Technical Paper 5

polders of the world

the flat wetlands of the world

their distribution and their agricultural potential

october 1982, the netherlands

ISM

polders of the world

The soils of the flat wetlands of the world

their distribution and their agricultural potential

prepared by
A.J. van Dam and C.A. van Diepen
International Soil Museum

for

Polders of the world, international symposium and exhibition,
Lelystad, The Netherlands, October 4-10, 1982

INTERNATIONAL SOIL MUSEUM, WAGENINGEN, THE NETHERLANDS - 1982

Druk: Verweij Wageningen b.v.

SUMMARY

On the basis of the FAO-Unesco Soil Map of the World an inventory has been made of soils with impeded drainage situated in landscapes with level topography. The impeded drainage conditions refer to the soils in their natural state. In many areas shown on the map some kind of water management is practised but the available information and mapping scale did not allow a subdivision on the basis of actual reclamation level of the soils. Therefore, it should be pointed out that the map is not a potential polder map, as such a map would require a separation between totally unreclaimed land and land where partial or complete water control has already been achieved.

However, independently of the present reclamation level, the soil data are sufficiently detailed for an assessment of the agricultural potential of the soils if it is assumed that conditions of optimal water control are attained. For each soil unit suitability ratings have been made for three major kinds of land use ("dry foot cropping", grassland and wetland rice), based on the occurrence of soil related constraints other than drainage problems. Four classes of suitability have been distinguished for each kind of land use.

Superimposed on this is a rating of the climatic suitability for plant growth, based on temperature regime only, assuming that crop growth is not hampered in any period of the temperature determined growing season by either excess or shortage of water. This resulted in the delineation of five temperature limitation zones or "heat belts" on the map.

Logically the next step of the appraisal should be the rating of the constraints related with either limited availability of water or problems for controlling excess water. These constraints depend very much on rainfall pattern, local run-off, groundwater and river flow, which together define the hydrologic conditions of a given area. However, they are so site specific, that their assessment could not be superimposed over the global soil and heat belt inventory. In a very general manner it has been indicated per soil unit, whether the drainage problems are related with stagnant water from local run-off (= ponding) or with flooding by rivers and seas. In addition, the extremely dry areas, where rainfall is never sufficient for growing a crop, form a special case. Therefore, areas with a so-called aridic rainfall regime have been delineated on the maps. In such areas the possibilities for water management are confined to rivers with catchments in more humid regions and to groundwater reservoirs. Outside the arid regions water management can also be based on the regulation of local run-off. It may be concluded that there is a clear need to establish a methodology for the assessment of the influence of hydrologic conditions on the agricultural use potential of wetlands.

The present study has been confined to physical environmental factors and no attempt has been made to include socio-economic conditions although it is understood that these are decisive for any planning of land reclamation schemes.

The results of the inventory are shown on a map of the world at scale 1:5 million of which also simplified versions are issued at strongly reduced scales. Area extents are presented in Tables giving world totals for each of the 45 mapped soil units as well as totals split over nine major regions, five temperature limitation zones, four suitability classes for three major kinds of land use, under separation of aridic and non-aridic areas.

A sizeable part of the inventoried soils is formed by the Fluvisols and Gleysols in tropical flood plains which have the highest potential for agricultural production under conditions of complete water control.

CONTENTS

INTRODUCTION

The inventory of the world's flat and wet soils has been undertaken by the International Soil Museum following a request by the Organizing Committee of the Polders of the World Symposium to make an appraisal of the world's land area where polder techniques could be applied successfully for agricultural development. Such lands were conveniently referred to as potential polder areas or empolderable areas. Ideally, the appraisal of potential polder areas should be a pre-feasibility study at a global scale aiming to identify the areas where the application of polder techniques would produce maximum benefits. For a given area a judgement on the feasibility of alternative lines of action for development takes into account soil conditions, hydrology, climate and socio-economic conditions of both the current and projected situations. Likewise, for a feasibility study at a global scale information is needed on soils, hydrology, climate and socio-economic conditions in the present situation and after land improvement. However, during the present inventory it became soon evident that at the world's scale only soil and climatic conditions are sufficiently well known in a comprehensive way to indicate their geographic distribution on a map and that on the other hand hydrologic and socio-economic data were not readily available for systematic incorporation in the global inventory at the same scale and within the short time available for its compilation. Consequently the appraisal of the flat and wet soils of the world for their agricultural potential is based on soil and climatic information only but it should be clear that the omission of hydrologic and socio-economic factors does not imply their lesser importance.

The following Chapters will deal with the criteria used for the selection and rating of soils and climate in the inventory. In addition an indication will be given how hydrologic and socio-economic conditions could further influence the appraisal.

1 THE SOIL INVENTORY

Objective and scope

The original objective of the inventory is to make an appraisal of the world's land resources likely to be improved by the application of polder techniques, or more generally, to identify those wet, flat lands where artificial improvement of the external drainage would lead to an increase of agricultural productivity. As it has not been possible during the inventory to distinguish between lands without any water control measures and lands under different degrees of water management, the objectives have been widened to include those lands, where the improvement of external drainage has contributed largely to increased agricultural production.

The procedure followed was to inventory firstly all soils having characteristics of permanent or periodic wetness, situated in landscapes with flat topography. In a second stage these soils were screened for their suitability for agricultural use based on all other soil properties but wetness. The type of drainage problems on soils with characteristics of wetness may vary from complete submergence to temporary shallow groundwater tabels and many differences exist in the recurrence and intensity of the drainage problems, but for the purpose of the inventory all these soils have been placed under the common denominator of soils with impeded drainage.

Sources of information

The soil inventory is largely based on the 1:5 million FAO-Unesco Soil Map of the World (FAO-Unesco, 1971-1979) in its original form, except for the South American continent. The two South America sheets were published in 1971 and since its compilation much new soil information has become available. In a recent study on the possibilities for empoldering in South America, also inspired by the Symposium "Polders of the World", and undertaken at the ISM's premises by students of the College of Forestry and Land & Water Management (HBCS) in Arnhem, the soil map of South America has been updated for the parts covered by flat, wet soils, using the nomenclature of the FAO-Unesco Legend (Van Essen et al., 1982). This updated map has been used for the soil inventory in lieu of the original map and will be implicitly included whenever reference is made to the FAO-Unesco Soil Map of the World.

The FAO-Unesco Soil Map of the World comprises 18 map sheets of 76 x 110 cm frame size covering the world's land area. The map sheets have been grouped into nine major regions (continents or subcontinents). The map is accompanied by ten exploratory volumes, the first of which constitutes the Legend, explaining the methodology and the definition of the soil units used for the compilation of the map. The other volumes are related to the major regions of the world. The complete series is as follows:

I Legend
II North America (2 sheets)
III Mexico and Central America (1 sheet)
IV South America (2 sheets)
V Europe (2 sheets)
VI Africa (3 sheets)
VII South Asia (2 sheets)
VIII North and Central Asia (3 sheets)
IX Southeast Asia (1 sheet)
X Australasia (2 sheets)

The boundaries between the major regions correspond with country boundaries (Figure 1).

The FAO-Unesco Soil Legend

The legend of the Soil Map comprises 106 different soil units which are subdivisions of 26 major soil units. These soil units were selected on the basis of knowledge of the formation, characteristics and distribution of the soils covering the earth's surface, their importance as resources for agricultural production. No separation had been made between soils in virgin conditions and under cultivation.

The soil units have been defined in terms of measurable and observable properties of the soil itself. Many of these properties are relevant to soil use and production potential and therefore have a practical application value. Consequently the soil units, which have been distinguished on the Soil Map of the World have value for predicting possible uses of soils.

For the compilation of the Soil Map of the World soil patterns have been estimated in terms of proportional occurrences of individual soil units within each landscape, or physiographic entity. Physiographic entities that are sufficiently large for representation on the map are identified as map units. A map unit consists generally of an association of individual soil units, composed of a dominant soil and of associated soils. If insufficient information is available to specify the dominant soil unit only the undifferentiated major soil unit is designated in the map unit. In such a case it is assumed that the whole map unit dominantly consists of the first individual soil unit listed under the major unit heading as presented in Volume I of the Soil Map of the World.

Map units are registered on the map by the symbol of the dominant soil unit, followed by a reference number. In addition the textural class and the slope class of the dominant soil are given. Further details on the environmental conditions in relation with soil distribution are given in the explanatory texts.

The soil units of the inventory

The inventory of the soils of the flat wetlands of the world is made by selection of map units of the Soil Map of the World on the basis of soil and environmental information as follows:

1 soil units
2 slope class
3 soil depth
4 type of landscape
5 climate

The map units are inventoried as if they were homogeneous and would consist uniquely of dominant soil units. The soil units which may be related with conditions of impeded drainage and which are therefore included in the inventory, are listed in Table 1 at the end of this Chapter. In total 38 soil units are listed belonging to 13 major soil units. Some of the soil units, like Bv, Lv, Ph, Q, and R (refer to Table 1) are not by definition soils with drainage problems and their selection for the inventory has been based on additional information on associated soils or on landscape. For example, Regosols of a coastal lagoonal landscape, associated with Fluvisols and Gleysols, are included, but Regosols of a coastal dune landscape are excluded. The FAO-Unesco

