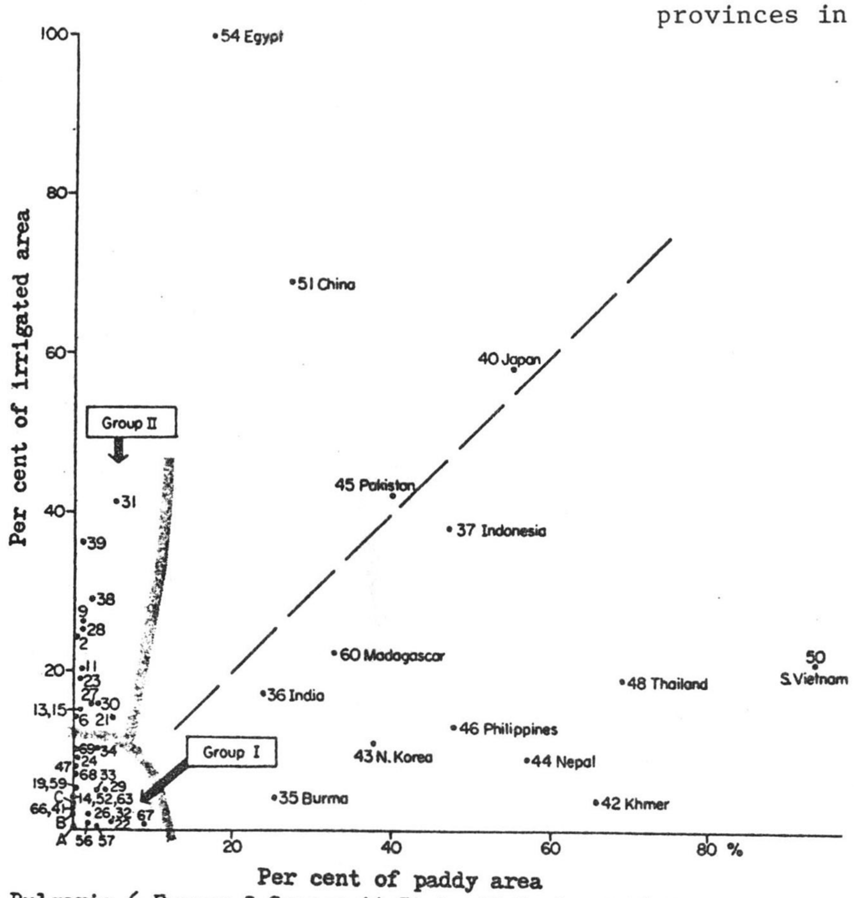
FIG. 14. RELATION BETWEEN TEMPERATURE[1)] AND RATIO Y/S[2) 3)]

(AFTER MURATA 1964 /16/)

1) Mean temperature in August and September

2) y : yield of brown rice in kg per 10 ares (average of 1957-1961)
   s : mean of solar radiation in cal/cm^2/day in the same two months

3) Each dot denotes the 46 provinces in Japan



2 Bulgaria, 6 France, 9 Greece, 11 Italy, 13 Portugal, 14 Rumania, 15 Spain, 19 U.S.S.R., 21 Cuba, 22 Guatemala, 23 Mexico, 24 U.S.A., 26 Bolivia, 27 Brazil, 28 Chile, 29 Colombia, 30 Ecuador, 31 Peru, 32 Uruguay, 33 Venezuela, 34 Afganistan, 38 Iran, 39 Iraq, 41 Jordan, 47 Syria, 52 Algeria, 56 Ghana, 57 Ivory Coast, 59 Libya, 63 Morocco, 66 Rhodesia, 67 Sierra Leone, 68 S. Africa, 69 Sudan, (A) Austria, Denmark, Finland, Poland, Sweden, Canada, Burundi, Ethiopia, Kenya, Melawi, Mali, Niger, Nigeria, Togo, Tanzania, Uganda, Upper Volta, Zambia. (B) Hungary, Yugoslavia, U.K., Tunisia. (C) Czeckoslovakia, E.Germany, W.Germany, Argentina, Turkey, Australia.

