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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Gerhild Boje-Klein[1]

ABSTRACT

The available data on problem soils (saline, sodic, acid sulfate, and organic soils) in South and Southeast Asia are assessed to focus rice breeding for adverse soils tolerance on areas with the greatest potential and demand. The information presented for each country consists of definitions, classification (according to national or international systems), extent, and, wherever possible, a map. The relevance of problem soil classification to rice culture is also considered. Information on general land use in the areas concerned, current and potential utilization for rice cultivation, the rice growing environment, management of the problem factor(s), and future land-use plans is given.

Recent soil maps show saline, sodic, acid sulfate, and organic soils occupying about 58 million ha in South and Southeast Asia. Those soils generally unsuitable for rice cultivation are excluded, as are soils with relatively favorable conditions where adverse soils tolerance is not essential. Furthermore, the demand for rice cultivation on problem soils is limited by various factors, so that the potential areas for adverse soils-tolerant rice varieties including areas where such rices may be grown during a land reclamation phase total roughly 23 million ha. The largest potential areas for saline and sodic soil-tolerant varieties occur in India and Pakistan, those for acid sulfate soil-tolerant varieties in Vietnam, and those for organic soil-tolerant varieties in Indonesia.

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Among problem soils, saline, sodic, acid sulfate, and organic soils were selected for their potential suitability for wetland rice cultivation. Development of high-yielding rice varieties tolerant of these soils holds promise for increasing rice production in handicapped areas. Breeding activities should focus on regions in South and Southeast Asia having the greatest demand and the greatest potential. Bhutan and Laos are excluded from this discussion because none of these problem soils occur there.

Saline, sodic, acid sulfate, and organic soils are dealt with as general soil types. Their variability with regard to single or multiple stress factors (nutrient deficiencies or toxicities) is not considered because of the lack of information on location-specific stress sets and their extent. Research on principal stress combinations has been carried out by Akbar and Ponnamperuma (1), HilleRisLambers (3), and Neue and Singh (5).

Soil data are recorded on a country basis and are not always comparable. In some countries not all of the four problem soils are recognized and mapped on a national level. Sometimes problem soils are mapped only in association with either nonproblem soils (e.g., saline-nonsaline soils) or other problem soils (e.g., saline-sodic soils). Overlapping of problem soils is common in dry areas (saline-sodic soils) as well as in coastal regions (saline-acid sulfate-organic soils in various combinations).

For each country, the definition, classification, and extent of problem soil areas are given according to the most recent suitable national soil map. The extent is not equivalent to future riceland. The suitability of these soils and their environments for cultivation of at least one rice crop per year is variable. Three categories may be recognized:

- nonrice problem soils, where limitations are very severe and inhibit rice cultivation;
- problem rice soils, where slight to moderate limitations could be compensated by adverse soils-tolerant rice varieties; and
- nonproblem rice soils, where adverse soils tolerance is not essential.

The most important constraint for wetland rice cultivation on saline, sodic, and acid sulfate soils is lack of water (or poor water control). The adverse effects of these soils are secondary and appear only when the water supply is inadequate for rice cultivation. Under abundant water (from irrigation or monsoon rains), soil problems disappear and the areas become most suitable for wetland rice. But, because monsoon rainfall is variable, adverse soils tolerance is still required in large areas.

For the assessment of the potential areas for adverse soils-tolerant rice varieties, information on the actual and future land use of problem soil areas was gathered. The present situation is outlined by data on general land use, utilization for rice cultivation, rice growing environment, and management of the problem factors. Some special requirements from adverse soils-tolerant rice varieties in different countries are mentioned, but others must be determined in detail by plant breeders.

Two prospects for the cultivation of adverse soils-tolerant rice varieties exist. Besides the demand for long-term annual cropping of problem soil areas, such rices are also favored as a temporary land-reclamation crop. Alternative plans considered by various countries are discussed.

CLASSIFICATION OF PROBLEM SOILS

Although the terms saline, sodic, acid sulfate, and organic soils are very general, their definition and classification are distinctly different among countries. Several qualitative (national or state soil series, based on soil morphology) and quantitative (Soil taxonomy [9] and FAO-Unesco legend [7]) systems as well as transitions (correlations of both) are used. In the last decade there has been a tendency to adopt the international classification systems. The ASEAN countries decided in favor of Soil taxonomy, while Burma uses the FAO-Unesco legend.

The soil names of international terminologies (which are given preference in the case of correlations) are explained in the following paragraphs, while the national or state soil series are discussed in the country reports.

INTERNATIONAL NOMENCLATURE

The FAO terms for soil units and phases derive directly from the legend of the FAO-Unesco soil map of the world (7).

Soil taxonomy (9) follows a hierarchical system (order, suborder, great group, subgroup, family, series, and soil type). The soil names are composed of formative elements at the different levels, the last syllable referring to the order, the penultimate syllable to the suborder, and the first one or two syllables to the great group to which the

soil belongs. Subgroups are indicated by an adjective preceding the term. For easier understanding of the relevant parts of the terminology, a simplified version in common language is used.

Information from sources other than Soil taxonomy and the FAO system is noted in this paper.

Saline soils

Because methods of determination and standards for saline soils are diverse among countries, the World map of salt-affected soils by the International Soil Science Society cannot present a uniform picture (4). Also, FAO and Soil taxonomy use different systems. With FAO the degree of salinity is expressed as the electrical conductivity (EC) of a saturated soil paste. The lower limit is 4 dS/m (International System of Units [SI], equivalent to mmhos/cm). Classes are: 4-8 = slightly affected, 8-15 = moderately affected, and >15 = strongly affected soils (2). In Soil taxonomy, the salt content (weight %) is the decisive criterion.

The typical saline soils are Solonchaks or Salorthids. The diagnostic property of Solonchaks is high salinity (EC > 15) at some time of the year within 125 cm in sandy soils, 90 cm in medium-textured soils, and 75 cm in clay soils (or topsoil salinity in strongly alkaline soils). Solonchaks are weakly developed soils and commonly have an accumulation of $CaCO_3$ or gypsum in the subsoil. Gleyic Solonchaks show signs of waterlogging within the upper 50 cm.

Although the concept of Salorthids is much narrower, their description as *very salty soils in wet places in the desert* is rather similar. Salorthids have a salic horizon ≥ 15 cm thick with at least 2% salt (the thickness multiplied by the salt content must be 60 or more). Their occurrence in arid regions is marked by the order Aridisols (*-ids*), while the penultimate syllable *-orth-* refers to only limited soil formation by weathering and to accumulation of salts and Ca. *Sal-* indicates the presence of the salic horizon within 75 cm of the surface.

Gypsiorthids are grouped with saline soils in some countries but should be excluded because of distinct differences in properties and behavior.

With modifications of the criteria for saline horizon, Salic subgroups are established in Chromusterts and Pellusterts as well as in Natraqualfs in India. The first two are Vertisols (clay soils with deep cracks when dry) in an ustic climate (with alternating wet and dry seasons, i.e., the monsoon climate in tropical and subtropical areas). They are differentiated by soil color into dark brown (Chrom-) and dark grey to black (Pell-) types. Natraqualfs are sodic soils and are discussed in the following section.

Because salinity also occurs in a wide range of other soils, provision is made in a saline phase overprint on the FAO soil map. The saline phase is defined by EC values higher than 4 dS/m within 1 m of the surface. Seasonal variations are considered. The saline phase is applied mainly in Fluvisols (recent alluvial soils) and Gleysols (waterlogged soils). The respective units are Eutric (fertile) and Calcaric (Ca-rich) in both, as well as Humic (topsoil high in organic matter, acidic) Gleysols.

In the same manner the saline phase is recognized and attached to Soil taxonomy terms in India. Generally it is present in Hydraquents (soft mud soils tidally flooded), Fluvaquents (very weakly developed wet floodplain soils), Haplaquepts (slightly more developed soils characterized by intense waterlogging), Halaquepts (principally sodic soils, discussed in next section), and Camborthids and Calciorthids (soils of arid regions with the formation of only a slightly altered horizon or accumulation of carbonates in the subsoil, respectively).

The saline phase is also common in acid sulfate and organic soils (the appropriate terms are explained subsequently).

Sodic soils

The classical sodic soils — Natrargids, Natrustalfs, and Natraqualfs — are characterized by a natric horizon. This is a subsurface horizon with clay accumulation, having a columnar or prismatic structure and an exchangeable sodium percentage (ESP) exceeding 15. The latter corresponds to severe alkalinity (pH >8.5).

For sodic soils in dry regions, the climatic factor dominates in the classification (Aridisols). At the suborder level, the clay illuviation (argillic) horizon is recognized and specified as the natric horizon at the great group level.

The presence of an argillic horizon is diagnostic for the order of Alfisols (with slightly acid to alkaline conditions), followed by a subdivision according to moisture regime (ustic = alternating wet and dry, aquic = wet conditions). The natric horizon is again indicated at the great group level. Natrargids are often saline, too, while Natrustalfs are affected to a much lesser extent. In Natraqualfs wetness is due partly to a perched water table above the compact natric horizon.

Halaquepts are sodic soils without a natric horizon. They are weakly developed soils (Inceptisols) with marks of intense waterlogging (aquic moisture regime) and ESP >15 in at least half of the upper 50 cm, decreasing with depth. Some of them are also saline. Efflorescence of Na and other salts on the soil surface is common in the dry season.

Chromusterts and Pellusterts, for which a natric subgroup has been defined, as well as Camborthids and Calciorthids with a sodic phase (ESP >15 in the subsoil), are described in the previous section.

Acid sulfate soils

The terms potential, true, and advanced acid sulfate soils describe successive developmental stages.

In the natural environment of their formation in young mineral or organic sediments tidally flooded mainly by brackish water, only potential acid sulfate soils occur. They contain sulfidic materials (rich in sulfides, more than can be neutralized by Ca), but due to permanent water saturation their pH is about neutral.

When drained, the sulfides are oxidized to form H_2SO_4, whereupon the pH drops sharply. The sulfuric horizon is marked by a strongly acid soil reaction (pH < 3.5) and the presence of straw-yellow jarosite (iron sulfate) mottles (there is a deviation in Vietnam). With time, S is leached downward in the profile by this process.

The FAO-Unesco legend and Soil taxonomy agree on the definition of sulfidic materials and sulfuric horizon but differ with regard to classification. In mineral soils, FAO classes all three types as Thionic Fluvisols (S-containing recent alluvial soils) with either diagnostic property or horizon occurring within 1.25 m of the surface. To differentiate between potential and actual acid sulfate soils, the subunit Thionic Gleysols (for waterlogged soils with a sulfuric horizon within the depth limit) was introduced in Bangladesh and Sabah.

In Soil taxonomy the three stages are clearly distinguished at different levels. Potential acid sulfate soils belong to the order Entisols (the least developed soils), while the others are Inceptisols (weakly developed soils). Their common wet condition is reflected in the suborders Aquents and Aquepts. The presence of sulfidic materials or a sulfuric horizon within 50 cm of the mineral soil surface is recognized at the great group level (Sulfaquents and Sulfaquepts, often with organic topsoils). Those advanced soils with less severe acidity (pH ≤ 4 besides jarosite mottles within a depth of 1.5 m from transition to normal soil conditions) in intertropical regions are classified as Sulfic Tropaquepts.

Organic acid sulfate soils classified with the Histosols are discussed next.

Organic soils

The term Histosol (from Greek histos = tissue) is likewise used in both the FAO legend and Soil taxonomy. Histosols form from more or less decomposed plant residues that accumulate in water. The organic soil materials (having at least 20% organic matter by weight in sandy soils, 30% in clay soils, and intermediate contents in medium-textured soils) are dominant in the upper 80 cm of the soil, either extending down from the surface or cumulatively.

In the FAO-Unesco legend the Histosols are distinguished by their fertility levels as indicated by the soil reaction (Dystric = infertile, acid; Eutric = fertile, non-acid). To specify acid sulfate conditions in Dystric Histosols, a subunit "with Thionic properties" is added in Sabah.

In Soil taxonomy the degree of decomposition is the first criterion for differentiation (low in Fibrists, partial in Hemists, and high in Saprists). Classified at great group level are

- Tropofibrists and Tropohemists, "tropo" indicating a warm climate with even temperature;
- Sulfihemists, having sulfidic materials within 1 m of the surface with potential acid sulfate conditions; and
- Medihemists and Medisaprists, occurring in the midlatitudes in a warm climate with winter and summer seasons, e.g., Bangladesh.

RELEVANCE OF PROBLEM SOIL CLASSIFICATION TO RICE

The relative tolerance of rice for soil salinity and sodicity is much better to investigate than tolerance for acid sulfate and organic soil conditions.

The lower limit in the classification of saline soils (4 dS/m) coincides well with the susceptibility of rice; yield decreases of 10% at 4.7 dS/m, 25% at 5.8 dS/m, and 50% at 7.4 dS/m have been recorded (6).

The criteria for sodic soils (ESP >15, pH of saturated paste >8.5) are low with regard to rice, which can tolerate ESP levels up to 55 and pH up to 9.3. A yield decrease of 50% occurs only at ESP = 80 (I.P. Abrol, Central Soil Salinity Research Institute, India, pers. comm.). The related physical soil problems are not effective in wetland cultivation.

In actual acid sulfate soils, the depth of the sulfuric horizon in the profile, not the tolerance for acidity, is used to indicate limitations for rice cultivation (where present within 50 cm, Sys and Paramananthan, 1984, unpubl. data).

Because of their low bearing capacity, the thickness of organic soils is their most important characteristic relative to rice cultivation.

Saline, sodic, acid sulfate, and organic soils as classified by FAO, Soil taxonomy, and other systems are not generally problematic for wetland rice cultivation, because the problem factors do not necessarily occur within the shallow root zone, nor do they necessarily exist during the wet season (in saline, sodic, and acid sulfate soils). But the classification indicates that salinity, sodicity, and acidity problems will appear when water is inadequate. Because only the lower limits are defined and the terms are open ended, soil problems may be so severe that rice cultivation is impossible.

For a better assessment, local research on the actual conditions in saline, sodic, and acid sulfate soil areas during the rice growing season are required. Because of the major influence of regional hydrological regimes, a direct conclusion from the classifications related to dry season conditions, with tables on plant stresses, is not possible.

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Bangladesh

On the Bangladesh general soil map (2), acid sulfate soils and peat are shown as general soil types, whereas salinity is indicated only as a phase of other floodplain soil units. This map resulted largely from reconnaissance soil surveys in 1964-75 and thus represents soil associations (which are correlated with Soil taxonomy [5] and the FAO-Unesco legend [4]).