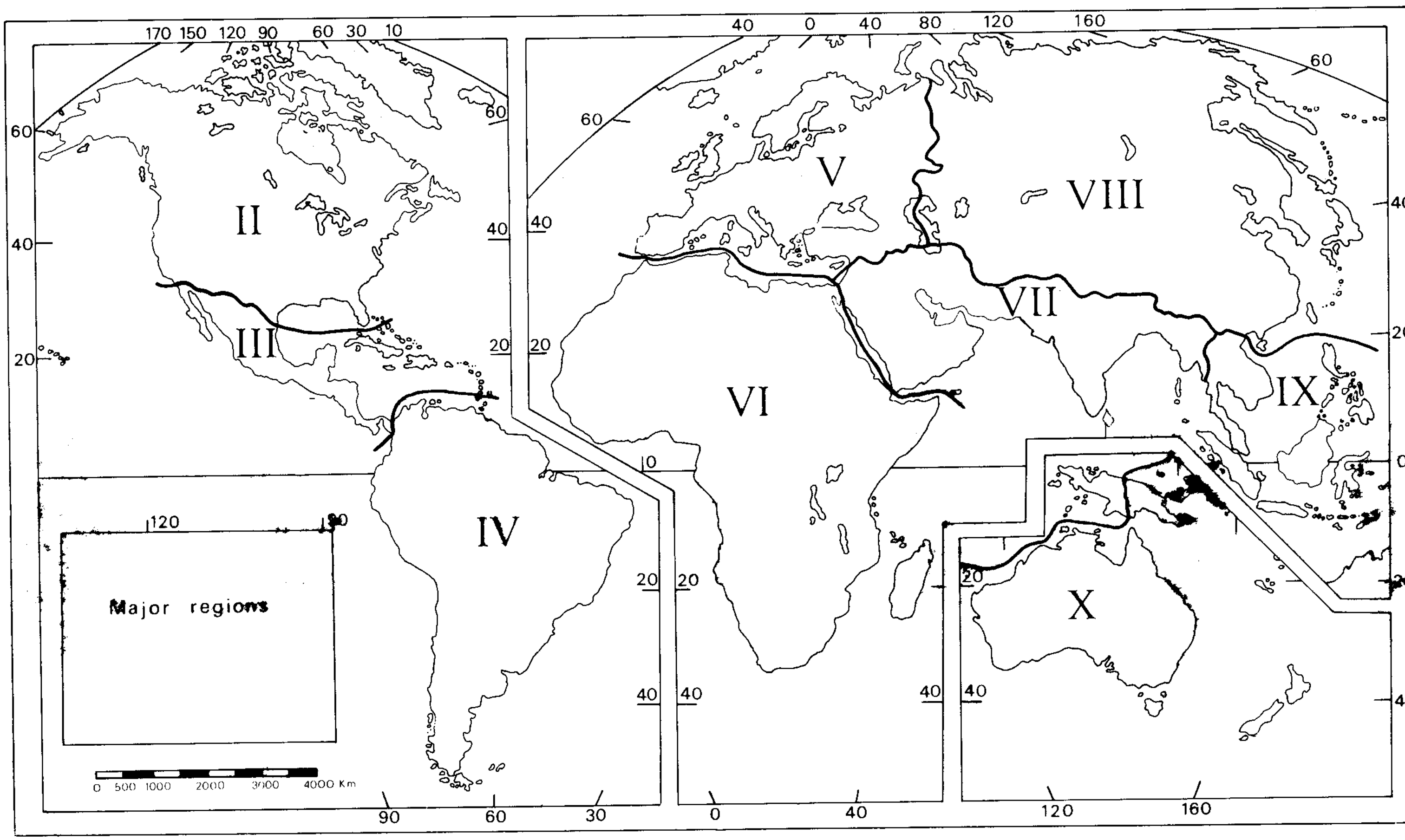


Figure 1. Major regions of the FAO-Unesco Soil Map of the World

soil map does not make a distinction between soils with actual drainage problems and soils which are artificially drained, and consequently reclaimed land such as polders are represented as areas of soils with impeded drainage.

It should be pointed out, that three Gleyic subgroups of the FAO soil legend have been deliberately left out the inventory despite their characteristics of wetness, namely Gleyic Podzoluvisols (Dg), Gleyic Greyzems (Mg) and Gleyic Phaeozems (Hg). It was reasoned that improvement of drainage conditions on these soils would in general not result in increased agricultural production. These soils occur in temperate zones and the period of waterlogging is restricted to the winter, so outside the growing season, and summer crops benefit greatly of the large moisture reserve stored in the soil.

In the inventory of flat wetlands topography is the second selection criterion after drainage. On the FAO-Unesco map the slope class 'a' refers to land with level to gently undulating topography, and in the inventory it has not been possible to make a fine distinction between level and gently undulating landscapes. Excluded have been the map units with sloping terrain (slope classes ab, b, and c). Also excluded are map units or parts of map units of the World Soil Map, which are marked with special symbols to indicate the presence of indurated layers or hard rock at shallow depth, or of many stones or gravel at the surface. Finally, all soils of the permafrost zone are excluded from the inventory.

Cartographic representation

On the map of soils with impeded drainage only the symbol of the dominant soil unit has been noted. Most of the major soil units have been assigned a specific colour. Some related soil units, e.g. the Fluvisol and Gleysols with high base saturation, are represented by the same colour. The used colours are more or less comparable with those used for the soil units of the Soil Map of the World. The area extents have been measured directly on the map. It was not feasible to obtain a higher accuracy by use of conversion tables based on mean scale departure ratios. A summary of the distribution of the inventoried soils by major region, by temperature limitation zone, by suitability class for three major kinds of land use, with separated figures for aridic areas are presented in annexed tables.

Brief explanation on the distribution of major soil units

The soil inventory has grouped together all wet and flat soils of the world, which vary greatly in age, climatic conditions, parent material, reclamation level and land use history, and although all wet and flat, occur under a wide range of hydrologic conditions and occupy different physiographic positions. Study of the soil forming processes, to which a particular soil subject, may provide an explanation for the nature of the soil as the result of the differentiating action of climate, water, vegetation, gravity and man upon the parent material since its appearance at the earth surface. Although such so-called genetic considerations are not mentioned in the FAO-Unesco Lengend, they have been taken into account during its design.

In the floodplains of rivers and estuaries the young Fluvisols and Gleysols occur. In dry regions the latter have often turned into Solonchaks and to some extent subsequently into Solonetz. Soils on terraces, which are former floodplains, situated somewhat above the present floodplain, have been exposed to soil forming processes for some period. On relatively recent terraces Cambisols occur. On older terraces in subhumid climates Luvisols are found. In tropical climates with strongly contrasting seasons also Planosols are widespread, while under warm and humid conditions Acrisols develop. Vertisols occur commonly in wide depressions in the tropics and subtropics with marked dry and wet seasons. Histosols are typical for swampy areas under any climatic regime, but are most widespread in the cold climates.

Table 1. Brief description of the inventoried soils in alphabetic order of the symbols used to represent them on the map (adapted from the FAO-Unesco legend), with glossary of some technical terms

A *Acrisols*
Soils characterized by illuvial accumulation of clay in the subsoil under conditions of low base saturation.

Ag *Gleyic Acrisols*
Acrisols, showing groundwater influence within 50 cm of the surface, which are periodically saturated with water unless artificially drained.

Ap *Plinthic Acrisols*
Acrisols having plinthite within 125 cm of the surface.

B *Cambisols*
Soils of medium to fine texture characterized only by weak alteration of the parent material in colour, consistence, or structure.

Bg *Gleyic Cambisols*
Cambisols having groundwater influence or a seasonally perched watertable within 100 cm but below 50 cm of the surface (if groundwater influence occurs within 50 cm of the surface, the soil is considered as a Gleysol).

Bv *Vertic Cambisols*
Cambisols showing cracks during the dry season, that close during the wet season due to the presence of swelling and cracking clays.

G *Gleysols*
Soils which are strongly and dominantly influenced by groundwater, showing groundwater influence within 50 cm of the surface and which lack any characteristic of strong soil development like e.g. illuvial horizons. Gleysols may be artificially drained.

Excluded from the Gleysols are the soils in recent alluvial deposits, which are defined as Fluvisols. Also excluded are cracking clay soils, which are Vertisols and very saline soils, which are Solonchaks.

Gc *Calcaric Gleysols*
1. Gleysols which are calcareous, due to the calcareous nature of the parent material
2. Gleysols, which have a horizon with very high content of lime or gypsum due to accumulation caused by upward moving groundwater. This horizon should be within 125 cm of the surface.

Gd *Dystric Gleysols*
Gleysols, having a low base saturation status but which are not calcareous.

Gh *Humic Gleysols*
Gleysols having a thick, very dark topsoil with a high humus content and a low base saturation, or having above the mineral soil a thick peaty or mucky surface layer (but not more than 40 cm thick), that has acid reaction (pH below 5.5).

Gm *Mollic Gleysols*
Gleysols having a thick, very dark topsoil with a high humus content and a high base saturation, or having above the mineral soil a thick peaty or mucky surface layer (but not more than 40 cm thick), that has neutral or alkaline reaction (pH 5.5 or more).

Gp *Plinthic Gleysols*
Gleysols, having plinthite within 125 cm of the surface.

J *Fluvisols*
Soils in recent alluvial deposits, still showing fine stratification, and unless protected by dikes, receiving fresh material at regular intervals from sea, river, or overland flow. Fluvisols are younger than Gleysols. However, during the compilation of the Soil Map of the World, different interpretation of the definitions between contributors to the map have resulted in a mixing up of both units.

Jc *Calcaric Fluvisols*
Fluvisols which are calcareous.

Jd *Dystric Fluvisols*
Fluvisols having a low base saturation status.

Je *Eutric Fluvisols*
Fluvisols having a high base saturation status, but which are not calcareous.

Jt *Thionic Fluvisols*
Soils having mineral or organic materials which are rich in sulfides or sulphuric acids, or both, at less than 125 cm from the surface. There are two kinds of Thionic Fluvisols:

1. Waterlogged soils of coastal mud plains with neutral soil reaction which are so rich in sulfides (mainly pyrite, FeS_2) that they will turn into extremely acid soils if their drainage is improved. These soils are known as potential acid sulfate soils.
2. Extremely acid soils, developed from sulfidic muds after improvement of soil drainage by oxidation of sulfides to sulfate and sulfuric acids. These soils are known as cat clays or actual acid sulfate soils.

L *Luvisols*
Soils characterized by illuvial accumulation of clay in the subsoil, under conditions of high base saturation.

Lg *Gleyic Luvisols*
Luvisols having or showing signs of a seasonally perched watertable within 50 cm of the surface.

Lv *Vertic Luvisols*
Luvisols, showing cracks during the dry seasons, that close during the wet seasons because of the presence of swelling and cracking clays.

O *Histosols*
Soils, formed under very wet conditions by accumulation of organic material, deposited on the surface, to considerable thickness. Generally, an organic soil (peat or muck) should contain at least 20 percent organic matter and have a thickness of at least 40 cm to be considered a Histosol. Histosols are saturated with water for prolonged periods unless artificially drained.

Od *Dystric Histosols*
Acid Histosols characterized by a pH of less than 5.5.

Oe *Eutric Histosols*
Fertile Histosols characterized by a pH of more than 5.5.

P *Podzols*
Acid sandy soils characterized by a marked illuvial accumulation or organic matter and aluminum with or without iron.

Pg *Gleyic Podzols*
Podzols showing groundwater influence within 50 cm of the surface, which are periodically saturated with water unless artificially drained.

Ph *Humic Podzols*
Podzols which are characterized by the illuviation of dispersed organic matter with little or no iron.

Q *Arenosols*
Old sandy soils that show characteristics of strong weathering or soil development. Excluded are stratified sandy soils, which are Fluvisols, and sandy soils with typical features of Podzols, as well as sandy soils without soil development, which are Regosols.

