Problem soils: their reclamation and management

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INTRODUCTION

Most agriculture in the developed countries is nowadays being practised on the soils most suitable for that purpose. Because of this trend and because of the steadily rising productivity of these soils, EEC countries and the U.S.A. have even been able to reduce their cultivated area. The situation in the developing countries is in marked contrast. There, although the productivity of the better soils could still be improved substantially, and although enormous land reserves exist in some of the countries (for example, Latin America), much of the agriculture in developing countries is nevertheless practised on soils that are unsuitable or only marginally suitable. In large areas of Asia and Africa, overall productivity is declining because of soil exhaustion and because areas of problem soils are being taken into cultivation. In many developing countries, good soils are scarce, and not even far-reaching political and socio-economic changes can solve the problems of the many low-income farmers who are totally dependent on a small plot of land of limited productivity.

There is scope for some alleviation through investment projects for irrigation, drainage, flood control, and settlement. But the success of such projects depends greatly on the soil. There have been too many unforeseen repercussions on soil quality and land use performance—too many examples of soil compaction, salinization, sodification, erosion, acidification, subsidence, and inundation—all of which happened because the projects did not fully take into account the problems posed by the soils. They failed to develop locally adapted farming systems or appropriate management techniques for problem soils.

Many kinds of problem soils exist in the world, each of them hampering agriculture in one way or another (DUDAL 1976). Red tropical soils, sandy soils, and shallow soils pose problems of soil fertility and soil conservation. Other soils pose problems of water management. This article looks at some of the latter soils: vertisols, peat soils, acid sulphate soils, planosols, fine-textured alluvial soils, saline and sodic soils. Their potential is often discussed in development projects when they occur in conjunction with soils that are easier to manage. Sometimes, when they predominate in hitherto unexploited areas, they attract investments that might be better channelled into more promising sectors of the agricultural economy.

By drawing attention to these soils, by emphasizing the ways their properties affect their reclamation and improvement, by discussing some of the lessons learned during the last decades, and by mentioning local solutions to the proper use of these soils, we hope to contribute to a better understanding of the problems encountered and the risks involved when such soils are used for agriculture.

VERTISOLS

W. A. Blokhuis

Properties

Vertisols are a specific group of poorly-drained fine-textured soils that, like most poorly drained clay soils, are generally found on sedimentary plains, both on level land and in depressions. Smaller areas of vertisols are found on hillslopes and piedmont plains. They occur in climates ranging from sub-humid temperate and mediterranean to semi-arid and sub-humid tropical, with marked dry and wet seasons. The distinctly seasonal rainfall ranges from 150 mm to 2000 mm but is generally between 500 and 1000 mm per annum.

The largest expanses of vertisols occur in Africa (105 million hectares), Asia and the Far East (57.8 million hectares), and Australia (48 million hectares); see Table 1 and Figure 1.

Vertisols owe their specific properties to the dominance of swelling clay minerals, mainly montmorillonite. They show a great uniformity in physical characteristics, since these are largely dictated by the high clay content (40–80 per cent) and by the specific clay mineralogy.

In the dry season the soils develop wide and deep cracks. These cracks close when the clays swell after the first rains. The swelling causes tensions leading to internal mass movements in the soil (churning or pedoturbation). This causes a characteristic structure to develop, with wedge-shaped structural aggregates in the surface soil and large, slickensidefaced planar soil blocks lower in the solum.

Under the poor drainage conditions that are common in vertisol regions, leaching of soluble weathering products is severely restricted, pH is above 7, and there is much available calcium and magnesium. These conditions favour the formation of smectite-type clay minerals, notably montmorillonite.

In semi-arid areas, free carbonates and gypsum accumulations are common. Saline and sodic vertisols may develop under irrigation, but they are rare under natural conditions.

Most vertisols have a rather high but unbalanced fertility status. Vertisols can produce crops year after year at a sustained, albeit low level, without being fertilized or manured. This is because the pedoturbation continuously brings subsoil to the surface. Any nutrient deficiency problems can easily be remedied: nitrogen is always too low and often phosphate is too. Some fixation as trical-

Table 1.
Regional distribution of vertisols (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO Agro-Ecological Zones Project, Rome).

Region	Area (10^6 ha)	Area (million ha) per length of growing period[1]			
		<90 days	90–180 days	180–300 days	> 300 days
Africa	105.0	38.7	42.3	22.8	3.2
Near and Middle East	5.7	1.6	3.1	1.0	–
Asia and Far East	57.8	14.6	38.7	3.9	0.6
Latin America	26.9	2.7	6.7	10.1	7.4
Australia	48.0	–	–	–	–
N. America	10.0	–	–	–	–
Europe	5.4	–	–	–	–
World total	258.8				

[1] The growing period is the period (in days) during a year when precipitation exceeds half the potential evapotranspiration, plus a period required to evapotranspire an assumed 100 mm of water from excess precipitation (or less if not available) stored in the soil profile (FAO 1978).

cium phosphate may occur, but it is far less than in the acid tropical soils (oxisols, ultisols) of wetter regions. Response to potassium is variable. Secondary elements and micronutrients are often deficient. In the last decade it has been shown that careful fertilization can double or triple the yield of crops such as sugar cane and cotton (DUDAL 1965).

Vertisols differ in surface characteristics and these strongly influence their reaction to soil tillage operations. There are two broad groups:

- the *self-mulching vertisols*. These have a fine (granular or crumb) surface soil, 2–30 cm thick, during the dry season. This fine tilth is produced by dessication and soil shrinkage. When such soils are ploughed, the clods, after being subjected to repeated wetting and drying, disintegrate. When this mulch is well developed, seedbed preparation is hardly necessary,
- the *crusty vertisols*. These have a thin, hard crust in the dry season. When ploughed, crusty vertisols produce large, hard clods that may persist for 2 to 3 years before they have crumbled enough to permit the preparation of a good seedbed (DUDAL 1965). Such soils require mechanical tillage if they are to be cultivated.

The self-mulching versus crusting characteristic is related to the tensile stress of the soil. One of the factors that influence this stress is soil texture. In the Sudan, vertisols were found to be self-mulching when they had clay contents of 60–80 per cent, whereas crusty vertisols in the same region were more sandy and less clayey (e.g. 50 per cent clay; 35 per cent sand). Soils are also strongly self-mulching when they contain appreciable amounts of fine, sand-sized calcareous concretions: these apparently disturb the continuity of the clayey soil material. JEWITT et al. (1979) found that the surface mulch of vertisols in the Sudan is not well-developed where the rainfall exceeds 500 mm. Other observations have shown that under higher rainfall vertisols do not generally contain calcareous concretions. Very high amounts of sodium favour the formation of a hard surface crust.

Problems

When dry, vertisols have a very hard consistence, whereas when wet they are very plastic and very sticky. The optimum soil moisture range for tillage (moist soil with a friable consistence) is narrow and vertisols are rarely in this state for long. With the use of heavy machinery, however, tillage operations can also be performed in the dry season. Mechanical tillage in the wet season causes serious soil compaction. Really wet land is impassable.

Dry vertisols with a surface mulch or fine tilth have a high infiltration rate. When the soil is wet, however, the clays swell, closing the cracks and surface macropores. The soil thus becomes almost impermeable.

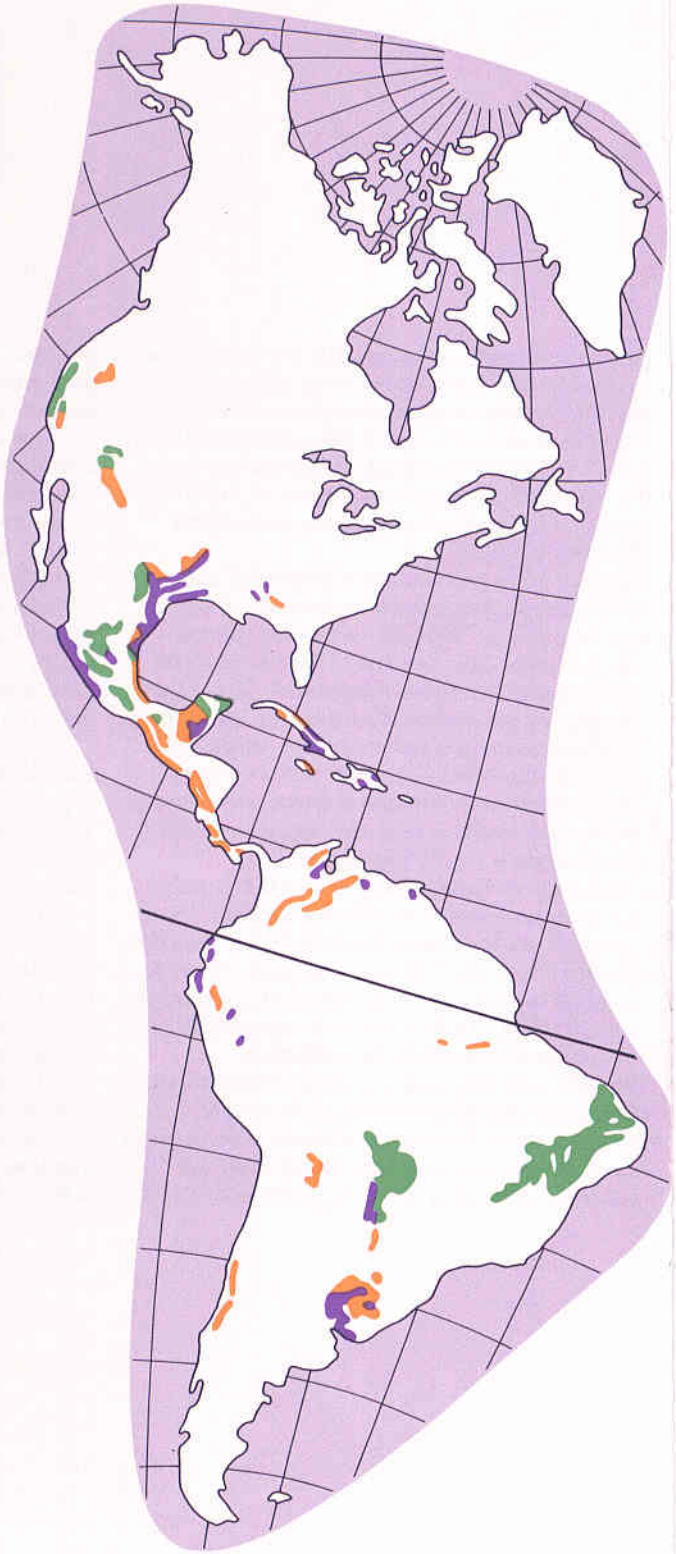
Vertisols have a very low hydraulic conductivity: there is practically no water movement once the soil has reached its field capacity. As moisture penetration is limited, the volume of soil in which water is stored is small. Flooding can be a major problem in areas with higher rainfall because stagnant water can hamper tillage operations. The surface water can be drained by open drains, or crops can be grown on ridges and the intervening furrows used to direct the excess water to a main collector drain. Mole drainage is virtually impossible.

As vertisols have a low structural stability they are very susceptible to water erosion. Slopes above 5 per cent should therefore not be used for arable cropping, and on gentler slopes contour-cultivation with a groundcover crop is advisable, or the land can be used for pasturage. When terracing, sufficient surface drainage must be provided to avoid slumping.

Successful forest plantations have been reported from some countries, but in general tree crops do not do well on vertisols: they lean and their roots can be broken when large cracks develop in the soil. In addition, the low subsoil porosity in the wet season discourages root development.

The adverse physical properties of vertisols have been a major obstacle to agricultural land-use in low-technology societies: these soils are 'heavy' in the true sense of the word and are very difficult

Figure 1.
Worldwide distribution of vertisols (adapted from FAO/UNESCO Soil Map of the World 1971–1979).

