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Environmental Determinants Affecting the Potential Dissemination of High Yielding Varieties of Rice*

——A Case Study of the Chao Phraya River Basin——

by

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Section I Introduction

High yielding varieties (HYVs) of rice, such as IR-8, have a great yield potential thanks to their high responsiveness to nitrogen. Various pre-requisites must be satisfied, however, in order to realize their potential. These include physical environmental conditions which determine the magnitude of dissemination. Within the potential HYV acreage pre-determined by environmental factors, other conditions related to technological, economical, and social factors further determine the rate of dissemination.

The objective of this study is to examine, in terms of physical environmental conditions, the possibility of the dissemination of HYVs in the Chao Phraya River basin of northern and central Thailand. General environmental conditions are first reviewed briefly in Section II. This discussion is based on various reports and on the writer's own five-year study in Thailand. In Section III, a regional division of rice land in the basin is attempted, based on present physical environmental conditions and modes of rice cultivation. This work was carried out in close co-operation with a geologist, an irrigation specialist, and a soil scientist: each had the field work experience in the basin under discussion. In Section IV, HYV dissemination possibilities and concomitant environmental obstacles are examined for each of the six rice-cultural regions presented in the foregoing section. Finally, there is discussion on potential HYV acreage and possible processes of dissemination in the basin taken as a whole.

In this study, HYVs are taken to be a rainy season crop. The dissemination of HYVs as a dry season crop is not discussed for the following reasons. First, rainy and dry season environmental conditions are distinctly different; their bearing on dissemination should be discussed separately. Second, although dry season rice acreage

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is significant in some countries such as West Malaysia and Ceylon, it is still very limited in continental Asia, including Thailand; furthermore, the substantial increase in dry season rice acreage seems unlikely in the near future.

In this paper, HYVs denote the semi-dwarf rice varieties characterized by short stature, stiff straw, and erect leaves of dark green color. They grow more slowly than native *indica* varieties (NVs) at the initial growth stage, and are usually insensitive to longer or shorter day-lengths. Since these morphological and physiological characteristics of HYVs are closely related to their ability to render high yield, even though certain newly developed HYVs at different institutes might differ in their grain quality or their resistance to diseases, they do not differ significantly in these basic characteristics.

Section II General Consideration of the Environmental Conditions Required for Dissemination of HYVs

Climatic condition

Among climatic factors, rainfall is the most decisive factor affecting the annual fluctuation and the regional differences of rice production. This is mainly due to inadequate water control. Even where rainfall, in its amount and distribution, is most suitable for rice cultivation, certain facilities are needed for stabilized rice production. This is true particularly in the case of HYVs, which require precise water control to be discussed in detail later. Where rainfall is less suitable, greater investment is needed for more sophisticated facilities on a larger scale. Technical and economical difficulties involved in effecting better water control depend not only on rainfall but also on other environmental factors, particularly on topography. Therefore, rainfall as a determinant of HYV dissemination should always be discussed in relation to water control facilities.

Biologically, temperature and solar radiation are the basic climatic factors affecting plant growth. However, they do not seem vital to the question of the dissemination of HYVs. This is true, firstly because these two factors do not seem to differ significantly within tropical monsoon Asia in so far as main season rice is concerned; temperature and solar radiation are generally suitable for any HYVs of rice developed in the region. And secondly, the effect of these two factors as well as of other climatic factors, though it might indeed be considerable, cannot be detected because the overwhelming influence of good or poor water conditions serve to conceal them.

One can conclude that, aside from rainfall, there seems to be no climatic obstacle that can seriously deter the dissemination of HYVs as the main season crop of tropical monsoon Asia.

Soil conditions and nutrient supply

Some soils have excessive salinity, toxicity, acidity, root development inhibiting texture, and other defects. These characteristics are difficult or often impossible to be modified and the application of fertilizers to these soils is ineffective. However, these soils occupy only a small portion of the present rice growing area of Asia. Soils presently under rice cultivation can generally be said to be suitable for NVs and for HYVs as well.

However, inherent soil fertility differs greatly from one place to another. High or low soil fertility affects the dissemination of HYVs because an ample supply of plant nutrients is one of the necessary conditions of HYVs' realizing their yield potential. Nevertheless, the importance of inherent soil fertility is not necessarily so great because nutrients can be supplemented in the form of fertilizer. A brief explanation of the inter-relation between inherent soil fertility, fertilizer application, and the amount of nutrients required by HYVs is given schematically below.

Under favorable environmental conditions with proper cultivation practices, fertilizer-supplied nutrients are efficiently absorbed by rice plants. By increasing the size and number of plant leaves, they help develop greater leaf area. The resulting greater leaf area catches more solar energy, some portion of which is stored in the grain. In any variety of rice, the greater the leaf area, the smaller is the proportion of assimilated energy utilized for grain formation. Therefore, yield increase through the application of fertilizer is a synthesis of two conflicting components: (a) an increasing total assimilation due to enlarged leaf area, and (b) a decreasing proportion of energy converted to grain formation.

The rate of total assimilation through the increase of nutrient supply rises greatly when the total amount of nutrients is below a certain level. The proportion of assimilated energy directed to grain formation remains high at a low level of nutrient supply but cuts off sharply when the nutrient supply exceeds a certain level. Therefore, when nutrients are supplied in limited amounts, rice varieties which can quickly develop greater leaf areas are advantageous. On the contrary, when nutrients are abundant, rice varieties which can convert a greater proportion of their assimilated energy to grain formation are advantageous. Schematically, NVs belong to the former category and HYVs to the latter. If the nutrient supply to NVs exceeds a certain level, they do not respond to further increments of fertilizer. HYVs do not necessarily outyield NVs if their nutrient supply is below that same cut-off level.

The critical level of nutrient supply cannot be expressed in terms of a set amount of fertilizer, because the actual amount of nutrients supplied to a plant is the sum of nutrients derived from the soil and from fertilizers. However, it can be expressed roughly in terms of corresponding yield levels. Reviewing numerous reports on fertilizer trials conducted in various countries, including those conducted by the writer himself, one can say that most NVs cease to increase in yield when their nutrient supply results in a yield level somewhere between 3–4 ton/ha[1]. HYVs respond best to nutrient supplies that result in yields of 6 ton/ha or more[2].

Therefore, where at present the yield level of NVs is 3–4 ton/ha, or more either thanks to exceptionally high soil fertility as in the case of the experimental farm of IRRI, or due to the application of fertilizers, a further raise in yield level seems very difficult without the adoption of HYVs. Where present yields are very low due to poor soil fertility, HYVs would not necessarily respond better than NVs when the yield level aimed at by fertilizer application is 3–4 ton/ha or less.

Water conditions

HYVs require much stricter water conditions than do NVs. They can be listed as follows.

First, water depth must be kept below a certain level, one much shallower than that tolerable by NVs. This is because of the short stature and moderate rate of initial growth of HYVs. Excessive water depth at any stage of growth will totally ruin the adoption of HYVs. Farmers have no choice but to plant tall NVs where deep water conditions make it physically impossible to plant HYVs.

Second, the field must be submerged for the fixed duration of growth. The growth period of HYVs is not as long as that of many NVs because the longer the growth period, the smaller the proportion of total assimilated energy utilized for grain formation; an extended growth period would result in poor response to heavy fertilizer application. One hundred and twenty days, 20–30 days in the nursery and the rest in the main field, is the standard growth duration of HYVs. Due to the non-sensitivity of HYVs to day-length, their growth duration does not vary significantly regardless of the time of planting.

Most paddy fields in tropical Asia are dependent on the south-west monsoonal or summer rains. The start of the rainy season is often very erratic. And even after it seems to have started, dry spells sometimes prevail. The water depth of paddy fields increases gradually with the advancement of the rainy season and reaches a maximum at the end of the rainy season or just after. The time of water recession from the paddy fields seems relatively constant, partly because the end of the rainy season is more regular than the start and partly because it is possible to drain water to rivers if topographical conditions are suitable. Photo-period sensitive NVs are well

1) Throughout this paper yield per hectare represents the yield of unhulled, rough rice or paddy. The conversion rate of unhulled rice to milled rice is approximately three to two in tropical Asia.