Qa *Albic Arenosols*
Arenosols consisting of white sand to a depth of at least 50 cm from the surface.

Ql *Luvic Arenosols*
Arenosols with some lamellae of accumulated clay within 125 cm from the surface.

R *Regosols*
Soils showing little or no soil development consisting of loose materials. Regosols are usually, but not necessarily sandy. Included in the definition of Regosols are wind blown deposits like, e.g. dunes.

Rd *Dystric Regosols*
Regosols having a low base saturation status.

Re *Eutric Regosols*
Regosols having a high base saturation status, but which are not calcareous.

S *Solonetz*
Soils with very bad physical properties due to the presence of sodium-clays and dispersed humus. Slight percolation with sodium containing water has resulted in a structureless surface soil above a soil horizon with columnar structure, characterized by illuvial accumulation of clay, bearing sodium (and/or magnesium) on its base exchange complex.

Sg *Gleyic Solonetz*
Solonetz showing groundwater influence within 50 cm of the surface, which are periodically saturated with water unless artificially drained.

Sm *Mollic Solonetz*
Solonetz, having a thick, very dark, topsoil with a high humus content and a high base saturation.

So *Orthic Solonetz*
Ordinary Solonetz.

V *Vertisols*
Heavy clay soils, showing deep wide cracks during the dry seasons, that close during the wet seasons because of the presence of swelling and cracking clays. They are hard when dry and sticky when wet.

Vp *Pellic Vertisols*
Black or dark gray coloured Vertisols (dark colour is related with impeded drainage).

W *Planosols*
Soils with a bleached sandy horizon, which extends from the surface or from the lower topsoil downwards to a slowly permeable layer (e.g. a dense compact clay) within 125 cm depth. The (nearly) impervious layer causes periodically waterlogged conditions in at least the lower part of the white sandy horizon. This bleached sand or silty sand results from the complete removal of clay and iron (and bases), a process that occurs in soils subject to contrasting periods of waterlogging and drought.

Wd *Dystric Planosols*
Planosols, having a low base saturation in the slowly permeable horizon.

We *Eutric Planosols*
Planosols, having a high base saturation in the slowly permeable horizon.

Wh *Humic Planosols*
Planosols having a thick, very dark topsoil with high humus content and a low base saturation or having above the mineral soil a thick peaty or mucky surface layer (but not more than 40 cm thick), that has acid reaction.

Wm *Mollic Planosols*
Planosols, having a thick, very dark topsoil with high humus content and a high base saturation, or having above the mineral soil a thick peaty or mucky surface layer (but not more than 40 cm thick) that has neutral or alkaline reaction.

Ws *Solodic Planosols*
Planosols with some sodium-clays in the slowly permeable horizon. They are formed from Solonetz by partial leaching of the sodium from the exchange complex.

Z *Solonchaks*
Saline soils, characterized by a high concentration of soluble salts, harmful for plant growth. There are, however, saline soils which are not classified as Solonchak, but are considered saline phases (subdivisions of soil units) of other soils, e.g. of Fluvisols, Histosols, Solonetz, or Vertisols.

Zg *Gleyic Solonchaks*
Solonchaks, showing groundwater influence within 50 cm of the surface, which are periodically saturated with water unless artificially drained.

Zm *Mollic Solonchaks*
Solonchaks, having a thick, very dark topsoil with high humus content and a high base saturation.

Zo *Orthic Solonchaks*
Ordinary Solonchaks.

Zt *Takyric Solonchaks*
Solonchaks of heavy clay, that form a platy crust at the surface, cracking in a polygonal pattern.

Table 1 (continued) - Glossary of some technical terms

alluvial - resulting from deposition by rivers or streams, by sea or in lakes.
base saturation - percentage of the exchange complex occupied by bases.
- high base saturation means that the exchange complex is dominated by bases, indicating high fertility status.
- low base saturation means that the exchange complex is dominated by H-ions, indicating low fertility status.

eluvial - resulting from removal of soil substances out of a soil horizon by a washing down process.
exchange complex - all soil particles that contribute to the maintenance of a reservoir for storage of plant nutrients, that can be extracted by plant roots and can be replenished by amendments of fertilizer. The capacity of the reservoir depends largely on the clay and humus compounds in the soil, while the filling degree of the reservoir is indicated by the base saturation level.
horizon - a natural soil layer, either surface soil or subsoil, that formed parallel to the land surface during the natural development of the soil.
illuvial - resulting from the process of washing down of soil substances into a soil horizon.
parent material - unaltered sediment or rock material from which a soil forms.
plinthite - a red mottled clay of firm consistency which occurs sometimes in the subsoil of poorly drained soils, especially in the tropics. Upon exposure to the atmosphere plinthite changes irreversibly to very hard ironstone.
profile - a vertical cross-section of a soil through all horizons.
soil development - the degree to which parent material has been altered by soil formation.
soil formation - the process by which parent material is transformed (into soil) by the action of climate, water, gravity, plants, animals, and man.
texture - the relative proportions of sand, silt, and clay in a soil

fine texture	- more than 35 percent clay
coarse texture	- more than 65 percent sand and less than 15 percent clay
medium texture	- intermediate proportions

2 SOIL SUITABILITY EVALUATION

General

For the appraisal of potential polder areas for agricultural land use information should be available on soils and soil related constraints, hydrology, climate, and socio-economic conditions. In the preceding Chapter the characteristics of the inventoried soils have been described. The present Chapter will concentrate on the soil related constraints for agricultural production associated with each soil. In a later stage climatic constraints will be superimposed. while hydrology and socio-economic conditions are not systematically inventoried.

Throughout this Chapter reference is made to the principles outlined in the Framework for land evaluation (FAO, 1976). In terms of the Framework the exercise discussed below is concerned with the assessment of land performance when used for specified purposes after the accomplishment of major land improvements. A comparison of this projected with the actual situation cannot be made due to the great variation in reclamation levels, on each soil unit occurring in different regions and countries.

The major land improvements that are supposed to be achieved in the evaluation include all measures to create a situation, in which optimal moisture supply can be guaranteed during the whole temperature determined growing season. Examples of such improvements are drainage of swamps, reclamation of salinized land and large irrigation schemes. The kind of improvements required for each soil unit cannot be given in detail. In general, they depend largely on the kind of drainage problems. Therefore, these drainage problems are discussed first as well as some other reclamation problems related with physical aspects of the land. These generalities are followed by the description of the soil suitability procedure, that has been applied to each individual soil unit of the inventory. The results of the suitability evaluation are summarized in a Table.

Drainage problems

The impeded drainage conditions or drainage problems refer to the soils in their natural state. These problems are related with flooding by river or sea, or with the accumulation of rainwater, or a combination of both. It is convenient to make a distinction between flooding and ponding, which are defined as follows:

Flooding - the active passage of surface water from elsewhere over the terrain concerned accompanied by scouring and sedimentation.
Ponding - the passive accumulation of rainwater on the terrain concerned due to its low and flat position and/or the presence of an impermeable layer in the soil.

The Fluvisols and Gleysols are subject to flooding, while most of the other soils with impeded drainage have poor drainage conditions due to ponding (Table 2).

Reclamation problems

When reclamation of an area is considered attention should be paid to the occurrence of possible problems related with the physical condition of the land. Two main kinds of problems of reclamation are mentioned here:

1. Vegetational hinderance
   This constraint refers to the unease of clearing the present vegetation, e.g. when a land area is under mangroves, it has to be cleared for agricultural land use. However, it is not possible to establish valid relations between the natural vegetation and the soils on which it grows, or vice-versa, becase such relations depend very much on the climate and the hydrological conditions and are therefore very site specific.
2. Constraints for building constructions
   The following types of constraints may be present:
   a) Seepage in soil and substratum
      Seepage normally occurs in coarse-textured sandy material.
   b) Consistence of substratum
      Unripe clay often called mud clay, has a very loose packing of the particles. This clay type is characterized by a weak consistence. Also peat is characterized by a very weak consistence of the substratum.
   c) Swelling and shrinking
      This constraint refers to soils which consist dominantly of swelling and shrinking clays, i.e. Vertisols. For engineering purposes Vertisols are problem soils because the internal pressure, resulted by swelling often causes walls of houses to crack. In general, Vertisols endanger the stability of many structures.

Assessment of the agricultural potential of the soils with impeded drainage

For the assessment of the agricultural potential of the soils it is assumed that conditions of good water control prevail i.e. optimal improvement of external drainage has taken place. This kind of assessment is called potential soil suitability in the Framework. For each soil unit suitability ratings have been made for three major kinds of land use based on the occurrence of soil related constraints, i.e. limiting physical land qualities. Four suitability classes are recognized (Table 2). Class 1 is considered to be highly suitable, Class 4 is considered to be not suitable for a specific land use.

Table 2. Soil suitability classes (after improvement of external drainage)

Class 1.	Highly Suitable	Soil having no significant limitations to a specified use
Class 2.	Moderately	Soil having moderately severe limitations to a specified use
Class 3.	Poorly Suitable	Soil having severe limitations to a specified use
Class 4.	Not Suitable	Soil having limitations to a specified use which appears so severe as to preclude any possibility of successful use

It should be clear that the classes refer to a qualitative suitability rating in which relative suitability of soils is expressed in qualitative terms only. The class rating for individual soil units was achieved by intuitive estimation of relative production potential of each soil unit in relation with all other units. The estimates are based solely on central concepts of the soil units, without paying attention to the wide range in soil characteristics that may occur within each soil unit.

The soil suitability classes are subdivided in subclasses, in order to indicate the nature of the soil related constraints, that limit the production potential of a given soil unit. The concerned limiting physical land qualities related to productivity from crops and those related to reclamation are listed in the alphabetical order of their symbols (Table 3).

Table 3. The limiting physical land qualties

a	bearing capacity
c	conditions for germination
j	soil toxicity
m	moisture retention capacity
n	nutrient availability
p	workability of the land, referring to dry feet and wetland rice production or accessibility to land for cattle related to soils with cracking clays and/or resistance of grass to trampling down by cattle
r	rootability
u	constraint for building constructions - seepage in soil and substratum
v	constraint for building constructions - swelling and shrinking clays
w	oxygen availability
y	constraint for building constructions - consistence of substratum
z	salinity or alkalinity

To reflect the order of importance of the limiting land qualities three degrees of limitations of the land qualities are recognized:

strong limitation - underlined capital letter
moderate limitation - capital letter
weak limitation - small letter

The three major kinds of land use for which ratings have been made are dry foot cropping, grassland and wetland rice. Dry foot cropping refers to the group of agricultural crops which require aerated soils. Grassland is supposed to be intensively used. Extensive grazing lands are not considered. Wetland rice is used to denote the wet cultivation of rice.

