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IDENTIFICATION AND MANAGEMENT OF PROBLEM SOILS OF THE TROPICS AND SUBTROPICS

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IDENTIFICATION AND MANAGEMENT OF PROBLEM SOILS OF THE TROPICS AND SUBTROPICS

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There is hardly any soil in the world that has no limitations for plantgrowth and cropping, not even assuming ideal moisture and temperature regimes. Some groups of soils of the Tropics and Subtropics present however major problems as regards their management. These will be reviewed in this introduction, with special attention to the well-drained acid or crusting soils of the Tropical and Subtropical Uplands.

1. SOILS OF MOUNTAINOUS LANDS ("steepland soils")

Two main groups can be distinguished: a) soils derived from recent volcanic materials, especially volcanic ash - Black Volcanic Soils; and b) usually shallow soils derived from other rocks and sediments - Shallow Mountain Soils.

1.1 Black Volcanic Soils

The Black Volcanic Soils (Andosols/Andepts) are prevalent in the Pacific, Papua-New Guinea, Indonesia (Java, Sumatra), Eastern and Central Africa (Ethiopia, western Kenya, northeastern Tanzania, Rwanda, northeastern Zaire, southern Cameroon), and parts of the Andean mountain range in Latin America (Mexico, Costa Rica, Colombia, Ecuador, Chile). These are in general areas with high population density. In temperate regions major occurrences are in Japan, USA (Oregon) and New Zealand.

The parent materials of the soils may be lava flows (often basaltic), but more commonly pyroclastics ("tephra": ashes of varying grain sizes from rhyolitic, dacitic and andesitic volcanoes).

Physico-chemically, Andosols are characterized by high percentages of allophanes ("short-range-order" clay minerals) and/or volcanic glass ("cinders"), resulting in high specific surfaces and strongly pH-dependent surface charges of the solid phase. Accessory properties are: high friability, low bulk density and high Phosphate (and Sulphate) adsorption.

Most Andosols have a high organic matter content and are deeply rootable. Their permeability for water and their water storage capacity are high, and they are often little prone to erosion because of a high porosity and high inherent structure stability. Some however contain dense and permanently hard layers ("duripans", called "cangagua" in Ecuador) making them particularly liable to erosion.

From fertility point-of-view the main drawback of the Andosols is their high P-retention ("fixation") due to the peculiar nature of the clay minerals. They are often acid, but variants with high base status occur too (e.g. in parts of western Kenya). Depending on the nature of the ashes, micronutrients may be either in short supply or occur in excessive quantities ("toxicity").

In general, Andosols are suitable for a wide range of crops, including horticultural ones, wherever rainfall is sufficient - the predominant situation - and temperatures are not too low.

Tillage is easy, but traffic is often difficult. This not only because of steep topography, but also because of an often "smeary" character of the soil material ("thixotropy").

The open and friable nature of the soils provides for an ideal environment for insect pests. Because of a low termal conductivity of the soils (especially of the cindery types), the range of temperature regimes suitable for cropping is somewhat narrower than at non-volcanic soils: stronger altitudinal limitation.

Research needs:

- Nature of the clay-minerals and its effect on the chemical and rheological properties.
- Development of special field and laboratory methods for their identification, and subdivision relevant for their use possibilities.

New Zealand and Japanese soil scientists are particularly active in studying these soils.

1.2 Shallow Mountain Soils

Shallow Mountain Soils (mainly Cambisols/Inceptisols) occur in many countries of the Tropics and Subtropics. The most extensive area is probably the middle-slope section of the Himalaya range (Pakistan, Nepal, Bhutan, India, China), but also many parts of the Andean Cordilleras are involved (Peru, Venezuela) and parts of the Rift Valley system of Africa (Ethiopia, Burundi, Tanzania, Malawi).

The soils have little in common except their shallowness, stoniness and short-distance spatial diversity (intricate patterns). Parent materials are of many kinds and this factor, combined with strongly varying slope class and a wide range of temperature and moisture regimes, gives rise to soils of strongly differing humus content, acidity, clay mineralogy, texture, density, etc.

Because weathering of the rocks is never very strong, the physico-chemical stability of the soils if often very low. This, and the steep slopes, make the soils particularly liable to erosion at cultivation or grazing.