2) It is true that there have been many examples reported of very high yields obtained by NVs or even by floating rice. But they have not yet been investigated in enough detail to develop a firm system of cultivation technique or to suggest a desirable model of plant type to the breeder.

adapted to this variable duration of submergence.

When the coming of the rains is earlier than usual, planting must be done earlier as well. Otherwise deep water makes planting impossible, particularly in the case of short stature HYVs. Planting earlier than usual influences the date of maturation of NVs very little, whereas HYVs mature after a fixed number of days. This implies that HYVs must sometimes be harvested before the termination of the rainy season. Under heavy rain and deep water conditions, the harvesting, drying, and transporting of grain, along with other necessary processings, result in high costs and a lower quality grain product. When the coming of the rains is later than usual, planting is delayed. Or when a dry spell damages crops, farmers must begin afresh their planting. Yet while NVs can still mature in the face of water recesssion, HYVs may suffer from drought at the later growth stage.

Thus, besides damage from excessive water depth, excessively long water submergence due to early monsoon rains or the undrainability of fields will discourage the adoption of HYVs. Farmers might encounter too many problems at the time of harvest and thereafter. Too short a duration of submergence, arising in most cases from the late coming of the rains, totally prevents the dissemination of HYVs.

A drought during the course of plant growth damages a rice crop regardless of the rice variety used. However, actual financial loss differs according to the amount invested in inputs. A probability of drought, say, once in every few years, would not rule out the planting of HYVs; they might temporarily be adopted in some areas. But fear of drought would inhibit the spending of large amounts of money on fertilizer application and other inputs, so the yield could not be expected to be as high as experimental trial results might suggest.

Present dissemination trends

Areas fully satisfying the environmental conditions stated above are very limited in fact. Yet HYVs are being planted in more and more areas where environmental and other factors are not necessarily favorable. Consequently, the average yield of HYVs in certain districts surveyed is disappointedly low, often below 3–4 ton/ha. From the biological point of view, such low yield levels with HYVs, though they might be higher than with NVs, cannot, as explained previously, be attributed to their inherent yield potential.

However, about one half of the fields observed might have presented yields higher than the average of total observations. The very high yield at some fields could be attributed to the high yield ability of HYVs. HYVs can be considered to have been successfully disseminated to about one half of their total acreage if their average yield is at the 3–4 ton/ha cut-off level. The lower the average, the smaller the area of successful dissemination.

Areas where HYVs are actually planted but their yield is lower than 3–4 ton/ha are considered to be unsuccessfully disseminated. There may be various reasons for the unimpressive yield of HYVs, for instance, insufficient fertilizers and other chemicals, poor water conditions, and improper cultivation. Regardless of the reasons why HYVs have sometimes failed to realize their yield potential, sustained successful adoption of HYVs does not seem likely unless certain steps are taken to raise their yield.

Summary

Section II is here summarized in chart form.

Environmental conditions	Suitability for dissemination
(1) Climatic conditions	
Rainfall	Water control facilities are necessary to ameliorate unfavorable rainfall patterns
Other climatic factors	Generally suitable
(2) Soil conditions	
Defects unamendable by fertilizer application	Successful dissemination unlikely
Other soil properties	Generally suitable
(3) Nutrient supply	
Sufficient supply due to rich soil or fertilizer application	Further yield increase difficult without HYVs
Insufficient supply due to poor soil or small amount of fertilizer application	NVs and HYVs are competitive as long as the yield is below 3–4 ton/ha
(4) Water conditions	
Excessive water depth	No dissemination possible
Duration of submergence	
Too long	Difficulties in harvesting and other operations
Too short	No dissemination possible
Occasional drought	Successful dissemination unlikely

Section III An Attempt at a Regional Division of the Chao Phraya Basin

Physiography

The big river basins of continental south and southeast Asia have a more or less similar physiographical pattern. The Chao phraya basin is no exception.

In the northern mountainous region, *intermountain basins* develop. In these rela-

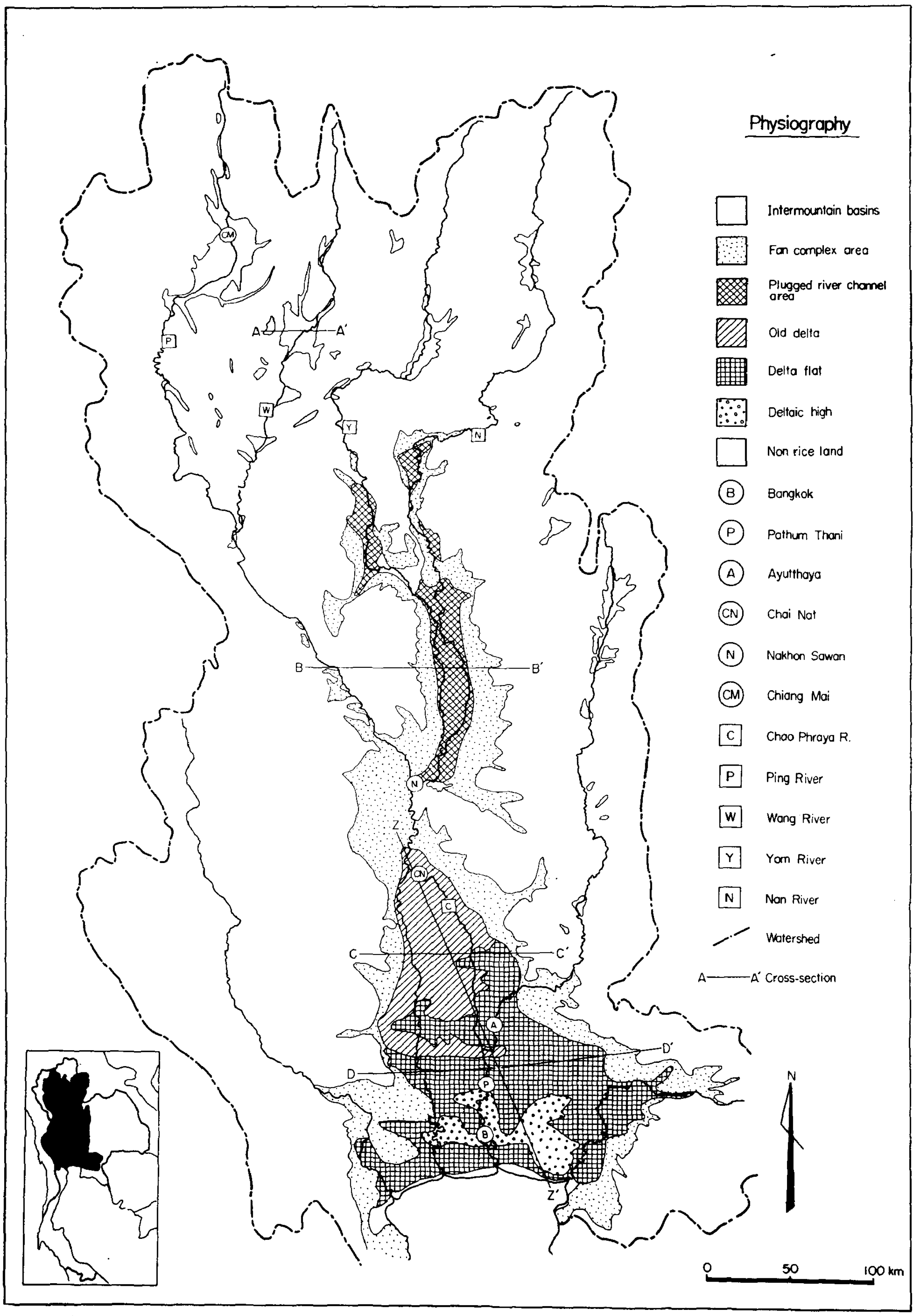

Fig. 1 Map Showing the Physiographic Regions of Rice Land in the Chao Phraya River Basin (drawn by Y. TAKAYA)

tively small basins, several terraces are formed on both sides of rivers. Rice is grown on lower terraces. Water flow slows down when it comes out of the mountainous area. A resulting deposit of coarser grains forms alluvial fans. These various-sized fans can be seen in the marginal area of the low-lying plain. The plain along the tributaries of the Chao Phraya River is separated from the southern plain by hills close to the river between Nakhon Sawan and Chai Nat. These hills block the flow of water, causing floods upstream.