All ratings for all three kinds of land use are made under the assumption that there is high farm management level characterized by high inputs of fertilizer, high yielding crop varieties and use of heavy machinery. This is done for technical reasons only and it is not meant as a judgement on the appropriateness of such a farming system after reclamation. But it seems reasonable to assume that high investments for land improvements and water management are economically justified only for a system of intensive agriculture. The relevant type of intensive agriculture in each case will depend on size of holdings, cropping pattern, costs of labour, and many other factors.

There are some important differences in the ratings of soils for wetland rice and dry foot cropping. This is due to the differences in soil tillage requirements. In lowland rice system, the ease of puddling a soil is very important. Puddling is the soil management practice, conducted for the purpose of destroying the topsoil structure. Puddling can be defined as the process of breaking down soil aggregates into a uniform mud, accomplished by applying mechanical force to the soil at high moisture contents.

The overall results, i.e. drainage problems, problems of reclamation and soil suitability ratings for the major kinds of land use of each inventoried soil unit are presented in Table 4.

Concerning the suitability ratings, Table 4 shows that the soil related constraints of the Gleyic Cambisols (Bg), the Calcaric, Eutric and Mollic subgroups of the Gleysols (Gc, Ge, Gm), and the Calcaric and Eutric Fluvisols (Jc, Je) are negligible for each major kind of land use. These soil units have the highest potential for agricultural purposes. When the soils belong the Suitability Class 2 for a specified kind of land use, they are still attractive but will be appreciably inferior to Class 1 soils for that kind of land use due to existing moderately severe soil related constraints. The remainder of the inventoried Fluvisols (J) and Gleysols (G), and the Luvisols (L) are classified as Class 2 soils for at least two major kinds of land use.

All other units are classified as Class 3 or Class 4 soils for at least two major kinds of land use. Those soils are marginally or not suitable for the specified kinds of land use. Furthermore, it should be noted that the Gleyic Luvisols (Lg), the Podzols (W) and Solonchaks (Z) are most suitable for wetland rice cropping because their number and/or degree of their limitations are low for wetland rice in comparison with both other land uses.

Table 4. Suitability evaluation for the inventoried soil units[1]

Soil unit	Drainage problems: Flooding	Drainage problems: Ponding	Problems of reclamation	Suitability rating[2]: Dry foot cropping	Grassland	Wetland rice
Ag		X		4cJNw	4jNw	4N
Ap		X		4cjrwN	4jNrw	4Nr
Bg		X		1	1	1
Bv		X	y	2pw	2w	2p
Gc	X		y	1	1	1
Gd	X		Y	2n	2n	2n
Ge	X		Y	1	1	1
Gh	X		Y	2n	2n	2n
Gm	X		Y	1	1	1
Gp	X		y	2nr	2nr	2nr
Jc	X		uy	1	1	1
Jd	X		uy	2n	2n	2n
Je	X		uy	1	1	1
Jt	X		Y	3J	2J	2j
Lg		X		2cw	2w	1
Lv		X		2cpw	2pw	2p
Od		X	Y	4AmN	4AmN	4AN
Oe	X	X	Y	3Am	3Am	3A
Pg		X	Uy	4MN	4MN	4MNa
Ph		X	U	4MN	4MN	4MN
Qa	X	X	U	4MN	4MN	4MN
Ql	X	X	Y	4MN	4MN	4MN
Rd		X	u	4MN	4MN	4MN
Re		X	u	4MN	4MN	4MN
Sg		X	Y	4CnPRWZ	3npRWZ	3npZ
Sm		X		4CPRWZ	3pRWZ	3pZ
So		X	y	4CnPRWZ	3npRWZ	3npZ
Vp		X	V	3PRW	3PRW	2Pr
Wd		X		4acjMNpRW	3ajMNRW	2aN
We		X		4acMpRW	3aMRW	2a
Wh		X		4acMnRW	3aMnRW	2an
Wm		X		4acmRW	3amRW	2a
Ws		X		4AcmNRWZ	4AMNRWZ	3ANZ
Zg		X	y	3nZ	3nZ	2nZ
Zm		X		3Z	3Z	2Z
Zo		X	y	3nZ	3nZ	2nZ
Zt		X	y	3nZ	3nZ	2nZ

1 for the meaning of the symbol see Tables 1, 2, and 3

2 underlined capital letter - strong limitation
capital letter - moderate limitation
small letter - weak limitation

3 CLIMATIC SUITABILITY FOR PLANT GROWTH

Objective and methodology

In the preceding chapter the suitability of the inventoried soils has been discussed for three major kinds of land use. The suitability assessment is based solely on soil related constraints, under the assumption that water supply and drainage conditions are optimal.

Likewise, this chapter deals with climatic suitability for plant growth under the assumption that sufficient water is available for crop growth from rainfall, soil moisture storage and/or irrigation, and that also soil constraints do not play a role at this stage. The moisture regime being waived aside by these assumption, the climatic suitability of a given area will depend only on the temperature regime as only temperature regime will determine the length of the growing season. Its assessment allows to predict the agronomic potential of climatic zones. For the purpose of the present study, the agronomic potential is expressed in potential cropping intensity, that is the possible number of crops that can be harvested consecutively from the same tract of land within the period of one year. As in reality different crops have different growth cycles, optimum temperatures, photoperiodicity etc. it is convenient to define a universal reference crop. This crop would have a fixed growth cycle of three months and be adapted to a very wide range of climatic conditions, except to low temperatures. If one month is allowed for soil preparation and harvest operations the crop cycle is four months. Consequently, when no temperature limitations exist, a maximum of three crops per year can be obtained.

It seems meaningful to make a distinction between the following zones on the basis of potential cropping intensity (in relation with the reference crop):

0 Zone in which cropping is not well possible, because the summer season is too cold or too short. In fact, such zones are in use as extensive grazing lands or under lowly productive forests. Perhaps some adapted crops can be grown, but not a reference crop.

1 Zone in which at least one crop per year is possible, but less than two. This zone corresponds with the temperature regions. In the milder parts some second crop could be grown after the reference crop, but not a second reference crop.

2 Zone in which at least two crops per year are possible. This zone corresponds with the subtropical regions, where a short winter prevents the cultivation of three reference crops.

3 Zone in which three crops per year are possible. This zone corresponds with the warm tropical regions, where no temperature limitations exist.

Furthermore, in conformity with the soil evaluation for wetland rice it seems appropriate to delineate also those areas where at least one crop of rice can be grown. The climatic suitability for rice will be assessed indepently of the four temperature limitation zones described above, but will equally be based solely on temperature requirements of rice, assuming that sufficient water is available.

In this way the temperature related constraints for crop growth are made visible for large zones on the world map, giving an indication to which extent agricultural production could be increased under conditions of optimal water and soil management.

Most climatic classification systems, are based on a correlation between climatic and natural vegetation and do not allow to separate humidity factors from temperature influences. The approach of the recent Agro-Ecological Zones project (FAO, 1978) presents very useful elements, but its methodology is fully developed only for purely rainfed conditions on uplands, and in addition, covers only developing countries. Also the USDA concepts of soil temperature regimes contains very useful elements, but no information is available at a global scale. Therefore the climatic classification system of Papadakis (1966) has been selected, as this system is based on a combination of humidity and temperature regimes, which are also defined separately, thus allowing to consider each of them independently of the other. In addition his climatic subdivisions are based on the characteristics of climates from a crop ecologic point of view. These include such important features as winter severity, duration of the frost-free season, summer heat, and humid and dry seasons. Finally, Papadakis provides worldwide coverage. Of the definition of the climatic features only temperature regimes will be discussed here.

Temperature regimes according to Papadakis

To study winter severity Papadakis has chosen five important crops with decreasing winter resistance and studied their geographic distribution and behaviour in the whole world. On this basis the earth has been divided in 13 zones of increasing winter severity, going from the equator to the poles. These winter severity or winter types and their definition in terms of temperatures are summarized in Table 5. In a similar way, the world has been divided by a series of summer heat belts. These summer heat belts or summer types and their limits in terms of temperatures are recorded in Table 6.

Papadakis has distinguished temperature regimes by means of combinations of the defined winter- and summer types. All possible combinations of winter and summer types with corresponding defined temperature regimes are presented in Table 7. In addition, for each existing temperature regime, the estimated potential cropping intensity is given. This will be discussed below.

Interpretation of the temperature regimes of Papadakis in terms of number of crops possible per year

Temperature regimes with the summer type P or p, are considered to be too cold and/or have a too short growing season for crop growth. They are indicated in Table 7 by number 0.

All temperature regimes with winter type Ct or warmer do not have temperature limitations all the year round, i.e. three crops a year are possible. The assumption has been made that in the colder part of the year more winter resistance crops are grown. These temperature regimes are indicated in Table 7 by number 3. Very extensive areas in tropical regions belong to this zone.

The temperature regimes, with combinations of the winter types, Av, av, and the summer types G, g, c, and O and the Av - M combination are considered to be suitable for two crops per year. They are indicated in Table 7 by number 2. Areas characterized by such temperature regimes occur in the mediterranean and warm steppe regions.

The remainder of the combinations of winter- and summer types are considered to be suitable for one crop per year and are indicated in Table 7 by number 1. Most of the temperate regions are included in this zone.

Problems arise with the translation of the established climates of Papadakis (defined in terms of both temperature and humidity regimes), if a given climate is associated with more than one potential cropping intensity, due to a wide range in winter types, occurring within the same climate. This is the case with climates where rainfall limitations are the main differentiating factor in the climatic definitions, e.g. CO. In such cases the boundaries of the cropping intensity zones (or temperature limitation zones) have been based also on interpretation of data from other sources.

Because most inventoried wetlands are situated in lowland areas, not much attention has been paid to the climates of mountainous areas. Therefore, they are not delineated in detail on the map.

Interpretation of climates for their suitability for rice

According to the system of Papadakis the temperature regimes with summer type O or warmer are considered to be suitable for rice cultivation (at least one crop per year). However, the definitions of the various climates do not always specify exactly the actual summer temperature type. Consequently, for the establishment of the rice boundary additional sources of information have sometimes been used.