The definition of the saline phase agrees with the international standard. Corresponding mapping units are

- no. 4 calcareous grey floodplain soils and noncalcareous grey floodplain soils with some calcareous alluvium and acid sulfate soils: saline (Haplaquepts, some Fluvaquents, Sulfaquepts-Calcaric and Eutric Gleysols, some Calcaric Fluvisols, Thionic Fluvisols, Thionic Gleysols)
- no. 8 noncalcareous grey floodplain soils: part saline (Haplaquepts-Eutric Gleysols)
- no. 10 noncalcareous grey floodplain soils and noncalcareous dark grey floodplain soils: saline (Haplaquepts-Eutric Gleysols)

The extent of saline soils is 1.426 million ha (S. M. Saheed, Soil Resources Development Institute [SRDI], pers. comm.) of which 0.389 million ha occur in the largely unsurveyed Sundarbans under mangrove forest. The subdivision by salinity level reflects dry season conditions:

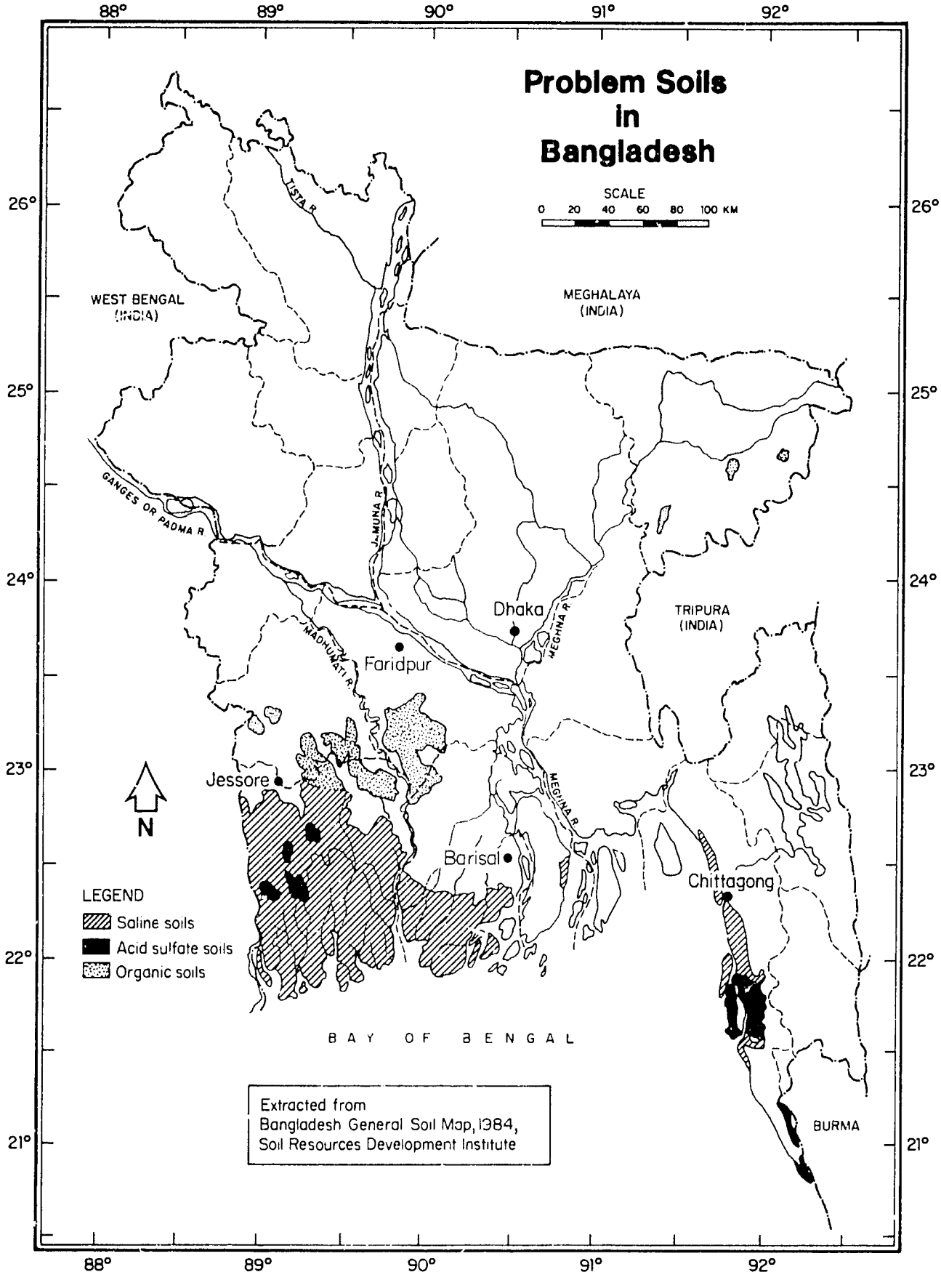
Subdivision	Salinity (dS/m)	Area (million ha)
Slightly saline	4-8	0.605
Moderately saline	8-14	0.256
Strongly saline	>14	0.010
Strongly saline mud area	>14	0.166
Sundarbans, moderately to strongly saline		0.389
		1.426

In the monsoon, soil salinity levels drop below the critical limit of 4 dS/m in most areas (H. Brammer, FAO, pers. comm.; R. Rahman, SRDI, pers. comm.) except in previously strongly saline soils in regional spots, mudflats, and the southwest Sundarbans (S. M. Saheed, SRDI, pers. comm.). Land accretion from the sea in some coastal areas is equivalent to loss by erosion in other parts, so that the shoreline as seen from the 1779 map of Rennel (copy in Soil Resources Development Institute, Dhaka) is relatively stable, as is the extent of saline soils (S. M. Saheed, pers. comm.).

Sodic soils are so minor in extent that they cannot be mapped. Most patches cover only a fraction of a hectare, and many have disappeared during the last 20 yr, having been reclaimed by rice cultivation.

Those acid sulfate soils separately mapped (in unit no. 5, kosh soils) are mainly well developed as Sulfaquepts-Thionic Gleysols, but some potential acid sulfate Sulfaquents-Thionic Fluvisols are included (2). They are saline by nature. On older maps (5) the whole of the Sundarbans are shown to be occupied by acid sulfate soils, but recent surveys in several parts revealed that, due to the influence from the Ganges-Madhumati river system with its Ca-rich waters and sediments, those soils have been neutralized, and only in the westernmost Sundarbans may potential acid sulfate soils have formed (S. M. Saheed, pers. comm.). The acid sulfate soils on the east coast of Bangladesh are presently clear of mangrove and are turning from potential to true acid sulfate soils. The extent of acid sulfate soils outside of the Sundarbans, where they are included in the saline soils, is 0.061 million ha (S. M. Saheed, pers. comm.).

The organic soils, being highly organic and well decomposed, are termed Peat-Medisaprists, Medihemists-Eutric Histosols, and locally Dystric Histosols (mapping unit no. 6 [2]). They are extensive and of considerable depth in basin areas, where on the margins they are usually overlain by a clay topsoil. In this position the soils are perennially wet and deeply flooded during the monsoon, when the basins appear like lakes, as shown on the Rennel map. In wet conditions the soil pH is neutral, but it turns medium to strongly acid if dried (5). The peat area totals 0.425 million ha, of which 0.114 million ha are shallowly covered by mineral soils (S. M. Saheed, pers. comm.).


Problem Soils in Bangladesh
SCALE
0 20 40 60 80 100 KM
88°
89°
90°
91°
92°
26°
25°
24°
23°
22°
21°
WEST BENGAL (INDIA)
MEGHALAYA (INDIA)
TRIPURA (INDIA)
BURMA
BAY OF BENGAL
TISTA R
JAMUNA R
GANGES OR PADMA R
MADHUMATI R
MEGHNA R
Dhaka
Faridpur
Jessore
Barisal
Chittagong
N
LEGEND
Saline soils
Acid sulfate soils
Organic soils
Extracted from
Bangladesh General Soil Map, 1984,
Soil Resources Development Institute

Seasonally saline arable land is traditionally cultivated with rice under flooded, nonsaline conditions during the monsoon (transplanted aman). In the main area in southwest Bangladesh, the land generally lies fallow during the rest of the year, while in the smaller parts of the east coast another rice crop (broadcast aus) or jute can be grown earlier in spring (5).

The permanently saline inland spots occur within the acid sulfate soil area.

In the perennially saline coastal mudflats, efforts are made to stabilize the land by mangrove afforestation, pushing seaward at 12,000 ha/yr. In the back, areas rise above the tidal flood level and merge with the seasonally saline arable land (M. H. Q. Huda, Bangladesh Space Research and Remote Sensing Organization, pers. comm.). The mangrove area in the Sundarbans has been declared a forest reserve so salinity is of no consideration there.

The utilization of acid sulfate soils is related to their dry season (DS) salinity. Strongly saline spots are used for shrimp culture and salt farming, whereas moderately saline land is planted to transplanted aman rice, which gives low yields.

Only part of the organic soils — those with a clay topsoil on the basin fringes — are planted to rice (aus and deep water aman). Areas too deeply flooded (>3 m) or with soils that are peaty throughout (very low bearing capacity) are left under swamp grasses and sedges. Organic soils are also removed and used for fuel.

The demand for increased rice production is strong in Bangladesh, which has an average rice deficit of 1.5 million t/yr. At the same time the population increases 3.5% every year. According to the Master Plan Organization (1), self-sufficiency in food grains is projected for 1990, which may be achieved sooner for rice.

On a national level, problem soils are unimportant relative to the overall soil potential, which has not been fully realized. But, because of the general pressure for more food, an integrated project initiated under the Master Plan Organization (1) will assess development possibilities for arable seasonally saline land in the southwest, which is the most extensive and promising among the group of problem soil areas.

Because only 9% of the country's area is under forest and the mangrove areas in the Sundarbans are strictly protected and unavailable for the expansion of riceland, the desired increase has to come from existing riceland (approximately 0.860 million ha), and additional rice has to be grown in the traditional fallow periods (boro in the postmonsoon or aus in the premonsoon). In some areas two short-duration rice crops or rice followed by an early-maturing dryland crop (e.g., pulses) can be grown without irrigation, but for most of the land, irrigation is essential. Unfortunately, large areas lack fresh water. This is the main development constraint, and of greater importance than soil salinity. If irrigation water is made available in DS (by storage of rainwater or diversion from rivers), the costs involved do not favor its use for rice cultivation but rather for salt-tolerant dryland crops like barley, wheat, or legumes to economize on water consumption (3). Yet the great demand for rice gives it an advantage over other crops. Normal irrigation of rice in DS will prevent soil salinization under local climatic conditions, so salt-tolerant rice varieties will generally not be needed for this region.

Acid sulfate soil areas (0.061 million ha) may be considered for rice culture only if a variety adapted to Sulfaquepts is developed.

In the organic soil area, winter (boro) rice could be more widely grown where there are clay topsoils (0.114 million ha), but tolerance for organic soils is not a principal requirement; purely organic soils are unsuitable for rice cultivation.

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Brunei

The FAO-Unesco soil map of the world shows that a large part of Brunei's area is occupied by organic soils (0.183 million ha, Dystric Histosols). They are associated with Humic Gleysols and include some Thionic Fluvisols (1).

Coastal soil salinity is probably as low and unimportant as in the neighboring Malaysian states of Sabah and Sarawak. On acid sulfate soils, rice is grown in the Mulaut project, with irrigation and liming as amendments (2).

There are also plans for mechanized rice cultivation on 4,000 ha of organic soils (W. J. Burrows, Sinaut Agricultural Training Center, Brunei, pers. comm.). Emphasis is given to optimal management so that the price of rice produced in reclaimed problem soil areas will be similar to or less than that of imported rice. The target is self-sufficiency in rice, anticipating the time when Brunei's oil will be exhausted (2).

A rice variety adapted to organic soil conditions (to be developed in the IRRI-Indonesia cooperation in tidal swamp rice) would be very useful.

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Burma

Although all four problem soils occur in Burma, sodic, acid sulfate, and organic soils do not appear on the Soil map of Burma 1983 (6) because of their small extent.

The saline soils mapped are confined to the Irrawaddy Delta and coastal areas. The Burmese soil classification is derived from the Russian system, which is based on morphology. The diversity in nomenclature (1, 3, 6, and district soil survey reports) is overcome by recent correlation with the FAO-Unesco legend (7).

The saline soils can be subdivided into three types with increasing salinity:

- Saline Gleysols (mapping unit no. 11) occupy the Delta area, which is still influenced by tidal waters (1). Their extent is 0.248 million ha (3). The legend of the FAO-Unesco soil map (8) for this area (Gleyic Solonchak) is not appropriate, because the term Solonchak is part of the Burmese soil classification (3) but in another context. Also, these soils were not originally saline.
- Mangrove forest soils (mapping unit no. 10) are common near the coast. The indication of this area as "Thionic Fluvisol" on the FAO-Unesco soil map (8) is incorrect because these are saline Humic Gleysols (3). They cover an area of 0.707 million ha (3).
- Saline tidal alluvium soils (Saline Fluvisols) occur even closer to the sea. Although they are not recorded on any soil map, their extent is given as 0.292 million ha (3).

Saline soils thus total 1.247 million ha.

Sodic and saline-sodic soils have also developed in the central part of Burma (Shwebo district, etc. in the dry zone), the area of compact alkaline soils being 6.475 ha (3).

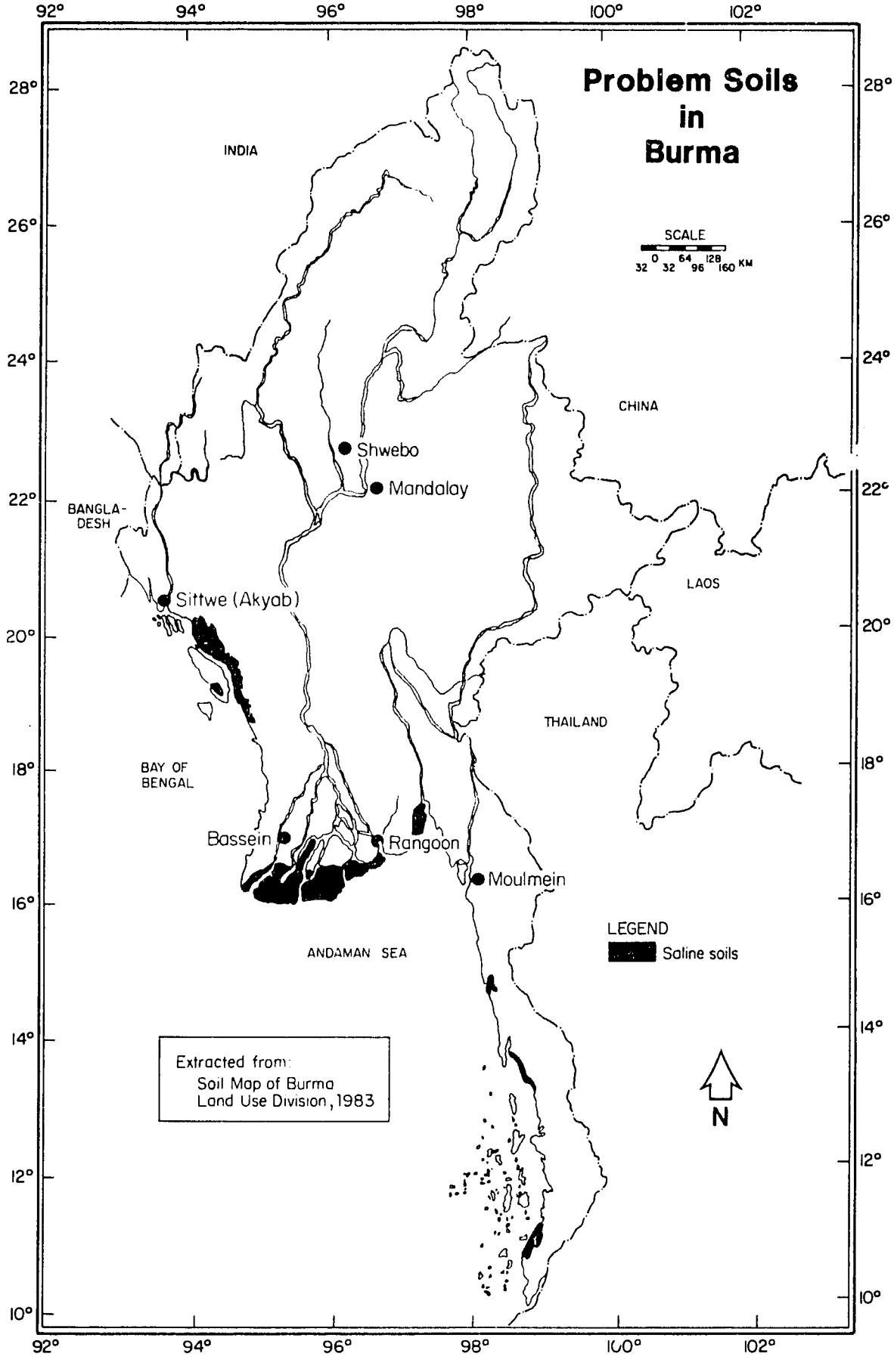
Relevant portions of the Irrawaddy Delta were checked for acid sulfate soils upon special request of the World Bank in connection with a loan for a large embankment project. In local patches accounting for an area of 5,000-10,000 ha, pyrite layers occur buried in the profiles at 1.5-2 m depth (1). Thus, these soils do not even qualify as acid sulfate soils (9); they occur within the saline soils area.