In general the lands concerned have been sparsely populated in the past, with farming systems adapted to the harsh environment, cf. the pre-Colombian Incaic terraces. With the recent strong increase in human and animal population and under influence of agricultural mechanization and introduction of fertilizers, small farmers are often pushed out of the fertile valleys to these mountain lands. As a consequence their inherent ecological fragility is often tried beyond capacity. This results not only in a serious loss of a plantgrowing medium at the spot, but also in large-scale negative effects downstream: silting up of dams, flash floods, etc. Effective counter-measures are usually beyond the capacities of the individual small farmer or animal herder. In many places moreover an acute shortage of firewood and animal browse has developed. Rehabilitation of such lands (by bench terracing, tree plantings, etc.) out of necessity has to be a community effort, at which financial and technical support of the Central Government or a Foreign Donor is often indispensable.

The food-for-work philosophy of FAO's Freedom From Hunger/World Food Programmes has in a number of cases yielded tangible results in such areas, but it is still chicken-feed in comparison to the extent and the gravity of the problem.

Site-adapted agroforestry techniques can be helpful, but require detailed base-line surveys as regards physical resources and socio-economic conditions (farming systems research). In some cases, massive re-settlement in downstream areas may be the only immediate solution.

Research needs:

- Study of ancient land management techniques of the traditional steepland populations
- Development of mountain cultivars of ground covering herbs and grasses.

The recently established International Centre for Integrated Mountain Development (ICIMOD) in Nepal may provide answers to some of the most urgent problems of the Shallow Mountain Soils.

2. ACID SOILS OF THE HUMID AND SUBHUMID UPLANDS

2.1 The Yellowish Soils of the Tropical Forest Regions

The soils of the humid tropical forest regions of low altitude are predominantly very deep, yellowish, strongly weathered and acid (xanthic or orthic Ferralsols, ferric Acrisols and ferralic Cambisols or Arenosols/ Haplorthox, Paleudults, Tropepts, oxic Quarzipsamments).

They occur over very large expanses in the Amazon and Congo regions, but also in many parts of the Malaysian archipel (Malaysia, Kalimantan, Sumatra). Human population density was very low until recently, not only because of the low fertility of the soils, but also because of the unsavoury climatic conditions (diseases, pests) and difficult access. This picture is now changing rapidly (transmigration in Indonesia, road building in the Amazon region).

The parent materials are often pre-weathered sediments of Tertiary-Pleistocene age, but also large areas with acid crystalline basement rocks are concerned (e.g. in Gabon). Physico-chemically most of the soils are characterized by high percentage of low-activity clay minerals, viz. kaolinite and sesquioxides (goethite, gibbsite, hematite). Apart from the clay minerals the only soil constituent is sand-size quartz and fine gravelly sesquioxide nodules; silt-size particles and weatherable minerals - as a source of nutrients - are practically absent. The soils are however deep, of uniform or near-uniform texture throughout, well drained and porous, with a fairly high degree of inherent stability, because of the inertness of the clay minerals. This results in a low liability to erosion. Because of their friability and porosity they are easy to work (high "arability") and easily and deeply rootable. For the same reasons their effective moisture storage per unit of volume has always been assumed to be quite high. It turns out, however, that this is only 10% or so - comparable to temperate zone sandy soils - because a large part of the moisture is held onto the soil mass with a force stronger than plants can exert for extraction. In areas with a distinct dry season (e.g. the eastern and southwestern parts of the Brazilian Amazon) there can occur a distinct moisture stress for annual, shallowly rooting crops, after the smoothing-over influence of the forest vegetation has been taken away.

In the soil itself, nutrients are in general in very short supply: the low cation-exchange capacity (less than 16 meq per 100 grams of clay, often not more than 1 to 5 meq), in combination with a low base saturation (less than 50%, often 10-15% only) and the virtual absence of weatherable primary minerals (less than 4% of the sand fraction), makes the soil quite sterile in the chemical sense.

The soils may have rather high percentages of exchangeable Aluminium which has a negative effect on root development of crops; their absolute amounts are however never very high. Micronutrients for crops and animals are in low supply.

Most of the nutrients are in fact stored in a thin humus-rich topsoil and in the forest vegetation itself. Nevertheless, in the absence of dense or poorly drained layers lower down in the soil profile can the forest vegetation obtain adequate foothold, a degree of nutrient capture through deep rooting from the less weathered substratum, and a biologic environment suitable for quick and effective recycling of nutrients. The quality of the seemingly very monotonous forest cover (timber volume, penetrability, species diversity) varies quite strongly with such subsoil variations - as borne out by early FAO forest inventories and recent radar-based natural resources mapping by the Radamproject of Brazil.

The traditional shifting cultivation system - 2 to 3 years mixed cropping after slash-and-burn land preparation -, although resulting in an ungainly visual landscape at short term, is a well-adapted low-technology use of these tropical forest lands. At high-technology level the same can be said for the growing of perennials such as rubber and oilpalm (Malaysia!) or plantation forestry. At land preparation for these purposes care should be taken not to destroy the humus-containing topsoil - as once again demonstrated by the experiences in the Jari project on the north bank of the lower Amazon.