Table 5. Winter types and their definition in terms of temperatures of the coldest month (Papadakis, 1966)

Type		average of the lowest	average daily minimum	average daily maximum
Ec	equatorial	above 7°C	above 18°C	
Tp	warm tropical	idem	13-18°C	above 21°C
tP	medium tropical	idem	8-13°C	above 21°C
tp	cool tropical	idem		below 21°C
Ct	citrus tropical	-2.5 to 7°C	above 8°C	above 21°C
Ci	citrus	idem		10 to 21°C
Av	warmer oat	-10 to -2.5°C	above -4°C	above 10°C
an	cooler oat	below -10°C		5 to 10°C
Tv	wheat-oat	-29 to -10°C		above 5°C
Ti	warmer wheat	above -29°C		0 to 5°C
ti	cooler wheat	idem		below 0°C
Pr	warmer spring crops	below -29°C		above -18°C
pr	cooler spring crops	idem		below -18°C

Table 6. Summer types and their definition in figures (Papadakis, 1966)

Type		minimum length frost free season	average t_{max} over n warmer months	average t_{max} of warmest month	average t_{min} of warmest month
G	warmer cotton	4.5 months	above 25°C ; n=6	above 33.5°C	
g	cooler cotton	idem	idem	below 33.5°C	above 20°C
c	coffee	12 months	above 21°C ; n=6		below 20°C
O	rice	4 months	21 to 25°C ; n=6		
M	maize	4.5 months	above 21°C ; n=6		
T	warmer wheat	idem	above 17°C ; n=4		
t	cooler wheat	2.5 to 4.5	idem		
P	polar taiga	less than 2.5	above 10°C ; n=4		
p	polar tundra	idem	above 6°C ; n=2		

Not shown are figures for alpine and frigid summer types.

Table 7. Temperature regimes, their definition in terms of winter- and summer types according to Papadakis (1966) and estimated potential cropping intensity

summer type	winter type												
	Ec	Tp	tP	tp	Ct	Ci	Av	av	Tv	Ti	ti	Pr	pr
G	EQ 3	TR 3	tR 3		Ts 3	SU 2	CO SU 2	CO 2	CO 1	CO 1	CO 1	CO 1	
g	Eq 3	Tr 3	tR 3	tr 3	TF Ts 3	Su TF 2	CO TF 2	CO 2	CO 1	CO 1	CO 1	CO 1	
c		Tt 3	Tt 3	Tt 3									
O				tr 3		MA Tf 2	Tf 2	Tf 2	Tf 1	Co 1	Co 1	Co 1	
M						MA Tf 2	PA TE Tf 2	TE Tf 1	Tf 1	Co 1	Co 1	Co 1	
T				tt 3		Mm tf 2	Ma tf 1	Ma tf 1	tf 1	Te 1	Te 1		
t						tf 2	Pa tf 1	Pa tf 1	Pa tf 1	te 1	te 1	co 1	co 1
P						aP o	aP pa o	aP ma pa o	aP ma pa o	aP ma pa o	Po	Po o	Po o
p									ap o	ap mp o	po o	po o	po o

Temperature regimes

EQ hot equatorial
Eq semi-hot equatorial
TR hot tropical
Tr semi-hot tropical
tR cool winter hot tropical
tr cool tropical
Tt tierra templada
tt cool tierra templada
TF low tierra fria
Tf medium tierra fria
tf high tierra fria
Ts semi-tropical
SU hot subtropical
Su semi-hot subtropical
Mm super-marine
MA warm marine
Ma cool marine
ma cold marine
mp marine tundra
TE warm temperate
Te cool temperate
te cold temperate
PA pampean
Pa patagonian
pa cold patagonian
CO warm continental
Co semi-warm continental
co cold continental
Po taiga
po tundra

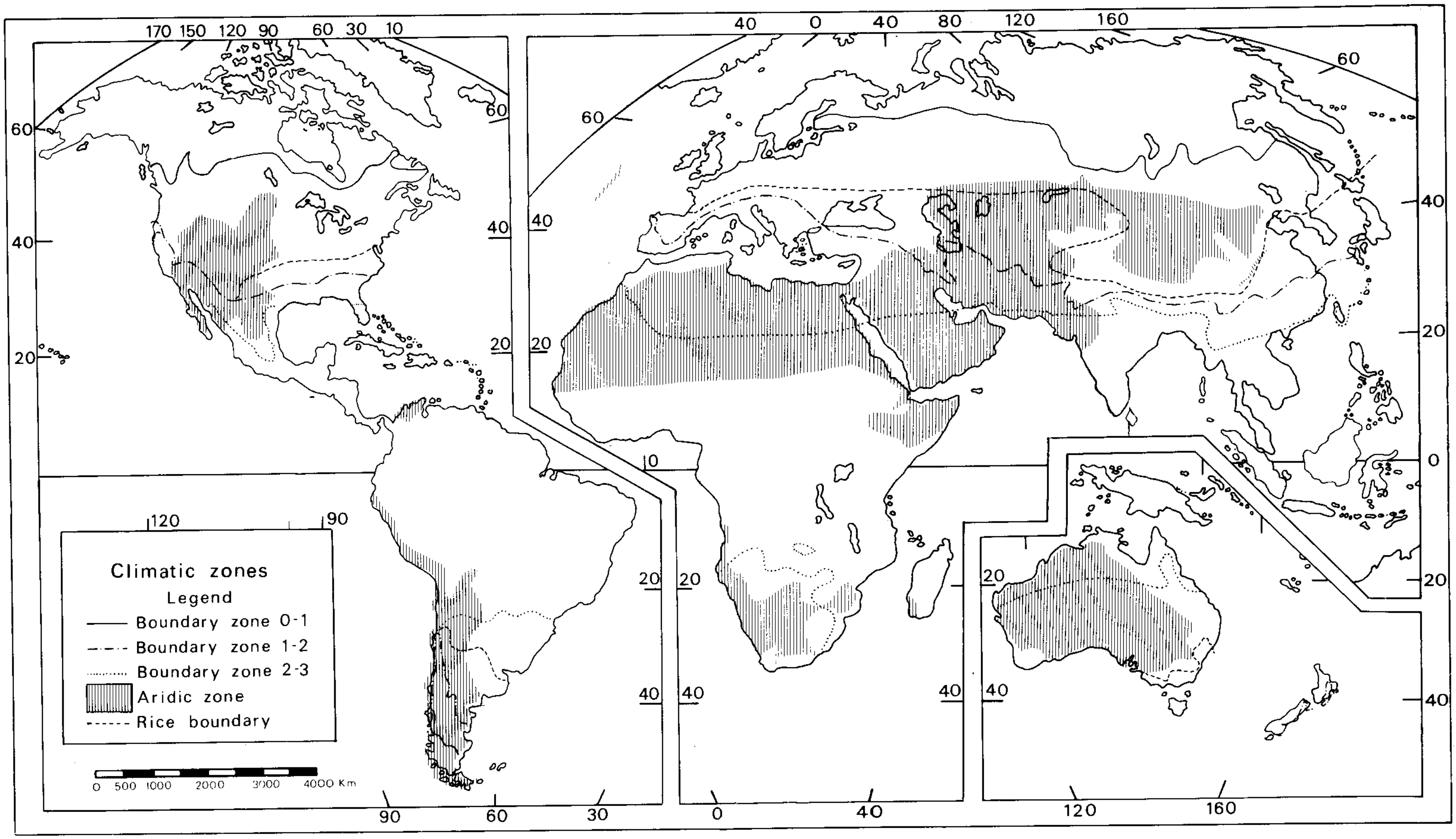


Figure 2. Temperature limitation zones for agricultural production on the world (interpreted from Papadakis and other sources) and distribution of aridic areas

4 HYDROLOGIC ASPECTS

The agricultural development potential of the wetlands occupying low lying parts of drainage basins, depends very much on the hydrologic regime. In Chapter 3 a distinction has been made between flooding and ponding, as two main kinds of submergence. Ponding is controlled by the local rainfall pattern and by run-off from nearby sites, and is closely related with stagnant groundwater. Flooding is controlled by rainfall and terrain conditions in the whole catchment and is related with river flow. Often combinations of local and distant effects occur. This explains the dynamic nature of the hydrologic regime, difficult to represent in a static way on a map.

For a given site the hydrologic regime can be characterized by the depth, intensity and duration of submergence. During the wetland inventory a need was felt to have a system for classifying hydrologic regimes in terms of their constraints for agricultural production caused by water excess on the one hand and of their potential for use as a water resource on the other hand. Both removal of constraints and development of potential can be expressed as increase in opportunities for agricultural production. On the other hand increased agricultural production may be outweighed by adverse effects like decreased fish catch and environmental losses.

A first proposal for such a classification of submergence regimes, with the positive effects of possible empoldering is given below:

1) Permanent or near permanent submergence within the temperature-determined growing season resulting in a year-round limited accessibility and a high infrastructure damage. Depending on temperature regime, one to three crops more can be grown after empoldering.
2) Temporary submergence within the temperature-determined growing season resulting in a substantially limited accessibility and infrastructure damage. After empoldering one crop more can be grown.
3) Occasional and/or short submergence outside the temperature-determined growing season resulting in temporarily limited accessibility and some damage to infrastructure. Empoldering protects infrastructure and widens choice of crops.

There is a possibility that a flood classification will be developed by the IGU Working Group on the Geomorphology of River and Coastal Plains (IGU, 1982), which has initiated a project to prepare a geomorphological map of flood-affected areas and drainage basins of the world, scale 1 to 5 million.

At present no reference can be made to a satisfactory classification system for hydrologic regimes, that would fit in the suitability assessment. The best correlation with the regional distribution of hydrologic regimes is probably provided by the rainfall regime. There are two extreme types of rainfall regime with many intermediate types in between, as follows:

- Areas with aridic (extremely dry) rainfall regime. Rainfall is very erratic and never sufficient for growing a crop. Crop growth is completely dependent on irrigation. There are no possibilities for building up water reservoirs from local run-off. The development of water resources has to rely on rivers, originating from distant well-watered areas, and locally also on groundwater reservoirs. Drainage is however very important to prevent salinization. Many soils are actual or potential Solonchaks or Solonetz. Well known examples of this situation are the valleys of the Nile, the Indus, and Euphrate and Tigris which have high potential for development. But valleys of streams with very irregular discharge stemming from local run-off have no potential for development of water resources.

- Areas where rainfall exceeds always evapotranspiration. Rainfall is always abundant and largely sufficient for crop growth. Crops and farm operations suffer because of excessive wetness. Land management of low lying areas is primarily concerned with drainage. Under such conditions the development of water reservoirs for irrigation is completely superfluous.
- Intermediate areas with semi-arid and sub-humid climates, and usually having a seasonal rainfall pattern. Large variations in rainfall distribution exist. On low lying lands, periods that drainage is needed alternate with periods of irrigation needs. Storage of water from local run-off (small rivers, streams) for use for irrigation is often beneficial.