FIG. 15. PERCENTAGES OF IRRIGATED AND RICE AREAS TO TOTAL ARABLE ARE IN 76 COUNTRIES

(SOURCE : FAO PRODUCTION YEARBOOK, VOL. 25. (1971))

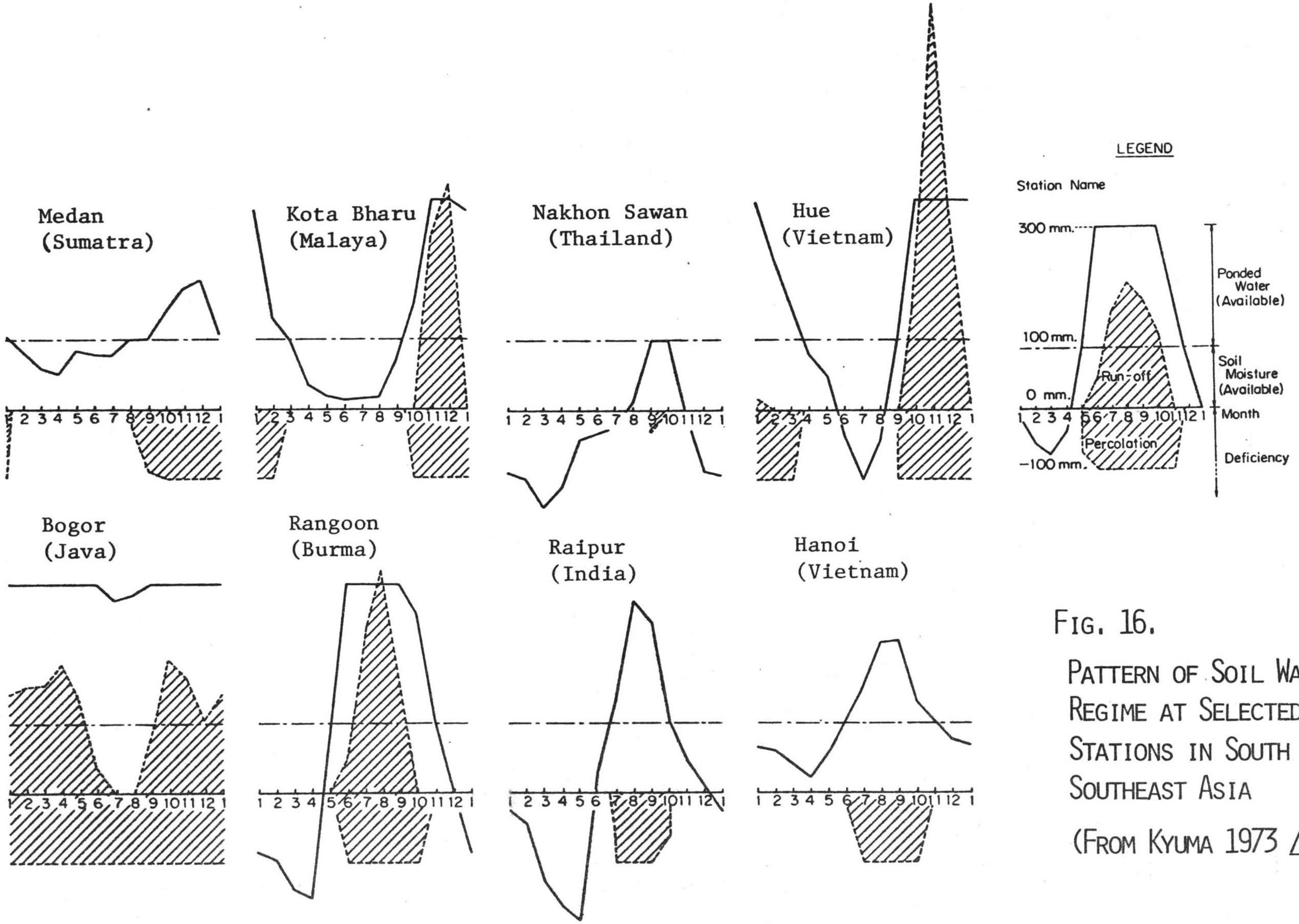


FIG. 16.