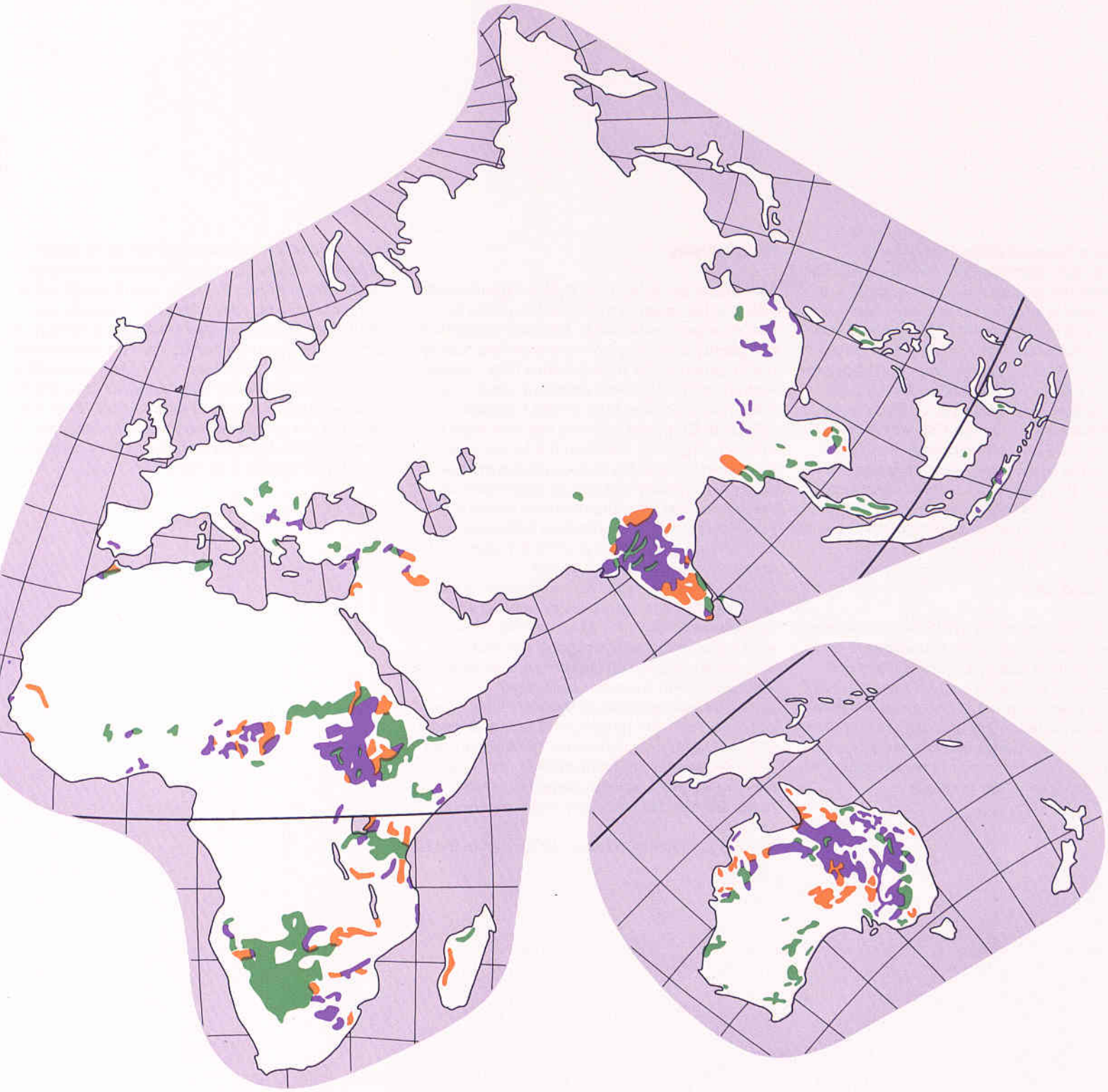


dominant
covering 30–100% of the soil association

not dominant (associated)
covering 20–30% of the soil association

not dominant (inclusions)
covering 5–10% of the association

source: FAO/UNESCO soil map of the world



to work with hand-powered implements.
Saline and sodic vertisols may develop under irrigation when the irrigation water is of poor quality. Once such a situation exists, soil improvement becomes very difficult. In some cases vertisols with measured exchangeable sodium percentages (ESP) of 40 and above – well above the 15 per cent that has been used to define sodic soils – have produced good yields. Sodic soils with such exceptionally high ESP's have been found to contain the zeolite mineral analcime, and part of the sodium may occur trapped within this mineral. In standard laboratory procedures, part of this 'zeolite sodium' is extracted, in addition to the 'plant-available sodium' that occurs adsorbed on the clay surfaces.

Present land use

In many tropical countries vertisols have been left uncultivated because of their management problems, even though nearby kaolinitic clays and coarse-textured soils with a much lower nutrient status have been cropped. Large areas of vertisols are still uncultivated or are used for grazing. A relatively small proportion is used for crop production, mainly in rain-fed agriculture, whereas a minor part is cropped under irrigation.

Possibilities

The Gezira Scheme in the Sudan (approximately 700,000 hectares) is a successful gravity irrigation project on vertisols. Irrigated agriculture has greatly benefited from the excellent quality of the irrigation water from the Blue Nile. Cotton was and still is the main crop, but since about 1960 diversification from cotton has been achieved. Cropping intensity has also been increased, largely by reducing the fallow period. Both tendencies have necessitated a gradual change from hand and animal labour towards mechanization. Machinery is now in use for tillage operations in combination with weed control, for crop protection, and for the cleaning and maintenance of irrigation canals.
Extensive mechanized crop production schemes with rain-fed agriculture occur in areas with precipitation over 500 mm. Mechanization has proved successful in the reclamation of these areas if they have uniform soil conditions over extensive level plains and a scanty vegetation.
Sudan's large expanses of vertisols are a great potential asset for agriculture. There is considerable scope for an extension of the mechanized schemes and for intensification of non-irrigated farming. As well, enough water is available to allow a considerable increase in the area under irrigation.
Vertisol cultivation in India, unlike that in the Sudan, is generally rain-fed agriculture on smallholdings. Nearly 20 million hectares of vertisols are fallowed during the rains and cultivated after the rains have receded; the main crops are sorghum and maize. It is also possible for vertisols to produce two crops – one in the rainy season and one afterwards – provided that tillage operations and planting dates are carefully planned (and this is difficult because of the unpredictability of the onset of the monsoon) and that crop varieties with an advantageous maturation period are selected (VIRMANI et al. 1977).

PEAT SOILS

P. M. Driessen

Properties

True peat soils have an organic matter content of 65 per cent or more and a minimum depth of 50 cm; they form where the production of organic debris exceeds its decay because of low soil temperatures, waterlogging, severe acidity or oligotrophy, or a combination of these. Peat soils occupy some 240 million hectares worldwide, mainly in boreal and temperate regions. An estimated 32 million hectares occur in the tropics, of which more than 20 million are in the coastal lowlands of southeast Asia (Table 2, Figure 2).

The chemical and physical characteristics of peat soils differ greatly from those of mineral soils. Consequently, the reclamation and use of peat for agriculture requires an entirely different approach. If properly reclaimed and managed, most peat soils can be highly productive on a sustained basis.

The wide variation in the physical characteristics of peat is matched by an equally wide variation in chemical properties. The composition of the organic fraction is largely determined by the floristic composition; lignin, cellulose, hemicellulose, proteins, sugars, and 'humus substances' (including the agressive humic and fulvic acids) are the main components.

Although calcareous peats are not rare, most virgin peats are acid (pH 3.5–5.5) and, compared with mineral soils, contain only low quantities of plant nutrients per unit volume. Often there are very few available micronutrients. Yet, even thick and rain-dependent peats may support a luxuriant climax vegetation. Nutrients are taken up by this vegetation, temporarily stored and subsequently returned to the soil in litter and other plant debris. Removal of the natural vegetation as a reclamation measure interrupts this cycle and is often followed by a rapid decrease in natural soil fertility.

Not all nutrients contained in the peat are readily available for uptake by crops. Only a few per cent of the nitrogen present is available to plants: the rest is tied up in stable organic compounds. Phosphorus is also partly fixed. The availability of potassium is better, but contents are commonly very low.

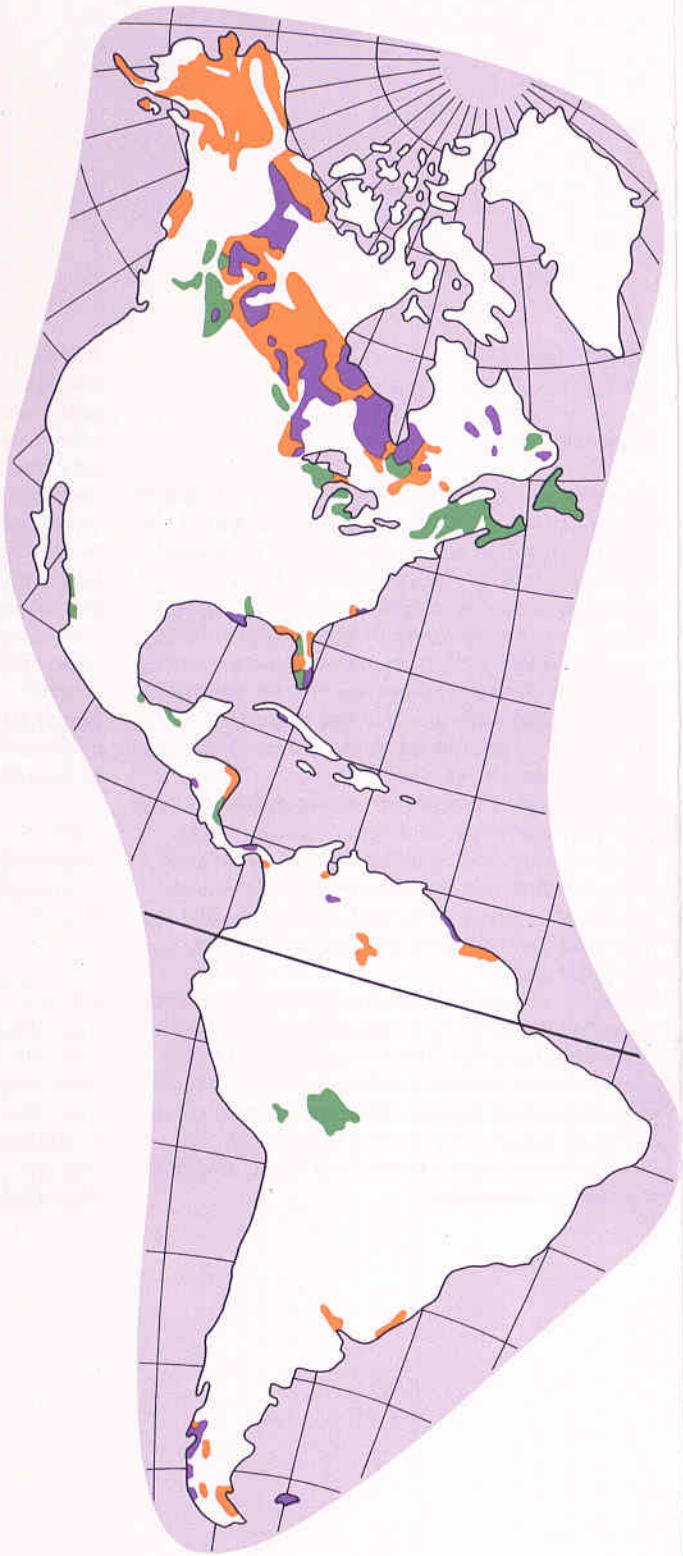
Problems

The major differences between peat and mineral soil material are peat's low bulk density, colloidal nature, and specific thermal properties. Its high porosity creates problems if peats that are almost saturated with water are reclaimed for the cultivation of dryland crops. The necessary drainage removes groundwater buoyancy and is invariably associated with compaction of the loose peat mass and with considerable subsidence of the

Table 2.
Regional distribution of peat soils (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO Agro-Ecological Zones Project, Rome).