The plain south of Chai Nat and north of Ayutthaya is considered to have been a delta in the Pleistocene period. Today the plain itself is a large terrace slightly higher than the present delta developing further south. The Chao Phraya River and its distributaries flow through this *old delta*, forming natural levees immediately beside the water channels themselves and the depressions behind the levees. As the various streams have often changed their courses, a complex surface configuration has resulted.

Further south of Ayutthaya, the topography is typically flat, except for higher elevations called barrier-islands. These relatively higher places develop near the coast and are considered to have been formed mainly through the effect of the sea.

For water control the most relevent physiographic feature is land gradient. The possibility of gravity irrigation and drainage depends on this factor. The cross-sections in Fig. 2 clearly show how the low-lying plains are distinctly flatter than the *intermountain basins* and *fan-terrace complex area*, while the *old delta* is intermediate.

Water conditions

Water conditions in the *intermountain basins* and in the peripheral areas of the low-lying plains are distinctly different from those in the other areas of the Chao Phraya basin in the following two ways. First, the mean gradient of land is steep enough that irrigation and drainage can depend solely on gravity. Second, any water control measures can but little affect water conditions downstream. Therefore, once irrigation water becomes available, it can be relatively easily distributed and cheaply managed. Drainage can be done similarly without worrying about the influence of drainage water on the water balance of plains downstream. Consequently, the primary problem in improving conditions in these areas is that of obtaining sufficient amounts of water.

Maximum irrigable area is roughly determined by the ratio of the area to be irrigated to the catchment area which stores rain water and eventually supplies it. The potential irrigable area suggested by this ratio exceeds the actual area of paddy land in most of the *intermountain basins* and in some areas of the *fan-terrace complex area*. In these areas, a traditional system of water control consisting of simple weirs made of stones, tree branches, and mud and corresponding ditches has been well developed and is still working effectively. The basic principle of modern facilities is same as the traditional one: diversionary barriers with corresponding canals.

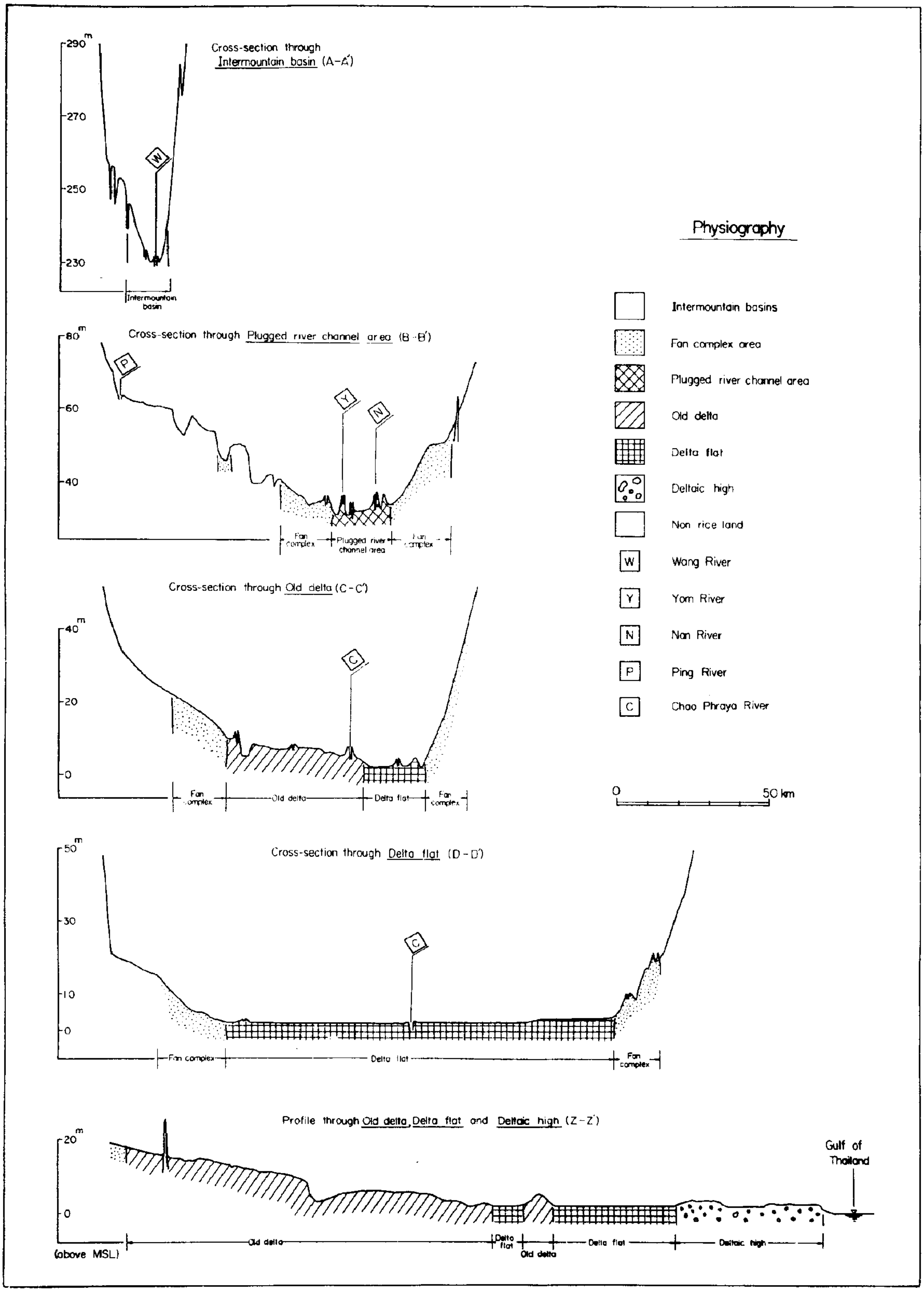

Fig. 2 Cross-sections and a Profile of the Chao Phraya River Basin (drawn by Y. TAKAYA)