Well-managed pastures may also be successful, by planting adapted cultivars of grasses and leguminosas immediately after slash-and-burn land preparation (Falesi, 1976). In practice, however, it often concerns large ranches with less than careful management. Experience in Brazil has shown that at such ranches the animal productivity declines rapidly after about six years, through compactation of the topsoil, the proliferance of obnoxious woody herbs and the multiplication of insect pests. It is moreover difficult to restore a forest cover on such degraded ranching land because of dry spells and excessive insect fretting. The result is often a low bushy type of wasteland for many years (c.f. "alang-alang" fields in Sumatra).

Continuous cultivation of annual crops on year-round basis with high-technology inputs such as regular tillage, fertilizing, and chemical weed and pest control, has always been considered impossible. In recent years, however, a pilot programme of such an advanced farming system has been introduced in the Yurimaguas area of the Peruvian Amazon by US soil scientists and agronomists (Buol, Sanchez et al). This programme has demonstrated that it can be done. The technology has therefore been much advocated as the solution for the humid tropical forest zone: concentration of high-technology food production on relatively small areas, leaving the surrounding forest intact. At farmer's level, however, the method is turning out to be less than successful. Not only does it require too heavy investment in capital and labour for year-round chemical weed- and pest control, but there is also a need for frequent machine-operated tillage to keep that particular soil in well-aerated condition and to prevent its large-scale washing-away at the occasional excessively heavy rain shower. In practice, the traditional shifting cultivation tends to increase rather than to diminish in the wide surroundings of Yurimaguas. At present, therefore, the Yurimaguas group of scientists is also developing intermediate and low-technology farming systems (alley cropping, tree crops).

It should be pointed out that the Yurimaguas soil may be representative for some of the fringe areas of the low-altitude humid tropical forest zones, but is not so for their main, central parts. The soil concerned, though acid as well, is texture-differentiated, with significant percentages of silt, has a less than stable structure (appreciable percentage of water-dispersable clay), and a high-activity clay mineral assemblage (25-30 meq per 100 gr of soil; hence 5 to 10 times more active than the xanthic Ferralsols of for instance Manaus/Belem, Yangambi or Malacca). This observation may illustrate that the "transfer-of-technology" value of advanced in-situ agronomic research does hold good only if the spatial diversity of the soil conditions in the humid tropics is established and taken into account. It should be noted that the extent of Ferralsols on the existing FAO-Unesco soil maps has been strongly over-emphasized. With the advance of remote sensing supported mapping, it is now becoming apparent that within the regions of low-altitude humid tropics there are not only parts with high-activity clays like at Yurimaguas and Acre, but also very sizeable expanses of land with either steep topography, or with excessive percentages of cobbly or massive laterite concretions and sheets, or with excessively drained very sandy soils, or with imperfectly drained soils with white sandy topsoil (Rio Negro area, Kalimantan, eastern part of Congo-Brazaville). These lands are definitely unsuitable for any type of agricultural use. Their original vegetation not only protects the land from irreversible degradation, but also in itself may consist of a very specific floral and faunal species composition ("niches"), of unique value as natural germ plasm/gene banks - for future breeding programmes, medicinal or ornamental use, etc. (Conservation of sizeable areas of virgin forest on the better soils - for instance the Terra Roxa patches in the Brazilian Amazon - would however be a most urgently required policy action).

Research needs

- Development of adapted methods to characterize the different soils, including the nature of their organic matter, and their inherent structure stability

- Further development of a methodology for multi-purpose land evaluation (forest reserves, forest production areas; perennial cropping, upgraded forms of shifting cultivation). Socio-economic research on acceptance of such a methodology at forest-people level, ensuring effective planning of alternative land uses on a sustained basis - c.f. the recently started "Tropenbos" programme.
- Understanding of the processes involved in the functioning of the many subsystems of the tropical forest ecosystem.

The latter has already been taken up by the IUBS at its proposed networks of research on "Tropical Forests Diversity" and on "Tropical Soils Biology and Fertility". The second network aims at improvement of soil fertility in the tropics by biological means, through comprehensive studies of the basic interactions between Litter, Plant and Soil.