There are only 800 ha of organic soils (called peat, equivalent to Histosols [7]), which border several lakes in the northeast mountain region (5).

The three zones of saline soils differ greatly with regard to land use and rice cultivation. More than half of the saline gley soils area (0.136 million ha [2]) is planted to local salt-tolerant rice varieties under rainfed conditions, yielding 2.2 t/ha (U Hla Aye, pers. comm.). These soils are not regarded as problem rice soils (1).

Although by land-use classification the mangrove forest area (still inundated at high tides) is not suitable for any other purpose, it gets gradually reclaimed with time for rice cultivation. The saline tidal alluvium (with daily inundation by tides) is barren and generally unusable (3). These last two zones have not been considered for agriculture, so the extent of saline soils usually referred to is that of saline gley soils only.

There is an extremely strong demand for increased rice production because of the growing population and the desire for an exportable surplus. Equal priority is given to increasing rice yields on fertile soils and developing rice cultivation on marginal soils. The reclamation of saline soils in the Irrawaddy Delta will be facilitated by the World Bank embankment project. The geological situation -- high rate of sedimentation of nonsaline terrestric materials -- leads to the gradual growth of the Delta seawards by 60 cm/yr and an annual increment in height, which favor natural desalinization. The land reclaimed will be planted entirely to rice. Since 1980, the Applied Research Division of the Agricultural Corporation and IRRI have cooperated in breeding salt- and submergence-tolerant varieties for this region, through which the country's riceland will increase by approximately 1 million ha in the near future


Problem Soils in Burma
SCALE
32 0 32 64 96 128 160 KM
INDIA
CHINA
LAOS
THAILAND
BANGLA-DESH
BAY OF BENGAL
ANDAMAN SEA
Shwebo
Mandalay
Sittwe (Akyab)
Bassein
Rangoon
Moulmein
LEGEND
Saline soils
Extracted from:
Soil Map of Burma
Land Use Division, 1983
N
92° 94° 96° 98° 100° 102°
10° 12° 14° 16° 18° 20° 22° 24° 26° 28°

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

India

Saline and sodic soils occur in various parts of India, interspersed with normal soils, so that they cannot be separately mapped on a small scale (12). They are either part of soil associations (13) or are indicated by cross-hatching (4). A small area of saline organic acid sulfate soils (4, 7, 8, 10, 14) is found in one location.

The soils are classified according to Soil taxonomy (2, 12, 15) at the great group level. Additional Salic and Natric subgroups were introduced with lower requirements in the criteria for salic and natric horizons. Earlier information on salt-affected soils based on Richard's definition (saline = EC >4 dS/m, ESP >15, pH <8.5; sodic = EC <4 dS/m, ESP >15, pH >8.5; both within 1 m depth) is retained and used at the phase level to indicate seasonally affected soils (12).

Saline soils

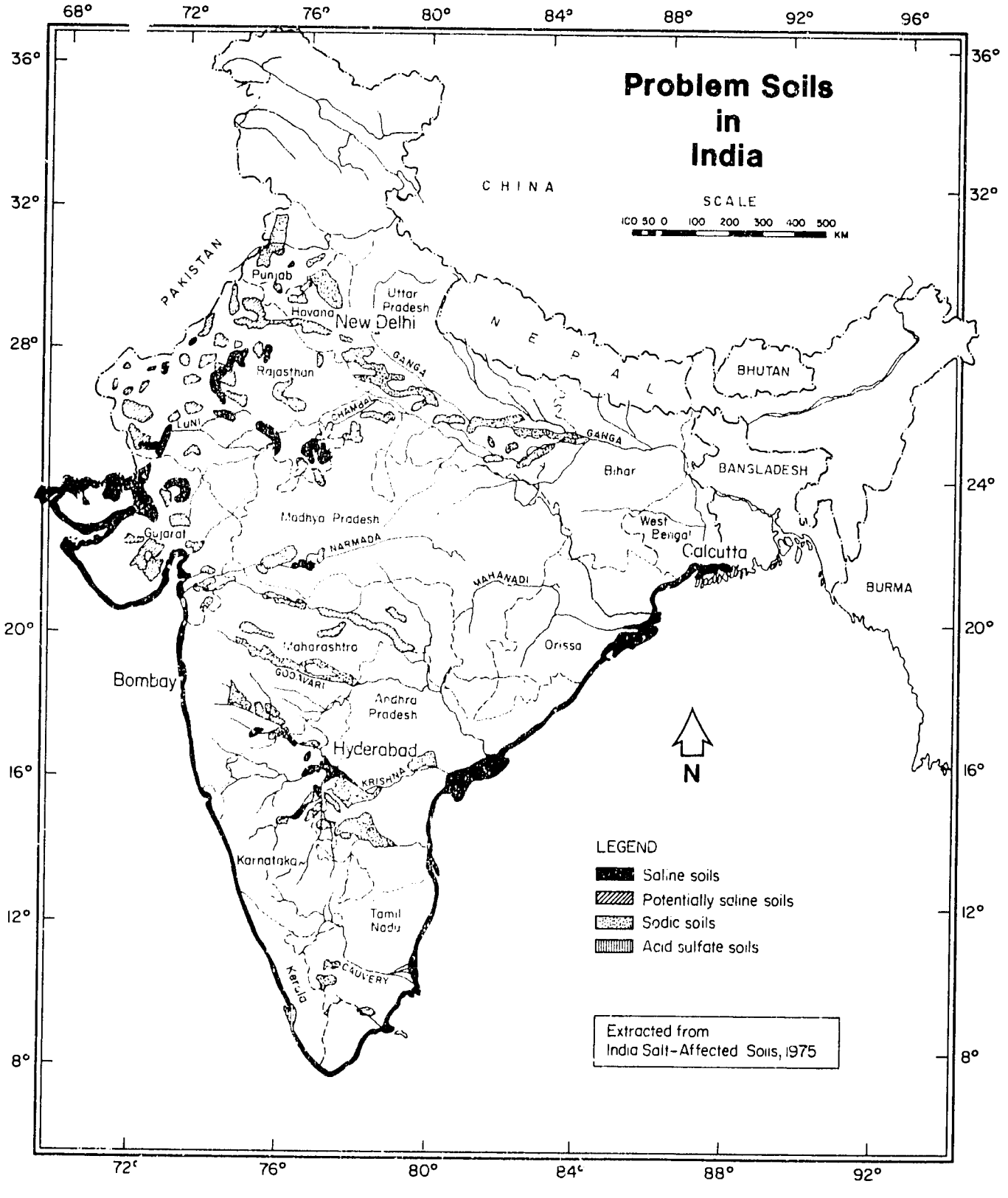
There are three categories of saline soils in India: coastal salt-affected soils, inland salt-affected soils in medium and deep black soil regions, and inland salt-affected soils in arid and semiarid regions. The extent of these 3 is 5.5 million ha (3).

Coastal salt-affected soils. The most common soils are Fluvaquents (saline phase), found in patches along the coastline (12) and in mangrove areas. In the arid region of Gujarat, Salorthids and Natrargids have developed (12). Salic or Natric Chromusterts have formed in basaltic material under semiarid conditions in the deltas of the Godavari, Krishna, and Cauvery Rivers in Andhra Pradesh and Tamil Nadu (2). In the humid climate of West Bengal and Orissa, the deltas of the Ganges and Mahanadi Rivers are partly occupied by Halaquepts (saline phase) (12). The classification of the saline, organic acid sulfate soils in Kerala is unfortunately not conclusive (2, 12).

The distribution and extent of coastal salt-affected soils (16) are as follows:

State	Area (million ha)
West Bengal	0.820
Gujarat	0.714
Orissa	0.400
Andhra Pradesh	0.276
Tamil Nadu	0.100
Karnataka	0.086
Maharashtra	0.064
Kerala	0.026
Goa	0.018
Andaman and Nicobar Islands	0.015
Pondicherry	0.001
Subtotal	2.520
Area under mangrove	0.574
Total	3.094

Inland salt-affected soils in medium and deep black soil regions. Most salt-affected Vertisols occur in the Deccan Plateau, with some in southern Gujarat. The typical soils in this semiarid climate come from basaltic rocks and are Salic, Natric, or Salinatric Chromusterts and Pellusterts (2). Areas where the salts are present only in the lower subsoil but render the soils saline-sodic upon irrigation (raising the groundwater table) are mapped as potentially salt-affected soils and are included in the map. Salt-affected Vertisols (3, 8) occupy 1.42 million ha in the states of Karnataka, Madhya Pradesh, Andhra Pradesh, Maharashtra, and Gujarat.


Problem Soils in India
SCALE
100 50 0 100 200 300 400 500 KM
CHINA
PAKISTAN
NEPAL
BHUTAN
BANGLADESH
BURMA
Punjab
Haryana
New Delhi
Uttar Pradesh
Rajasthan
GANGA
CHAMBAL
LUNI
Bihar
West Bengal
Calcutta
Gujarat
Madhya Pradesh
NARMADA
MAHANADI
Orissa
Maharashtra
GODAVARI
Bombay
Andhra Pradesh
Hyderabad
KRISHNA
Karnataka
Tamil Nadu
CAUVERY
Kerala
N
LEGEND
Saline soils
Potentially saline soils
Sodic soils
Acid sulfate soils
Extracted from
India Salt-Affected Soils, 1975

Inland salt-affected soils in arid and semiarid regions. Different climates are reflected in the degree to which soils are salt-affected. In the arid areas of Gujarat and Rajasthan, Salorthids, Natrargids, Halaquepts, and Gypsiorthids are the dominant salt-affected soils. Under less severe conditions in Punjab, Haryana, and western Uttar Pradesh, Camborthids and Calciorthids (saline-sodic phase) are prevalent (12). Also included are potentially salt-affected soils (4). The extent of salt-affected soils in dry climates (3, 8) is thus 1.0 million ha.

Sodic soils of the Indo-Gangetic plains

The main soil great groups in the Indo-Gangetic plains are Natrustalfs in Punjab and Haryana, and Natraqualfs in western Uttar Pradesh. Part of the Natraqualfs are saline and constitute a Salic subgroup. In eastern Uttar Pradesh and Bihar, as well as in the border areas of Rajasthan and Madhya Pradesh, Halaquepts are the common type of sodic soil (12). The extent of sodic soils in the northern alluvial plains (3, 8) is 2.5 million ha.

Saline organic acid sulfate soils

Saline organic acid sulfate soils are classified with the coastal saline soils. In those acid sulfate soils, reported to occupy 0.5 million ha in West Bengal (A. K. Bandyopadhyay, CSSRI, Canning, pers. comm.) the sulfuric horizon appears at such great soil depth that it is insignificant for agriculture as well as for classification purposes. Only when this material is brought to the surface, as in excavations, does it become oxidized and severely acid. Anyhow, these soils are included in the coastal saline soils.

Utilization

On the coastal saline soils rice is grown as a monocrop in kharif (wet season, Jun-Sep) in all states except Gujarat, where severe salinity remains; in other regions with higher rainfall, salinity levels are low to moderate or even nonsaline under submergence (5). Confined to low-lying areas with poor drainage, most of the land is waterlogged (about 50 cm of water stagnating on the soil surface throughout the cultivation period, making the field inaccessible). The salts there get diluted rather than removed. The acidity in the coastal saline soils of Kerala is also neutralized a few weeks after the onset of the monsoon (3).

Adapted to the local flood pattern, rice is transplanted at the start of the rains in areas with constant waterlogging (e.g., West Bengal) or after the flood peak when the water recedes (e.g., Kerala). In the first situation the problems for the rice plant are salinity in the sensitive early stages, and subsequent waterlogging. The second situation is favorable. Because of the traditional technique of precultivating salt-resistant Pokkali rice on mounds in the fields and transplanting it when soil and water conditions are suitable, the Kuttanand tract is the rice bowl of Kerala (5). Under difficult environmental conditions, traditional rice varieties yielding about 1 t/ha are widely grown. Water is generally inadequate to grow a second rice crop; most areas have saline groundwater (5). Where ponded water is used to irrigate winter rice in West Bengal, the recurrence of salinity in the dry season is prevented and the land is reclaimed (6).

The climatic conditions in the areas of mainly saline and potentially saline soils do not favor the cultivation of wetland rice. Irrigated rice is grown only in river valleys in the Deccan plateau (9). The demand for irrigation is high in that region, where dryland crop yields are not assured. To prevent the potentially saline soils from becoming saline in the root zone, only marginal irrigation of dryland crops is practiced. But in the expanding areas of heavily irrigated cash crops (e.g., sugarcane) waterlogging and salinity problems appear after a few years. Then rice is cultivated, but yields gradually decline. The problem would only be aggravated by the use of salt-tolerant varieties. Adequate drainage is the only remedy but is difficult to provide in these dense clay soils. Rice cannot be grown during the reclamation process because of its high water and drainage requirement.

Some of the saline and sodic soils in the arid and semiarid regions of Gujarat and Rajasthan will be included in the Namada and Rajasthan canal command areas (12), but they may or may not be cultivated with rice. The potentially saline and saline soils in the Indo-Gangetic plains will be reclaimed together with the sodic soils and will come under the rice - wheat rotation common there.

Despite extremely high sodicity (ESP≤80, pH≥10.5) the total area of sodic soils is planned for reclamation. Of the previously barren areas, 300,000 ha have been turned into productive rice or wheat land. With irrigation water supplied by canals or tubewells, the reclamation is begun with rice cultivation. Only on the worst sodic soils do tolerant grasses like *Diplachne fusca* need to be grown for the first 2 yr. Because of their higher sodicity tolerance, traditional varieties are cultivated first, followed by high yielding varieties. Because sodicity is restricted to the topsoil and upper subsoil, the problem disappears in a few years. Rice yields then increase up to 6 t/ha (3, 11). Where faster reclamation is desired or on soils with ESP near 100, gypsum is applied as an amendment to reduce ESP to 30-40 (for wheat). This measure is economically very favorable, because it is a one-time investment and gypsum is subsidized up to 75%.

Sodic soils occur extensively in village common land. For these areas, afforestation techniques have been developed. Fast-growing trees are planted in deep holes filled with improved soil material (1). The final shares of rice and forest in the reclaimed sodic soil areas cannot be determined yet.

Because nearly all the arable land in India is already under cultivation, attention is drawn to the land classified as cultivable wasteland (17 million ha) and barren uncultivated areas (22 million ha). To keep up with the increasing national demand for food crops and other commodities, the target is to bring 5 million ha of these lands into production annually (either as fields, forest, or grassland). The reclamation of saline and sodic soils is preferred, because it is more feasible than that of badly eroded areas, for example. Priority is given to the sodic soils in the Indo-Gangetic plains, which will be important rice soils in the future (3).