Region	Area (10^6 ha)	Area (million ha) per length of growing period			
		<90 days	90–180 days	180–300 days	> 300 days
Africa	12.2	0.5	3.1	4.9	3.7
Near and Middle East	–	–	–	–	–
Asia and Far East	23.5	0.3	0.2	6.9	16.1
Latin America	7.4	1.1	0.2	3.6	2.5
Australia	4.1	–	–	–	–
N. America	117.8	–	–	–	–
Europe	75.0				
World total	240.0				

Figure 2.
Worldwide distribution of peat soils (adapted from FAO/UNESCO Soil Map of the World 1971–1979).



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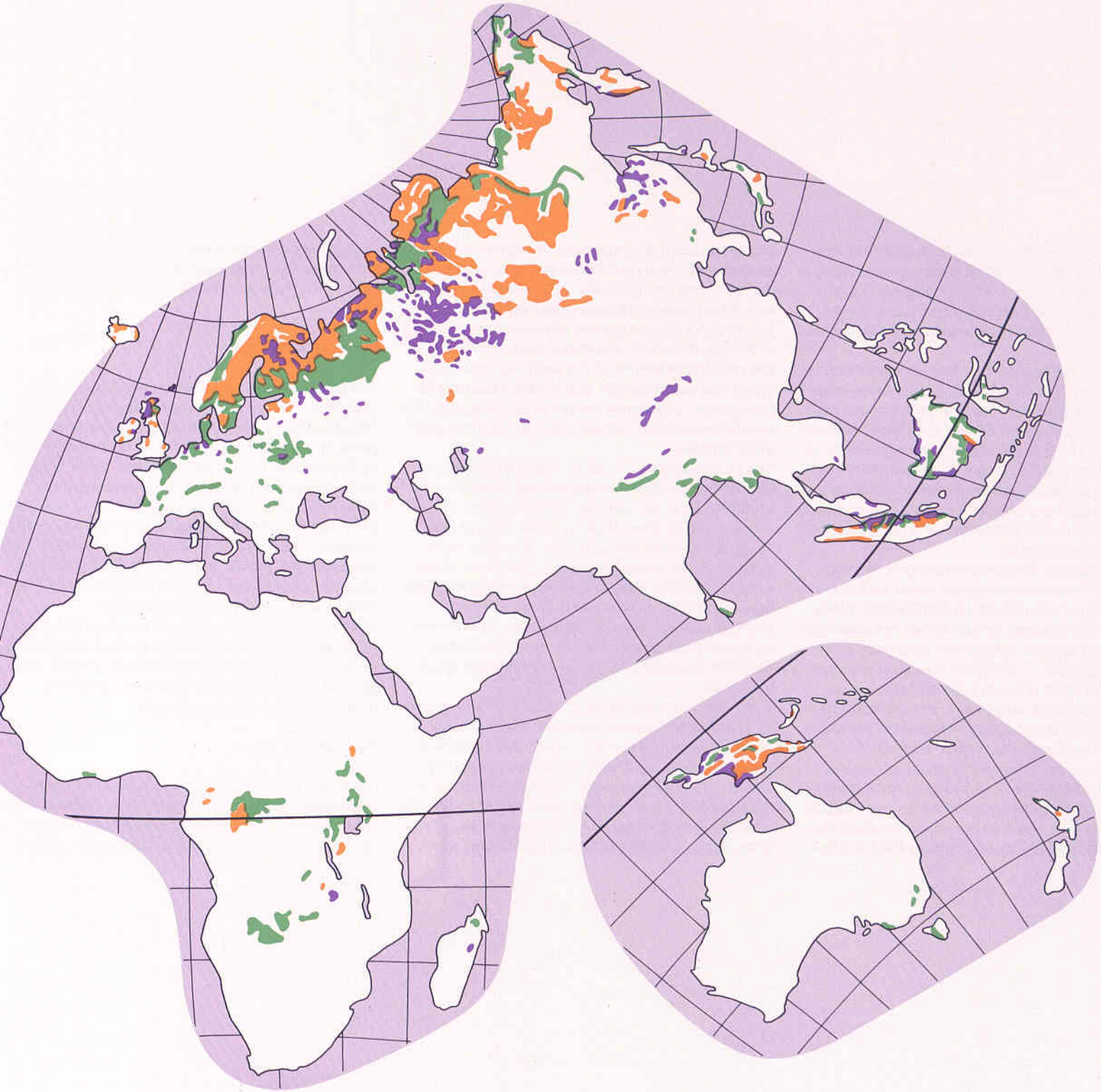


land surface. In addition, the high pore volume and the flexibility of fibrous peat material result in a low bearing capacity which hampers the construction of roads, buildings, and water works, and causes top-heavy crops and trees to lean or fall.

Sudden deep drainage may lead to considerable drying and shrinkage of peat. The process is accelerated in bare soils; the low heat conductivity of the organic material allows very high temperatures to build up in the upper few centimetres of peat soils exposed to direct solar radiation. This causes irreversible transformation of colloids and makes the peat crumble to a dry powder with unfavourable physical properties and a high susceptibility to wind erosion.

The obvious way to conserve peats is to keep them under a permanent plant cover and to maintain a shallow watertable. Unfortunately, these measures can seldom be combined because most arable crops need a sufficiently deep root zone for good growth. In addition, wet peat soils are colder than most mineral soils and this retards crop development. Artificial drainage can seldom be avoided. Drain spacings depend on the drainage depth required, the type of peat, its degree of decomposition, density of packing, heterogeneity, and content of wood or mineral admixtures. Drainage systems are likely to need adjustment after some years of operation because the changes induced in water regime affect the hydraulic properties of the peat. It is often contended that reclaimed peats have physical properties that are ideal for agriculture. This is only partly true. Most peat soils have good water-holding and rooting properties and allow easy harvesting of tubers, rhizomes, or peanut pods. However, the perishable nature of the peat requires intelligent soil management and costly measures to combat the degrading effects of shrinkage, settlement, compaction, mineralization, burning, and wind erosion.

The commonly low chemical fertility of peats causes problems when the natural vegetation is abruptly replaced with agricultural crops. This interrupts the cycling of plant nutrients and leads to rapid chemical exhaustion of the peat, particularly where annual crops are grown on oligotrophic material. Only a few years of exploitation may lead to nutrient levels that are too low for the natural vegetation to regenerate. It is mainly this process that accounts for the loss of thousands of hectares of tropical peat swamp forest each year.

Controlled burning of peat lands is often applied as a means to liberate nutrients, particularly where agriculture is practised on a subsistence basis. Burning undoubtedly has a stimulating effect on plant performance but in the long run it destroys the upper (= best) part of the soil profile and seriously damages the structure in the underlying strata. Burning is an inefficient procedure anyway because no crops can be grown at the time of burning and most of the nutrients are lost to the atmosphere or leached out of the rooting zone.

Present land use

The boundary between reclamation and use of peat soils is often somewhat arbitrary; cropping can actually be a reclamation measure. In the first years of cultivation, crop choice is co-determined by factors such as subsidence rate, water regime, and compaction/firmness of the rooting zone. After a few years, land subsidence decreases and becomes a matter of mineralization of the organic material rather than shrinkage or compaction. The soil becomes 'stable' and its increased bearing capacity permits the cultivation of trees and top-heavy crops like papaya and banana.

Peat lands in temperate areas are often used as pastures to avoid the need for deep drainage, but in the tropics a lack of suitable high protein grasses and a score of socio-economic problems hinder livestock farming on peat.

Possibilities

In Europe the reclamation of bogs dates back to ancient times when roads and ditch systems were constructed in peat areas situated above mean sea level. Peat reclamation was already a normal

practice in the early Middle Ages and gained new impetus in the 15th century when windmills were introduced to complement gravity drainage.
Large tracts of peat land were reclaimed in western Europe in the 19th and 20th centuries, when improved equipment and legislation made it possible to convert exploited peat bogs into good quality agricultural land. A similar development took place in other peat areas in the temperate zone; millions of hectares were reclaimed for the production of grains and potatoes in the U.S.S.R. and also on the American continent.
The reclamation of tropical peat lands is more recent. Peat bogs in the tropics are commonly opened by individual farmers although some medium-sized centrally controlled projects have also been implemented, particularly in southeast Asia. Examples of successful farming pursuits on tropical peat are the pineapple plantations of Malaysia and some prosperous horticultural areas on peat in Peninsular Malaysia, Sarawak, and Kalimantan. The results obtained by experimental stations suggest that reclaimed peats hold out good prospects for the cultivation of a wide range of crops, including several oil crops, fibre crops, stimulants, and vegetables. The high and recurrent inputs required account for the marginal use that is at present being made of tropical peat soils. However, where capital-intense farming is justified, even initially poor peats can be reclaimed to highly productive soils.

ACID SULPHATE SOILS

N. van Breemen

Properties

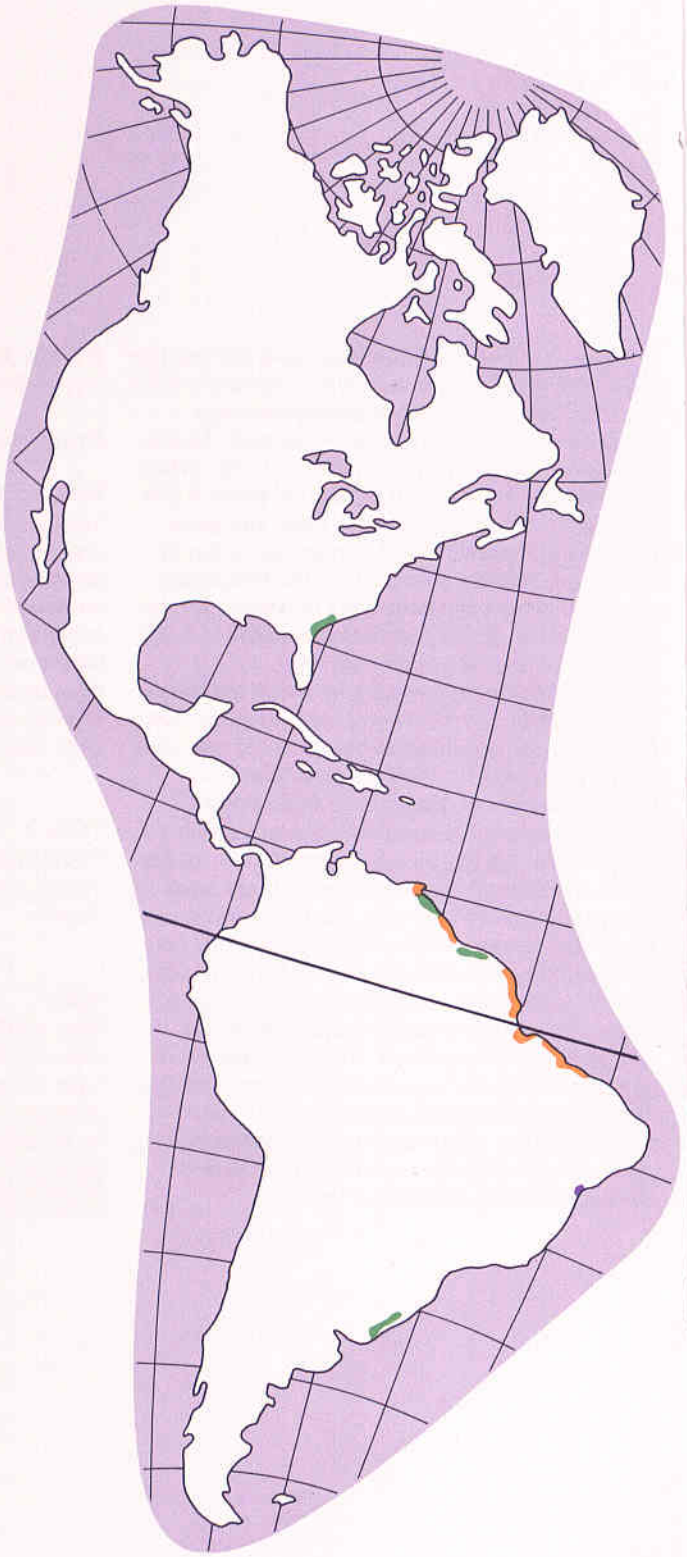
Most acid sulphate soils occur in the tropics, in low-lying coastal land formerly occupied by mangrove swamps. Their most important characteristics are a field pH of below 4, owing to the oxidation of pyrite to sulphuric acid, and a generally high clay content. If samples of the pyrite layers are air-dried in the laboratory, the pH may drop by a further 2 units. Other properties such as organic matter content and cation exchange capacity may vary widely.