2.2 Reddish Soils of the Subhumid Savannah Regions

In the subhumid tropical zones the soils are, on the average, more reddish than yellowish. They may be very deep, uniformly textured, very strongly weathered and very acid (rhodic or acric Ferralsols/Ustox or Acrox/Sols Ferralitiques rouges) like in the Cerrado zone of central Brazil, part of the Llanos of Venezuela, parts of northern Mozambique, Zambia and Tanzania. Others are less deep, texture differentiated, less strongly weathered and only moderately acid (ferric Acrisols/Ustults/Sols ferrugineux tropicaux) like in the Forest-Guinea zone of West Africa, many parts of subhumid Eastern Africa, southern Thailand, etc. This difference in weathering stage is related to the length in time that the landforms concerned have been stable, and hence the degree to which more humid climates of the past have left their marks in the presentday soil profile.

Except for their colour and moisture regime, the Cerrado soils of central Brazil are very comparable to the main soils of the humid tropics with forest cover: very deep, stable, with low or even extremely low-activity clay minerals, little silt, high percentage of exchangeable Al, and high to very high P fixation (because of more iron oxides than in the yellowish ones, also accounting for the higher stability). The present vegetation is a fire-resistant and Al-tolerant climax of tree savannah of very low nutritive value.

Until recently, it was believed that the improvement and effective occupation of these soils by mechano-chemical or biological means was virtually impossible. Internationally supported agronomic research at several agricultural centres, notably the EMBRAPA-CPAC Centre at Planaltina near Brasilia, has proven that high-technology management of these soils can be very successful. Its economic soundness is moreover proven by the vast increase in commercial farming with the new techniques in the wide surroundings of Brasilia.

The crux of the technology is the deepening of the rootable layer by thorough mixing of the soil with lime till at least 1 m depth. Such thorough mixing of Ca (and Mg and P) can be done either by deep plowing or by sulphate-strengthened leaching of superficial dressings. This eliminates the exchangeable Al that otherwise acts as a firm barrier to deep rooting and thereby would induce physiological drought of crops at dry spells within the rainy season. Deep placing of slowly desintegrating rock phosphate in the soil overcomes the high P fixation, without loss of this expensive fertilizer by leaching to the substratum. (When suitable rock phosphates are not available then application of super-phosphates turns out to be still a feasible proposition for annual crops such as maize.)

Other fertilizers, including micronutrients, are added in accordance with the specific requirements of the crop and the detailed chemistry of the soil. Rotational growing of leguminous crops, including soybeans, helps diminish the need for application of N-fertilizers.

The economic success is in part due to the fact that not only are the soils very stable and open-surfaced - no need for repeated tillage after heavy showers, and small erosion hazard -, but also because large tracts of flat or nearly flat lands are concerned. The pronounced dry season moreover prevents the proliferation of weeds and pests, thereby reducing the costs of their control. These are all factors not prevalent on many of the yellowish Ferralsols of the humid tropics.

The agronomic experiences on the cerrado lands of Brazil may well be transferable to parts of Eastern-Southern Africa with similar topographic, soil and climatic conditions: the "high-veld" areas of northern Mozambique and Zambia, parts of Tanzania and some parts of the "medium-potential" climatic zone of Kenya. Most subhumid areas of tropical Africa however have different soils, often on dissected uplands of acid crystalline rocks: less weathered and less acid, but with a lower inherent stability and smaller potential rooting depth (less deep soils and/or with high percentages of laterite gravel). Percentages of exchangeable Aluminium may be lower than in the Ferralsols discussed above, but the total amounts of Al may be substantially higher because of somewhat higher activity of the clay-minerals assemblage. Most important however is their tendency to surface compaction after rainshowers. It implies a need for repeated tillage before and after sowing or planting, for sufficient rainfall penetration, for aeration and for prevention of erosion, the latter of the sheetwash type mainly. This repeated tillage, if done with heavy machinery, has by itself a detrimental effect on the less than stable subsoil, making it prone to gully erosion on these usually quite undulating lands. An additional problem is the low reliability of the rainfall, often bimodal, in many African regions with these soils. This type of problems and their prevention has been amply demonstrated at the soil management trials on the permanent-cropping plots of IITA, Ibadan-Nigeria (Lal and co-workers) and at the ICRAF experimental sites east of Nairobi in Kenya. Intercropping, alley cropping, contour plowing, bench terracing and use of only light machinery at land clearing and tillage, are solutions, but obviously at lower level of feasibility in a macro-economic sense.

To be complete, one should mention that both in the humid and subhumid tropics there are excellent soils, developed often on permeable basic rocks or on older volcanic deposits: the Nitosols (sensu stricto) of the FAO-Unesco Legend. They are deep, dark reddish brown, porous, of extremely stable structure. These soils have low to medium-active silicate clay minerals (including meta halloysites) and relatively high amounts of free (active) iron oxides, their combination resulting in relatively high specific surface of these throughout clayey soils, with associated good moisture and nutrient storage facilities. Many of the older agricultural research stations of Africa and Asia, and small-holder pioneer settlements in forest zones, are located on these special soils - giving an erroneous impression of agricultural potential of the region as a whole.