On the world map of level soils with impeded drainage the aridic zones have been delineated, based on various sources of information (Van Wambeke, 1981 and 1982; FAO-Unesco, 1971-1979). It was not practical to delineate other climate determined moisture zones with higher rainfall, because their relevance for the management of wetlands occurring in such zones, could not be indicated.

5 EXTENTS OF THE INVENTORIED SOIL UNITS

The results of area extent calculations are presented in the following pages and need only few comments.

The area extents have been obtained by measuring first the acreage of each single area on the map. Total extents per soil unit have been determined by adding all acreages of the same unit that occur within a major region, a climatic zone, or the aridic zone. A summary of the figures on area extents is presented in Tables 8 and 9.

For more detailed information Appendix 2 should be consulted. The results show that the total extent of the inventoried soil units comprises 12.6 million sq.km. Taking into account that world's land surface is estimated on 134 million sq.km, this means that about 9.5% of the land surface in the world is occupied by the inventoried soils with impeded drainage. Comparison of extensions of single major soil units over the world shows that Fluvisols and Gleysols are the most widespread soils in the inventory. Another conclusion is, that almost all Orthic Solonchaks (Zo) occur in the aridic area and that they account for more than 50% of the total extent of the inventoried soil units lying in the aridic zone. It is clear that the soils with no soil related constraints and no climatic limitations, i.e. class 1 soils with cropping potential 3 have the highest agricultural potential. These soils are the Gleyic Cambisols (Bg), Calcaric Gleysols (Gc), Eutric Gleysols (Ge), Calcaric Fluvisols (Jc), and the Eutric Fluvisols (Je).

Table 8. Extents of the inventoried soil units

Soil[1] unit	Extents (00 sq.km)[2]										Soil[1] unit
	Major regions									World	
	II	III	IV	V	VI	VII	VIII	IX	X		
Ag	1045	--	99	--	--	--	--	887	517	2548	Ag
Ap	790	99	6362	--	--	--	--	171	248	7670	Ap
Bg	--	--	162	195	3	--	3	342	--	705	Bg
Bv	--	135	--	448	228	--	--	14	--	825	Bv
G	--	--	--	--	728	--	--	--	--	728	G
Gc	--	32	40	--	--	185	1013	--	--	1270	Gc
Gd	709	26	4317	31	961	49	--	377	8	6478	Gd
Ge	824	182	1540	477	2207	1565	4255	891	--	11941	Ge
Gh	94	--	63	39	1275	283	543	459	23	2779	Gh
Gm	463	73	453	756	277	--	4725	--	--	6747	Gm
Gp	--	79	--	--	150	--	--	--	--	229	Gp
J	--	--	--	--	355	--	346	--	--	701	J
Jc	36	35	--	1143	1948	1572	1262	--	--	5996	Jc
Jd	11	--	550	--	233	3	1444	1506	--	3747	Jd
Je	349	182	5047	2509	3218	984	1385	983	728	15385	Je
Jt	--	--	200	--	401	183	--	545	--	1329	Jt
Lg	284	73	--	2046	1021	--	--	--	17	3441	Lg
Lv	--	31	--	--	--	--	--	--	--	31	Lv
O	427	--	32	--	--	--	--	--	--	459	O
Od	2718	229	132	2057	46	32	3301	1712	10	10237	Od
Oe	--	--	84	96	123	--	1441	704	41	2489	Oe
Pg	476	--	23	3205	--	--	--	140	--	3844	Pg
Ph	--	--	--	--	206	--	--	--	--	206	Ph
Qa	--	--	458	--	95	--	--	--	--	553	Qa
Ql	--	--	--	--	55	--	--	--	--	55	Ql
R	--	--	42	--	--	--	--	--	--	42	R
Rd	--	40	74	--	101	--	--	28	--	243	Rd
Re	127	254	--	--	154	--	--	--	--	535	Re
S	--	--	263	--	--	--	367	--	--	630	S
Sg	--	--	--	--	--	--	210	--	--	210	Sg
Sm	440	--	980	51	--	--	1150	--	--	2621	Sm
So	308	--	197	708	809	--	948	--	--	2970	So
V	--	--	--	--	179	--	--	--	--	179	V
Vp	710	1002	629	307	3111	1103	903	179	217	8161	Vp
W	--	--	--	--	72	--	--	--	--	72	W
Wd	--	33	155	74	--	--	--	--	--	262	Wd
We	612	54	1285	--	453	--	115	--	--	2519	We
Wh	--	21	--	--	--	--	--	--	5	26	Wh
Wm	--	--	917	--	--	--	--	--	--	917	Wm
Ws	--	--	666	--	216	--	32	--	1731	2645	Ws
Z	--	--	54	--	142	--	995	--	--	1191	Z
Zg	--	--	305	157	169	533	713	--	--	1877	Zg
Zm	--	--	--	--	--	--	1011	--	--	1011	Zm
Zo	12	24	199	63	1002	4028	1401	--	1409	8138	Zo
Zt	--	--	--	--	39	--	227	--	213	479	Zt
Totals	10435	2604	25328	14362	19977	10520	27790	8938	5167	126121	

[1]no small letter means undifferentiated

[2]territory of the Netherlands is 340, France is 5470, and U.S.A. is 93630 (00 sq.km)

Table 9. Extents of the inventoried soil units within the temperature limitation zones exclusive of the aridic areas

Soil[1] unit	Extents (00 sq.km)					
	Aridic areas excluded					
	World	Temperature limitation zone				
		cropping potential 0	1	2	3	suited for rice
Ag	2548	--	178	919	1451	2548
Ap	7670	--	187	603	6880	7670
Bg	705	--	188	10	507	702
Bv	782	--	448	41	293	334
G	453	--	--	--	453	453
Gc	727	7	0	503	217	687
Gd	6478	--	313	314	5851	6320
Ge	11314	201	782	4182	6149	10531
Gh	2737	6	619	124	1988	2050
Gm	6528	30	5221	574	703	3233
Gp	228	--	--	--	228	228
J	701	--	396	--	355	361
Jc	2563	--	1257	622	684	175
Jd	3744	866	589	--	2289	2300
Je	11814	435	2944	1540	6895	8700
Jt	1295	--	--	--	1295	1295
Lg	3420	--	2179	184	1057	1268
Lv	31	--	--	--	31	31
O	459	--	186	167	106	286
Od	10227	5217	2849	--	2161	2211
Oe	2352	310	1090	--	952	952
Pg	3844	3182	23	187	452	639
Ph	206	--	--	107	99	206
Qa	553	--	--	--	553	553
Ql	55	--	--	--	55	55
R	21	--	--	--	21	21
Rd	243	--	--	74	169	243
Re	456	107	20	--	329	329
S	276	--	89	--	187	187
Sg	179	--	179	--	--	--
Sm	2621	440	120	980	--	247
So	1539	--	1064	96	379	583
V	179	--	--	69	110	179
Vp	7965	--	237	2059	5669	6904
W	72	--	--	--	72	72
Wd	262	--	8	136	118	262
We	2465	--	602	74	1189	2342
Wh	26	--	--	--	26	26
Wm	917	--	--	713	204	704
Ws	2459	--	32	1579	848	2410
Z	310	--	176	--	134	134
Zg	676	--	146	303	227	412
Zm	1011	--	1011	--	--	5
Zo	588	--	356	163	69	291
Zt	149	--	11	2	136	136
Totals	103849	10801	24531	16926	51591	69275

6 ACKNOWLEDGEMENTS

The authors wish to thank Mr. W. Wolters, Polders of the World Symposium, for his cooperation and advice, and Mr. A. Jansen, who had started the present inventory. They thank also Dr. W.G. Sombroek, Director of ISM, for his support and advice.

Special thanks are due to Mr. T. Wechgelaar for drawing all maps and doing many calculations. Thanks are also due to Mrs. Y.G.L. Karpes-Liem for typing this paper. The assistance of Mr. W. Bomer and Mr. W.C.W.A. Bomer with the map exhibition is acknowledged, too.

The Ministry of Social Affairs has contributed to the realization of this study by providing funds for the creation of a temporary job.

7 LITERATURE CONSULTED

Driessen, P.M. (1978). Problem rice soils: peat soils. In: Intern. Rice Res. Inst. - Soils and rice. Los Banos, p. 781-800.

Essen, C. van, W. Folkerts, and S. Oudendag (1982). Polders in Zuid Amerika, een studie naar de mogelijkheid om gronden in Zuid Amerika in te polderen. Wageningen, 112 pp.

FAO (1976). A framework for land evaluation. Soils Bull. 32. Rome, 72 pp.

FAO (1978-1981). Report on the Agro-Ecological Zones Project, methodology and results, Vol. 1-4. World Soil Res. Rep. 48. Rome.

FAO-Unesco (1974). Soil map of the world 1:5 million. Vol. I: Legend. Paris, 59 pp.

FAO-Unesco (1971-1979). Soil map of the world 1:5 million. Vols. II-X, Paris.

ICID (1979). Irrigation, drainage and flood control, Vol. 28.2. Intern. Comm. Irrig. Drainage.

I.G.U. (1982). Report of the Working Group on the geomorphology of river and coastal plains, Vol. 2. Soil Survey Inst., Wageningen, 52 pp.

ILRI (1980). Land reclamation and water management. Developments, problems and challenges. ILRI Publ. 27. Wageningen.

International Rice Research Institute (1978). Soils and rice. Los Banos, Philippines. 825 pp.

Moormann, F.R. and N. van Breemen (1978). Rice: soil, water, land. IRRI, Los Banos, 185 pp.