Besides the development of reclamation management technology, the Central Soil Salinity Research Institute is also strongly involved in breeding saline and sodic soil-tolerant rice varieties. IRRI varieties are used as parents to add the high yielding components to traditional varieties adapted to local conditions (CSR varieties for both soil types).

On coastal saline soils with a stagnant water regime at the research station in Canning (West Bengal), yields of 4 t/ha under moderate salinity (EC 5-8 dS/m) and 2.5t/ha under high salinity (EC 8-10 dS/m) have been achieved (6). These efforts are aimed mainly at a yield increase on existing coastal riceland.

For an estimation of the potential area for salt-tolerant varieties, the figure for coastal saline soils needs to be reduced. Those soils in arid regions (Gujarat) are unsuitable, whereas the mangrove area will be preserved and is not available for rice cultivation. Because total desalinization in some states is dependent on the monsoon and thus uncertain, these soils may still be considered. Also, in West Bengal and Orissa, with dominantly favorable conditions, salinity is caused sporadically by seawater inundation during cyclones (5).

Affected Vertisols will have to be excluded, as tolerant varieties are disadvantageous with regard to increasing salinity. Where rice is grown after reclamation, salt tolerance is no longer required.

Probably not all or a large fraction of the saline soils in arid and semiarid regions will be reclaimed by rice cultivation.

Altogether, the potential area for salt-tolerant varieties is approximately 2.8 million ha, while high sodicity-tolerant varieties might be used during the reclamation of a maximum of 2.5 million ha.

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Indonesia

The 1976 (4th edition) Generalized soil map of Indonesia (6), scale 1:2,500,000, shows only one of the relevant problem soil types: organic soils. The Indonesian term Organosol is defined by an organic matter content of more than 20% by weight in sandy soils to more than 30% by weight in clayey soils for more than 50 cm depth. This definition is rather similar to that of Histosols in Soil taxonomy (7).

The Indonesian organic soils are generally acid (pH 3-5) and consist mainly of woody material in different stages of decomposition. Organosols are mapped in three units according to topographic position:

- no. 1 plains and tidal plains
- no. 2 basins and valleys
- no. 3 folded, uplifted mountains

Mapping units 1, 2, and 3 have an extent of 27.063 million ha (unpubl. from Soil Research Institute [SRI] files).

Not all these soils can be considered problem rice soils, because some are generally unsuitable for rice cultivation. This applies to mapping unit no. 3, occupying approximately 0.1 million ha at altitudes above 2,000 m. But the far greater and most important areas to be excluded are the thick lowland peats, which were the only type of organic soils recognized and mapped in the past. By definition these are soils with more than 65% by weight organic matter for more than 50 cm depth (1). They cover approximately 17 million ha (4).

The extent of problem soils can only be estimated, because neither saline, sodic, nor acid sulfate soils are mapped at the national level. A further complication is the overlapping of problem soil types in the vast coastal plain areas. Also, the relevant portions of saline and acid sulfate soils among the alluvial soils (18.913 million ha, unpubl., from SRI files) have not been determined. The area delineated by the approximate line of pronounced tidal influence is about 8 million ha, equally shared between Alluvial and Organosol. Only a small portion of this land is probably affected by salinity, since tidal influence is expressed mainly by a fluctuating groundwater table (not necessarily saline water), and salt concentrations are generally very low in this humid region.

Tentative estimates for acid sulfate soils range from 1.5-2.0 million ha (3) to 3.3-4.0 million ha (Driessen, 1976, unpubl. data), apparently referring to mineral, mainly potential acid sulfate soils and partly including those underlying organic soils that do not affect the extent of problem soils.

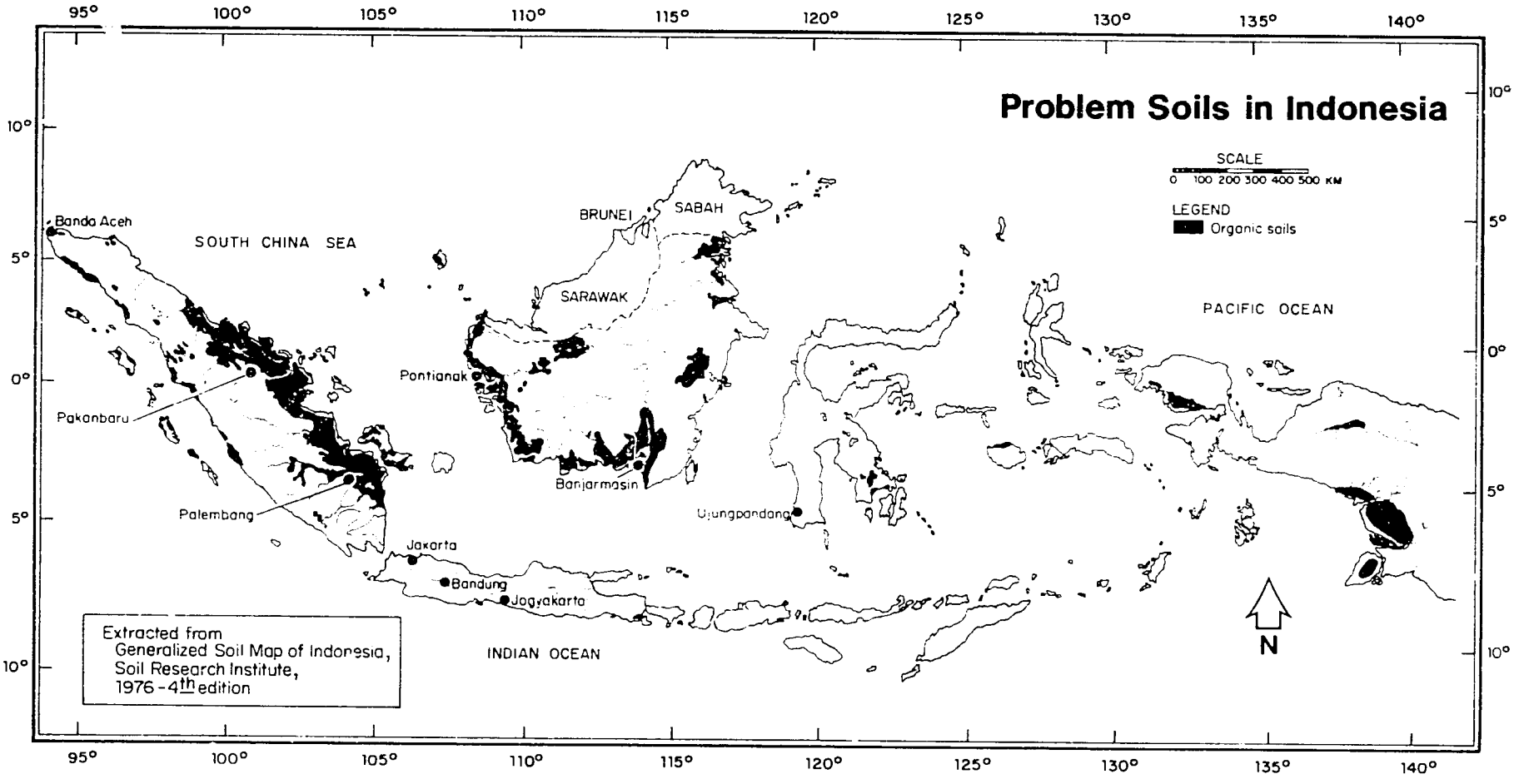
Because of physical soil problems (bearing capacity), the depth limit for rice cultivation on organic soils is close to their depth limit of 50 cm. Naturally, those soils with a higher mineral (plant nutrient) content are more favorable. Their share of 10 million ha may be regarded as the approximate extent of the potential area for organic soil (partly saline, partly acid sulfate)-tolerant varieties (the suitability of a small part of the peat area being compensated by some of the less organic soils unsuitable because of greater soil depth) at the present level of knowledge.

The soils of tidal swamp areas (which have been undergoing reclamation by the Department of Public Works since 1970) present a transition to mineral soils. They are alluvial soils with a 10- to 50-cm-thick organic layer (histic epipedon) over mineral, generally potential acid sulfate soil. Rice occupies 200,000 ha, with local varieties still in use (5). These have a natural salt tolerance of 8-10 dS/m (A.M. Fagi, pers. comm.) and yield 1-1.5 t/ha (5). Farmers have developed an effective system of alternate raised beds, in which upland crops are cultivated, and furrow beds, in which rice is grown (sorjan system) using water control and P fertilizer.

This region is a main target area for breeding rice varieties with adverse soils tolerance as part of the government's transmigration project. In a joint workshop in 1981, IRRI and the Government of Indonesia formulated research priorities for tidal swamp rice (2). Relevant problem soils in tidal lands, the larger coastal plains, and river valleys would be:

- potential acid sulfate soils with an organic surface layer, and
- mineral-rich and moderately shallow organic soils.

Because development of these areas always includes measures of water control, salinity is disregarded as a problem factor.


Problem Soils in Indonesia
SCALE
0 100 200 300 400 500 KM
LEGEND
Organic soils
SOUTH CHINA SEA
PACIFIC OCEAN
INDIAN OCEAN
BRUNEI
SABAH
SARAWAK
Banda Aceh
Pakanbaru
Palembang
Pontianak
Banjarmasin
Ujungpandang
Jakarta
Bandung
Jogyakarta
N
95°
100°
105°
110°
115°
120°
125°
130°
135°
140°
10°
5°
0°
5°
10°
Extracted from
Generalized Soil Map of Indonesia,
Soil Research Institute,
1976 - 4th edition

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Kampuchea

Of the four types of problems soils, only saline and acid sulfate soils occur in Kampuchea.

Although the General soil map of the Kingdom of Cambodia (1) is dated 1963, it shows great conformity with the corresponding part of the FAO-Unesco soil map of the world (4). The legend of the Kampuchean soil map refers to great soil group terms of the 1949 USDA classification system, which is based on soil morphology (6).

The 0.1 million ha of saline soils are part of the coastal complex occupying the narrow coastal plain fringe. The coastal complex consists of two different kinds of soils that occur closely intermixed and are therefore mapped as a single unit (no. 16) — saline alluvial clay soils and regosols on dune sands, with minor inclusions of red-yellow podzols, acid lithosols, alluvials, and alumisols (3). The extent of these soils is 0.213 million ha.

The synonym for acid sulfate soil in Kampuchea is Alumisol (mapping unit no. 9). There is only one main type of this soil present in the country. The standard soil profile description uses other criteria than Soil taxonomy (5), and thus an exact correlation with either Sulfaquepts or Sulfic Tropaquepts (problem or nonproblem rice soils) is not possible. But because rice yields are low on Alumisols, they can be considered problem rice soils. Alumisols occur as minor inclusions on the Mekong plain; as alluvials, cultural hydromorphics, and plinthite podzols; and in the coastal complex and as acid lithosols and grey hydromorphics in coastal areas. They occupy 0.283 million ha.

In the early 1960s most of the area of coastal saline clay soils remained under mangrove bush vegetation, but the 10% under cultivation was planted to rice. Yields ranged from 0 to 400 kg/ha on natural saline soils and reached 800 kg/ha in diked areas after a few years of desalinization (3). The 1982 Huke map of rice area by culture type (2) does not show any rice cultivation in this region.

The acid sulfate soil area was more extensively used for cultivation (1962: 50%), with rice as the main crop, although yield levels were very low (0-1.5 t/ha [3]).

The Soil Commission declared that there was enough other land with good development potential that the acid sulfate soils could remain idle until inexpensive and abundant sources of lime and fertilizer were available. The saline soils were also given low priority for development because of the expensive engineering work required for desalinization (3). Under these circumstances IRRI varieties with specific adverse soils tolerance offer new opportunities for rice production.

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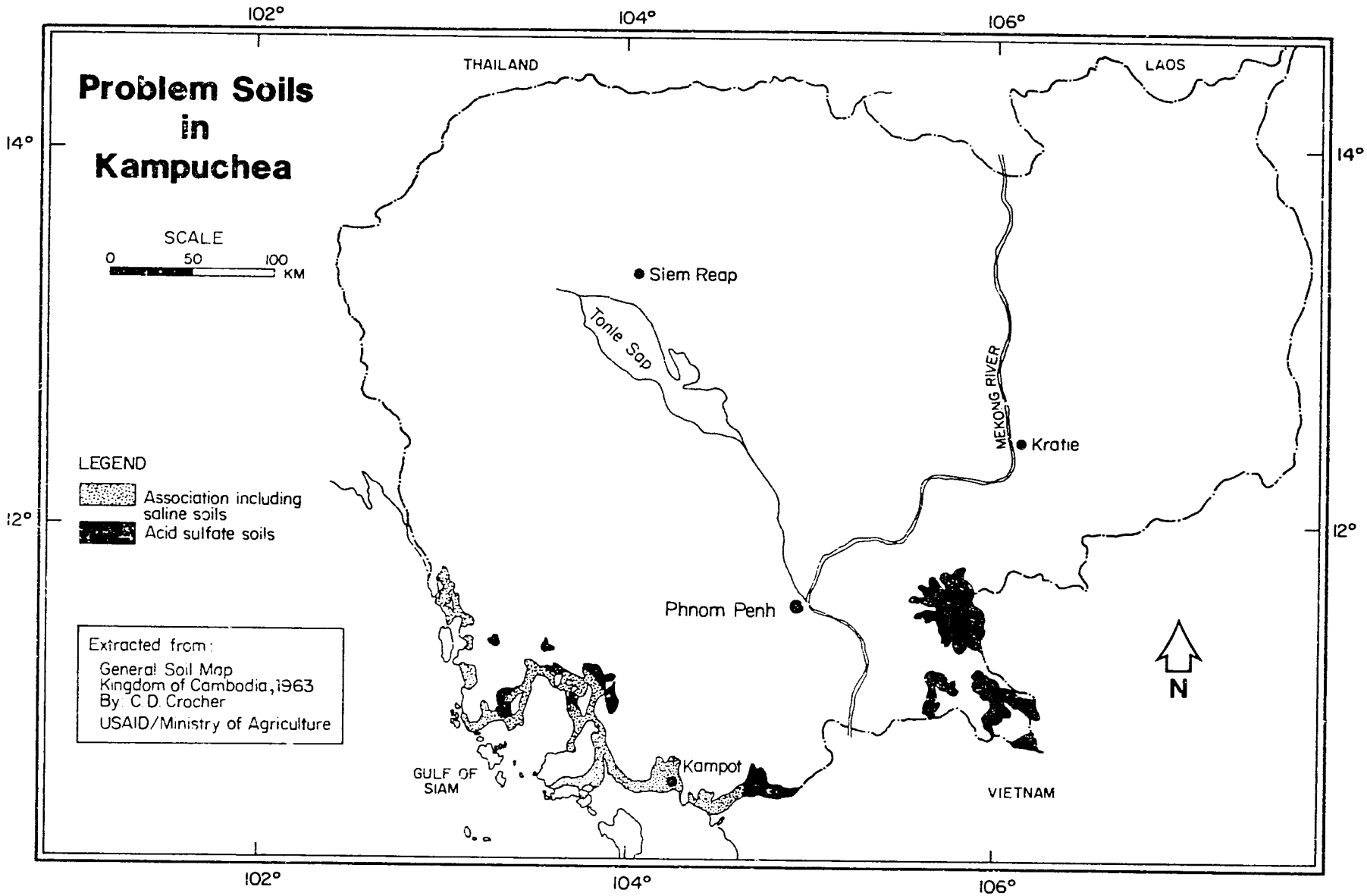

Problem Soils in Kampuchea
SCALE
0 50 100 KM
LEGEND
Association including saline soils
Acid sulfate soils
Extracted from:
General Soil Map
Kingdom of Cambodia, 1963
By: C.D. Crocher
USAID/Ministry of Agriculture
THAILAND
LAOS
VIETNAM
GULF OF SIAM
Siem Reap
Tonle Sap
MEKONG RIVER
Kratie
Phnom Penh
Kampot
N
102°
104°
106°
14°
12°

Malaysia

The three regions of Malaysia — Peninsular Malaysia, Sabah, and Sarawak — are autonomous in using different systems of soil classification and mapping.