Potential acid sulphate soils have a near-neutral pH but become strongly acid upon drainage and oxidation. The total area of actual and potential acid sulphate soils is rather small: about 10 million hectares are known to occur in the tropics, and the world total probably does not exceed 14 million (Table 3, Figure 3).
In addition, some 20 million hectares of coastal peats, mainly in Indonesia, are underlain by potential acid sulphate soil. In spite of their relatively limited areal extent, planners and agronomists have been paying much attention to acid sulphate lands, mainly because of their apparent suitability for agriculture (especially for rice) and their often close proximity to good to excellent agricultural land.

Table 3.
Regional distribution of acid sulphate soils (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO Agro-Ecological Zones Project, Rome).

Region	Area(10^6 ha)	Area (million ha) per length of growing period			
		<90 days	90–180 days	180–300 days	> 300 days
Africa	3.7	0.4	0.7	1.5	1.1
Near and Middle East	–	–	–	–	–
Asia and Far East	6.7	–	0.2	5.1	1.4
Latin America	2.1	–	0.1	0.8	1.2
Australia	–	–	–	–	–
N. America	0.1	–	–	–	–
Europe	–	–	–	–	–
World total	12.6				

Figure 3.
Worldwide distribution of acid sulphate soils (adapted from FAO/UNESCO Soil Map of the World 1971–1979).



dominant
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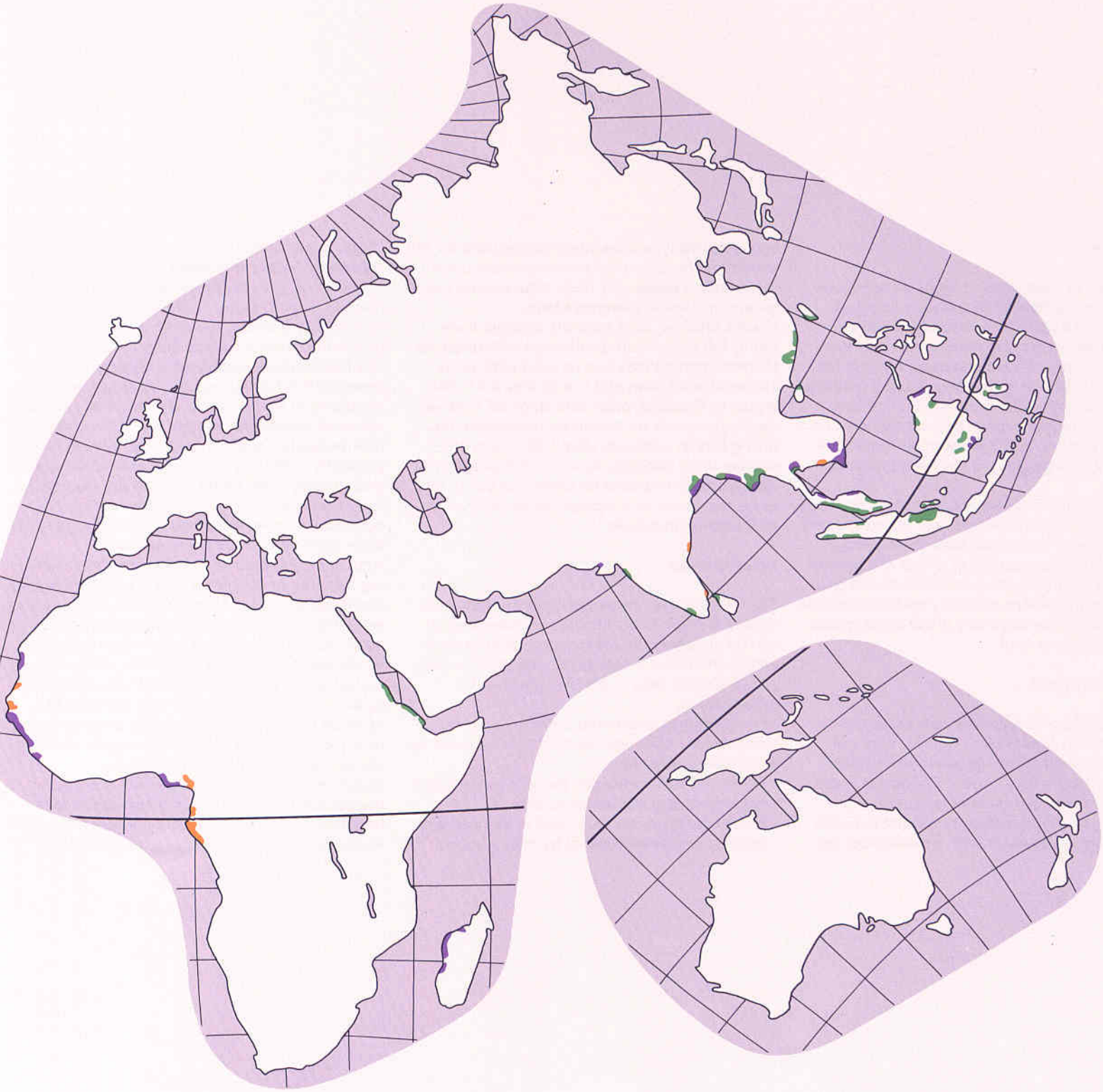
source: FAO/UNESCO soil map of the world



Problems

The growth of most dryland crops on acid sulphate soils is hampered by the toxic levels of aluminium and the low availability of phosphorus. Toxic levels of dissolved iron plus low phosphorus are the most important adverse factors for wetland rice. In the near-neutral potential acid sulphate soils (Sulfaquents, Sulfic Fluvaquents), high salinity, poor bearing capacity, uneven land surface, and the risk of strong acidification during droughts are the main disadvantages.
Young acid sulphate soils (Sulfaquepts) in which the pyritic substratum occurs near the surface are often more acid than those soils (Sulfic Tropaquepts, Sulfic Haplaquets) in which this horizon is found at greater depths. Acid floodwater generated in large swamps with very acid Sulfaquepts, as in Vietnam, may adversely affect crops grown on adjacent better land.

Present land use

Most potential acid sulphate soils are under natural vegetation (mangrove swamps, tidal marshes) or are used for mangrove forestry (charcoal, nipa thatch, nipa sugar). Fishponds in potentially acid land can be fairly productive, provided that the pyritic substratum is not exposed and oxidized. In climates with a marked dry season, potentially acid swamps can be used for salt extraction. In some tidal swamps where the surface water is seasonally fresh, tidal swamp rice is grown on cleared mangrove land.
Young, shallow, acid sulphate soils are commonly left uncultivated, although with good water management they can be used with some success for oil palm and rice as they are in Malaysia. In Thailand, older acid sulphate soils are used extensively for broadcast deepwater rice, giving low to moderate yields. Droughts and sudden deep flooding, however, are probably at least as much to blame for lower rice yields on these older soils as are phosphorus deficiency and aluminium toxicity.

Possibilities

The older, deeply developed acid sulphate soils require no specific reclamation measures, and can be greatly improved by good fertilizer application, moderate dressings of lime (1–5 ton/ha) and, probably most important, good water management.
In reclaiming or improving potential and young acid sulphate soils two diametrically opposite approaches are possible:

- Pyrite and soil acidity can be removed by leaching after drying and aeration, and
- Pyrite oxidation can be limited or stopped and existing acidity inactivated by maintaining a high watertable.

Additional liming and fertilization, especially with phosphorus, are usually necessary with either method. Liming alone, while technically and agronomically feasible, is always prohibitively expensive on these very acid soils.
The first method, combined with leaching by seawater has been used with some success in experiments in Sierra Leone, and these efforts have attracted considerable attention. The method can only be applied under specific conditions: close proximity to the sea, an appreciable tidal range and strongly contrasting wet and dry seasons. Even then, costly annual dressings of lime are still necessary, and no instances of a successful large scale application have been reported.
A far more elaborate reclamation method involving leaching to remove acidity is being applied in the Mekong Delta of Vietnam. There, strongly acid soil, often with a shallow pyritic substratum, is excavated to make 3–5 m wide ridges separated by ditches 2 m deep and 3 m wide. Although pyrite oxidation and leaching must be extremely rapid under those conditions, it may still take 5 to 10 years before the soil is suitable for crops other than the highly acid-tolerant pineapple, which is planted immediately after the ridging.
Clearly, such reclamation measures are usually uneconomic. Most of the available experience from field and laboratory experiments shows that leaching is too slow to remove an appreciable

and relatively immobile fraction of the soil acidity (mainly adsorbed aluminium, adsorbed sulphate and basic sulphate such as jarosite) from most of the soil within an acceptable time. However, leaching is often necessary to remove accumulations of soluble acid salts (Al-Fe-Mg sulphates) near the surface of rice fields on young acid sulphate soils after a dry fallow, and to remove acid surface water generated above flooded, reduced acid sulphate soils. This is usually done in the course of the growing season by lateral drainage of surface water after repeated wet tillage.

The second reclamation method, maintaining a high watertable to stop pyrite oxidation and to inactivate existing soil acidity, has the advantage that its effects are usually noticeable within two years or so. This is especially true in young acid sulphate soils that are generally high in organic matter. Upon waterlogging, soil reduction caused by microbial decomposition of organic matter lowers acidity and may cause the pH to rise rapidly to near-neutral values. The method is particularly suitable with rice cultivation, but even in oil palm plantations in Malaysia, maintaining a shallow watertable has given far better results than deeper drainage with intensive leaching.

The crucial factor is, of course, the availability of fresh water for irrigation. Large-scale engineering schemes for reclaiming potentially acid, and usually strongly saline, coastal swamp are rarely economic. In the Muda irrigation project in Malaysia, where patches of Sulfaquepts occur among better soils, improved water management and intensive irrigation have dramatically increased the productivity of these highly acid soils.

So, unless sufficient fresh water is available and other prerequisites for good water management exist, potential acid sulphate soils and young, strongly acid sulphate soils should not be reclaimed, but are better left for other types of land use (conservation, forestry, fisheries and, sometimes, salt pans). If fishponds are constructed on such land they should be kept shallow, because deep excavation will cause the water to turn toxic. The injudicious reclamation of seemingly suitable land in coastal swamps by excluding salt water through diking and by excavating fishponds has led to the destruction and abandonment of thousands upon thousands of hectares of mangrove land in southeast Asia and Africa. The less toxic and deeper developed older acid sulphate soils are moderately suitable for rice and can be improved by sound agronomic practices, such as growing adapted cultivars and applying phosphorus. By intensifying water and soil management, including dry season irrigation, the productivity of these soils for rice will increase and they can probably be made productive for a wide variety of annual and perennial dryland crops.