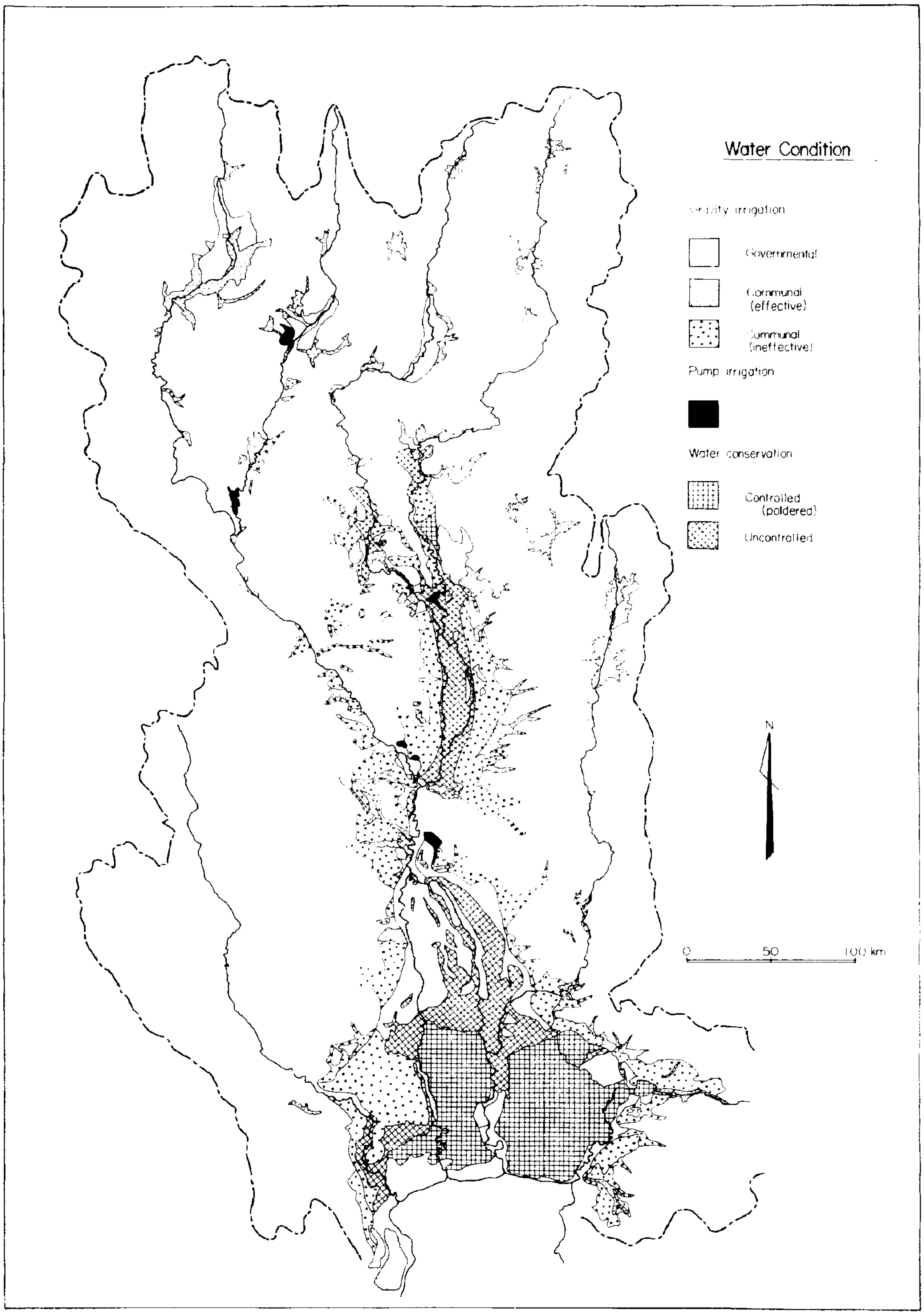

Fig. 3 Map Showing the Water Conditions of Rice Land in the Chao Phraya River Basin (drawn by Y. KAIDA)

In large areas of the *fan-terrace complex area*, the actual area planted is more than the maximum irrigable area determined by the ratio explained above. Due to the coarse texture of soil material on the alluvial fans, surface water permeates deeply and flows down as groundwater. Though various community operated water control devices are also seen in these areas, they are not effective because of the chronic water shortage. Effectiveness of modern facilities is similarly limited for the same reason.

In the low-lying plains, extremely flat topography makes it difficult or often practically impossible to control the water depth of individual fields by gravity. Rain water as well as water spilled over from natural levees remains on the plain until it is exhausted by evapo-transpiration and/or flows gradually to the sea. Thus, water conditions of the localities on the plain depend mainly on slight differences in relative elevation.

Measures undertaken until now to improve water conditions have aimed at obtaining a more uniform and more stable spread of flood water over a larger area in the plain. First, a huge storage dam on the upper Ping river has partially removed the problem of seasonal water level fluctuation along rivers down stream. Second, the diversionary barrage at Chai Nat, which regulates water flow to distributary streams and the main canals, has resulted in wider dispersion of water over a greater area. Water from these channels can be gravity-irrigated to the higher places on the *old delta* ,between Chai Nat and Ayutthaya; general flatness, however, requires a very precise alignment of ditches for water distribution. Substantial areas remain which do not share the benefits of this scheme mainly owing to the poor alignment of lateral canals and ditches.

Third, water south of Ayutthaya is controlled by polders. These polders are not perfect enough to completely separate the inner from the outer areas, and the control of water is mainly managed through the difference in water levels between the inside fields and the outside canals. Therefore, in practical terms the effect of the polders is limited to the prevention of extreme flood or drought. The higher elevation of the *deltaic high area* permits rice transplantation, though the basic water conditions are similar to those in the polder area.

There are two regions in the plain where even flood control is impossible. One is the narrow plain along the Nan and Yom rivers. The other is the deep water area bordering the higher places of the *old delta*. Flood water drainage all collects into these areas. Improved water conditions in higher-lying places has been made possible at the expense of this area, which has become a sort of water trashing area.

"Irrigated area" in the official statistics of the Thai government denotes areas epuipped with facilities for water control which are under government supervision. Actual water conditions of the "irrigated area" differ greatly, depending on whether gravity irrigation or conservation irrigation is practiced. The latter, of course, refers to controlled flood water irrigation. Yet, areas which are not included in the "irrigated area" do not necessarily lack irrigation facilities.

Soil

There are almost no defects in soil properties in the Chao Phraya basin which cannot be amended by fertilization. The major soil property affecting present paddy production and probably to affect the initial dissemination of HYVs is soil fertility.

Most paddy soils are located on alluvial deposits which were originally transported by rivers. As the parent rocks within the basin do not significantly differ in terms of soil fertility, differing soil fertilities can largely be explained in terms of weathering. Climatic conditions within the basin are quite uniform in so far as the weathering process is concerned, so the degree of weathering one encounters corresponds roughly to the length of time elapsed since the deposition of the sediment. Thus, the soils on older geological formations are generally more weathered and less fertile than those found on more recent sedimentations.

Soils on higher terraces in the *intermountain basins* are less fertile than those on lower ones. Soils developed on semi-recent alluvia in the *fan-terrace complex area*, similarly, are less fertile than most of those in the lower plain. The formation of the *old delta* south of Chai Nat is quite old but the fertility of the soils on it is medium to high because the region has constantly received a fresh supply of sediments. Within the *old delta*, soils in depressions are more fertile than those on levees. Soils derived from brackish water sediments are young but infertile due to strong acidity caused by the oxidation of accumulated sulfur compounds. The soils on the marine alluvium are the freshest and richest in terms of plant nutrients. Except for small areas where salinity is excessive, soil fertility here is highest in the Chao Phraya basin.

Rice production

Seeds are directly broadcast in about one third of the total rice growing area of the Chao Phraya basin. Topography and water conditions bear a close relationship to the distribution of broadcast and transplanted rice fields. As shown in the accompanying map, the broadcast method is practiced in the *plugged river channel area*, in the low-lying part of the *old delta*, and in the *delta flat*. Lack of micro-relief and the unifom submergence of an extensive area within short duration make it difficult to manage the nursery properly or to keep the water depth of the main fields shallow enough for young seedlings to be planted. These disadvantageous physical conditions aside, broadcast rice regions satisfy minimum water requirements for the extensive cultivation of NVs of different plant height having variable growth duration characteristics. Consequently inherent soil fertility is the primary factor determining yield levels. The highest average yield is obtained in the extremely deep water area where floating rice is grown. The great volume of flood water which enters these areas annually replenishes plant nutrients. The broadcast fields in the depression area of