Peninsular Malaysia

A semidetailed soil survey is being carried out in Peninsular Malaysia according to the Soil taxonomy system (11), but the most recent soil map of the region is still the 1970 Generalized soil map of West Malaysia (9), using terms of the Thorp and Smith (13) classification based on morphological characteristics. This map is directly derived from the more detailed 1968 Reconnaissance soil map of Malaysia (13, 17), which was chosen as the basis for this research. The legend of the Reconnaissance map consists of the state soil series, some of which are grouped together into associations for mapping purposes. No special attention nor mapping unit is given to saline soils as such. Sodic soils do not occur.

The acid sulfate soils, all formed on sulfidic marine clays, qualify as Thionic Fluvisols according to the FAO-Unesco legend (16). Furthermore, they were characterized and correlated with Soil taxonomy by Paramananthan (11) as follows:

- profiles with A/C horizontation
  - Kranji series: saline potential acid sulfate soils. Typic (Hydric) Sulfaquents, very fine, mixed
  - Linau series: potential acid sulfate soils with organic topsoils. Typic Sulfaquents, fine, mixed
- profiles with A/B/C horizontation
  - Guar series: shallow (60 cm deep) acid sulfate soils. Typic Sulfaquepts, very fine, mixed
  - Sedu series: moderately deep (70 cm) acid sulfate soils. Typic Sulfaquepts, very fine, mixed
  - Telok series: deep (100 cm) acid sulfate soils. Sulfic Tropaquepts, very fine, mixed

The grouping is somewhat unfortunate with regard to problem rice soils, because the Telok series, presenting an intergrade type to nonproblem rice soils, should be included. The mapping unit and extents of these soils are as follows:

Unit	Series	Area (million ha)
no. 2	Kranji	0.274
no. 3	Linau and Sedu	0.063
no. 4	Telok and Guar	0.043
		0.380

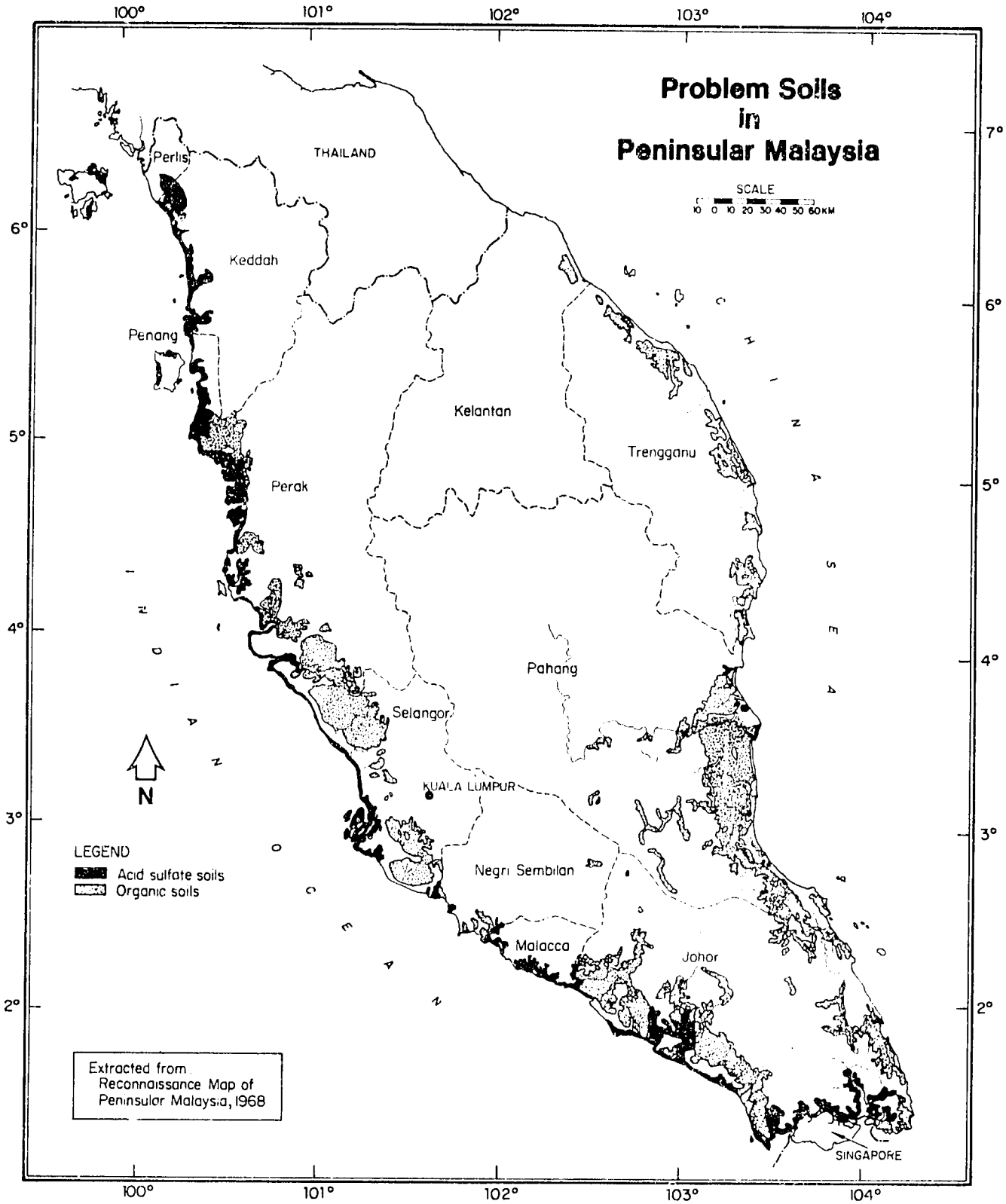
The organic soils are defined by an organic horizon of more than 50 cm depth. They are subdivided by loss on ignition (organic matter content) into organic clay (25-35%), muck (35-65%), and peat (>65%).

According to international standards (Soil taxonomy, FAO-Unesco), some of the organic clays do not qualify as true Histosols with regard to organic C content. But this is compensated by a stricter depth requirement, so there is probably not much difference. Among the organic soils, the organic clays have the greatest natural potential for rice cultivation. The distribution and extent of organic soils are as follows:

Unit	Description	Area (million ha)
no. 8	Briah-organic clay and muck	0.180
no. 9	Organic clay muck	0.168
no. 10	Peat	0.800
		1.148

Only acid sulfate and organic soils are recognized as problem rice soils, because they require special management practices for agricultural use. No attention is given to saline soils, because salinity is considered easily removable by irrigation and drainage.

Most acid sulfate soils are saline potential acid sulfate soils (Sulfaquents) under mangrove vegetation. Extensive cultivation of the more advanced acid sulfate soils (Sulfaquepts, Sulfic Tropaquepts) is due to successful management — keeping the water table continuously above the sulfuric horizon. The shallow depth require-


Problem Soils
in
Peninsular Malaysia
SCALE
10 0 10 20 30 40 50 60KM
THAILAND
Perlis
Keddah
Penang
Perak
Kelantan
Trengganu
Pahang
Selangor
KUALA LUMPUR
Negri Sembilan
Malacca
Johor
SINGAPORE
N
LEGEND
Acid sulfate soils
Organic soils
Extracted from
Reconnaissance Map of
Peninsular Malaysia, 1968
100°
101°
102°
103°
104°
7°
6°
5°
4°
3°
2°

ment of ≥30 cm of nonpyritic topsoil gives rice an advantage over other crops (oil palm, rubber, coconut, cocoa). Thus, one-third of the cropped area (approximately 30,000 ha) is under rice, mostly in large irrigation schemes with double cropping. The yields obtained correspond to 80% of those on fertile soils (Zahari Abu Bakar, pers. comm.).

The organic acid sulfate soils (included in the organic soils: Sulfihemists, Sulfohemists) are generally not utilized for agriculture; most are swamps. Only a small fraction of their area has been used to date for the cultivation of oil palm, pineapple, sago, coconut, rubber, and vegetables (3). No rice is grown on peat and only very little on organic clay and muck soils; the extent is too small to be recorded. Also, in present projects and future plans (e.g., West Johore Development Project, mainly on organic soils), rice cultivation is excluded because other crops are more profitable. At present, self-sufficiency in rice production is not a principal objective in Peninsular Malaysia. The government tries, though, to keep the level of locally produced rice at 80% of the state consumption (M.J.B. Hashim, pers. comm.).

For a [illegible] portion of their respective areas, the problem factor [illegible] of saline acid sulfate and organic soils are overcome by special management, so there is no pressing need for breeding rice varieties with specific adverse soils tolerance for Peninsular Malaysia.

Sabah

The highest level in soil classification is the soil unit (corresponding to the FAO-Unesco system [16] with some modifications). Further subdivision follows a list of successive criteria, the first of which is parent material, leading to soil families, which are further differentiated according to regional soil characteristics (3). The mapping units (at scale 1:250,000 [3]) are soil associations, consisting only of components of different soil families. Thus, there is no separate mapping of the problem soils concerned, nor specification of their exact extent. The set of maps was incomplete when this research was done.

Salinity and alkalinity (sodicity) are not regarded as significant at the higher levels of soil classification but appear only as sixth and seventh criteria in the sequence of subdivision.

The Weston association (mapping unit no. 1) comprises the soils of tidal swamps in which the various types of (saline) acid sulfate soils occur:

- potential: Thionic Fluvisol (on sulfidic alluvium)
- organic: Dystric Histosol with thionic properties (on sulfidic peat)
- true-advanced: Thionic Gleysol (on alluvium)

The area — 0.417 million ha — remains mostly under mangrove forest (9).

The organic soils are mainly Dystric Histosols. They constitute the mapping units Klias and Sitipang (associated with minor parts of Humic Gleysol and Gleyic Podzol, respectively), but because they also occur in the same position in other mapping units, the figure for their extent seems appropriate. These soils have developed in thick peat, which is easily identified by its characteristic heath vegetation (9). The extent of these soils is as follows:

Unit	Association	Area (million ha)
no. 7	Klias association (dominant FAO soil unit: Dystric Histosols)	0.121
no. 15	Sitipang association (dominant FAO soil unit: Dystric Histosols)	0.004
		0.125

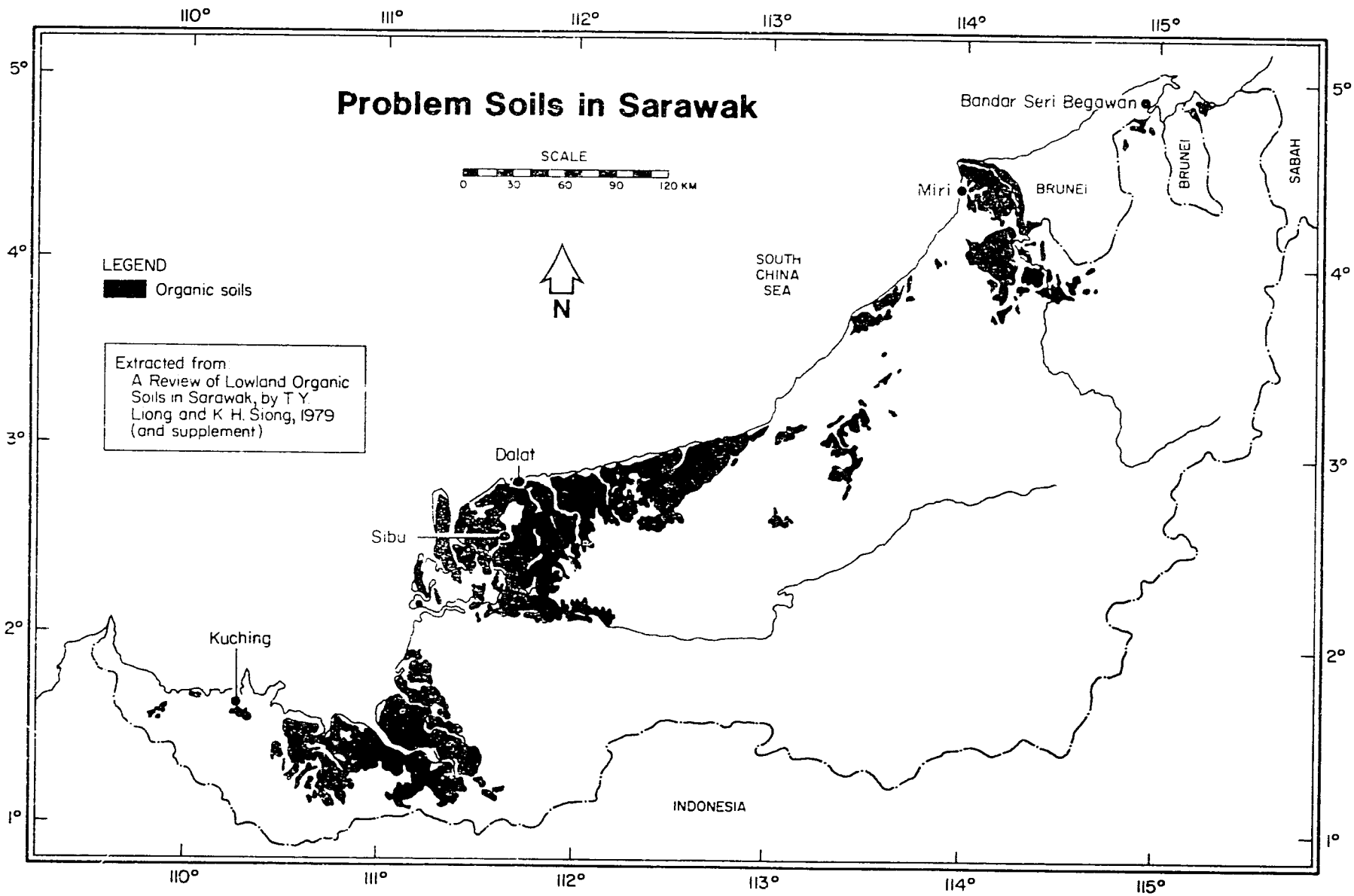
The Weston, Klias, and Sitipang soil associations are regarded as unsuitable for rice cultivation and as a result are left largely undisturbed (9). Because only 10% of the agriculturally suitable land is currently being cultivated (3) and the total rice area is small (approximately 40,000 ha [8]), there seems to be no demand for rice varieties with tolerance for specific problem soils.

Sarawak

The new soil classification system developed in Sarawak (7) has been used in recent soil surveys but has not been applied to the state soil map, which dates from 1968 (13). Problem soils mapped are saline and organic soils. Acid sulfate soils were recognized only recently and are listed as potential acid sulfate soils within the saline soil area. Sodic soils are not found.

The definition and subdivision of saline soils are based on the conductivity of the soil groundwater (not soil saturation extract) and therefore cannot be directly compared with international standard values (8). The limit to separate saline gley soils from other gleys is 0.5 dS/m at 25 °C. Sarawak soil scientists declare this value too low to have much practical significance for agriculture; they consider a level of 1.0 or 1.5 dS/m more appropriate to indicate salinity as a farming problem (16). Saline gley soils are thus not shown on the sketch map, nor is their extent given.