PLANOSOLS

R. Brinkman

Properties

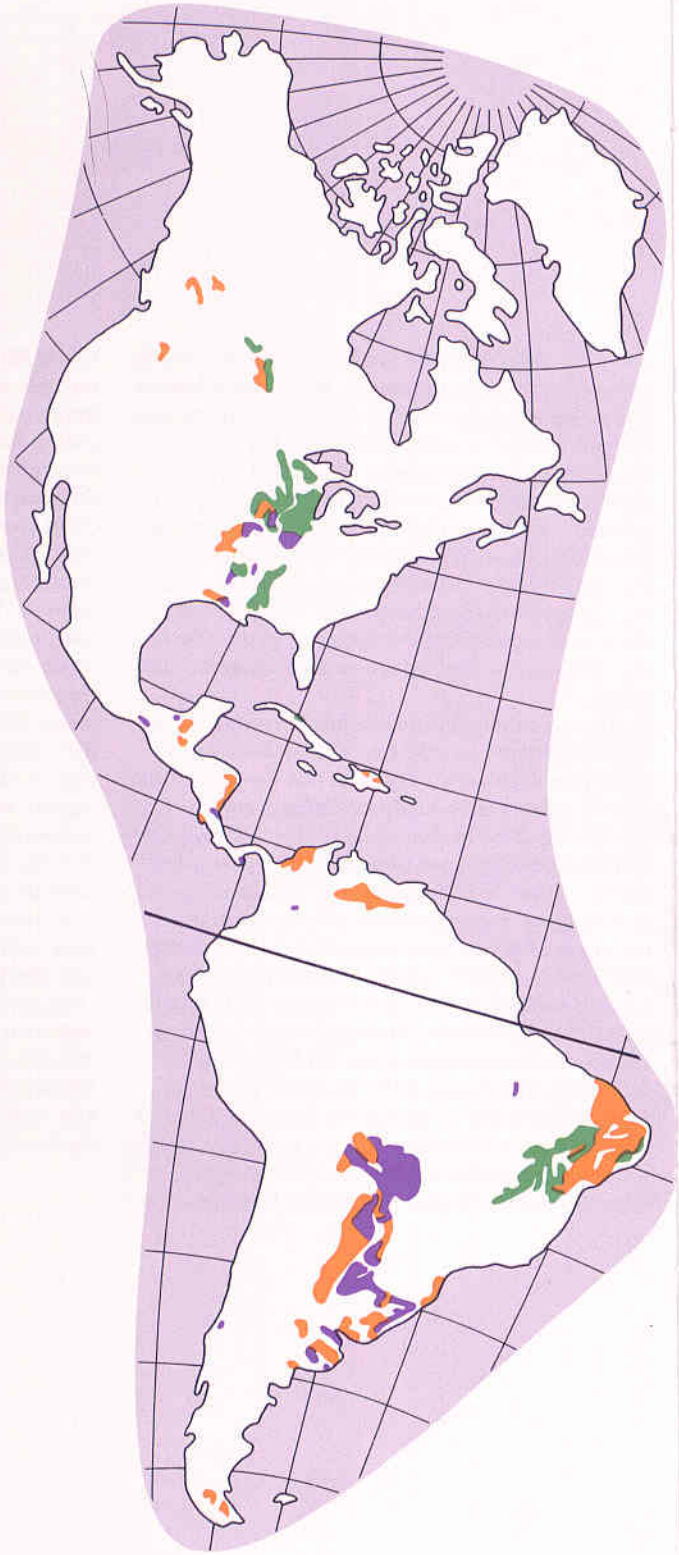
Planosols and other acid, seasonally wet soils occupy some 151 million hectares worldwide, mainly in subhumid and wetter climates with a pronounced alternation between wet and dry seasons. The largest expanses of planosols occur in Latin America (767 million hectares); see Table 4, Figure 4.

They are most extensive on nearly level parts of the landscape above normal river levels, but may also occur in river plains, for example those of the Brahmaputra (Bangladesh) or the Luena (Zambia). These soils are also found in less strongly seasonal climates where a nearly level land surface combined with a low hydraulic conductivity of the subsoil or substratum causes periodic waterlogging.

Planosols have lower clay contents in their surface horizons than in their slowly permeable deeper horizons. Other acid, seasonally wet soils generally show the same trend but less markedly. The activity of the clay fraction (cation exchange capacity and moisture retention) is normally lower in the surface soil than in deeper horizons.

In extreme cases the upper soil horizons have a very low structural stability; if silty, they may be like concrete in the dry season and like a very

Figure 4.
Worldwide distribution of planosols (adapted from FAO/UNESCO Soil Map of the World 1971-1979).



dominant
covering 30–100% of the soil association

not dominant (associated)
covering 20–30% of the soil association

not dominant (inclusions)
covering 5–10% of the association

source: FAO/UNESCO soil map of the world

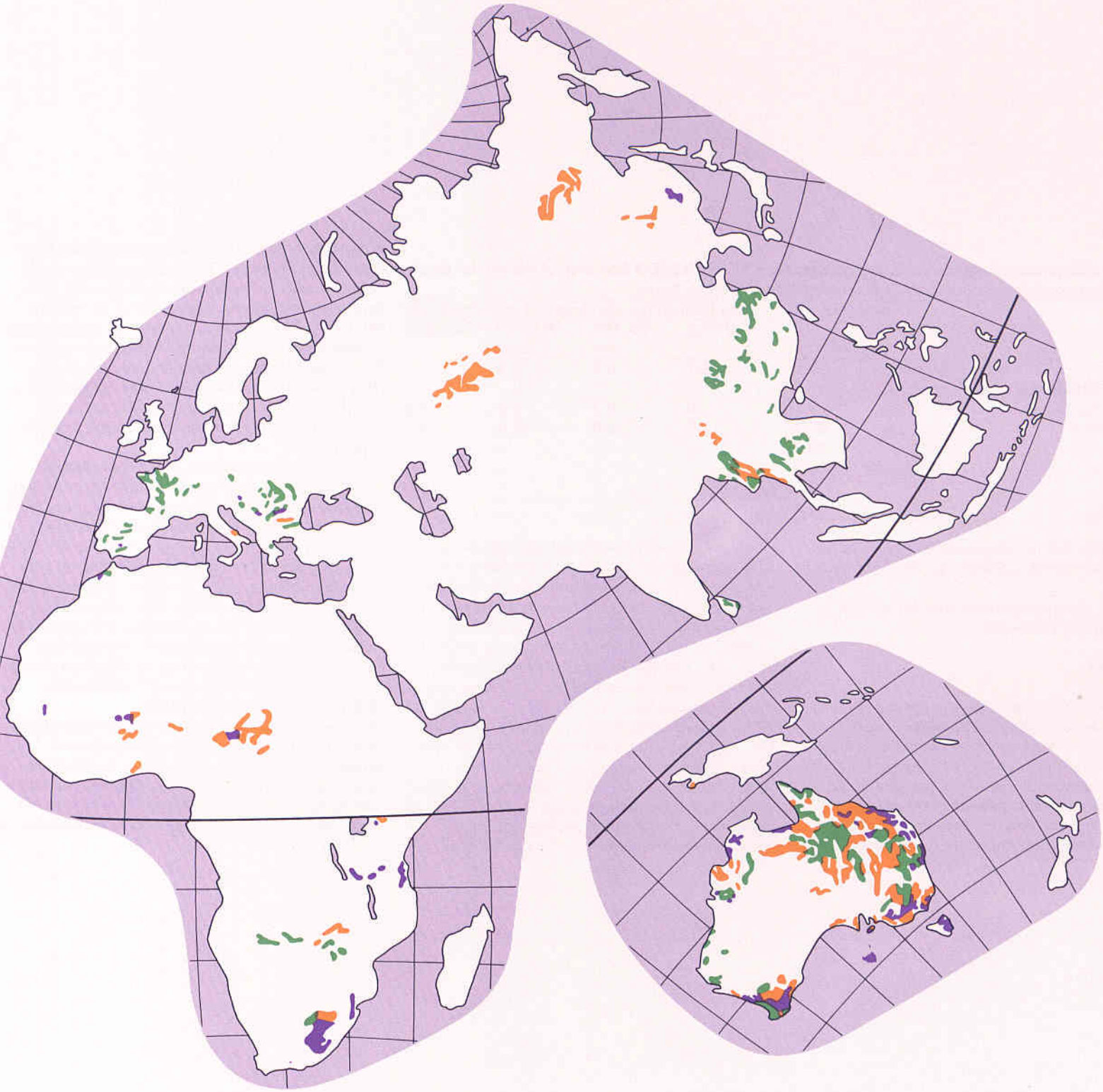


Table 4.
Regional distribution of planosols (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO-Ecological Zones Project, Rome).

Region	Area (10^6 ha)	Area (million ha) per length of growing period			
		<90 days	90–180 days	180–300 days	> 300 days
Africa	15.9	8.1	5.5	2.3	–
Near and Middle East	–	–	–	–	–
Asia and Far East	2.7	0.2	0.7	1.6	0.2
Latin America	67.2	7.7	23.0	32.5	4.0
Australia	49.3	–	–	–	–
N. America	12.3	–	–	–	–
Europe	4.0	–	–	–	–
World total	151.4				

heavy syrup, with extremely low bearing capacity, when waterlogged or inundated in the wet season.
When dry, the sandy topsoil may be very compact but is not cemented.

Problems

Plants tend to root shallowly in these soils. The seasonal waterlogging that hampers the growth of most crop plants and trees alternates with drought conditions, whose severity depends on local climatic conditions. This drought period also depresses yields and limits the choice of crops, or may prevent dry-season crop production where no irrigation water is available.

Under natural vegetation, less strongly developed acid, seasonally wet soils generally have porous upper horizons that are at least moderately stable. The stability appears to be due to slight cementation by silica rather than to organic matter, iron oxides, or clay. The porous structure is easily destroyed by cultivation, particularly by puddling, and is not easily re-established. Puddling over the years produces a very compact traffic pan, which retains some bearing capacity when wet. Once the traffic pan has been disturbed by deeper cultivation, even though this was done when the soil was dry, its bearing capacity when waterlogged becomes very low, so that even buffaloes used as draught animals tend to sink.
Besides these problems directly due to their peculiar hydrology, these soils tend to have a low natural fertility level. They are normally strongly acid but without aluminium toxicity in the surface horizons; deeper horizons may be toxic to the roots of sensitive plants, such as certain citrus cultivars, particularly when fertilizers are applied. Even slight salinity, as occurs in patches on the 'low terrace' in northeast Thailand, for example, may bring about aluminium toxicity at the soil surface, which hinders the germination of most crop plants.
Where the parent material of the soils already contains low-activity clays, the still lower activity and low content of clay in the surface horizons of planosols severely limit their capacity to retain added fertilizers. If liming is practised to eliminate aluminium toxicity, the dosage needs to be carefully established since it is easy to overlime these soils to or above neutrality, which may induce new nutrient deficiencies. Besides the usual low fertility level of these strongly weathered soils, there may be silica deficiency, as observed in paddy rice cultivation in northeast Thailand (KAWAGUCHI and KYUMA 1969).
Where planosols are less strongly weathered and occur, for example, over a swelling clay substratum as in southern Tanzania or on the Madhupur and Barind tracts in Bangladesh, the cation exchange capacity of the surface soils in normally adequate and there is no silica deficiency.