On the other hand, there are wide-spread occurrences of soils with banks of laterite gravel or massive ironstone sheets (petro-plinthite), in particular in West Africa. Though most of these occurrences have originated under different edaphic and climatological conditions than the present ones, they are a strong impediment for agricultural use of the land. This not only in respect of tillage (use of implements) but also because of the reduction of the total soil volume that can store moisture and nutrients (even though the laterite itself may contain a reserve of nutrients in pockets of weatherable minerals). Little or nothing can be done to improve these stony soils, but the popular reports of hazards of large-scale "lateritisation" at deforestation are giving an overly negative impression on the nature of the problem - which is more a long-term geologic-geomorphologic process (changes in climate and in erosion base) than a short-term pedological one.

Research needs:

- Study of factors and processes determining surface and subsoil instability of Ferralsols and Acrisols, and development of adapted tillage-no tillage practises (c.f. tillage rating indices of Lal 1985)
- Basic studies of P, S, and Al behaviour in representative examples of different subtypes of these soils (and from different agroclimatic environments)
- Development of methods for plant-growth oriented physico-chemical characterization of the soils, not only in the lab but also at field surveys
- Methods for characterizing organic matter and its biological activity by non-destructive means
- Research in age and stability of landscapes in relation to degree of soil weathering
- Interdisciplinary research on laterites and lateritization processes, including agreement on nomenclature of its textures and structures.

The recently created International Board of Soil Research and Management (IBSRAM) has already taken on the Acid Red and Yellow Soils of the Tropical Uplands as a major item in its soil management networking concept.

3. CRUSTING SOILS OF THE SEMI-ARID UPLANDS

On the drier tropical and subtropical uplands the main problem is not soil acidity but an unfavourable soil structure, especially as regards the topsoil. In many situations the overhead climatic conditions would allow the growing of one annual crop in most years. A three month rainfall of 700-1000 mm is sufficient for crops like millets, sorghum, cowpeas and groundnuts to provide economic yields. It then depends on whether this rainwater can fully penetrate and be stored in the soil for dryland agriculture to be successful.

Moisture storage per-se is usually not a bottleneck, unless the soils happen to be very sandy (Arenosols) or very shallow (Lithosols; Cambisols, lithic phase). Many of the soils in the semi-arid tropical areas have effective depths of 100 cm or so, with a subsoil structure and a clay minerals assemblage that guarantees an effective soil moisture storage capacity of at least 100 mm. A critical factor is however the degree to which the surface condition allows the rainwater to penetrate, right from the start of the rainy season.

Many soils of the semi-arid savannahs have a sandy topsoil. This can be because the over-all texture of the parent materials is sandy (wind-transported coversands, or braiding-river deposits). Another cause is strong textural differentiation between topsoil and subsoil as a result of the pedogenetic illuviation process (formation of an "argillic"-B horizon) acting on autochtone parent materials (sedimentary or crystalline basement rocks). These sandy topsoils may or may not be prone to a form of crusting called sealing, i.e. the formation of a thin layer (1-5 mm) at the surface of the soil that is very dense and hard when dry, without any porosity, and sometimes even water repellant with algae growth: tile conditions. As secondary processes, local sheetwash processes may then cause the formation of sheets of loose coarse sand on top of the sealed layer and wind action may furthermore result in sandy micromounds (Valentin '85).

As a result of the sealing, rainwater falling on bare ground cannot penetrate into the soil, and therefore runs off side-ways, even at very gentle slopes. It may take more than one full month of rain before this sealed layer is sufficiently softened and broken up to allow rainwater to enter the soil.

An added problem of this sealing is the impediment or straining of seedling emergence; this because of the strength needed to break through the crust, and the formation of a oxygen-deficient layer immediately below it.

To be complete: practically all soils in regions with seasonal rainfall and absence of a cold (frost) season, have a tendency to surface compaction. Occasional dry-season showers, sunbaking and cattle trampling cause a hard surface layer. What counts is the degree to which the topsoil material re-compacts, re-seals after being tilled. The "liability to re-sealing after tillage operations" is therefore the right name for the soil property concerned.

Examples of failure of large-scale crop-production schemes abound (schemes on groundnut, cotton, maize, fuelwood production). Such schemes tended to be located on large unoccupied areas of smooth topography with theoretically sufficient rainfall for one crop and no apparent soil limitation - until actual cultivation started. It is not without reason that the traditional farmers have avoided such areas in the past!