In organic soils there is a discrepancy between soil classification (16) and mapping. The peat soils mapped are equivalent to Histosols (13) (FAO-Unesco: Dystric Histosols; Soil taxonomy: Tropofibrists, small occurrence of Sulfihemists; partly saline [9]). The bulk of organic soils are lowland peats, which are very extensive in recent floodplains but are also found as small pockets in interior valleys where drainage is poor. Andriesse (1) divides them into basin and valley peats. Basin peats form


Problem Soils in Sarawak
SCALE
0 30 60 90 120 KM
N
LEGEND
Organic soils
Extracted from
A Review of Lowland Organic Soils in Sarawak, by T.Y. Liong and K.H. Siong, 1979 (and supplement)
Bandar Seri Begawan
Miri
BRUNEI
BRUNEI
SABAH
SOUTH CHINA SEA
Dalat
Sibu
Kuching
INDONESIA
110°
111°
112°
113°
114°
115°
5°
4°
3°
2°
1°

domes up to 15 m high, whereas valley peats are flat and in many places mixed with mineral material from erosion (muck soils) or interlayered with river deposits. Mountain peat soils at high altitudes cover only very small areas (9).

On the Soil map of Sarawak (13), peat soils are differentiated into a shallow (< 1 m depth) phase and a deep (> 1 m, commonly >3 m depth) phase. Their total extent is 1.66 million ha, their shares being 0.182 million ha (11%) for shallow peat soils and 1.478 million ha (89%) for deep peat soils.

Most saline and potential acid sulfate soils, as well as the organic soil areas, are still under natural forest vegetation. According to the Agriculture capability map (3), these lands are in the lowest class, where limitations are so severe that agriculture is not feasible without land reclamation. In the embanked areas of reclaimed saline and potential acid sulfate soils, other more profitable crops are grown. Rice, with its low return, is regarded as the poor farmer's crop.

Among the peat soils, valley peats are cultivated more than basin peats because of their more favorable soil conditions; a certain mineral content and the raw woody material of the soils generally allow cultivation to a depth of 1 m of organic soil. Crops adapted to these strongly acid soils (pH<4) are widely grown. Sago is well suited to undrained peat, as is pineapple to drained peat (9). Coconut (mainly in saline organic soils), rubber, and rice do not give satisfactory yields (11).

During the energy crisis in 1973, when self-sufficiency in rice was important, the potential wetland rice areas in Sarawak were studied (7). Priority was given to the development of fertile soil areas first (yields then were only 1 t/ha), organic soil areas next, and saline and potential acid sulfate soil areas last. Self-sufficiency is no longer the target, but the production of 80% of the local demand for rice.

Because good agricultural land will become more scarce in Sarawak as the population rises, land development focuses on organic soil areas because of their extent, proximity to population centers, and relatively better accessibility than the mountain interior. The cultivation of several crops has been achieved, but efforts to improve the organic soil conditions for rice cultivation and varietal selection have not solved the sterility problem (9). So there is a demand for rice varieties with tolerance for organic soils.

Because only a fraction of the shallow peat soils (0.182 million ha) is to be planted to rice, and because of the geographical position of the organic soil areas, Sarawak would benefit from rice varieties to be developed in the IRRI-Indonesia cooperative project under similar environmental conditions.

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Nepal

Of the problem rice soils, only saline soils are present in Nepal, occurring in patches in the Terai, the country's modest share of the Ganges plain. The extent of these soils is very minor. Organic soils (as included in the FAO mapping unit Bd 34 for Nepal [1]) have not been observed so far.

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Pakistan

Saline and sodic soils are important problem soils in Pakistan. The general term *salt-affected soils* includes saline, saline-sodic, and sodic soils with the following definitions (7):

Soil	EC	ESP	pH
Saline	>4 dS/m	<15	<8.5
Saline-sodic	>4 dS/m	>15	~8.5
Sodic	<4 dS/m	>15	>8.5

The determination of soil profile salinity or sodicity (within 1.8 m depth in more than 24,000 relevant profiles) gave a ratio of 28:63:9 among these soil types (7). Although these figures are not directly equivalent to the actual shares of the area, they may be regarded as such at the present level of knowledge. On the WAPDA salinity map (6) only those soils with surface salinity (EC ≥ 4 in the upper 15 cm, relevant with regard to rice cultivation) are shown; they occupy 25% of the area surveyed.

In view of rice cultivation practices (all irrigated in the wet season on the Indus plains [3]), the extent of salt-affected soils concerned needs to be reduced from 10.5 million ha nationwide to 5.8 million ha in the arable land on the Indus (and tributaries) plains — all other land is mountainous or desert — and to 3.2 million ha in the irrigated part of the Indus plains (2).

Pakistan has the world's largest canal irrigation system (8), which has caused a rise of the groundwater table in the plains, leading to secondary salinization in some low-lying areas covering only a very small extent. Most salt-affected soils date from ancient times, as their formation is typical in a continually arid and semiarid climate (2, 5), (primary salinity-sodicity).

The canal command area (CCA) comprises 13.5 million ha and will remain at this level for the near future. Within these boundaries, 11.2 million ha (83%) are cultivated and 2.3 million ha (17%) are left uncultivated. Rice is grown on 2.3 million ha.

Saline and sodic soils occur in an intricate pattern of patches in fields. They amount to 1.197 million ha, differentiated by land capability classes:

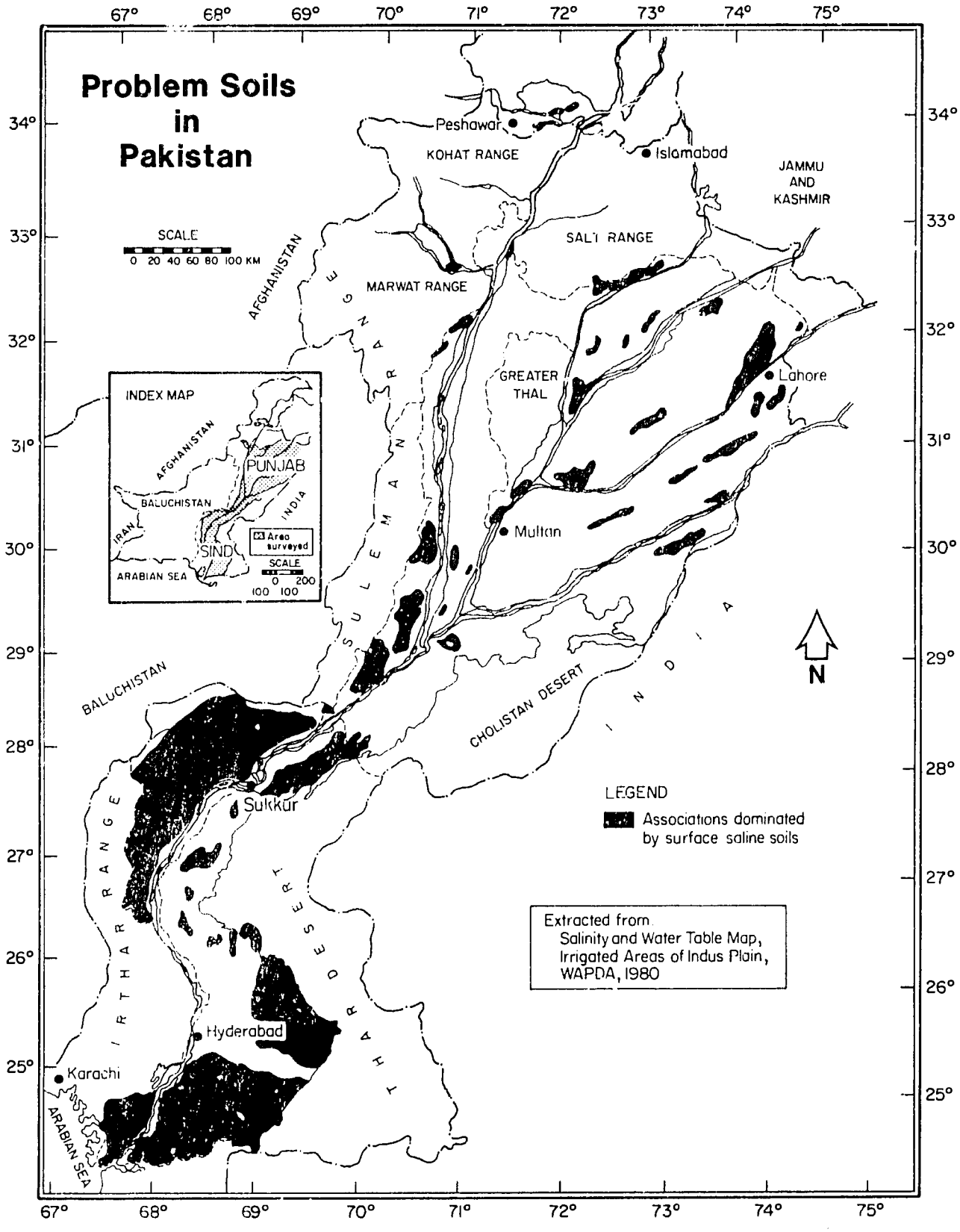
- class II, good land, slightly saline soils: 0.801 million ha
- class III, moderate land, porous saline-sodic and saline gypsiferous soils: 0.252 million ha
- class IV, poor land, dense saline-sodic soils: 0.144 million ha.

Salt-affected soils account for most of the uncultivated part of the CCA. Their total extent of 1.961 million ha is subdivided into cultivable land (1.426 million ha in areas where irrigation is possible) and uncultivable land (0.535 million ha) (4). Among the worst salt-affected soils are those in coastal areas, where seawater inundation, topography (flats), and arid climate all favor salinization.

Desalinization of the root zone is currently the only method practiced to make salt-affected soils agriculturally productive. This involves intensive leaching with surplus water and drainage of the soils, as well as a compulsory land-use pattern for 3-8 yr. Rice is invariably grown as a reclamation crop during summer, and a legume (e.g., clover) is raised during winter, which is too cold for rice. In severe cases this rotation is preceded by growing *Diplachne fusca* or *Sesbania aculeata*.

The persisting sodicity problem has generally not been tackled. The Rice Research Institute is now developing chemical measures such as applying gypsum or acids to decrease ESP from 30-40 in sodic soils to less than 15, mainly because of physical soil problems, which are very pronounced as the soils are poor in organic matter. Such a low ESP would not be essential for rice cultivation, but favorable for wheat, which is the common crop rotation in the rice tract of Pakistan. Land reclamation is limited by irrigation water shortage, which allows a cropping intensity of only 40% in summer and 60% in winter of the cultivated part of the CCA. Nevertheless, the reclamation rate between 1963-65 and 1977-79 was 82,000 ha/yr or a 25% decrease in the extent of salt-affected soils (8).

Most of the class II (slightly saline) soils are presently under rice cultivation (1). Yields of 1.2 t/ha of Basmati rice or 2.2 t/ha of coarse-grained IRRI varieties are 45% and 39%, respectively, below those on good land (M.A. Mian, Soil Survey of Pakistan, pers. comm.). A reduction


Problem Soils in Pakistan
SCALE
0 20 40 60 80 100 KM
Peshawar
KOHAT RANGE
Islamabad
JAMMU AND KASHMIR
SALT RANGE
MARWAT RANGE
AFGHANISTAN
SULEMAN RANGE
GREATER THAL
Lahore
Multan
INDIA
CHOLISTAN DESERT
BALUCHISTAN
Sukkur
LAR DESERT
THAR
KIRTHAR RANGE
Hyderabad
Karachi
ARABIAN SEA
N
LEGEND
Associations dominated by surface saline soils
Extracted from Salinity and Water Table Map, Irrigated Areas of Indus Plain, WAPDA, 1980
INDEX MAP
AFGHANISTAN
PUNJAB
BALUCHISTAN
INDIA
IRAN
SIND
ARABIAN SEA
Area surveyed
SCALE
0 200
100 100
67° 68° 69° 70° 71° 72° 73° 74° 75°
34° 33° 32° 31° 30° 29° 28° 27° 26° 25°

of yield decrease during land reclamation by salt- or high sodicity-tolerant rice varieties is desired.

The potential area to be cultivated with such rice varieties is 2.6 million ha within the CCA. Among the areas to be reclaimed, patchy salt-affected soils in the cultivated part are given priority. These are areas with topsoil salinity-sodicity and partially reclaimed soils (2) in which sodicity remains — Natric Camborthids (1). Also, the cultivable land in the so far uncultivated part might be reclaimed in the future if it were allocated irrigation water. Salt-affected soils previously excluded from the CCA are of no consideration (2).

The development of adapted varieties would allow a wider spread of irrigation water and increase the area of rice production. The demand for rice is tremendous in Pakistan, which is the world's third greatest rice exporter. A further expansion of rice exports is desired, while domestic consumption is also steadily increasing. The Rice Research Institute has recently joined forces with IRRI in the International Rice Salt and Alkali Tolerance Observational Nursery (IRSATON) program.

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Philippines

The strongly generalized 1972 Soil map of the Philippines (8) does not show saline, acid sulfate, or organic soils. Also, on the provincial soil maps (1948-72, scales 1:100,000-1:250,000) these soils are not separately mapped but appear in several local soil series (3). Through the present project to produce regional soil maps for the whole country using the Soil taxonomy (11) system, these soils can be estimated, but the project will take several years.

Saline soils are not defined by a limit value, but their occurrence is equated with tidal lands. In the coastal areas they cover an extent of 0.4 million ha (4). They largely overlap with acid sulfate soils (mainly Sulfic Tropaquepts [5], some Sulfaquents [10]; 7,000 ha [12] -20,000 ha [2]). In most areas soil salinity is only a seasonal phenomenon.

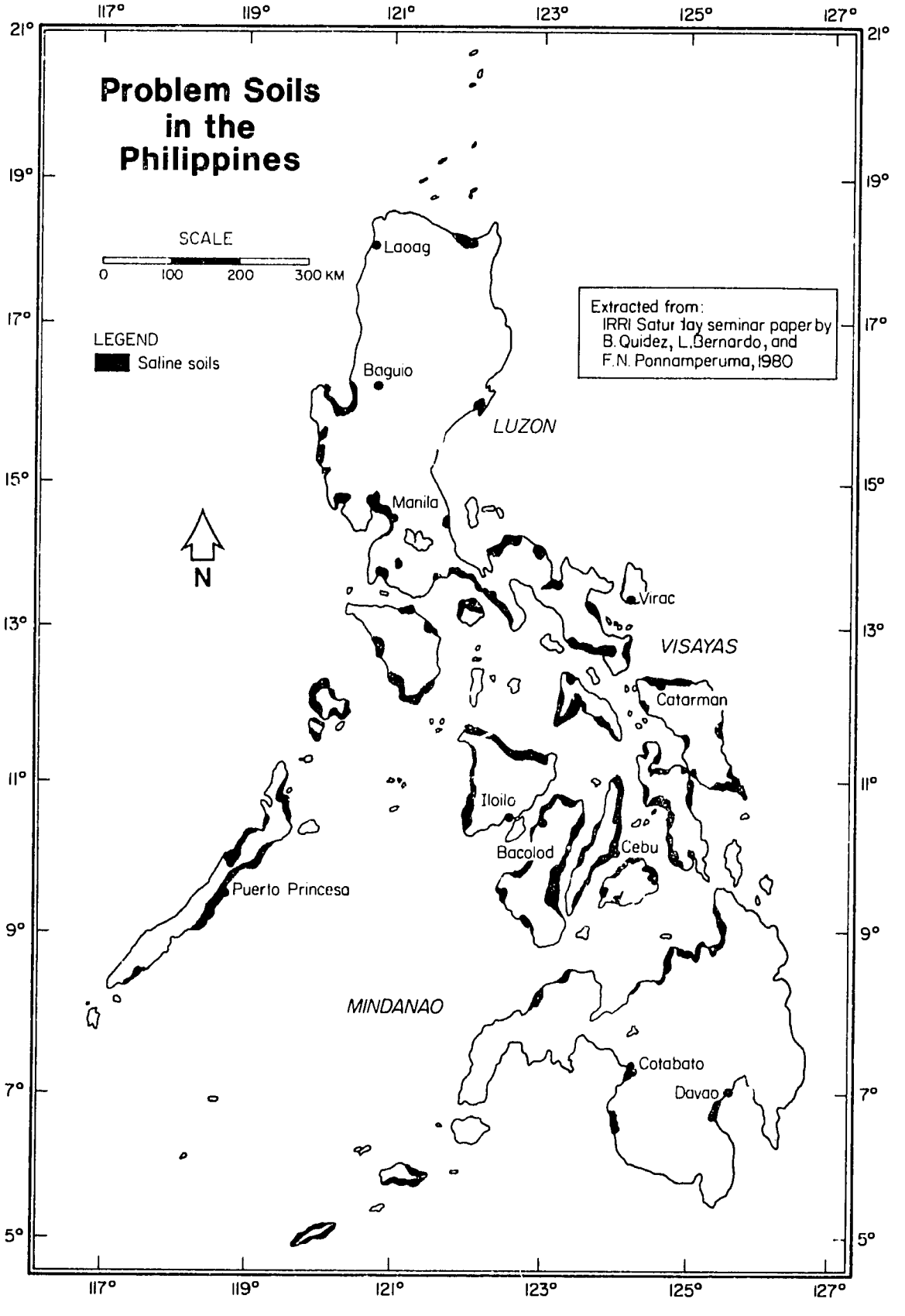
The organic soils, termed peat, correspond mainly to Tropofibrists or Eutric Histosols (7) and thus are distinctly different from the severely acid Dystric Histosols commonly found in South and Southeast Asia. They occur as freshwater inland peats and also as saline coastal peats (6). Their extent is estimated as 6,000 ha (12) to 15,000 ha (2).