PATTERN OF SOIL WATER REGIME AT SELECTED STATIONS IN SOUTH AND SOUTHEAST ASIA

(FROM KYUMA 1973 /18/)

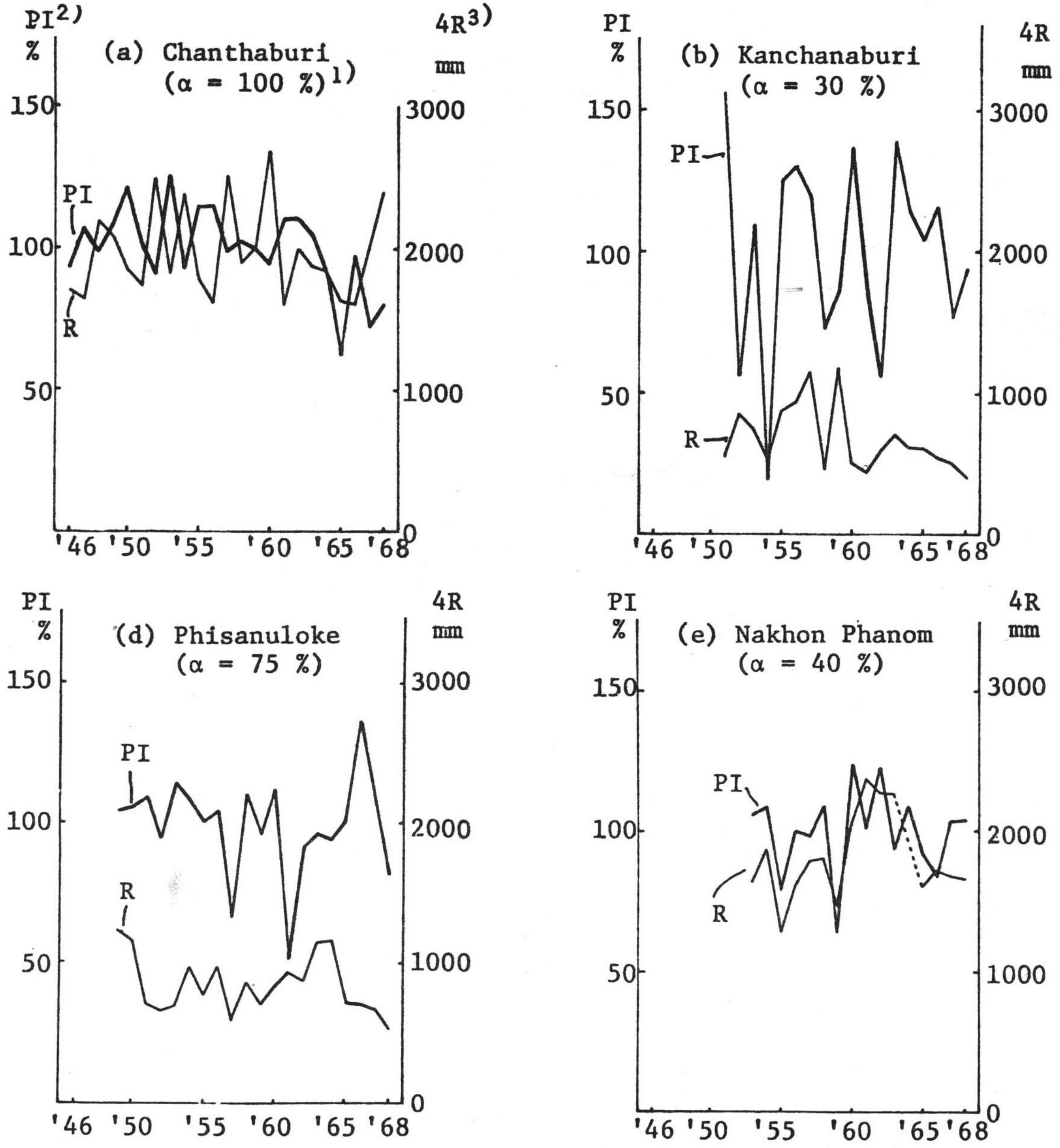


FIG. 17. YEAR-TO-YEAR FLUCTUATION OF RICE PRODUCTION AND SEASONAL RAINFALL AT SELECTED PROVINCES IN THAILAND

1) Percentage of recent alluvial soil area to total rice land area
2) Production Index (de-trended)
3) Sum of 4 months rainfall total