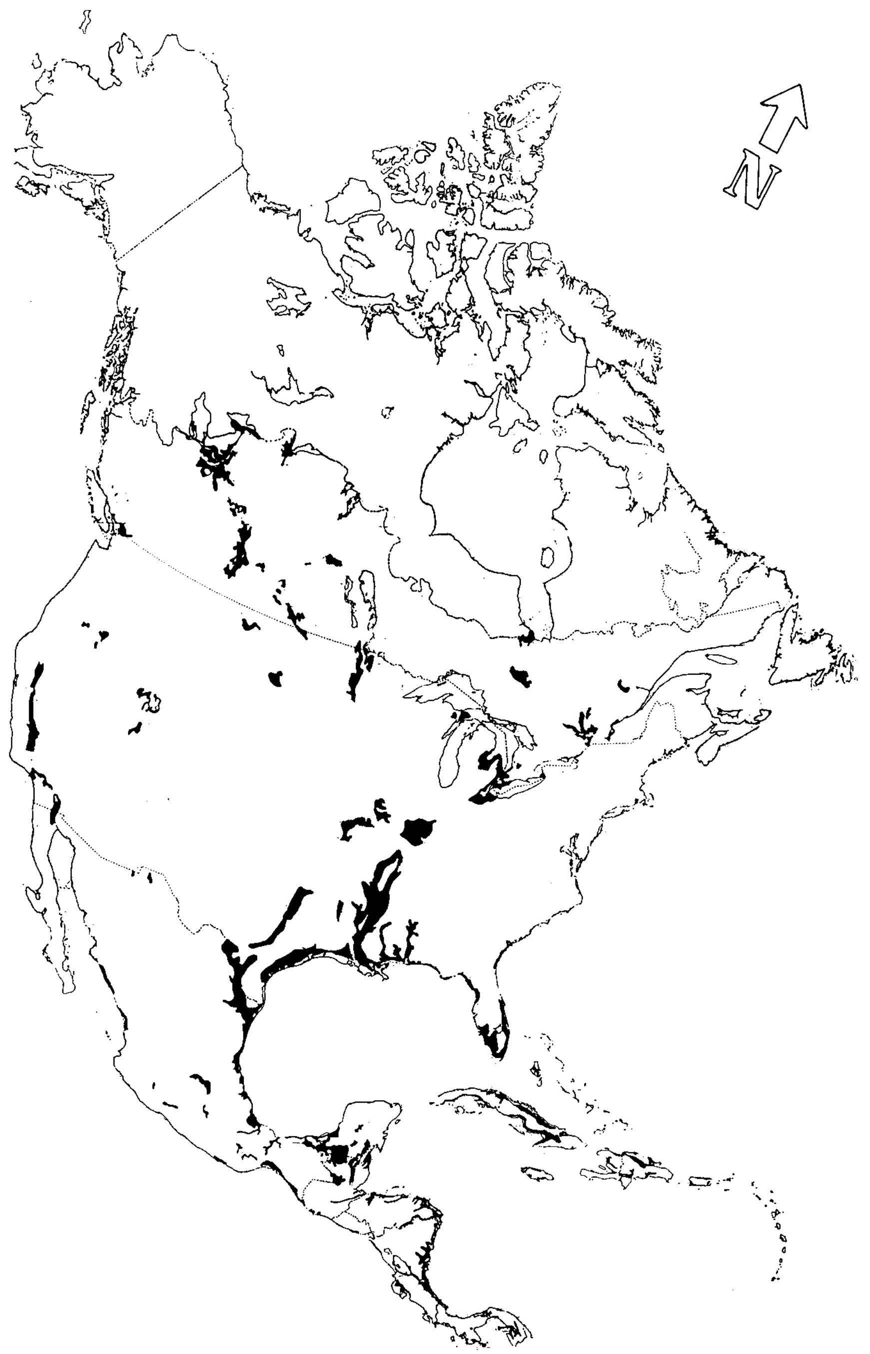
Papadakis, J. (1966). Climates of the world and their agricultural potentialities, Buenos Aires. 174 pp.

Sanchez, P.A. (1976). Properties and management of soils in the tropics. New York, 618 pp.

Van Wambeke, A. (1981, 1982). Calculated soil moisture and temperature regimes of Africa and South America. SSMS Techn. Mon. 2 and 3, Ithaca, New York.

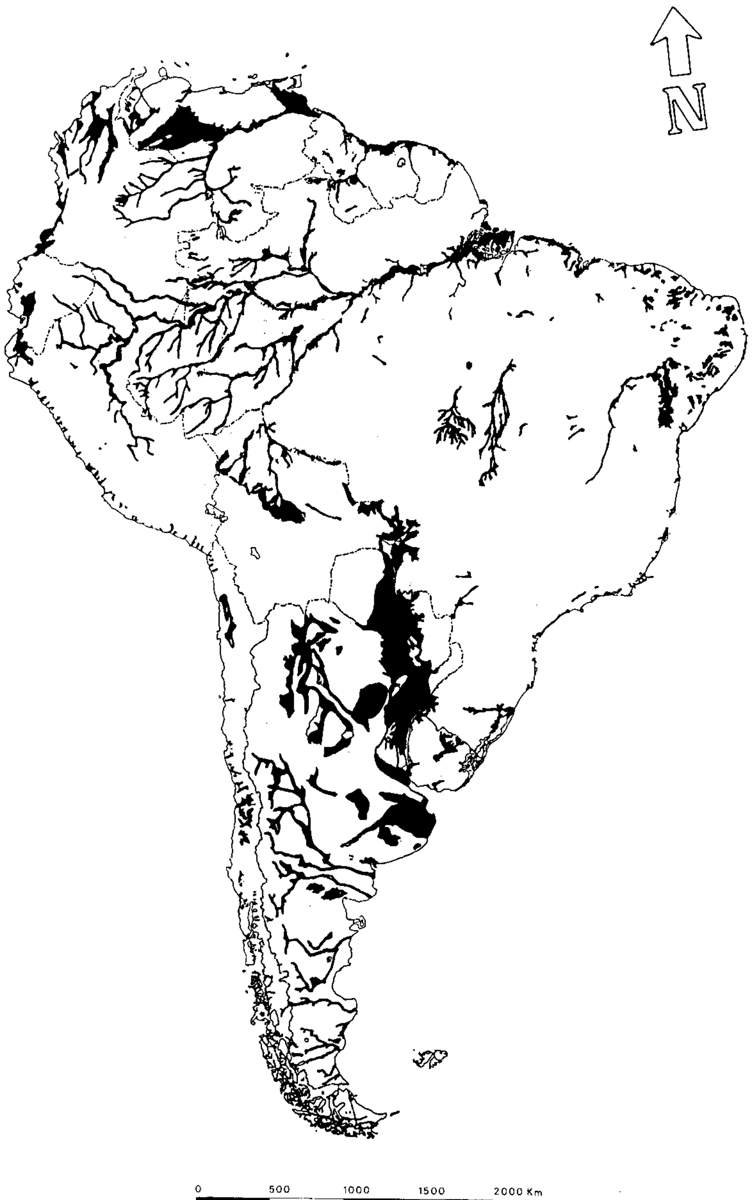
APPENDIX 1 World distribution of soils with impeded drainage showing all inventoried soils units except Ag, Ap, Od, Pg, Ph, Qa, Ql, Rd, and Re

1A North and Central America



Appendix 1 (continued)

1B South America

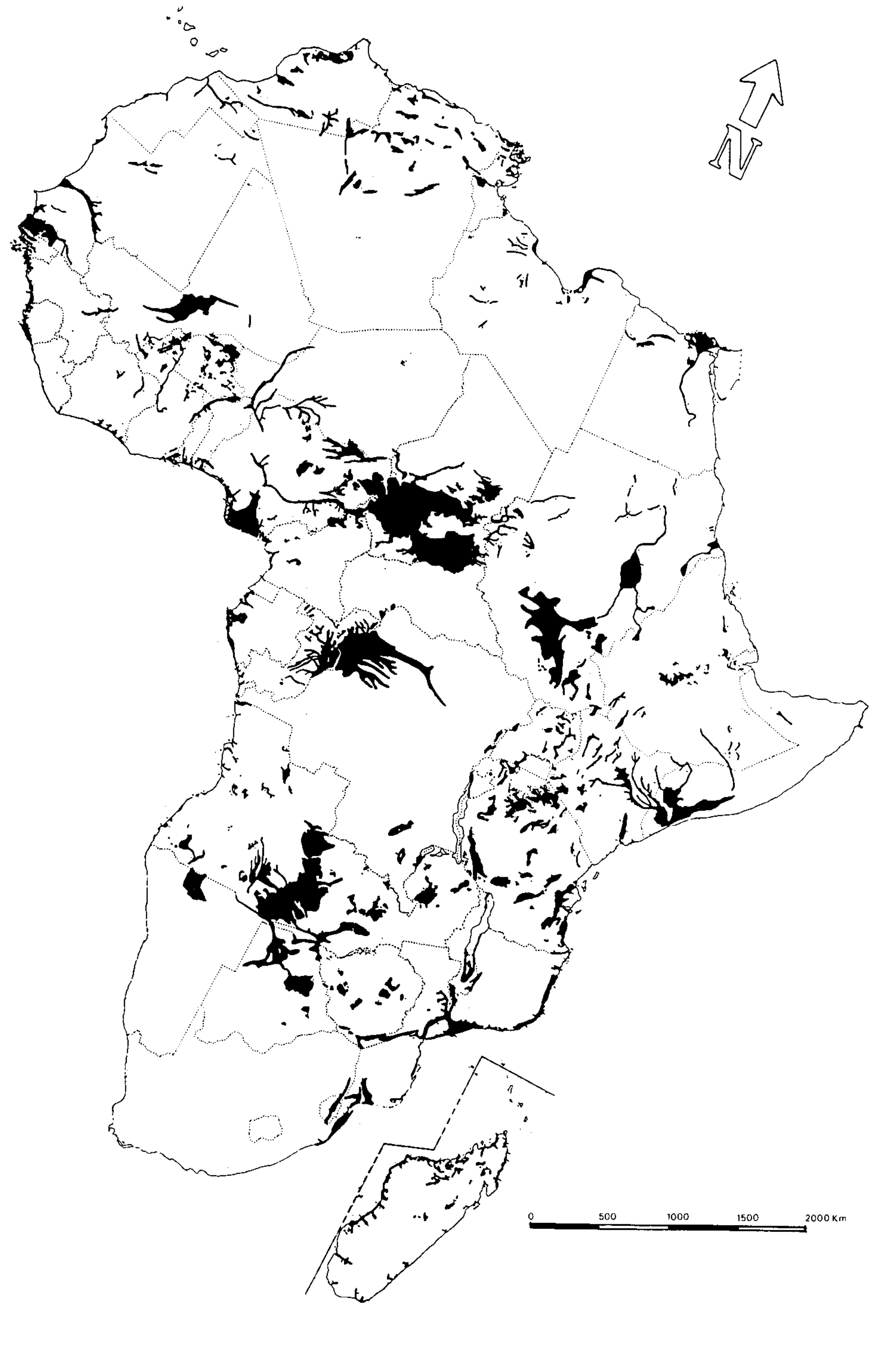


Appendix 1 (continued)

1C Europe and Southwest Asia

Appendix 1 (continued)

1D Africa



Appendix 1 (continued)

1E Central, North and South Asia

Appendix 1 (continued)

1F Southeast Asian archipel and Australasia

Appendix 2.1 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for North America (II)