The natural vegetation on saline soils — mangrove forests — covered 100,000-200,000 ha in 1977, but this area is continuously diminished as the land is converted into fishpond areas (176,000 ha then). To protect the coast, a strip of forest is to remain along the shore and trees are to be planted as belts on wide bunds in between the brackish-water fishponds. Maximum yields of fish are 4 t/ha per yr, but the level of attainable production is set at 2 t/ha per yr (4). At current prices, fish farming is a flourishing business with a high expansion rate.

The remaining 24,000 ha of tidal land are used mainly for rice cultivation in high rainfall areas. Rice is planted on the relatively higher parts of the land (to be safe from severe flooding, which is the main problem in the wet season) only after the rains have washed away the salts. Under such conditions modern varieties tested for their salt tolerance yielded about 4 t/ha (9). Unfortunately, these promising results can be achieved only in the limited area where rice is already cultivated. All the other tidal land is generally too saline even for salt-tolerant varieties. Rice cultivation there would be possible only after expensive land reclamation (12), which in turn would make salt-tolerant rice varieties unnecessary.

The only extensive adverse soil type for wetland rice — saline soil — is not even considered on the national scale, where the list of problem soils is headed by Ultisols followed by Andosols and Oxisols (1, 2). In the saline soil area, land use by mangrove forest and fishponds is economically and ecologically better than rice cultivation. Even salt-tolerant rice varieties could not become competitive. Thus, the government's Mangrove Resources Development Program for tidal lands deals entirely with the development of mangrove forest (forest product extraction from permanent forest land) and mangrove swamp fisheries (environmental protection and fish production) (4).

Because of the relatively small extent of saline, acid sulfate, and organic soils available for rice cultivation (less than 20,000 ha each), the Philippines is not a target area for breeding specific adverse soils-tolerant lines. Yet these problem soil areas can benefit directly from the experience at IRRI experimental sites there.


Problem Soils in the Philippines
SCALE
0 100 200 300 KM
LEGEND
Saline soils
Extracted from:
IRRI Satur day seminar paper by B. Quidez, L. Bernardo, and F.N. Ponnamperuma, 1980
N
Laoag
Baguio
Manila
LUZON
Virac
VISAYAS
Catarman
Iloilo
Bacolod
Cebu
Puerto Princesa
MINDANAO
Cotabato
Davao
117°
119°
121°
123°
125°
127°
21°
19°
17°
15°
13°
11°
9°
7°
5°

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Sri Lanka

Saline, sodic, and organic soils were classified as national soil great groups in Sri Lanka in 1961 (5) and were later correlated (6) with Soil taxonomy (10). Saline soils are termed Solonchaks, equivalent to Salorthids; sodic soils are Solodized Solonetz or Natraqualfs. From the organic soils termed bog and half bog, only bog soils qualify as Histosols, mainly Tropohemists. Half bog soils with lower organic matter contents are Tropaquepts/mineral soils (2).

Mapping units (7) are soil associations. Their extents determined from the map are

- Solonchaks and Solodized Solonetz = 0.112 million ha
- Bog and half bog soils (lowland area) = 0.089 million ha

Saline and sodic soils are found in the dry and arid zones (3), where they occupy flat coastal plains and tidal flats. Sodic soils are also part of other soil associations on undulating plains (2). Because saline and sodic soils always occur in low topographic positions, they are poorly drained in the wet season and are thus well suited to rice cultivation during that period (8). In 1972 the saline and sodic land was mostly barren with a patchy grass cover (2). Of the 0.112 million ha, only 7,300 ha were planted to rice, mainly rainfed in the wet (Maha) season (9). In the Batticaloa District, local salt-resistant varieties were being grown in the early 1950s (1). Land-use plans are to increase the rice area on saline and sodic soils. From the management practices recommended (2), it can be concluded that adapted rice varieties would also need to be flood tolerant.

Organic soils fill low-lying areas in the wet zone (3). Bog soils have developed in basin centers and half bog soils on the fringes (2). They are permanently waterlogged and acidic (pH 4.5-5.5 [3]). Bog soils are flooded periodically, partly with saline water. During floods they often float away, causing lodging of the rice crop (4). Most of the area is wasteland with natural swamp vegetation (2, 3). Some rice is cultivated, and expansion is planned for the bog area (7). Here salt and flood tolerance would be additional requirements for organic soil-adapted rice varieties. Detailed information on the desirable characteristics of suitable rices in tidal swamps (including saline and organic soils) was presented during a 1984 workshop (4).

In order to attain self-sufficiency in rice, higher production from all three problem soils is desired (4, 8). Yet, on a national scale, they are of minor importance in terms of extent and utilization (9). Thus they would benefit from adverse soils-tolerant rice varieties.

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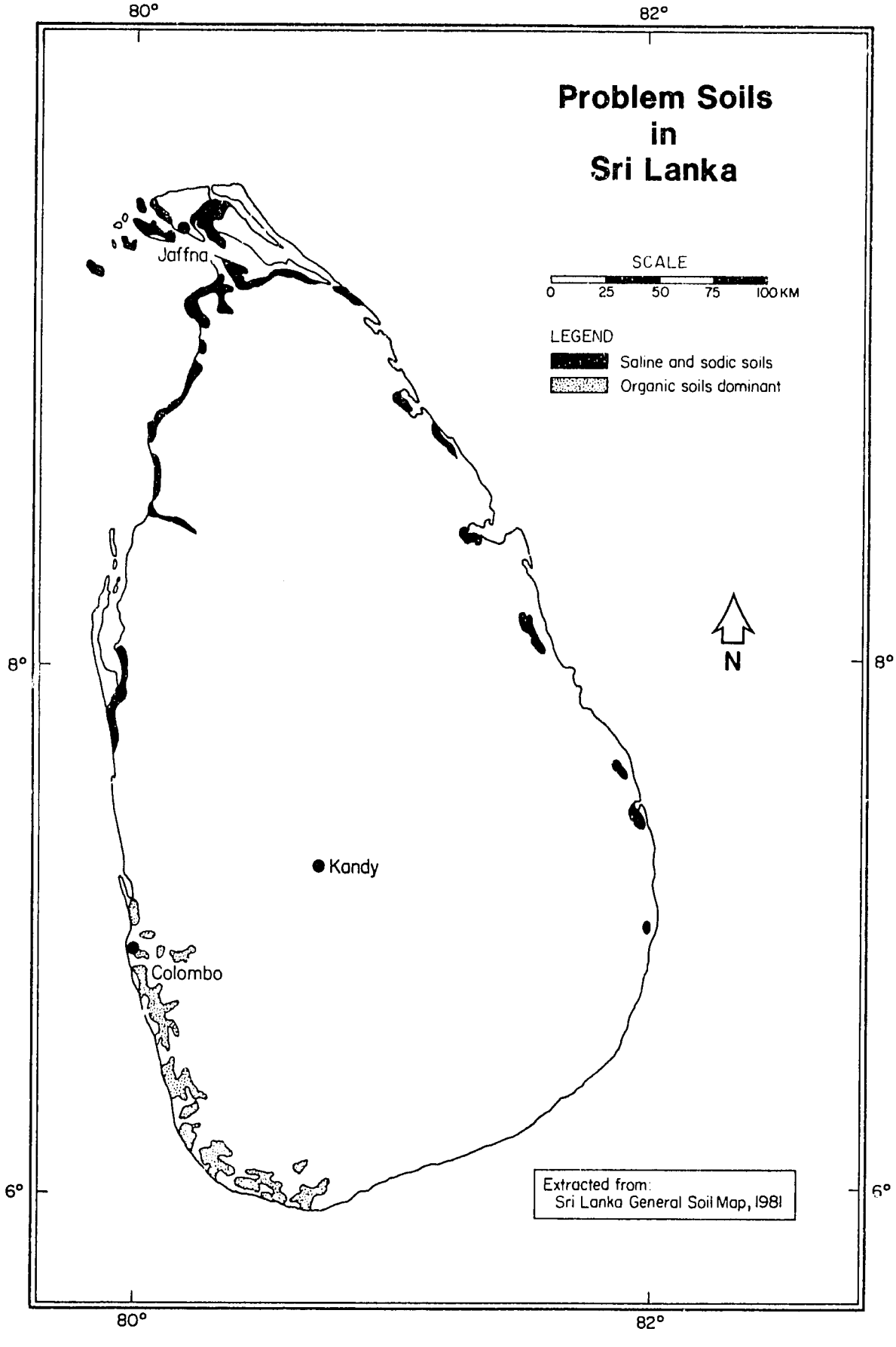

80°
82°
Problem Soils
in
Sri Lanka
SCALE
0 25 50 75 100 KM
LEGEND
Saline and sodic soils
Organic soils dominant
Jaffna
Kandy
Colombo
N
8°
6°
Extracted from:
Sri Lanka General Soil Map, 1981

Thailand

The most recent soil map is the 1979 General soil map of Thailand (3), in which Soil taxonomy (9) is applied. Mapping units are soil great groups with textural adjectives; sometimes two are grouped together for mapping purposes.

The saline soils are not easily distinguishable, because they are given no separate mapping unit. They overlap with Sulfaquents and may occur in Halaquepts. General knowledge and sketch maps by Panichapong (5) characterize Hydraquents as coastal saline soils. Saline soils occur as follows:

Unit	Description	Area (million ha)
no. 2	clayey Hydraquents	0.091
no. 6	clayey Hydraquents – loamy, clayey Sulfaquents (half of the area, (arbitrarily chosen)	0.19

The Halaquepts and Natraqualfs are permanent (saline) sodic soils occurring in the northeast. Thus, the figure for their extent is valid for the rainy season when rice is cultivated. In contrast, the Soil Salinity Division (Department of Land Development) deals mainly with temporary salinization (2.85 million ha for the dry season [1,2]). Sodic soils occur as follows:

Unit	Description	Area (million ha)
no. 18	loamy Halaquepts	0.071
no. 27	loamy Natraqualfs	0.189
no. 50	clayey Paleaquults — loamy Natraqualfs (half of the area, arbitrarily chosen)	0.057

Only the coastal potential acid sulfate soils – Sulfaquents — qualify as acid sulfate soils at the great group level according to Soil taxonomy. The corresponding criteria (upper boundary of sulfidic material or sulfuric horizon within 50 cm of soil surface) are highly significant regarding limitations for rice cultivation (Sys and Paramananthan, 1984, unpubl. data).

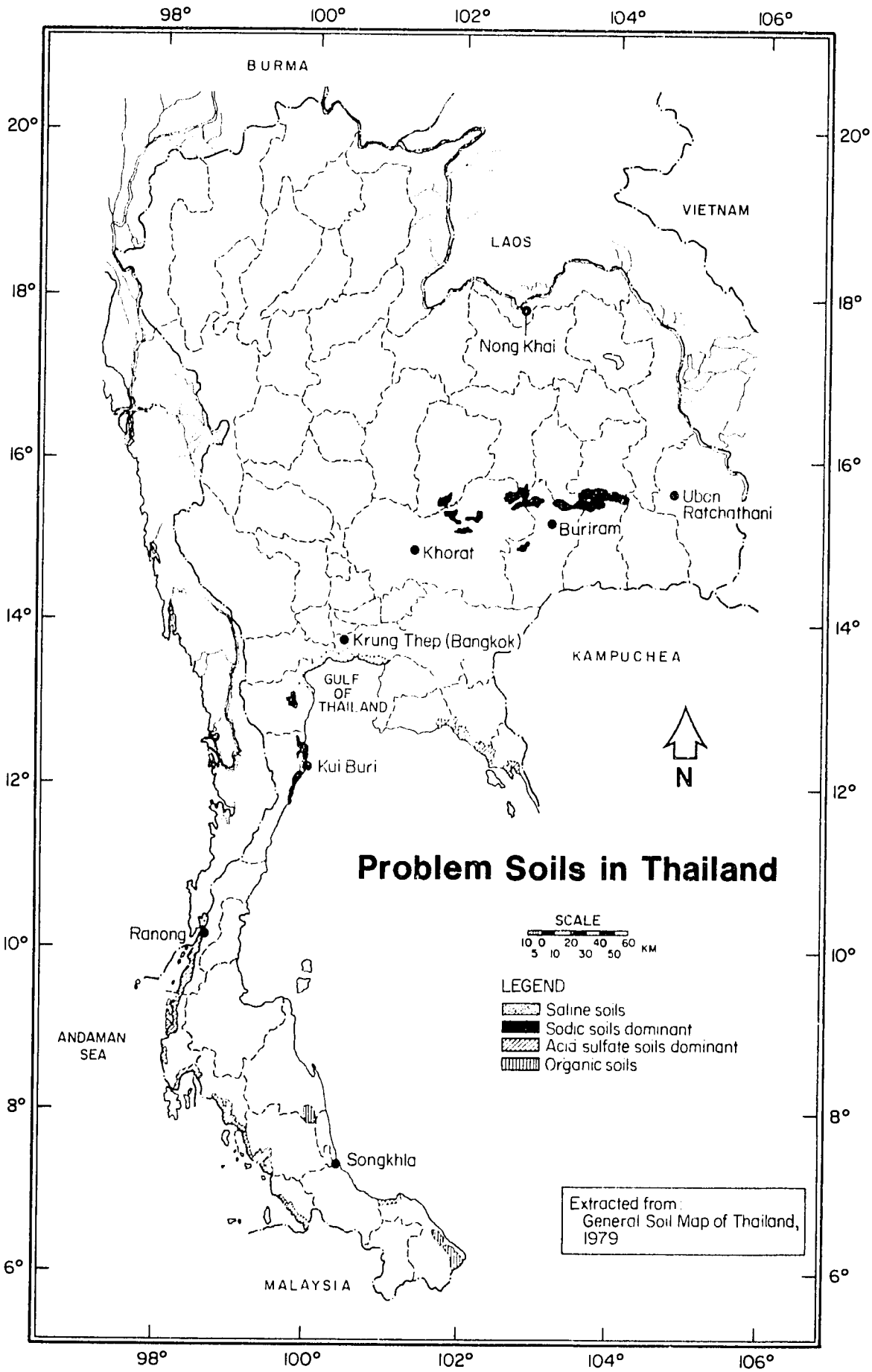
The advanced type of acid sulfate soil of the Bangkok plain as indicated on other maps (5,7) is an intergrade to normal soils (Sulfic Tropaquepts, having higher pH values and the sulfuric horizon at greater soil depth). With ample, Ca-rich water supply for one rice crop in the rainy season, further soil amelioration involves mainly liming and marling. Thus, the objective of the Acid Sulfate Improvement Project is to determine lime, marl, and P requirements using acidity classes up to pH 6.0 (4).