Studies in the Sudan-Sahelian zone of West Africa (Nicou, Sombroek), but also in Australia, Eastern & Southern Africa have demonstrated that this sealing process - or rather the liability to re-sealing - is occurring on soils with a broad size distribution of the sand fraction. A mixture of coarse, medium, fine and very fine sand particles, together with a fair percentage of silt and clay (each 5 to 10%) apparently favours a very close packing of particles, under the influence of raindrop splash and at low amounts of structure - and porosity stabilizing constituents like humus and iron compounds. At clear tops of any particular sand fraction - e.g. fine sand - lower amounts of silt, and/or higher amounts of clay this close packing is not achieved.

Sealing-prone mixtures of grain sizes occur in topsoils of the more acidic crystalline rocks like granites and gneisses, or sedimentary rocks like quartzitic sandstones, both containing a large supply of non-weatherable quarz-grains and relatively few sesquioxides or free lime. It concerns both sedentary soils and alluvial/colluvial ones with such rocks as source.

Sealing-prone mixtures are also prevalent on the older coversands in fringe areas of presentday deserts (Sahara, Kalahari, central Australia), viz. those conversands that have not been repeatedly re-transported by wind action with its automatic relative concentration of the fine sand fraction. Examples are the sealing "sables rouges" of the "brousse tigré" versus the non-sealing "sables jaunes" of the Sudan-Sahelian zone of West Africa (numerous French authors); the non-sealing "red-sand" plain versus the lower-level "sealing loam" plains of northeastern Kenya (Sombroek et al.).

The absence or presence of a re-sealing hazard has not only determined strong differences in types of vegetation, but also clear patterns of traditional cropping versus non-agricultural use of the land (grazing or "forest" reserves). The importance of grain size distribution at re-sealing liability has been summarized for West Africa by Ahn (....) and has also been recognized at the selection of experimental grounds of the ICRISAT Sahelian research subcentre near Niamey (West et al., 1984). The forthcoming international Symposium on "the assessment of surface sealing and crusting" (Gent - Belgium, Sept. 1985) will undoubtedly give more insight in the spatial distribution and the nature of sealing processes in the semi-arid tropics and subtropics.

Remedial action on sealing-prone soils is quite difficult. Repeated tillage before and during the crop growing season is normally uneconomical, whether done by mechanical means or by traditional practises (such as howing). Increase in the humus content of the topsoil is very difficult, not only because this would require several years of reservation of the very valuable source rainwater for soil improvement, but also because much of the fresh organic matter is oxidized during the hot dry season or brought deeper underground by termite activity. The organic matter needs to be humified soonest to become effective as an open-structure stabilizer. It is quite possible that part of the reported remedial action of P-fertilizing on these soils in the Sahel zone (PPS project) is due to a quickening of this humification process through increase of microbiological activity.

Application of artificial soil "conditioners", produced on the basis of polymer technology, may be a solution for the future. At present, however, most of the commerciable available conditioners would appear to be inadequate, if only because of the limited life-span of activity.

Most important at the development of large schemes or small-holders settlement in the agro-climatological zones concerned is a careful mapping of the various soil patterns, in relation to the sources of the parent materials and the geomorphological history of the land. At these inventories one needs to give special attention to topsoil properties, to the relationship soil-vegetation, and to the behaviour of the rainwater at the beginning of the rainy season.

In a number of physiographic situations it may be an economically sound proposition to further denude sealing-prone land units, thereby actively concentrating the rainfall on adjoining, lower lying and less sealing prone land units (water harvesting). This in fact is not unknown in traditional land use (North Yemen; northwestern Nigeria).

Finally, it should be mentioned that the pattern of sealing - non sealing sandy soils should also be taken into account at the current efforts to increase the supply of tree products (fuelwood, timber, cattle feed) through the establishment of communal village forest production patches. Unused space near such villages has often been in that condition precisely because of soil moisture supply limitations, and this will prevent rapid tree growth (c.f. experiences in the colonial period of northern Nigeria with plantations of Azadirachta).

Research needs:

- Further study of the nature of the "sealing" problem and the forces acting upon it
- Combined geological-geomorphological-sedimentological-pedological inventories of land patterns
- Study of materials and methods to suppress the sealing hazard through the application of industrial amendments, chemical fertilizing and/or by biological means.

4. POORLY-STRUCTURED SOILS OF SUBHUMID TO SEMI-ARID PLAINS

Two main categories of soils are involved, viz. the strongly cracking black or grey clay soils ("Black Cotton Soils"), and soils with hardpans at depth (Clay-pan Soils; Sodium-pan Soils).