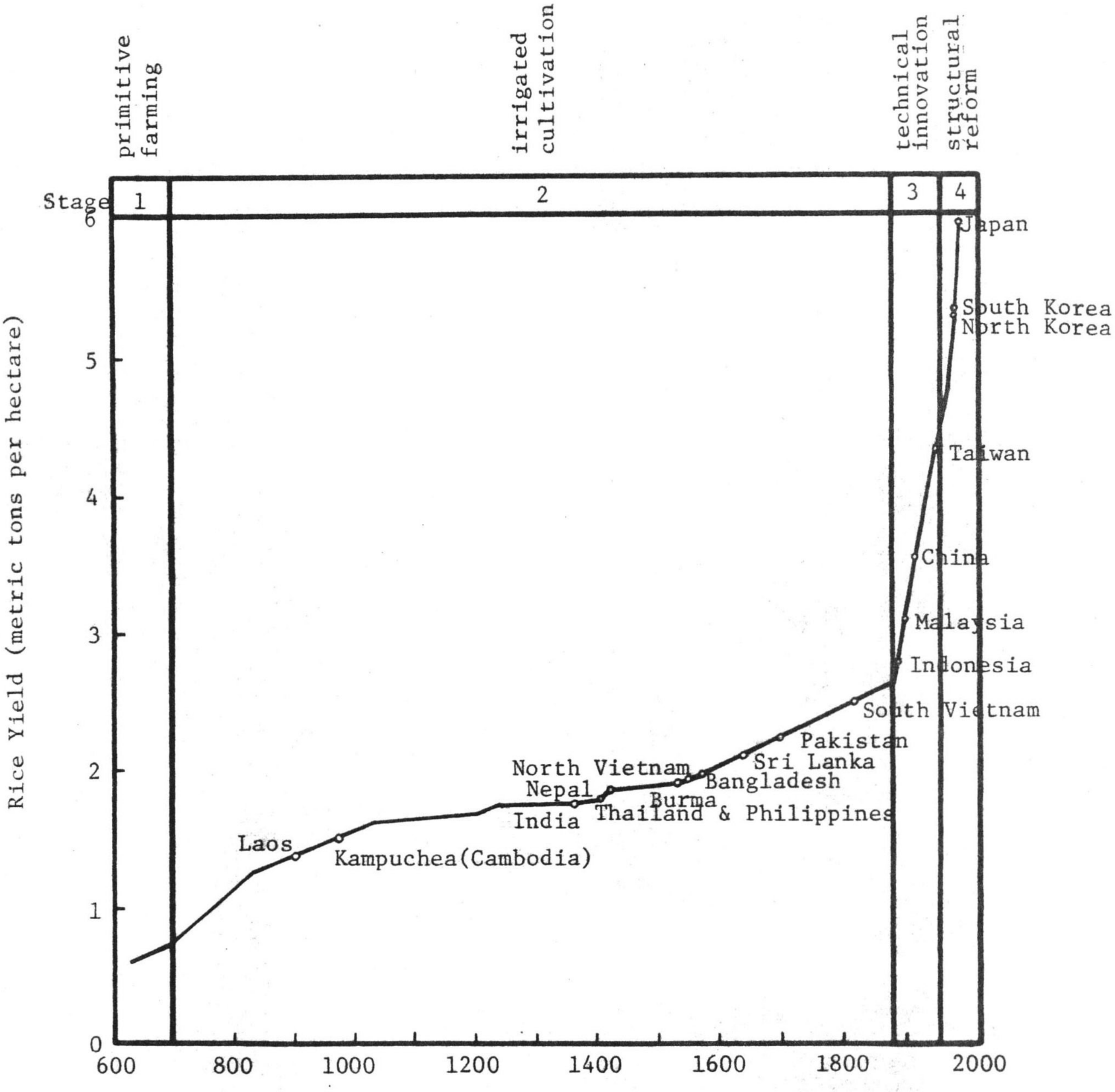


Fig. 18. Correlation of Intensification of Farming and Yield of Rice (based on historical progress of rice production in Japan) (From : Report of the Trilateral Food Task Force /22/)