Present land use

Planosols are used for a variety of purposes, partly depending on the climate. However, they generally support a lower intensity of use than soils which, under the same climate, have less extreme alternations in hydrology (i.e. are either better drained, or have a better moisture supply in the dry season).
Some planosols only support a sparse grass and sedge vegetation with scattered bushes; other areas are under grass, grass with scattered trees, or forest, depending on the amount and distribution of rainfall. Growth rates of forest, in terms of wood production, are commonly half to less than a third of those on well-drained soils with similar parent materials and environment.
In the tropics, particularly in southeast Asia, and in the Far East, large areas of these soils produce a single crop of paddy rice on bunded fields inundated during the rainy season. Some trials to produce dryland crops on the same land with irrigation during the dry season have met with little success; the soils seem better suited to a second crop of paddy rice with dry-season irrigation and fertilization. In temperate climates, planosols are mainly used as grassland or for arable crops such as wheat or sugarbeet. Yields are relatively low, mainly owing to waterlogging in winter or spring and drought in dry summers. Locally, as near Rome, some of this land has been abandoned by farmers and used for housing, with occasional minor disasters due to flooding in unusually wet winters.

Possibilities

Strongly developed planosols, whether with silty or with sandy surface horizons, are probably best left in their present state, without efforts at improvement.
Where paddy rice is currently being grown, a supply of irrigation water would make double-cropping possible. The provision of irrigation might be economic if yields are improved by the simultaneous introduction or increased use of more productive cultivars and of fertilizers. The soils should be allowed to dry out at least once a year, however. This should prevent or minimize possible micro-element deficiencies or toxicities due to extreme reduction. Some of these soils may require applications of more than just the three major fertilizer elements before high yields can be attained: their low fertility level may prove difficult to correct.
High productivity of dryland arable crops or grass is very difficult to achieve on these soils without great fluctuations from year to year. Narrow drain spacings would be required because of the low hydraulic conductivity of the subsoil or substratum, but the disturbance during their installation tends to cause the soil structure to deteriorate. Thus, the resulting yield increases, if any, are small. Besides oxygen deficiency in wet periods, both excessive soil density and aluminium toxicity may hinder or prevent roots from entering the subsoil. Experiments in several European countries, spanning a number of years after drainage and deep loosening of the subsoil, with and without deep placement of calcium carbonate, have failed to show conclusive economic results.
In climates with long drought periods and short infrequent spells of waterlogging, as in southern France or Italy, irrigation of grassland or of arable crops grown in the dry season may hold promise. However, wherever temperature regimes are favourable for rice, paddy rice cultivation would probably be more profitable.

SALINE AND SODIC SOILS

R. Brinkman

Properties

Of the various problem soils in the world, saline and sodic soils occupy by far the largest area (323 million hectares). They are most widespread in arid and semi-arid climates, but also occur in more humid climates, especially in coastal areas. Australia has the largest area of saline and sodic soils: 85 million hectares, followed by Africa: 70 million hectares and Latin America: 59 million hectares (Table 5). Figures 5 and 6 show the worldwide distribution of saline and sodic soils, respectively.

Saline soils are defined by the electrical conductivity of saturation extracts of certain soil horizons (FAO 1978) or by their soluble salt contents. The salt content may fluctuate, depending on evaporation and rainfall, or on irrigation history. Sodic (formerly called 'alkali') soils have at least 15 per cent exchangeable sodium that may decrease their physical stability. Many have a poor structure and a very low hydraulic conductivity. Most are alkaline, with a pH above 8.5 owing to the presence of sodium carbonate. Some are almost neutral and a few – mainly those not in arid and semi-arid zones – are acid. Some soils are both saline and sodic. There is no clear definition of sodic soils as such because the distinctions made by FAO (1974) and the SOIL SURVEY STAFF (1975) include a requirement that there is evidence of clay illuviation. In acid sodic soils and in sodic vertisols the 15 per cent limit is unsatisfactory because these soils do not show evidence of the characteristic low stability and poor structure except at appreciably higher proportions of exchangeable sodium.

Table 5.
Regional distribution of saline and sodic soils (based on data from FAO/UNESCO Soil Map of the World; length of growing periods according to FAO Agro-Ecological Zones Project, Rome).

Region	Area(10^6 ha)	Area (million ha) per length of growing period			
		<90 days	90–180 days	180–300 days	> 300 days
Africa	69.5	56.8	8.4	3.6	0.7
Near and Middle East	53.1	51.0	1.6	0.5	0
Asia and Far East	19.5	13.3	4.0	1.7	0.5
Latin America	59.4	32.2	9.2	12.7	5.3
Australia	84.7	–	–	–	–
N. America	16.0	–	–	–	–
Europe	20.7	–	—	–	
World total	322.9				

Problems

The salts or exchangeable sodium in saline and sodic soils hinder crop growth. For efficient crop production they must therefore be leached from the root zone. This procedure is itself problematical because in most regions with these soils, irrigation water is scarce. Some soils that are more difficult to reclaim may require several times as much irrigation water as others.

If the land is not carefully levelled before basin irrigation is carried out, any variations in the microrelief (of the order of 5–10 cm) will cause considerable differences in the amounts of irrigation water entering the soil. Saline and sodic patches may thus persist or develop rapidly, even in land originally non-saline. It may take up to two years before an area is satisfactorily levelled. For other methods of irrigation the land need not be so scrupulously level, but all methods need considerable care to ensure that the irrigation water is uniformly distributed.

Under favourable circumstances, most of the wa-

ter applied to saline soils percolates through and removes the salts. However, if evaporation is high or the hydraulic conductivity of the soil is low, much more water must be applied to ensure percolation. Savings can be made if the irrigation water can be applied during seasons with a low evaporation rate. Alternatively, the sustained infiltration rate may be increased by measures such as cultivation, deep ripping, gypsum application, or a combination of these. A further problem arises if the irrigation water is itself saline. The more saline the water, the longer it takes to leach the salts.

It should be noted that there is a critical level of the evapotranspiration/percolation ratio beyond which the soil cannot be reclaimed. This level depends on the ratio between the desired soil salinity level and the salinity of the irrigation water, and on the leaching efficiency of the soil.

In strongly structured soils or in soils with many large pores, the water moving along the cracks and pores hardly comes into contact with the soil and therefore removes fewer salts. To overcome this problem the large pores in the surface horizon can be destroyed by cultivation measures such as harrowing or puddling.

In principle, the sodium carbonate present in many sodic soils can be leached. However, the associated high proportion of exchangeable sodium can only be leached after it has been replaced by other cations. These may be supplied in different ways, for example from gypsum dissolving in the percolating water, or from calcium carbonate or clay minerals dissolved in acid. These amendments (i.e. calcium salts or acids) may be added to the irrigation water or applied to the soil surface.

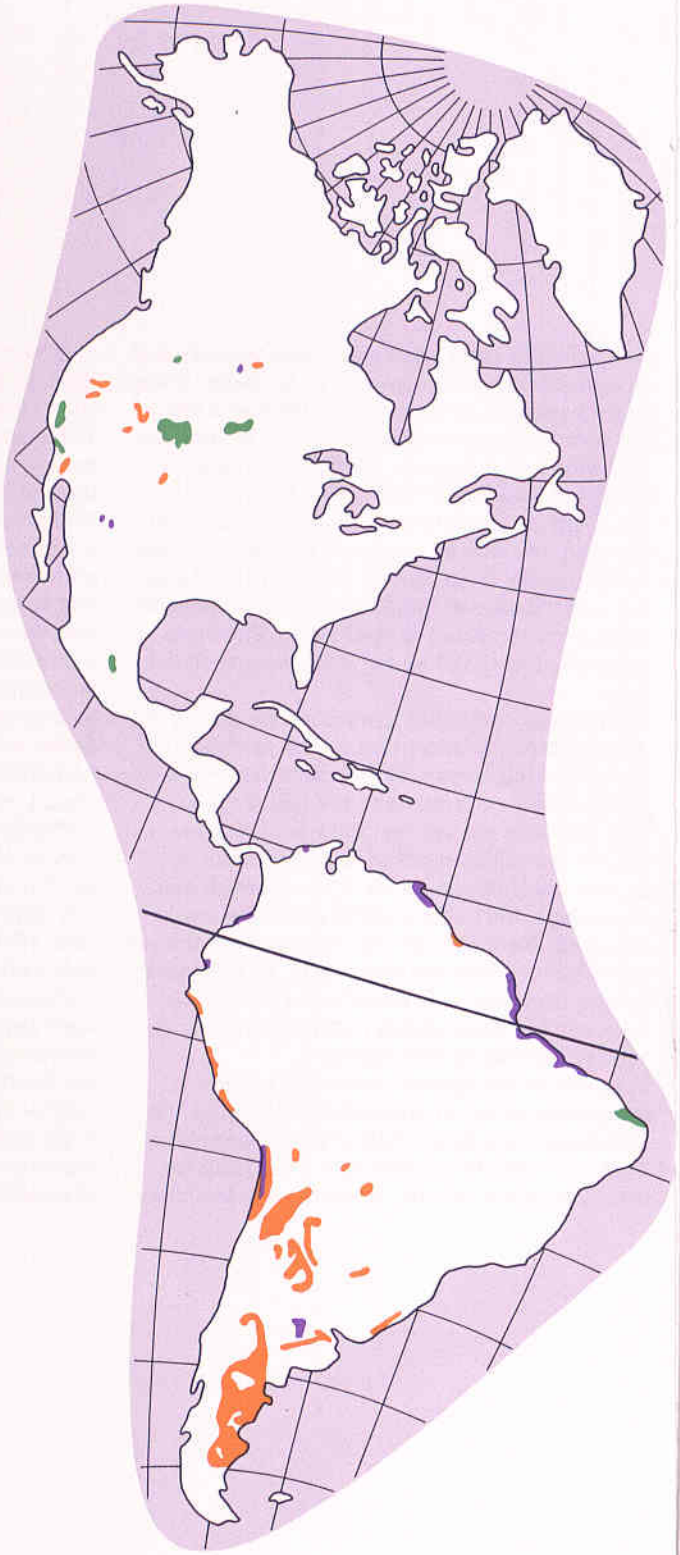
More water is required to leach a sodic soil than a saline soil. This is because the usual chemical amendments are less soluble than the usual salts and because sodic soils are generally less permeable than saline ones. If the percolation rate is much lower than the evapotranspiration rate, the amendment may have to be incorporated into the surface horizon and more applied superficially.

Sodic soils with a silt loam or silt texture and a homogeneous system of very fine interstitial pores have a very low saturated conductivity and leaching water barely moves through them under gravity. Water moves predominantly upwards under the influence of evaporation, and therefore any salts and sodicity accumulate near the surface. Moreover, there is virtually no air-filled pore space after water application until a fairly high suction is reached, at which point the soil material becomes almost dry. At present, the reclamation and use of such soils (which usually occur in tidal river deltas) for irrigated agriculture is neither economically nor technically feasible.

Even where the present permeability of the subsoil is good, reclamation of sodic soils is problematical. During the reclamation process the composition of the cations in the percolating water below the reclamation front is nearly in equilibrium with the original exchangeable cations, and may be mostly sodium. As a result, the total salt concentration may become too low to maintain flocculated conditions and the deeper horizons may coalesce into a virtually impermeable mass. To avoid this, saline reclamation water may have to be used in the early stages. Amendments supplying divalent cations are needed throughout the reclamation process.