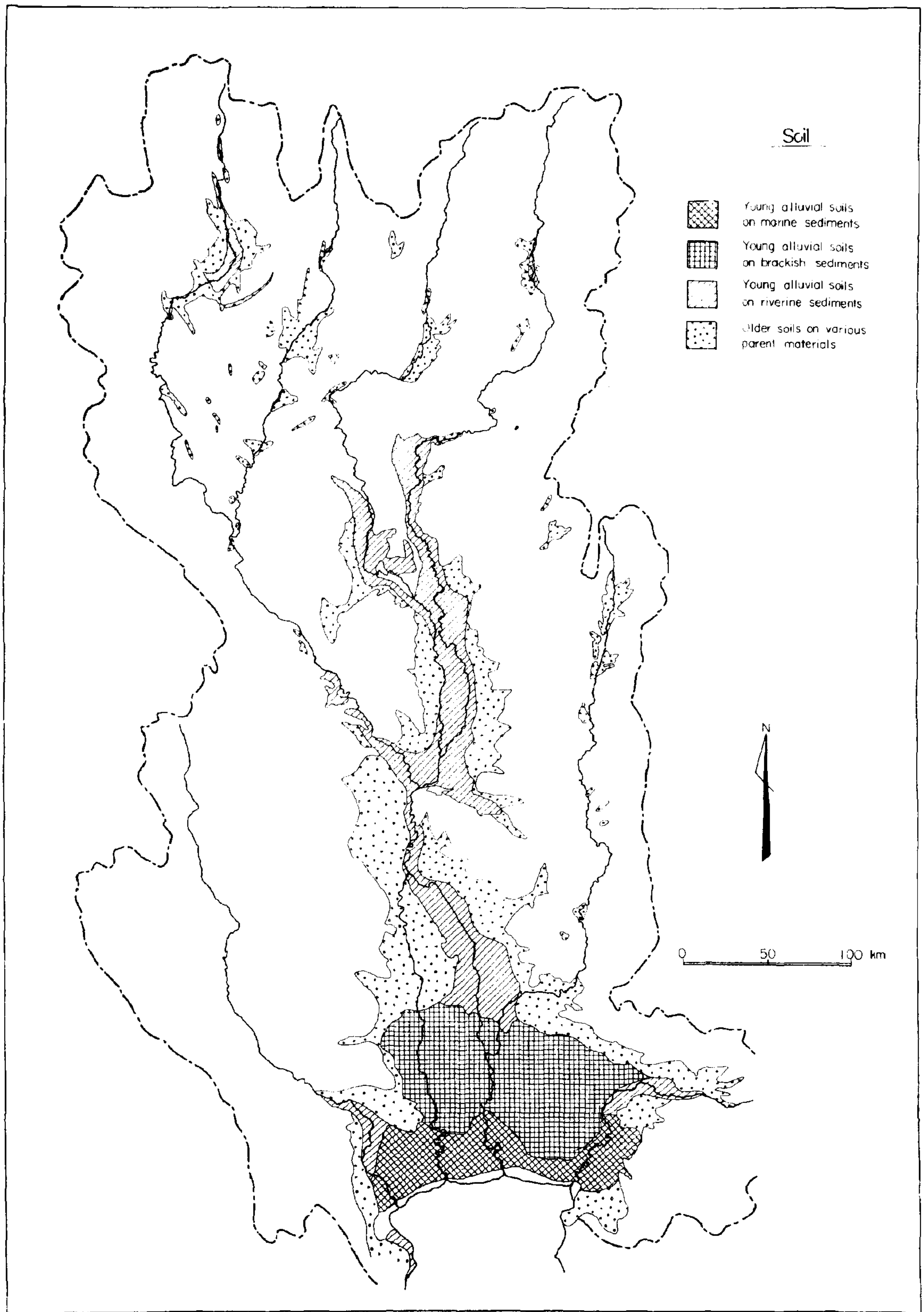

Fig. 4 Map Showing the Soil Conditions of Rice Land in the Chao Phraya River Basin (Cited from "A Simplified General Soil Map of Thailand 1 : 2,500,000" by F.R. MOORMANN and S. ROJANASOONTHON, with slight modifications)

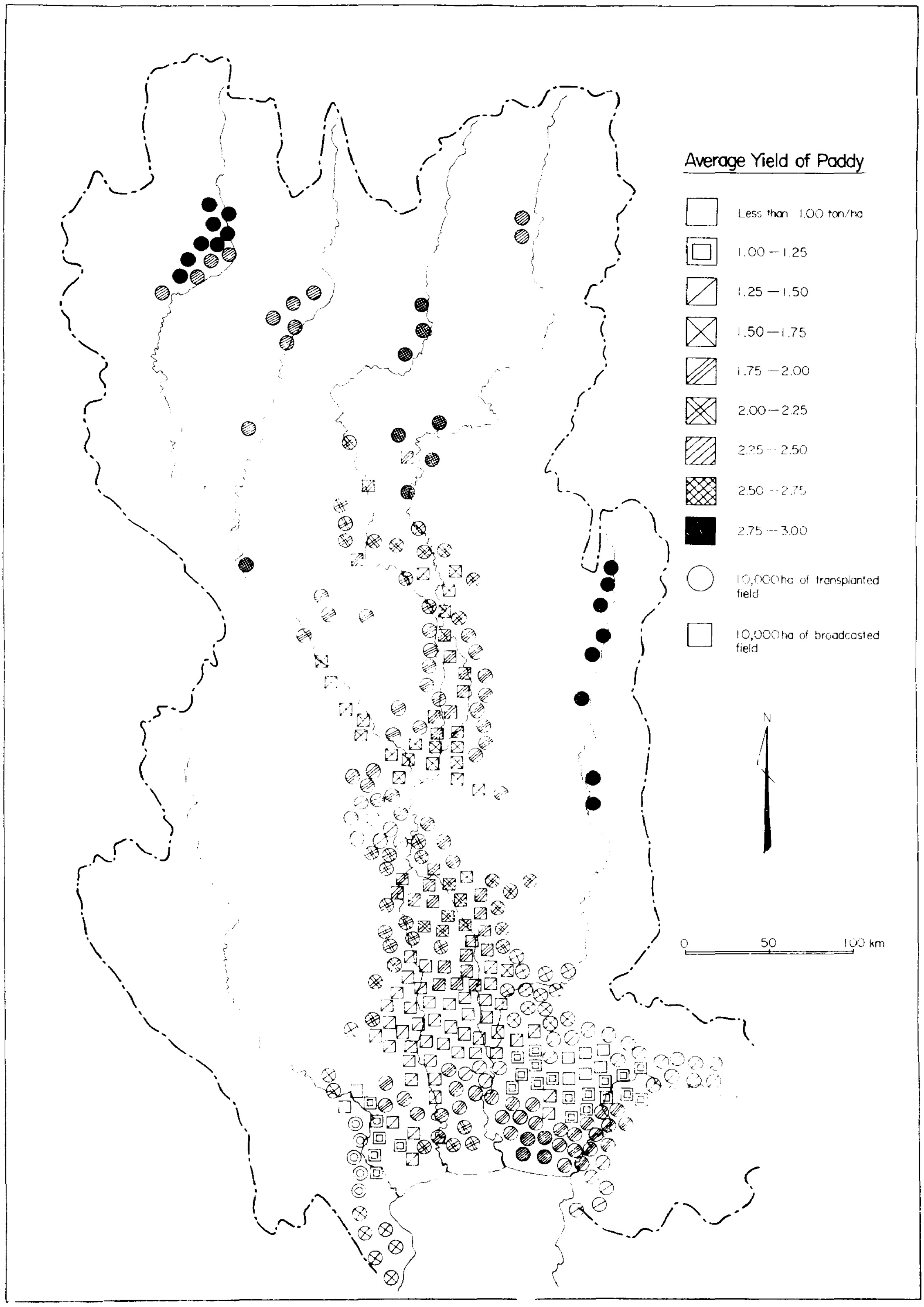

Fig. 5 Map Showing Average Paddy Yields in the Chao Phraya River Basin (drawn by H. FUKUI, based on the "Annual Report on 1964 Rice Production in Thailand", and the "Census of Agriculture, 1963")

the *old delta* also give good yields for mainly the same reason. Strong acidity in the brackish alluvial soil accounts for the lowest average yields in the *delta flat*.

The transplanting method is dominant in the remaining two thirds of total paddy area in the Chao Phraya basin. The highest yields are attaind in the *intermountain basin*, followed by the coastal *deltaic high* region. The high yields in these regions can be attributed to stable water conditions and to high soil fertility. In the *intermountain basins*, various intensive cultivation techniques unique to the region are observed. The yields of transplanted fields in the *fan-terrace complex area* and the *old delta* vary greatly, mainly according to prevailing water conditions. Chronic water shortages and generally low soil fertility account for low yields.

The average paddy area per farm family is partially a function of land productivity; the higher the yield, the smaller the paddy area per farm family. As shown in the accompanying map, total paddy produciton per farm family does not seem to be related so much to environmental conditions as to the following two factors. One is relative proximity to the centers of consumption and exportation, and the other is the existence of crops other than rice in the neighborhood. Except for some areas in the marginal zone, the former seems to be the dominant factor determining paddy acreage and production per farm family unit.

One can conclude that regional variations in productivity per unit area and per unit labor in the Chao Phraya basin are roughly explained by two things: environmental factors, such as topography, water, and soil, the relationship of demand to marketable production. Areas having higher yield levels, more intensive cultivation and/or more favorable physical conditions do not necessarily coincide with the major rice producing areas.

Regional division

The rice land of the Chao Phraya basin has here been divided into six regions in terms of environmental and other aspects of present rice production. Description of each individual region is here omitted in order to avoid repetition of what has been stated previously. A map and a table are appended which give the regional divisions and summarize relevant production features and environmental conditions in each area.

Section IV HYV Dissemination Possibilities in the Six Regions of the Chao Phraya Basin

In the traditional irrigation area

In this area the drainage of water to avoid both excessive water depth and prolonged submergence can be managed relatively easily thanks to favorable topographical conditions. In most of the area, the water supply is ample and dependable, or at least potentially is so. A gravity water distribution system is also well developed.