These soils predominate in the subhumid to semi-arid tropics, where they usually occur on extensive plains that are propitious for mechanized farming, often with irrigation. A group of Dutch soil scientists has summarized the identification, reclamation and management of these soils, at the occasion of the 25th anniversary of ILRI in 1980 (see hand-out). Therefore their discussion will be relatively short.

4.1 Cracking Clay Soils

The Black Cotton Soils or Vertisols occur in very large expanses in central India (a.o. ICRISAT), central-south Sudan (a.o. Gezira), Mexico, Uruguay-south Brazil, and eastern Australia. Minor areas can be found in practically all tropical and subtropical countries, wherever there is rich parent material (basalt, limestone, calcareous clayey sediments) in a position of accumulation rather than leaching of their weathering products.

The soils are moderately deep (more than 80 cm); of poor internal and often also poor external drainage; black, dark grey or dark reddish brown coloured; of high clay content; very strongly structured (prismatic), and with characteristic cracking features: In dry seasons V-shaped cracks occur right from the surface down to nearly the unweathered rock or sediment. These cracks close through swelling of the clays after the first rains, leading to internal displacement of soil material. This results in vertical homogenisation of the material through a churning process; in polished faces on the large structure elements ("slickensides"), and often in a microtopographic surface irregularity ("gilgay") associated with strongly varying depth of the soil at short distance. These specific properties are due to the dominance of swelling clay minerals, mainly montmorillonite.

Vertisols vary in depth (relatively shallow ones abound in India); in base status (they are usually basic, but acid ones are known, for instance in Venezuela); in degree of cracking and churning (relatively small in Gezira); in contents of free lime and salts; and especially in their surface properties. Some have a stable open surface structure of fine porous elements (crumb structure: "grumic" Vertisols), others have a thin crusty surface that is hard in the dry season and sealed-off in the rainy season ("mazic" Vertisols). The latter ones have special problems as regards rainwater penetration and at mechanical tillage to arrive at a good seed bed.

The main agronomic problem of Vertisols is the narrow range of soil moisture conditons at which they can be tilled: When wet they are very sticky and plastic, and machines or hand-implements get clogged and cause soil compaction. When dry the soil surface is often such hard that excessive machine or hand power is required for any tillage. Land preparation therefore can only be executed during a short period of time at the beginning of the rainy or irrigation season.

A second problem is their drainage. When wet the clays swell, closing off cracks and macropores, with very low infiltration and percolation rates and (horizontal) hydraulic conductivities as a result. Open surface drains and ridge cultivation is often the only feasible solution; mole or tile drainage systems break-down repeatedly because of the swell-shrink nature of the soil.

Annual crops rather than perennials should be grown on these soils, because roots of most shrubs and trees break at crack development in dry periods, and the stems are often inclined in different directions due to the swell-shrink process (as do telegraph and fencing posts!). This is also the reason why in natural state the Vertisol lands are usually devoid of trees or shrubs - with the exception of some adapted species like Acacia and Balanites spp. Road building through Vertisol areas requires deep in-filling of inactive construction material, to avoid the development of undulations and cracking-up of the surfacing material.

Successful agricultural management research for Vertisols has been undertaken in India, Australia and the Sudan, but in many other countries the lands concerned remain under-utilized, considering their over-all high-fertility status.

Research needs: basic physico-mechanical studies on the processes leading to the formation of the various Vertisols.

The IBSRAM organisation (see 2.2) is already organizing a network of management-oriented research.

4.2 Hardpan Soils

Often physiographically associated with Vertisols are the Clay-pan Soils or Planosols. They occur extensively in northeastern and southeastern Brazil, in the Parana basin (Brazil, Paraguay, northern Argentina), in Bangladesh, in the Chad basin, and in Australia. They are however found in many other countries, too, for instance in Kenya, where until recently they were often mistaken for Vertisols of the mazic type because their subsoil shows similar swell-shrink features.

Planosols are imperfectly to poorly drained and moderately deep in pedogenetic sense. Agronomically speaking they are quite shallow: they have a dense, coarse angular blocky to prismatic clayey layer("claypan"), abruptly underlying a more or less sandy topsoil which has a poor, massive structure unless quite humic. Just above the transition to the claypan these soils have a poorly drained layer because of water stagnation ("pseudo-phreatic level"). In this layer active destruction of clay particles takes place ("ferrolysis" process) and its environment is unsuitable for roots because of lack of oxygen.