Soil[1] unit	Extents (00 sq. km)					
	temperature limitation zone					total
	cropping potential				suited for rice	(0+1+2+3)
	0	1	2	3		
Ag	--	178	867	--	1045	1045
Ap	--	187	603	--	790	790
Gd	--	282	224	203	551	709
Ge	201	87	528	8	607	824
Gh	6	37	51	--	51	94
Gm	30	433	--	--	--	463
Jc	--	--	36	--	36	36
Jd	--	11	--	--	--	11
Je	61	--	288	--	288	349
Lg	--	133	67	84	151	284
O	--	186	167	74	254	427
Od	1919	799	--	--	--	2718
Pg	--	--	187	289	476	476
Re	107	20	--	--	--	127
Sm	440	--	--	--	--	440
So	--	213	95	--	95	308
Vp	--	--	710	--	--	710
We	--	487	125	--	612	612
Zo	--	12	--	--	--	12
Aridic areas only						
Jc			36		36	36
Je			56		56	56
So		203				203

[1]no small letter means undifferentiated

Appendix 2.2 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for Mexico and Central America (III)

Soil[1] unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Ap	--	--	--	99	99	99
Bv	--	--	--	135	135	135
Gc	--	--	--	32	32	32
Gd	--	--	--	26	26	26
Ge	--	--	--	182	182	182
Gm	--	--	--	73	73	73
Gp	--	--	--	79	79	79
Jc	--	--	35	--	35	35
Je	--	--	--	182	182	182
Lg	--	--	--	73	73	73
Lv	--	--	--	31	31	31
O	--	--	--	--	--	--
Od	--	--	--	229	229	229
Rd	--	--	--	40	40	40
Re	--	--	--	254	254	254
Vp	--	--	141	861	1002	1002
Wd	--	--	--	33	33	33
We	--	--	--	54	54	54
Wh	--	--	--	21	21	21
Zo	--	--	24	--	24	24
Aridic areas only						
Jc	--	--	35	--	35	35
Zo	--	--	24	--	24	24

[1]no small letter means undifferentiated

Appendix 2.3 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for South America (IV)

Soil[1] unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Ag	--	--	--	99	99	99
Ap	--	--	--	6362	6362	6362
Bg	--	--	--	162	162	162
Gc	7	--	33	--	--	40
Gd	--	--	90	4227	4317	4317
Ge	--	--	60	1480	1529	1540
Gh	--	--	57	6	6	63
Gm	--	--	82	353	453	435
Jd	--	--	--	550	550	550
Je	135	605	2123	2789	3362	5047
Jt	--	--	--	200	200	200
O	--	--	--	32	32	32
Od	--	--	--	132	132	132
Oe	--	--	--	84	84	84
Pg	--	--	--	23	23	23
Qa	--	--	--	458	458	458
R	--	--	--	42	42	--
Rd	--	--	74	--	74	74
S	--	--	--	263	263	263
Sm	--	--	980	--	247	980
So	--	--	--	197	197	197
Vp	--	--	148	481	629	629
Wd	--	--	70	85	155	155
We	--	--	454	831	1277	1285
Wm	--	--	713	204	704	917
Ws	--	--	--	666	666	666
Z	--	--	--	54	54	54
Zg	--	--	174	131	--	305
Zo	--	--	--	199	199	199
Aridic areas only						
Je	81	605	1270	1038	739	2913
R	--	--	--	21	21	--
S	--	--	--	76	76	76
So	--	--	--	14	14	14
Vp	--	--	--	91	91	91
Ws	--	--	--	186	186	186
Z	--	--	--	13	13	13
Zg	--	--	--	13	13	--
Zo	--	--	--	199	199	199

[1]no small letter means undifferentiated

Appendix 2.4 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for Europe (V)

Soil unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Bg	--	185	10	--	195	195
Bv	--	448	--	--	--	448
Gd	--	31	--	--	--	31
Ge	--	477	--	--	54	477
Gh	--	39	--	--	--	39
Gm	--	756	--	--	189	756
Jc	--	906	237	--	722	1143
Je	223	2216	70	--	392	2509
Lg	--	2046	--	--	27	2046
Od	1205	852	--	--	66	2057
Oe	--	96	--	--	--	96
Pg	3182	23	--	--	--	3205
Sm	--	51	--	--	--	51
So	--	708	--	--	120	708
Vp	--	237	70	--	70	307
Wd	--	8	66	--	74	74
Zg	--	107	50	--	93	157
Zo	--	63	--	--	63	63
Aridic areas only						
Gm	--	15	--	--	--	15
Je	--	218	--	--	150	218
Od	--	10	--	--	10	10
So	--	52	--	--	12	52
Zg	--	67	12	--	47	73
Zo	--	11	--	--	11	11

Appendix 2.5 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for Africa (VI)

Soil[1] unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Bg	--	--	--	3	3	3
Bv	--	--	41	187	228	228
G	--	--	--	728	728	728
Gd	--	--	--	961	961	961
Ge	--	--	277	1930	2207	2207
Gh	--	--	--	1275	1275	1275
Gm	--	--	--	277	277	277
Gp	--	--	1	149	150	150
J	--	--	--	355	355	355
Jc	--	--	1076	872	1948	1948
Jd	--	--	--	233	233	233
Je	--	--	414	2804	3218	3218
Jt	--	--	--	401	401	401
Lg	--	--	138	883	1021	1021
Od	--	--	--	46	46	46
Oe	--	--	--	123	123	123
Ph	--	--	107	99	206	206
Qa	--	--	--	95	95	95
Ql	--	--	--	55	55	55
Rd	--	--	--	101	101	101
Re	--	--	79	75	154	154
So	--	--	184	625	809	809
V	--	--	69	110	179	179
Vp	--	--	106	3005	3111	3111
W	--	--	--	72	72	72
Wd	--	--	--	--	--	--
We	--	--	149	304	453	453
Ws	--	--	--	216	216	216
Z	--	--	--	142	142	142
Zg	--	--	152	17	169	169
Zo	--	--	412	590	1002	1002
Zt	--	--	17	22	39	39
Aridic areas only						
Bv	--	--	--	43	43	43
G	--	--	--	275	275	275
Gh	--	--	--	42	42	42
Gp	--	--	1	--	1	1
Jc	--	--	976	604	1580	1580
Je	--	--	140	387	527	527
Jt	--	--	--	29	29	29
Lg	--	--	21	--	21	21
Re	--	--	79	--	79	79
So	--	--	183	429	612	612
Vp	--	--	87	18	105	105
We	--	--	54	--	54	54

Appendix 2.5 (continued)

Soil[1] unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Z	--	--	--	49	49	49
Zg	--	--	145	4	149	149
Zo	--	--	412	538	950	950
Zt	--	--	17	22	39	39

[1]no small letter means undifferentiated

Appendix 2.6 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for South Asia (VII)

Soil unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Gc	--	--	--	185	185	185
Gd	--	--	--	49	49	49
Ge	--	--	79	1486	1565	1565
Gh	--	--	--	283	283	283
Gm	--	--	--	--	--	--
Jc	--	78	1051	443	1572	1572
Jd	--	--	--	3	3	3
Je	--	--	42	942	984	984
Jt	--	--	--	183	183	183
Od	--	--	--	32	32	32
Vp	--	--	--	1103	1103	1103
Zg	--	--	30	503	533	533
Zo	--	--	3395	633	4028	4028
Aridic zones only						
Jc	--	--	806	27	833	833
Jd	--	--	--	3	3	3
Je	--	--	42	76	118	118
Jt	--	--	--	5	5	5
Zg	--	--	30	414	444	444
Zo	--	10	3395	616	4011	4011

Appendix 2.7 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for North and Central Asia (VIII)

Soil[1] unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Bg	--	3	--	--	--	3
Gc	--	543	470	--	1013	1013
Ge	--	845	3238	172	3916	4255
Gh	--	543	--	--	--	543
Gm	--	4233	492	--	2259	4725
J	--	346	--	--	6	346
Jc	--	1222	40	--	457	1262
Jd	866	578	--	--	--	1444
Je	97	1209	79	--	331	1385
Od	2093	1208	--	--	--	3301
Oe	310	1131	--	--	137	1441
S	--	367	--	--	115	367
Sg	--	210	--	--	24	210
Sm	--	1150	--	--	--	1150
So	--	948	--	--	377	948
Vp	--	--	828	75	903	903
We	--	115	--	--	--	115
Ws	--	32	--	--	--	32
Z	--	995	--	--	335	995
Zg	--	629	84	--	403	713
Zm	--	1011	--	--	5	1011
Zo	--	1401	--	--	302	1401
Zt	--	227	--	--	76	227
Aridic areas only						
Gc	--	543	--	--	543	543
Ge	--	627	--	--	420	627
Gm	--	186	--	--	--	186
Jc	--	949	--	--	282	949
Je	--	263	--	--	178	263
Oe	--	137	--	--	137	137
S	--	278	--	--	115	278
Sg	--	31	--	--	24	31
So	--	550	--	--	377	550
Z	--	819	--	--	355	819
Zg	--	529	--	--	146	529
Zo	--	1109	--	--	295	1109
Zt	--	216	--	--	76	216

[1]no small letter means undifferentiated

Appendix 2.8 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for Southeast Asia (IX)

Soil unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Ag	--	--	--	887	887	887
Ap	--	--	--	171	171	171
Bg	--	--	--	342	342	342
Bv	--	--	--	14	14	14
Gd	--	--	--	377	377	377
Ge	--	--	--	891	891	891
Gh	--	--	--	459	459	459
Jd	--	--	--	1506	1506	1506
Je	--	--	--	983	983	983
Jt	--	--	--	545	545	545
Od	--	--	--	1712	1712	1712
Oe	--	--	--	704	704	704
Pg	--	--	--	140	140	140
Rd	--	--	--	28	28	28
Vp	--	--	--	179	179	179

Appendix 2.9 Extents of the inventoried soil units within each temperature limitation zone and within aridic zones for Australasia (X)

Soil unit	Extents (00 sq. km)					
	temperature limitation zone					total (0+1+2+3)
	cropping potential				suited for rice	
	0	1	2	3		
Ag	--	--	52	465	503	517
Ap	--	--	--	248	248	248
Gd	--	--	--	8	8	8
Gh	--	--	11	--	11	11
Je	--	--	32	696	728	728
Lg	--	--	17	--	17	17
Od	--	4	6	--	4	10
Oe	--	--	--	41	41	41
Vp	--	--	143	74	103	217
Wh	--	--	--	5	5	5
Ws	--	--	1579	152	1714	1731
Zo	--	--	1358	51	1409	1409
Zt	--	--	6	207	211	213
Aridic areas only						
Zo	--	--	1195	51	1246	1246
Zt	--	--	4	71	75	75