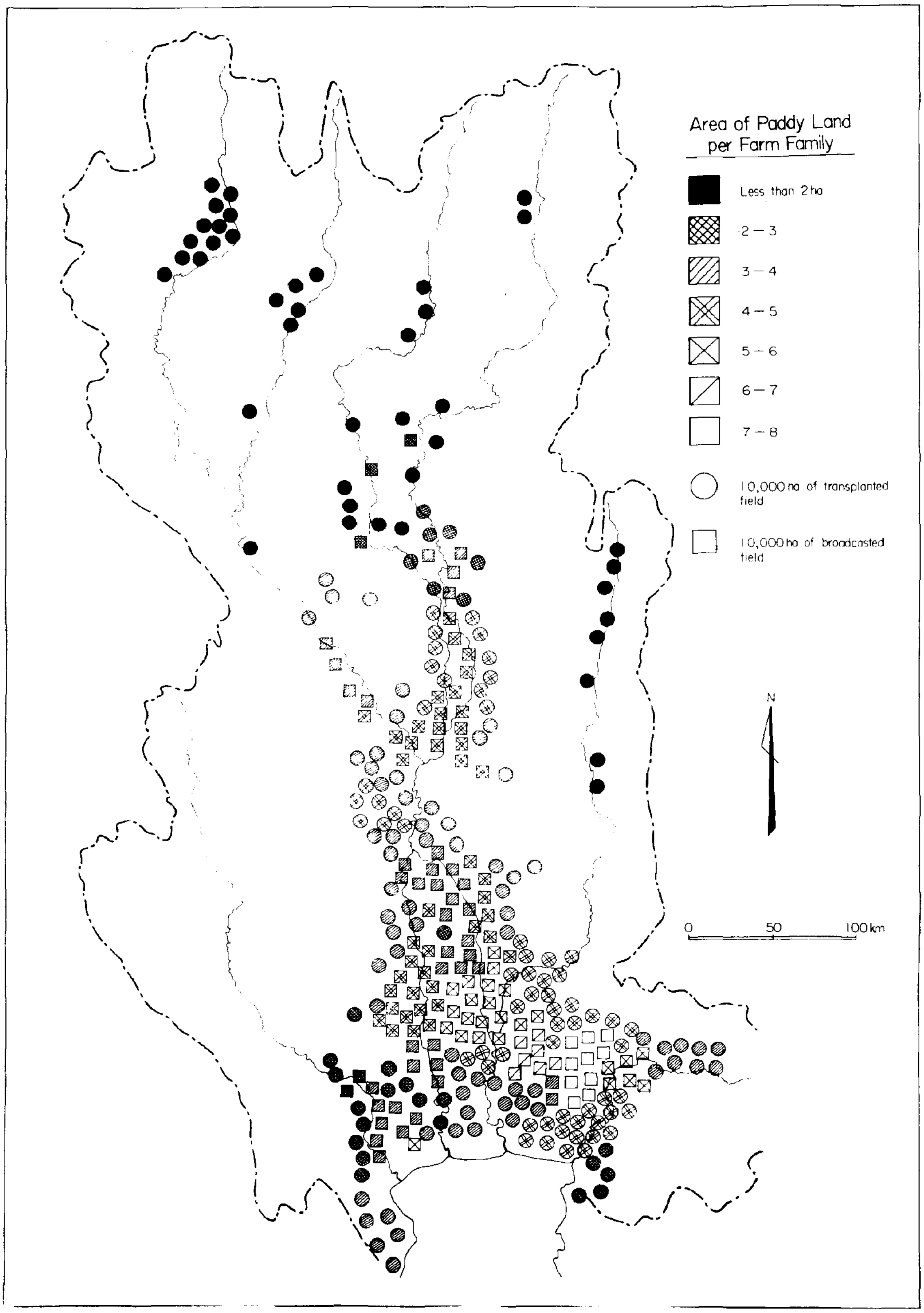

Fig. 6 Map Showing the Area of Paddy Land per Farm Family in the Chao Phraya River Basin(drawn by H. FUKUI, based on the "Census of Agriculture, 1963")

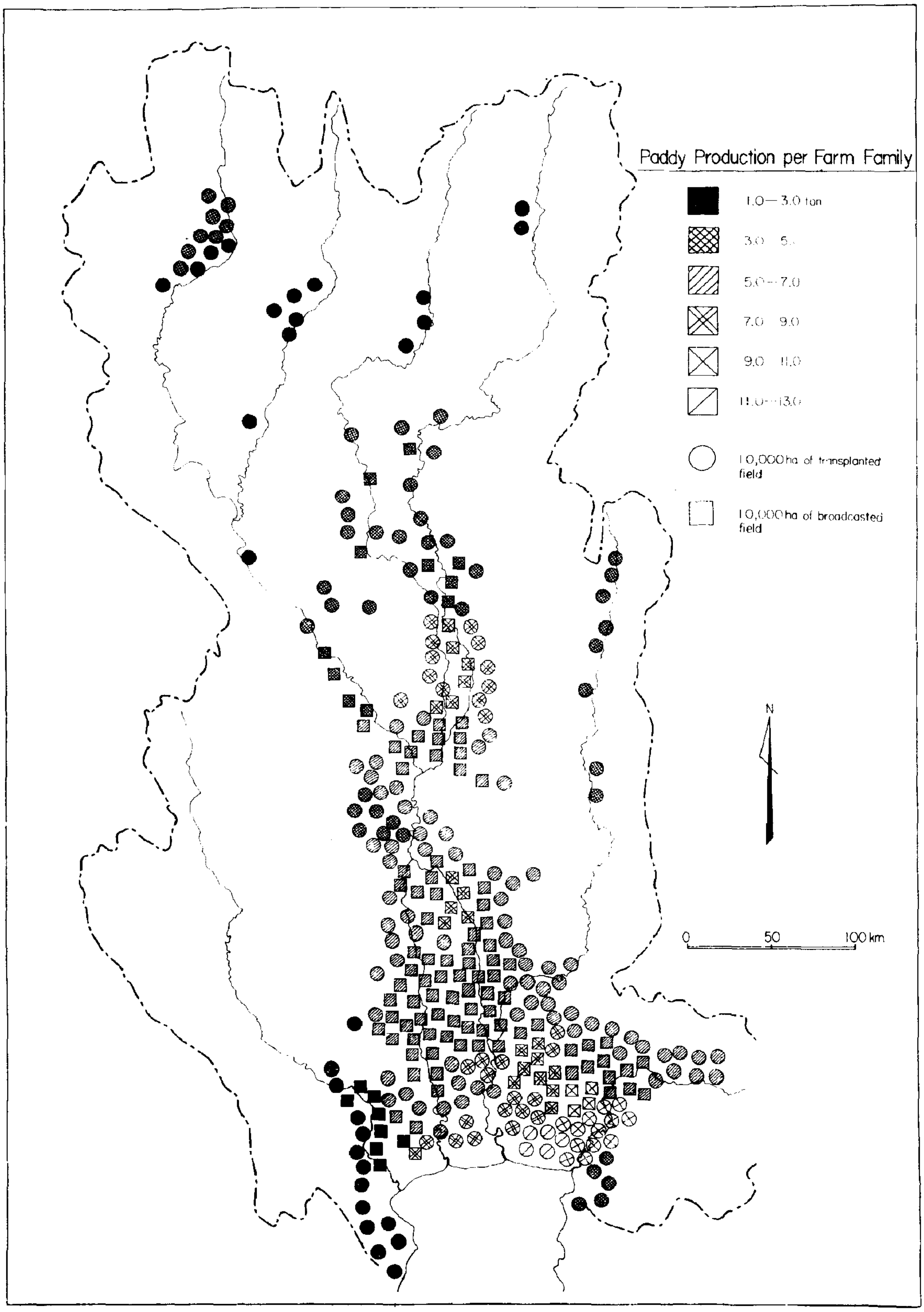

Fig. 7 Map Showing Paddy Production per Farm Family in the Chao Phraya River Basin (drawn by H. FUKUI, based on the "Census of Agriculture, 1963")