Saline and sodic soils can be reclaimed by lowering the watertable. Even when the problems of initial reclamation have been overcome, further problems can arise. Renewed salinization or sodification can occur. Soils with a low capillary conductivity (e.g. clayey soils) can usually be drained satisfactorily by installing a system of ditches or pipe drains, 1.5 to 2.5 m deep. However, soils with a higher capillary conductivity (e.g. silty soils) must be drained deeper to prevent salinization or sodification, unless the groundwater quality is good. Deep drainage in areas receiving a strong inflow of groundwater from adjacent regions poses economic problems. The installation of a system of ditches or pipes may then be prohibitively expensive unless the soil is intensively cropped without long fallow periods. Tube well drainage could provide a solution but, economically, there is the problem of either disposing of the effluent or, if possible, using it for irrigation

Figure 5.
Worldwide distribution of saline soils (adapted from FAO/UNESCO Soil Map of the World 1971–1979).



dominant
covering 30–100% of the soil association

not dominant (associated)
covering 20–30% of the soil association

not dominant (inclusions)
covering 5–10% of the association

source: FAO/UNESCO soil map of the world

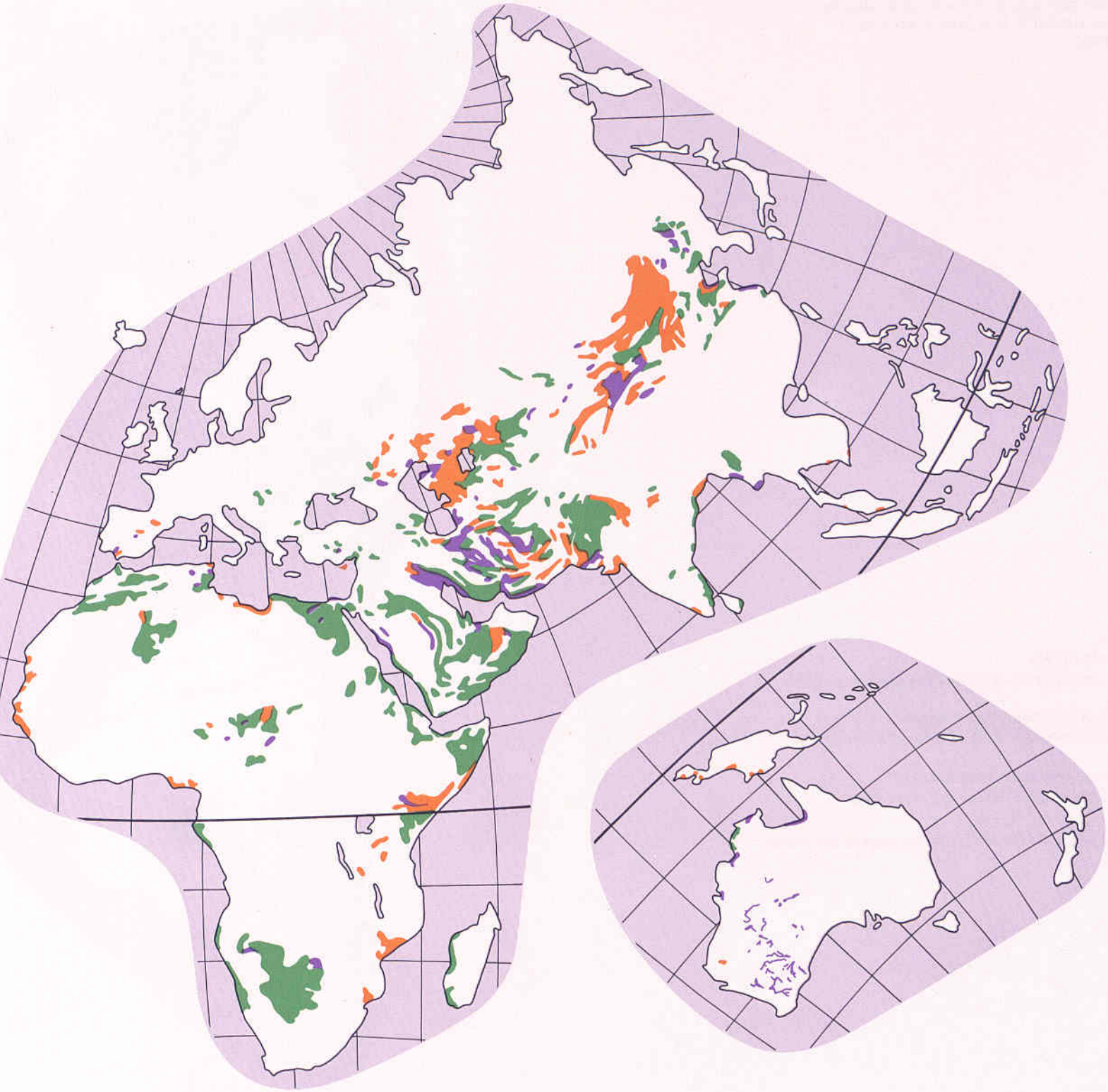
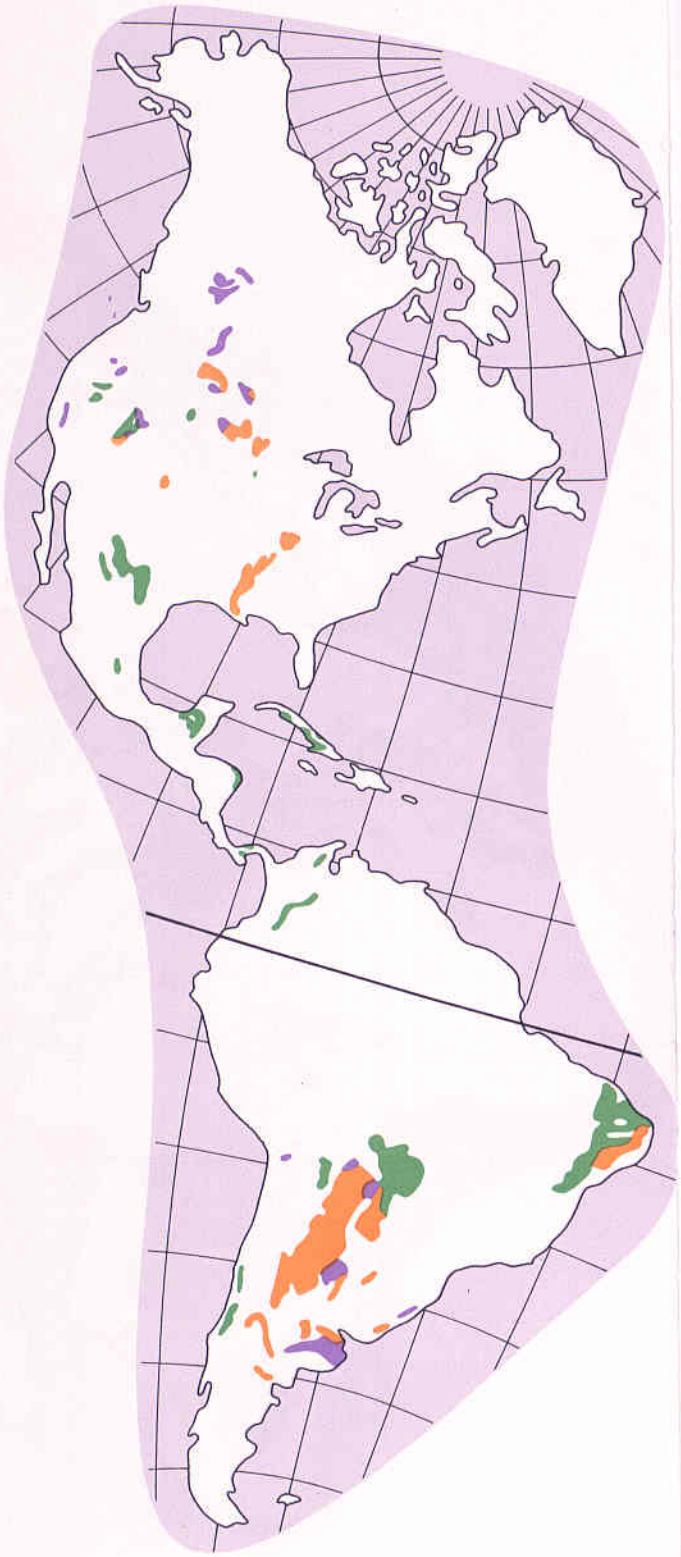


Figure 6.
Worldwide distribution of sodic soils (adapted from FAO/UNESCO Soil Map of the World 1971–1979).



dominant
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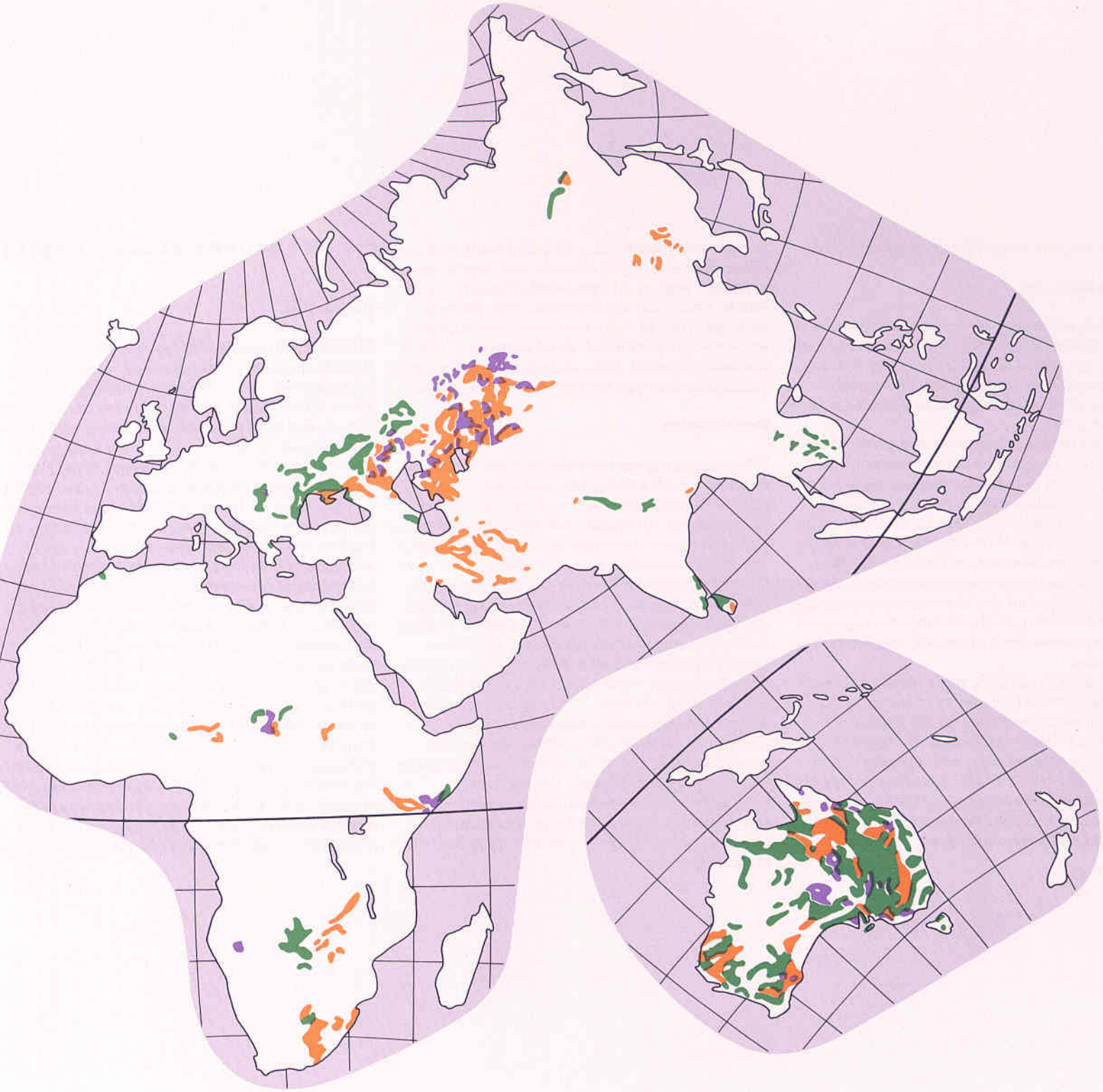
source: FAO/UNESCO soil map of the world



after it is mixed with good quality surface water.