Acid sulfate soils are as follows:

Unit	Description	Area (million ha)
no. 1	loamy clayey Sulfaquents	0.02
no. 6	clayey Hydraquents — loamy clayey Sulfaquents (half of the area, arbitrarily chosen)	0.19

The definition of organic soils according to Soil taxonomy, is within the range of the former terms peat and muck, and keeps the extent of these soils within the limits of former estimations (80,000 ha [5] to 60,000 ha [10]); Tropofibrists (mapping unit no. 88) occupy 0.073 million ha.

The present goal in rice cultivation is to increase production per hectare of favorable soil rather than to expand cultivation on problem soils. Thailand has been an exporter of 3 million t/yr; grain and cooking quality are the most important criteria and have priority over mere quantity.


Problem Soils in Thailand
BURMA
LAOS
VIETNAM
KAMPUCHEA
MALAYSIA
ANDAMAN SEA
GULF OF THAILAND
Nong Khai
Ubon Ratchathani
Buriram
Khorat
Krung Thep (Bangkok)
Kui Buri
Ranong
Songkhla
N
SCALE
10 0 20 40 60 KM
5 10 30 50
LEGEND
Saline soils
Sodic soils dominant
Acid sulfate soils dominant
Organic soils
Extracted from: General Soil Map of Thailand, 1979
98°
100°
102°
104°
106°
20°
18°
16°
14°
12°
10°
8°
6°

The agricultural potential map (6) classifies the entire area of saline Hydraquents and saline Sulfaquents as nonagricultural land in which mangrove forest should remain. In the coastal areas saline Hydraquents are presently used for shrimp raising, salt farming, fuelwood, and coconut, which produce higher incomes than land reclamation and subsequent rice cultivation (3). This is even more true of the saline Sulfaquents. Rice cultivation is insignificant on these soils.

Approximately 70% of the area of Halaquepts and Natraqualfs is planted to rice, with an average yield of 1.2 t/ha (11). At present, local varieties are preferred over IRRI varieties because of their tallness and consequent ability to survive floods. A suitable high-yielding variety for this area needs to be tolerant of submergence, drought, and sodicity recurring in the dry intervals of the rainy season.

The organic soils are mostly uncultivated. High organic matter content (>65%) and flooding (>1 m) inhibit rice cultivation. Only small patches of wetland rice occur on the fringes (10).

The prospects for increasing rice production in problem soil areas by using adverse soils-tolerant varieties are favorable for the sodic soils in northeast Thailand. Further adaptation to location-specific hydrological conditions during the rice growing season is of similar importance.

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PROBLEM SOILS AS POTENTIAL AREAS FOR ADVERSE SOILS-TOLERANT RICE VARIETIES IN SOUTH AND SOUTHEAST ASIA

Vietnam

In the 1984-85 land resources inventory program for the Mekong Delta (7), where the bulk of Vietnam's saline, acid sulfate, and organic soils are found, the soils were classified according to Soil taxonomy (4). But generally a descriptive system is used to classify national soil groups (9).

The saline soils along coastal plains are termed marine alluvials (9). From the FAO-Unesco soil map of the world, the extent of saline soils is given as 0.983 million ha (3). They are mainly weakly saline Eutric Fluvisols and Eutric Gleysols with a saline phase. Associated are Thionic Fluvisols, saline phase, and Gleyic Solonchaks with more than 100,000 ha each.

The coastal saline soils are only temporarily saline when intruded with saline water in the dry season (DS). In the wet season (WS), soil conditions are favorable for rice cultivation, and good yields are achieved using high yielding varieties such as IR42 (9). Thus, these soils are nonproblem rice soils.

Acid sulfate soils are very important, occupying about half the total area of the Mekong Delta and parts of the coastal areas of central and northern Vietnam (9). They occur in various types and stages of development (8). In their morphological characteristics many of them differ from those criteria used for their classification in Soil taxonomy or the FAO-Unesco legend (9). The relevant FAO figure for extent of Thionic Fluvisols is only 1.650 million ha, but the most recent Vietnamese figures (8) state 2.589 million ha of acid sulfate soils in the Mekong Delta alone, as follows:

Soil type and occurrence	Area (million ha)
Potential acid sulfate soils in tidal marshes and underneath mangrove forests	0.704
Shallow acid sulfate soils found in empoldered backswamps	1.015
Well-developed acid sulfate soils occupying large areas in the Plains of Reeds and the Plain of Hatien, plus scattered spots throughout the Delta	0.870

In the acid sulfate soil areas, land use is adapted to the great variability of the soils. Some of the mineral saline potential acid sulfate soils are traditionally used for shrimp raising in DS and rice cultivation in WS, giving good yields. Where these soils have an organic topsoil, crops other than rice are grown. Part of the saline potential acid sulfate soils are still under natural vegetation, mangrove, and *Melaleuca* forest (7). Where this land was recently cleared for cultivation and potential acid sulfate soils occur at a depth of 30-60 cm (of mineral soils), rice is grown by using a shallow drainage system (ditches 30 cm deep) to leach acidity from the nonpyritic topsoil at the start of WS (8).

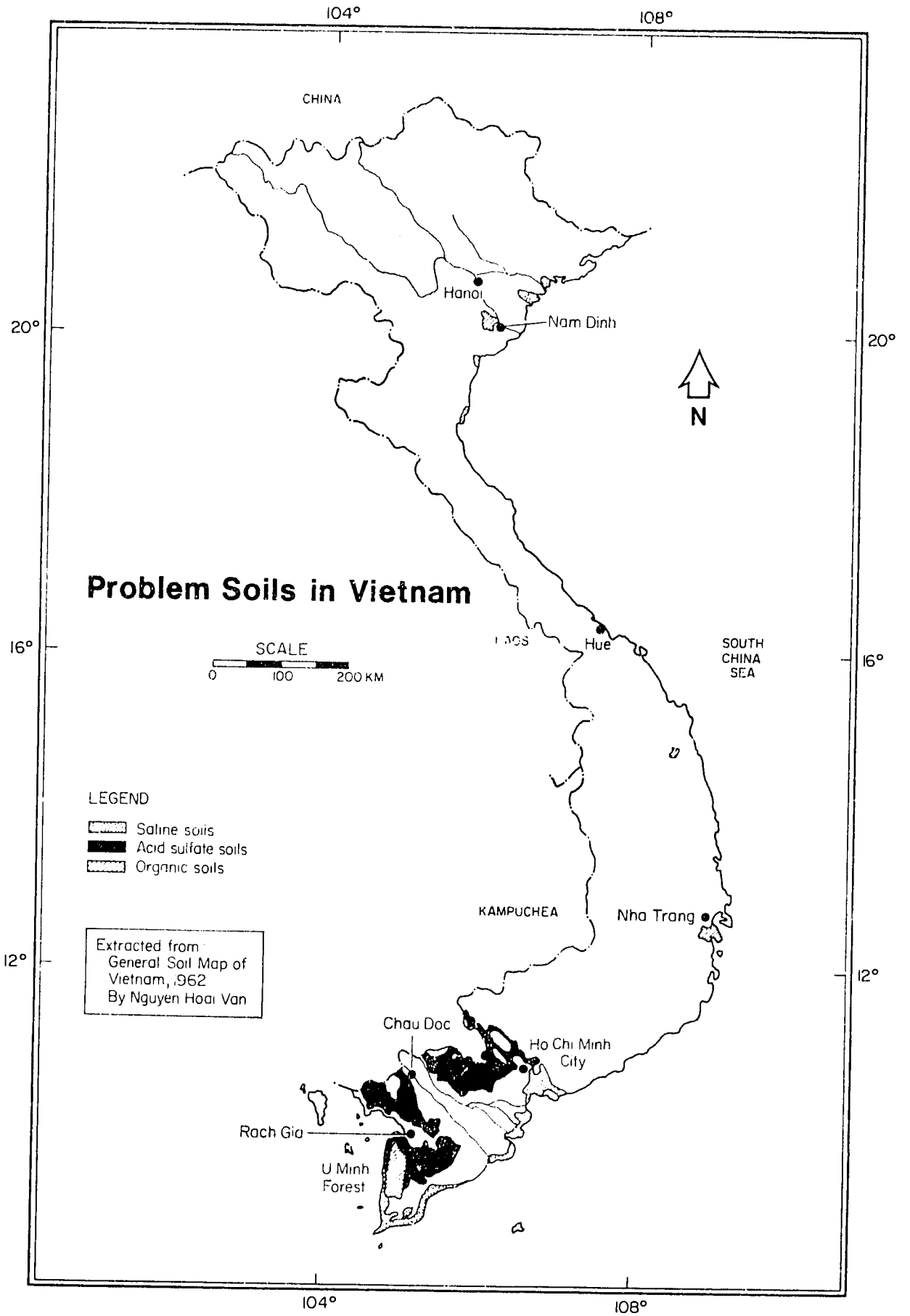
Acid sulfate soil conditions are harmful during the transition period from DS to WS when rice is already sown, but later disappear (6). The main variables determining agricultural possibilities in acid sulfate soils are

- depth of the sulfuric horizon (shallow or well developed),
- parent material (heavy clay and peaty clay are least favorable),
- occurrence in saline or freshwater areas, and
- shallow or deep flooding (7).

In areas with a shallow rainfed water regime and mainly young, shallow acid sulfate soils (jarosite present at 30-50 cm depth), land is reclaimed for rice cultivation by appropriate water management. In 1980 intensive shallow drainage systems covered an area of 90,000 ha (8). With P application, high yielding varieties give reasonable yields (9). In the same type of environment, raised beds were constructed for dryland crops such as sugarcane and pineapple, with moderate success (7).

In the deeply flooded acid sulfate soil areas, the soils are generally well developed (jarosite found below 50 cm depth). Floating and deep water rices are cultivated on the relatively better land (with very deeply developed acid sulfate soil—jarosite at 80-100 cm depth), but yields are low. The other parts are used to grow *Melaleuca leucodendron*, a profitable timber tree (7).

The organic soils, called peat, are equivalent to Dystric Histosols in the FAO-Unesco legend (2). They occur in the backswamps between the river floodplain and the


Problem Soils in Vietnam
104°
108°
20°
16°
12°
CHINA
Hanoi
Nam Dinh
N
LAOS
Hue
SOUTH CHINA SEA
SCALE
0
100
200 KM
LEGEND
Saline soils
Acid sulfate soils
Organic soils
KAMPUCHEA
Nha Trang
Extracted from General Soil Map of Vietnam, 1962 By Nguyen Hoai Van
Chau Doc
Ho Chi Minh City
Rach Gia
U Minh Forest

coastal plains (9). They are mostly underlain by potential acid sulfate soils at 0.5-2 m depth (8). The extent of Dystric Histosols is given as 0.183 million ha (3).

Only shallow peat soils (50-60 cm thick) are used for rice cultivation. Usually the fibrous materials are burned and rice is grown directly on them, or systems are established with upland crops on ridges and transplanted rice in the furrows. High yielding varieties give only low yields because of minor element deficiencies (9) that inhibit rice cultivation on deeper peat soils. Thus, the large peat dome in the U Minh forest area still supports a sizable *Melaleuca* forest (7).

Among the problem rice soils, Vietnamese interest is focused on acid sulfate soils. In delta areas, the government recently began large-scale agricultural development by land reclamation involving high investments in water management. This has been only marginally profitable or even unprofitable (7). Furthermore, the acid surface waters drained from the land are a threat to the environment (7). The development of acid sulfate soil-tolerant high yielding rice varieties might solve both problems. Cooperation between Vietnam and IRRI has begun in deep water rice (1), where the low yields of about 1 t/ha (7) are more due to plant type than to the weak acid sulfate soil conditions.

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Summary

Recent soil maps show that saline, sodic, acid sulfate, and organic soils occupy more 58 million ha in South and Southeast Asia (Table 1).

Table 1. Extent of problem soils in South and Southeast Asia.

Country	Soil[a] (million ha)				
	Saline	Sodic	Acid sulfate	Organic	Total
Bangladesh	1.4		0.1	0.4	1.9
Brunei				0.2	0.2
Burma	1.2				1.2
India	5.5	2.5			8.0
Indonesia	u		u	27.1	27.1
Kampuchea	0.1		0.3		0.4
Malaysia	u		0.8	2.9	3.7
Pakistan	6.2	4.3			10.5
Philippines	0.4				0.4
Sri Lanka	0.1	0.1		0.1	0.3
Thailand	0.3	0.3	0.2	0.1	0.9
Vietnam	1.0		2.6	0.2	3.8
Total	16.2	7.2	4.0	31.0	58.4

[a]u = unmapped or overlapping with other problem soil types.

With regard to the potential area for adverse soils-tolerant rice varieties, soils generally unsuitable for rice cultivation should be excluded, e.g.:

- saline and sodic soils in dry areas where irrigation is not possible,
- severely acid sulfate soils, and
- deep organic soils,

as should soils with favorable conditions where adverse soils tolerance is not required, e.g.:

- seasonally desalinized soils,
- moderately sodic soils,
- deeply developed acid sulfate soils, and
- organic soils with a mineral topsoil.

Furthermore, the demand for cultivation of adverse soils-tolerant rice varieties on problem soils is limited by a number of alternatives, e.g.:

- protection of the natural environment (e.g., saline soils in mangrove forest areas such as the Sundarbans of Bangladesh),
- land use adapted to environmental conditions (e.g., salt production and fish raising in saline acid sulfate soil regions in various countries),
- successful management of the problem factor (e.g., advanced water management on saline potential acid sulfate soils in Peninsular Malaysia),
- competition from more profitable crops (e.g., oil palm and pineapple on organic soils in Peninsular Malaysia), and
- abundance of nonproblem rice soils (e.g., Sabah).

The areas where adverse soils-tolerant rice varieties may be grown during a land reclamation phase (e.g., in the Indus plains, Indo-Gangetic plains, and Irrawaddy delta) are included in the total extent of roughly 23 million ha (Table 2).

Table 2. Extent of potential area for adverse soils-tolerant rice varieties in South and Southeast Asia.

Country	Area (million ha)				
	Saline	Sodic	Acid sulfate	Organic	Total
Bangladesh			0.1		0.1
Brunei				0.2	0.2
Burma	1.0				1.0
India	2.8	2.5			5.3
Indonesia			[a]	10.0	10.0
Kampuchea	0.1		0.3		0.4
Malaysia				0.2	0.2
Pakistan	2.6				2.6
Sri Lanka	0.1			0.1	0.2
Thailand		0.3			0.3
Vietnam	0.1		2.6	0.1	2.8
Total	9.5		3.0	10.6	23.1

[a]No figure available.

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