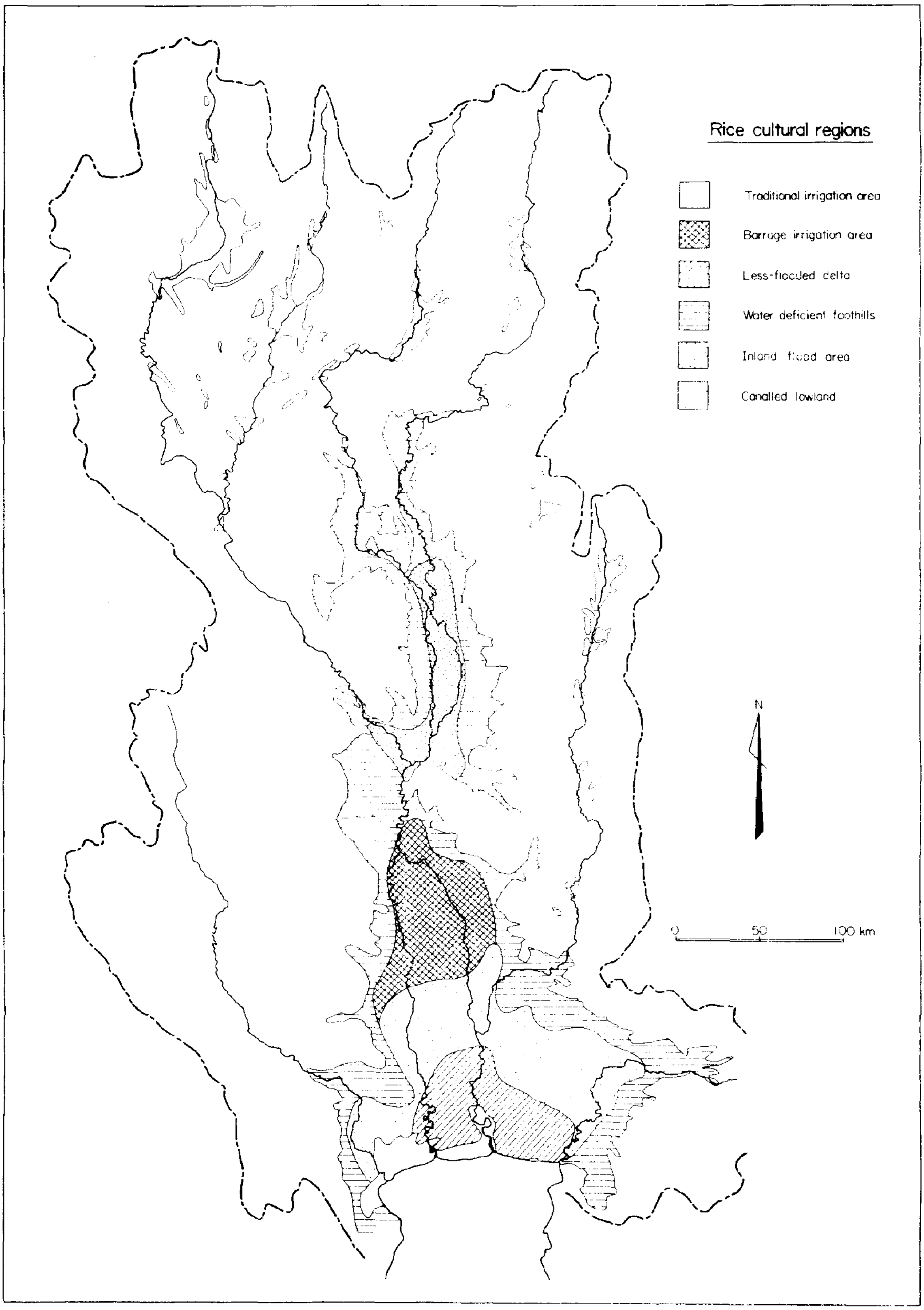

Fig. 8 Map Showing Rice Cultural Regions in the Chao Phraya River Basin (drawn by H. FUKUI)

Table 1 *Regional Division of the Chao Phraya Basin*

Rice-cultural regions	Physiography	Water conditions		Soil fertility		Transplanted /broadcast	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	Intermountain basin	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	Gravity Irrigation	Communal: Effective Ineffective	Riverine Alluvial Soils	Low	Transplanted	1. 0–2. 5	3–4	2–7	1, 310
Inland flood area	Plugged river channel area	Conservation Irrigation	Uncontrolled	Riverine Alluvial Soils	Medium	Broadcast	1. 5–2. 0	4–5	6–8	200
Barrage irrigation area	Old delta	G. I.	Governmental	Riverine Alluvial Soils	Medium	Transplanted	1. 8–2. 2	3–4	5–7	80
		Conservation Irrigation	Uncontrolled	Riverine Alluvial Soils	High	Broadcast	1. 8–2. 2	3–5	6–8	310
Canalled lowland	Delta flat	Conservation Irrigation	Uncontrolled Controlled	Brackish water Alluvial soils	Low	Broadcast	1. 0–1. 5	5–7	6–10	750
Less-flooded delta	Deltaic high	Conservation Irrigation	Controlled	Marine Alluvial soils	High	Transplanted	1. 8–2. 5	3–4	7–12	280

Thus, there are no physical obstacles to deter the dissemination of HYVs. But in order to carry out dissemination over the entire region, medium- to small-scale reservoirs and/or diversion barriers with aninter-connecting canal system are necessary. Peripheral parts of the *intermountain basin* can be then be irrigated.

In the water deficient foothills

Just as in the *traditional irrigation area*, excessive water can here be easily prevented. But water shortage is a more or less chronic hazard of the region. Water shortages in this region occur in the following two ways. One is a lack of water at the beginning of the growing season. If water is not available for 120 days before the time of water recession, HYVs cannot be planted. Day-length sensitive NVs, however, can mature within shorter period. Therefore, in areas where the coming of rain water tends to be late, NVs can be grown safely, while HYVs cannot.

The other type of water shortage in this region is caused by droughts after planting. In areas where the crop is likely to suffer from this kind of water shortage, HYVs may be adopted but the yield, as explained previously, will be low.

Therefore, in the case of the first type of water shortage, that caused by delayed rains, dissemination cannot occur. And in the case of the second type of water shortage, that caused by post-planting drought, successful dissemination is unlikely.

There are two ways to supply water to this region. By one, water can be diverted from a barrage constructed at the main river and transported along through adjacent foothills by a system of canals which parallel to topographical contour lines. By this methods, water supply can be made dependable, but the area that can be irrigated is restricted to the relatively low elevation areas of the zone transient between the alluvial fans and the low-lying plain. An existing example of this type of irrigation is the Chai Nat barrage. Canals fed by this barrage supply water not only to the *old delta* but also to some *water deficient foothills* to the east and west of the *old delta*. Similar projects are being planned and some are under construction. The major one to be completed in the near future is the Meklong project. Parts of the *water deficient foothills* along the Nan river will also be supplied with water from a storage dam being constructed.

Areas which cannot be served by this type of barrage-canal system must be supplied with water by the other method: the collecting of water from local streams. But this presents a major difficulty. The streams is undependable, being much affected by the erratic geographical and seasonal distribution of rainfall in the area.

In the inland flood area

Under present conditions in this region, HYVs cannot be adopted at all because of the excessive water depths and/or sudden rises in water level that occur early in the rainy season. A storage dam now under construction on the upper Nan river will be able to improve this unfavorable situation only to a limited extent. This dam is intended mainly to stabilize river flow in the Greater Chao Phraya Project area south of Chai Nat and to supply water to some of the *water deficient foothills* along the Nan river. As water from surrounding foothills will be drained into this region, the situation eventually to prevail will be similar to that of the depressional part of the *barrage irrigation area* and the northern part of the *canalled lowland*: that is, it will become a water trashing area.

In the barrage irrigation area

Depressions in this region as well as in neighboring regions, here included in the *canalled lowland* region are planted with deep water rice. The problem of deep water in these areas will not be improved by the construction of facilities to drain water from the higher parts of the *barrage irrigation area*. In fact, it will be physically impossible for HYVs to be planted here.