Present land use

Saline soils are mostly left in their natural state or used for extensive grazing. Fine fighting bulls are raised on the saline coastal lowlands of France and Portugal. Also sheep, goats, and camels graze the salt-tolerant vegetation of saline soils in semi-arid zones.
Depending on the salt content and depth of the salty horizon, cereals of a certain tolerance may be grown under rain-fed conditions: barley is often grown on saline soils in mediterranean and semi-arid climates; a less tolerant crop grown on these soils is wheat. With irrigation, rice is sometimes grown on fine-textured saline soils. Before the rice plants are transplanted the saline soil is repeatedly flooded and drained to promote the diffusion and removal of salts from the topsoil to permit a moderate yield of the salt-tolerant paddy-rice varieties.
On sodic soils, land use is more varied, depending on the chemical properties of the topsoil and on the drainage conditions. In the depressed areas of the Argentinian Pampa for instance, extensive areas of sodic soils with topsoils rich in organic matter (FAO: Mollic Solonetz) support good herds of beef cattle. In California, after the dense natric subsoil has been broken, irrigated citrus plantations are established.

But generally speaking, saline and sodic soils are either used in a highly adapted and mostly very extensive way, or are reclaimed with high capital inputs, thus requiring intensive, high yielding land use types to make such land improvements economically justified. A good example of this is the reclamation of saline soils in coastal Peru with subsurface drainage for high yielding sugarcane.

Possibilities

When assessing the potential of a saline soil, the depth to which a soil is salt-free is far more important than the degree of soil salinity. Similarly, in a sodic soil, structural stability and hydraulic conductivity are more relevant than the proportion of exchangeable sodium present.
Often the highest returns to irrigation water are obtained not by land reclamation but by increasing the cropping intensity on the best non-saline non-sodic land. Removing surface salinity on otherwise good land also gives very high returns. This requires an initial application of irrigation water to leach the salts, followed by a regular water supply to sustain intensive cropping.
If irrigation water is still available, the second priority is to reclaim moderately or strongly saline land with a good hydraulic conductivity.
Even with adequate hydraulic conductivity, sodic soils generally give much lower returns per unit irrigation water, since they require more water for their reclamation.

FINE-TEXTURED ALLUVIAL SOILS

L. J. Pons

Properties

Marine and fluviatile alluvial plains often include large areas of fine-textured (at least 35 per cent particles $<2\mu$) clay soils within depths of about 80 cm. These azonal soils may occur in any climate and their characteristics vary greatly, partly in association with the prevailing climate.
Fine-textured fluvial soils are found in the backswamps of river floodplains which, under natural conditions, are covered by fresh-water forest and are regularly inundated with river water containing fine sediment. Vast areas of marine coastal and estuarine plains are also partly or completely comprised of fine-textured clay soils formed by tidal inundations of salt marshes and mangrove by saline to brackish water containing fine silt.
The chemical composition of fluviatile fine-textured soils in river backswamps depends on the kind of sediment carried by the rivers. Soils poor in minerals are common in the floodplains of small rivers in humid tropical climates. Such soils have low contents of weatherable minerals and organic matter, their clay minerals are kaolinitic, and they are very poor in macronutrients and in many micronutrients. Their pH and cation exchange capacities are low and they have a high proportion of adsorbed aluminium ions some-

times causing aluminium toxicity. Of the fine-textured fluvial soils in the tropics, those richest in weatherable minerals are developed on sediments deposited by rivers that originate in volcanic or recently uplifted mountains and later flow through arid areas. Most rivers in temperate climates receive their sediments from catchment areas with young, shallow soils on mainly physically weathered rocks or loess. They normally transport sediments rich in organic matter and minerals. Those rivers in temperate or boreal climates that flow over old granitic or gneissic shields supply sediments that are relatively poor in weatherable minerals.
In contrast with fluvial fine-textured soils, the marine variety shows less variability in nutrient contents and contains potassium, magnesium, calcium, sulphate, and sometimes phosphorus. In coastal plains and estuaries the river sediment is not only enriched by contact with sea water but is also usually mixed with sediments transported from the sea floor. As a result, nutrient contents are increased, carbonates are sometimes added, and clay minerals are mixed.
The chemical composition of sediments in the humid tropics is poorer than that of similar sediments in arid or temperate climates. The low organic matter contents of both humid and arid tropical marine sediments, as compared with those of temperate and boreal marine sediments, is a major disadvantage of the soils developed on these sediments.

Problems

The main adverse physical conditions of the fine-textured fluvial and marine soils can be low structural stability, low permeability, poor workability and difficult conditions for root growth. The properties critical to agricultural development and use of these soils are organic matter contents, free carbonates, iron oxide contents, active clay minerals, and the amounts of adsorbed Na Ca and Al cations.
Tropical alluvial sediments have low primary organic matter contents and thus give rise to soils with a poor structural stability. Sediments in temperate and boreal zones are characterized by high to very high organic matter contents, well mixed with the clay particles, Although some of the organic matter is mineralized during ripening, enough remains to contribute to a favourable structural stability. Nearly all the fine-textured soils in humid temperate areas are noncalcareous: this also decreases structural stability. In the sediments of floodplains and some coastal plains in humid tropical areas, low contents of iron oxides are common and this also contributes to poor structural stability.
Large areas of very fine-textured alluvial clay soils are virtually impermeable for water and roots. In the humid tropics these dense marine and fluvial soils have low organic matter and iron contents, contain kaolinitic clays, and lack carbonates. In the humid temperate areas the dense marine 'knip' soils lack carbonates and are saline. In arid zones the dense soils are very saline and have low organic matter contents. Desalinization is a difficult and slow process.
Fine-textured soils are often difficult to work because they have a narrow workable moisture range. Insufficient drainage is also a restricting factor in the flat areas where these soils occur.

Present land use

In temperate climates the fine texture and poor drainage conditions of some alluvial soils formerly restricted their use to extensive grassland. As techniques of drainage and empoldering improved, it became possible to reclaim fine-textured fluvial and marine soils.
In humid temperate climates, however, large-scale rain-fed crop cultivation has not developed because of the difficulties of seedbed preparation, the problems of harvesting in wet conditions, and the poor drainage of these soils. Only some fine-textured alluvial soils with very favourable physical properties (high organic matter and iron contents, active clays and free carbonates – as in the Dutch IJsselmeerpolders; or high organic matter and iron contents and high amounts of adsorbed aluminium ions – as in the deacified acid sulphate

gyttja soils of Sweden) are used for intensive crop rotations and economic production. The majority of the fine-textured alluvial soils, showing medium to poor qualities are successfully used for intensive forms of grassland.
Semi-humid or semi-arid temperate climatic conditions, however, restrict the possibilities for grassland and favour crop production (which is now the most widespread land-use, even on physically poor soils).
In the humid tropics, people also learnt better land-use practices and in the course of several thousands of years very extensive grazing on alluvial soils was replaced by different forms of wet-land rice cultivation. With the exception of very acid soils, all kinds of fine-textured alluvial soils are now used for extensive and intensive rice cultivation. Few rain-fed crops are cultivated because of drainage and management problems. Tree crops are only grown on the alluvial soils of best quality, where the soils show high structural stability and the drainage problems can be overcome. A wide range of fruit trees is successfully cultivated with or without irrigation in the coastal plains of Java, Guyana, Malaysia, and Thailand.
In arid areas where no crops can be grown without irrigation, poor structural stability, resulting in impermeability, difficulties of root penetration, and the need for intensive drainage, militates against crop production.

Possibilities

Protection from flooding (diking) and drainage are the two main priorities for the reclamation of fine-textured alluvial soils, if necessary combined with proper application of lime and/or gypsum to improve structural stability and permeability. If the soil conditions of the sub-soils are favourable, deep ploughing may give considerable improvement.
Prior to any land improvement, soil surveys are needed to ascertain the relevant soil properties for the main land-uses. These surveys should include permeability measurements both in saturated and unsaturated conditions. Research on the way the permeability and the structural stability vary as well as on future subsidence under planned land-use is necessary.
In The Netherlands, new research on the fine-textured fluviatile backswamp soils and marine 'knip' soils has shown that intensive drainage combined with land use such as modern grassland on these already ripened soils may, in the long term, lead to slightly improved topsoil development, better subsoil structures, and an increase in permeability. Processes such as progressive physical ripening, slight desalinization, and an increase in biological activity contribute to these results.
Physically unripe or partly ripe fine-textured alluvial clay soils will develop cracks that may considerably improve their permeability. Especially in the tropics, however, low organic matter contents and the presence of low activity clays, sometimes combined with salinity may cause both low cracking and structural instability, resulting in impermeability upon ripening. In these cases wet rice cultivation may be the solution for economic land-use. Possible development of sulphate acidity is another danger, although moderate production of acids by oxidation of pyrite both with or without the presence of carbonates may improve structural stability. More research on these soil processes is needed.
Subsidence accelerated by reclamation and by improved drainage of the alluvial soils will affect the drainage systems and may necessitate extensive land levelling if wet rice is to be grown.
In arid and semi-arid climates, salinization is a hazard, and irrigation must always be accompanied by sufficient drainage, even for wet rice production. If peaty topsoils occur in alluvial plains in the tropics, and the alluvial soils are permeable enough for tree crops, these layers should not be burnt because they will help maintain the soil structure. With wet rice cultivation, however, the peat layers should be burnt to obviate management difficulties.
When research indicates that it seems dangerous to reclaim fine-textured marine alluvial soils (because of their salinity,impermeability, or proneness to acid sulphate development), alternative

land-use should be considered such as grazing, fishponds, shrimp production, mangrove cultivation for timber, and wild life conservation.

OUTLOOK FOR THE FUTURE

With the exception of the fine-textured alluvial soils, whose regional extent is not yet known, the world-wide distribution of the problem soils discussed in this article is presented in Table 6. Their total is an estimated 987 million hectares.

Of the 1,000 million hectares of alluvial soils known to exist in the world (FAO: Fluvisols and Gleysols), let us assume that half of them (or 500 million hectares) are fine-textured. Adding this to the 987 million hectares of Table 6, we arrive at a total of 1.5 billion hectares of soils with problems of water management.

Much has been learned about how to make some of these soils productive, but much still remains to be done. The technique of reclaiming saline and sodic soils is well advanced. Some peat soils have been used successfully for centuries. For acid sulphate soils, research is still needed to find a reclamation method that is at the same time economically feasible. Little is known about the many soil processes that come into play in the reclamation of fine-textured alluvial clay soils.

With the future world food situation causing more and more concern, the vast area of problem soils is posing a challenge to land and water specialists.

Table 6.
Worldwide distribution of a number of problem soils. (million hectares).

Type of soils	Vertisols	Peat soils	Acid sulphate soils	Planosols	Saline and sodic soils
Africa	105.0	12.2	3.7	15.9	69.5
Near and Middle East	5.7	0	0	0	53.1
Asia and Far East	57.8	23.5	6.7	2.7	19.5
Latin America	26.9	7.4	2.1	67.2	59.4
Australia	48.0	4.1	0	49.3	84.7
N. America	10.0	117.8	0.1	12.3	16.0
Europe	5.4	75.0	0	4.0	20.7
World total	258.8	240.0	12.6	151.4	322.9

Acknowledgement

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