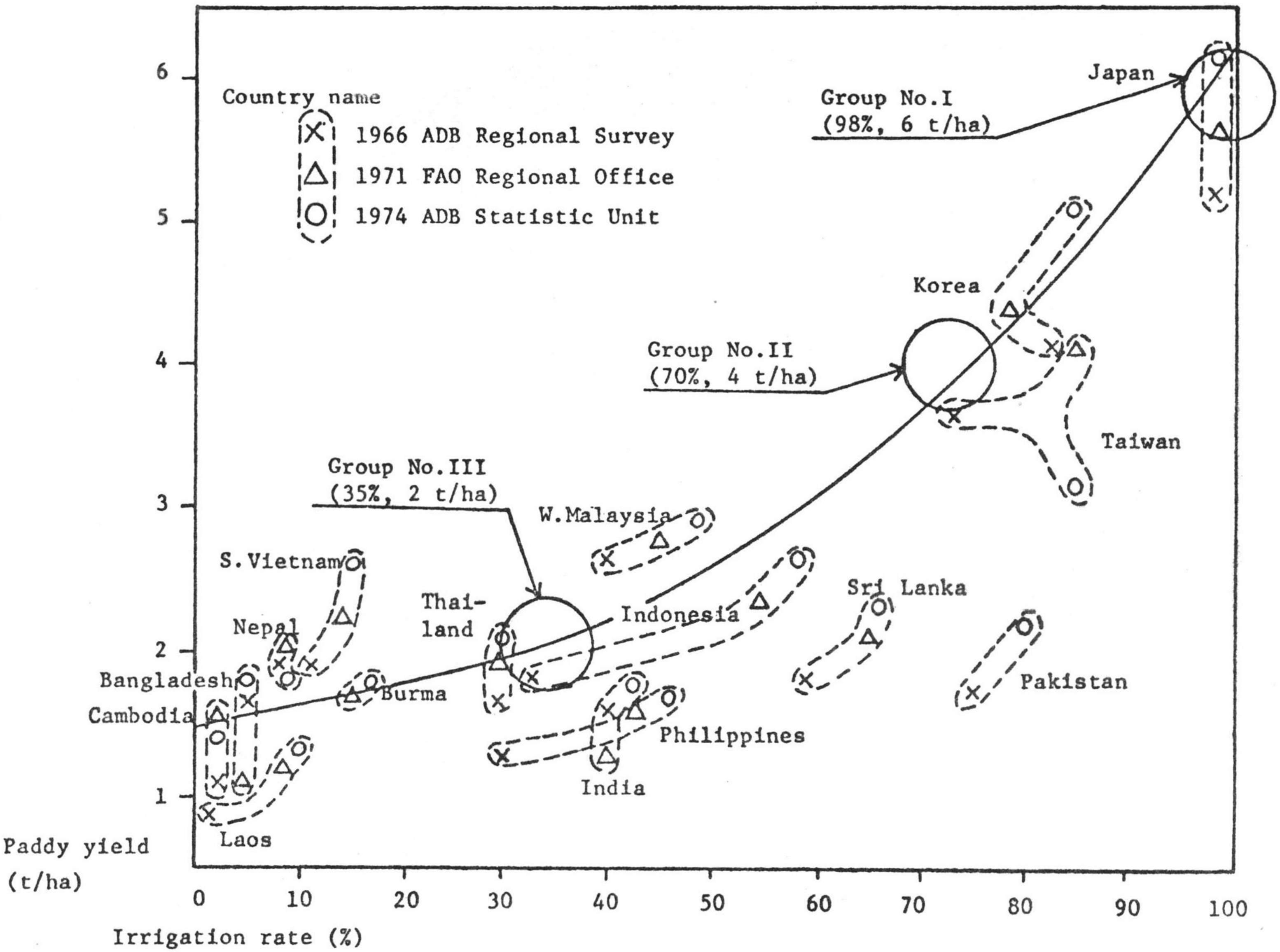


FIG. 19. RELATION BETWEEN IRRIGATION RATE AND PADDY YIELD

(FROM : OKITA AND TAKASE, 1976 /23/)