In higher elevations, further water supply improvements, including construction of drainage ditches, are necessary before rice can be assured a submergence of fixed duration. Though both gravity irrigation and drainage are possible, they cannot be managed by individual farmers, as precise alignment of ditches and control of water balance over the entire region are needed. Improvements until now have been aimed at the stabilization of water conditions for NVs. Further improvements are indispensable for the adoption of HYVs. These would depend on the refinement of present water control facilities.

In the canalled lowland

As stated before, the northern part of this region, bordering on the *barrage irrigation area*, offers no hope of HYV dissemination. The rest of the region is not so deeply flooded as the water trashing area, but it is still too deep for HYVs. Excessive water depth and too long a duration of submergence could be overcome only by poldering.

There are two kinds of polders. One can scarcely be called a polder in the strict sense. Piles of earth excavated for various purposes, such as canals, roads, and railroads, form polder-like high dikes, each of which surround quite a large area. This type of polder cannot guarantee the water conditions needed for HYVs.

The other kind of polder is one in the true sense of the word. The area of each polder rarely exceeds a few hectares and is cultivated quite intensively with high-value crops such as vegetables and fruits. The successful cultivation of HYVs is theoretically possible in these pump-equipped polders. There is no technical obstable to such polders being built on farmers' own initiative. Whether or not such polders will actually be used for HYVs, however, seems to depend on construction costs and anticipated profits from using them to grow HYVs. It is still too early to count on HYV dissemination by poldering.

In the less-flooded delta

In this region time of planting is the problem which demands the most careful consideration in connection with possible HYV dissemination. Three periods of HYV cultivation are conceivable:

(1) May/June planting and August/September harvesting,

(2) August/September planting and November/December harvesting, and

(3) November/December planting and February/March harvesting.

The area where the first period is possible seems limited because of the relatively small area where water availability is assured for such an early rainy season planting. In cases where water is available, however, excessive water depth is unlikely because the crop is harvested before the time of maximum water depth which occurs in October. But various inconveniences accompanying reaping and other operations during the rainy season would have to be overcome.

The second period offers the advantage that possible damage by excessive water depth is avoided by making the time of maximum water depth coincide with the time of maximum plant height. However, this method is not practical unless the field is drained at the time of planting in August or September. Drainage at this time of rainy season seems possible only in a limited area. Furthermore, drainage is difficult without the well organized collaboration of farmers, since the water control of individual patches of fields is practically impossible without complete poldering. Water might still remain in the field at harvest time and might cause trouble in reaping, but the other operations could be carried out without difficulty thanks to dry weather in December.

The area potentially capable of employing the third period seems also limited, partly because of the difficulty of carrying out drainage at the end of the rainy season and partly because of the difficulty of obtaining enough water during the dry season. This period, however, does give a crop the decided advantage of receiving greater solar radiation throughout the growth period.

Using any of the three periods discussed briefly above, the area of potential dissemination of HYVs seems limited. Complete poldering is necessary for HYVs to be adopted widely in this region too.

Modification of water balance in the deltaic plain

Water control projects thus far completed or about to be undertaken in the near future will not basically alter the water balance of the basin. If the plain could be freed from annual flooding, the agriculture picture would change drastically. The water trashing area would disappear and the cost of poldering would be greatly reduced.

The elimination of flood water from the deltaic plain can be achieved by the following: (a) the construction of reservoirs upstream, (b) the complete diking of all water channels, (c) increasing the drainage capacity of rivers, and (d) the construction of by-passes to drain water directly to the sea. The combination of two or more of these measures is technically and economically more feasible than the adoption of any one single measure. In the case of the Chao Phraya basin, several alternatives have but recently come under consideration. However, practically speaking, the complete elimination of flooding seems impossible. Present proposed plans indicate the inevitability of a water trashing area in combination with a large area maintained by conservation irrigation.

Section V Conclusion

Environmental conditions affect the dissemination of HYVs in various ways. It seems impractical to classify environmental conditions simply according to their relative suitability to the dissemination of HYVs. While certain conditions will totally deter dissemination, others may permit it but with yields unexpectedly low in view of the high yield potential of HYVs strains.

Generally speaking, HYVs will doubtless eventually be disseminated in the areas where gravity irrigation and drainage are possible. Whether such dissemination will be successful or not is dependent primarily upon potential water supply and the topographical conditions determining relative difficulty of gravity irrigation and drainage. In the Chao Rhraya River basin, gravity irrigation is possible in three regions: the *traditional irrigation area* of the *intermountain basin*, the *water deficient foothills* of the *fan-terrace complex area*, and the higher elevation areas of the *barrage irrigation area* on the *old delta*.

It seems most likely that the *traditional irrigation area*, with a total rice land of ca. 320×1,000 ha, will be disseminated with HYVs thanks to the high potential availability of water and the relative easiness of its distribution and drainage. Actual dissemination seems influenced more by factors other than environmental ones: namely, the seemingly smaller demand for marketable surpluses, due partly to remoteness from the consuming center, and the fact that glutinous rice is the main produce of northern Thailand.

Water deficient foothills occupy quite a large area and include a total rice land acreage of ca. 1,310×1,000 ha. Although its topography is suitable for irrigation and drainage, actual available amounts of water are very limited. HYVs will perhaps be adopted here; but their yields cannot be expected to be as high as their potential yield ability would suggest, because fear of drought will prevent the investment of a large amount in fertilizer inputs. Given the anticipated limited amount of fertilizer application and the generally poor inherent soil fertility of this region, HYVs and NVs should remain competitive here. The portions of paddy land in this region supplied by water from barrage-canal systems are places where HYVs can be successfully adopted.

Gravity irrigation and drainage is possible, but more difficult, in the higher elevation areas of the *barrage irrigation area* than in the other two regions just mentioned. Though the water supply here is abundant and becoming more dependable thanks to the construction of reservoirs upstream, facilities for irrigation and drainage must be further improved for HYVs to be successfully disseminated. HYVs could potentially be disseminated in the areas where rice growing by transplanting is presently practiced ; this covers an area ca. $80 \times 1{,}000$ ha.

Where gravity irrigation is impossible due to flat topography, HYV dissemination is practically impossible, even where flood water is controlled by conservation irrigation. In the Chao Phraya basin, conservation irrigation has been well developed and will be further improved and enlarged. Most of the *less-flooded delta* and about two-thirds of the *canalled lowland* are covered by this type of irrigation. In these areas, complete poldering is indispensable for the widespread dissemination of HYVs. But the construction of polders, while technically feasible, is economically impractical for relatively less valuable crops such as rice. Even conservation irrigation is impossible in the water trashing areas of the *canalled lowland* and *barrage irrigation areas*. Water conditions in the *inland flood area* are similar. As the drainage system of higher places is made possible only by sacrificing these lower ones, dissemination seems totally impossible. Only by drastically modifying the water flow of the whole Chao Phraya River system could the general water supply and rice production conditions of the low-lying plain be improved. The completion of such a project lies in the distant future ; yet even then, the complete elimination of floods is not to be expected.

As implied by the foregoing, paddy fields are distinctly different in deltaic and in non-deltaic regions. This is true also in their potential for HYV dissemination. Although the non-deltaic area is not the major rice producing region, cultivation practices there seem more labor intensive. Where inherent soil fertility is low, as is often the case in the non-deltaic region, farmers tend to react to the situation by increasing their consumption of fertilizer. Thus rice cultivation in the non-deltaic region already seems to have become more intensified. While the degree of intensification is dependent largely on environmental conditions, HYVs offer a further new and great potential when intensification reaches a more advanced stage.

In the deltaic area, rice cultivation is quite extensive and stable, thanks to natural flooding and the modification of conservation irrigation. Except for the *canalled lowland*, yields are quite high due to generally rich soils. The deltaic region forms the "rice bowl" of Thailand. However, intensified rice cultivation, including the adoption of HYVs, seems extremely difficult here.

Methodology similar to that used in this study is being applied in dividing other river basins of continental Asia into rice cultural regions. It cannot be said with certainty how well the regional division of other river basins will be correlated to that of the Chao Phraya River. However, the writer believes that the two broad categories of rice growing areas, deltaic and non deltaic, will become evident there too. Clear differentiation between the two regions seems meaningful, not only in studying the possible dissemination of HYVs, but also in laying over-all plans for agricultural development.

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