The suitability for plantgrowth therefore depends completely on the properties of the topsoil: it may be humic or low-humic; acid or non-acid; coarse sandy to fine loamy or silty; soft to very hard; and can vary in thickness from 20 cm to about 100 cm - depending on the nature of the parent materials and the weathering agressivity of the climate. In general, plantgrowth is fair at best. Under natural conditions the soils support only grassland, bushed grassland or low forest. The choice of crops is limited: dry-foot crops such as wheat, soybean, maize and cotton do poorly. Trafficability of the fields in the wet season is poor because of low bearing capacity: water-soaked topsoils of low structure stability.

Pasturing and paddy rice cultivation are the most appropriate uses. The latter crop in fact finds its natural niche here: puddling of bunded fields to obtain an anaerobic mudlayer above an impermeable layer is hardly necessary - it is there already!

Improvement of structure and drainage condition of Planosols is difficult. Mechanical breaking-up of the claypan is very expensive and often lasts for a few years only. Deep drainage for dry-foot crop growing through a tile drainage system is very costly because of the narrow spacings required and the high incidence of breakdown: the claypan has not only a very low (vertical) percolation rate and (horizontal) hydraulic conductivity, but often has swell-shrink properties like in Vertisols. Ferrolysis products may moreover clog the pipes. Repetitive mole-drainage in the water stagnation layer just above the claypan is in principle a good proposition, but the waviness of the surface of the claypan - vertical differences of 2-3 dm over distances of 5-10 m - may render this impractical at larger fields. Surface-ditch drainage, combined with cambered-bed preparation through judicious plowing, may be the only economical improvement at both large-scale and small-holders farming.

The Sodium-pan Soils or Solonetzes are in many ways comparable to the Planosols. On plains of old coastal sediments (e.g. the Lower Tana area of Kenya; the Lagunas areas of southern Brazil - eastern Uruguay) they occur often in close spatial association.

The dense subsoil layer of Solonetzes is not prismatic but columnar, with tongues of topsoil material in-between these very coarse structure elements. The subsoil has as added disadvantage that it is saturated with sodium or sodium + magnesium, giving the layer an extremely poor physical condition because of very low structure stability ("natric B horizon"). The arable topsoil is moreover quite thin and has often strong short-distance variation: from 40 cm to less than 5 cm. Plowing of these soils therefore often results in scraping-off and incorporating part of the sodic subsoil material, thereby further impairing the already weak structural stability of the topsoil. Trafficability is even worse than on the Planosols, because of the presence of water-soaked mini-depressions ("slick spots").

Improvement of Solonetzes may be feasible in some circumstances - for instance at their local occurrence within large areas of good soils, or at extreme population pressures - by massive applications of gypsum or incorporation of large amounts of organic matter (for instance from Sesbania spp). Normally however such soils should be left undisturbed.

Research needs: development of adapted cultivars of dry-foot crops and of adapted lightweight tillage machinery.

5. SALINE OR SALINIZATION-PRONE SOILS OF ARID-ZONE PLAINS

Many soils of the flatlands in arid and semi-arid regions have high salinity throughout (Solonchaks) or at some depth (Saline phases of Gleysols, of Cambisols etc.). The latter may or may not be connected with presence of a permanent phreatic level with saline water.

In areas with high evaporation and sediments of high-capillary rise character (very fine sands and loams), a contact between such groundwater and the rooting zone results in a high salinization hazard.

High-salinity adapted cultivars can be grown, but improvement of saline lands is often quite feasible: leaching with irrigation water of good quality results in very suitable soils unless there are high percentages of sodium in the soil (causing structure collapse and pan-formation once the salts have been washed out).

Successful long-term management of desalinized or salinization-prone land depends very strongly on a well designed deep-drainage system, to keep any permanent groundwater table from making contact with the moistened rooting zone. This applies also to situations where such a groundwater level originally - i.e. at the start of an irrigation scheme - was absent or at great depth (deeper than 10 m). There are many examples of irrigation schemes where a salinity problem - or a salinity + sodicity problem - developed after an initial period of success because of a slow but steady rise of a phreatic level thought to be too deep to have any influence (e.g. Kano plains in Northern Nigeria). The aspect of long-term success or failure of irrigation is especially sensitive in closed-basin areas, i.e. areas without external outlet of drainage water (e.g. the Konya basin of Turkey).

Research needs: The US Soil Salinity Lab. in Riverside - California and ILRI in Wageningen have contributed greatly to avoidance of deterioration of irrigation schemes, through applied research, publications and training of irrigation and drainage specialists of arid-zone countries. ILRI's past director may however be aware of still existing research needs.

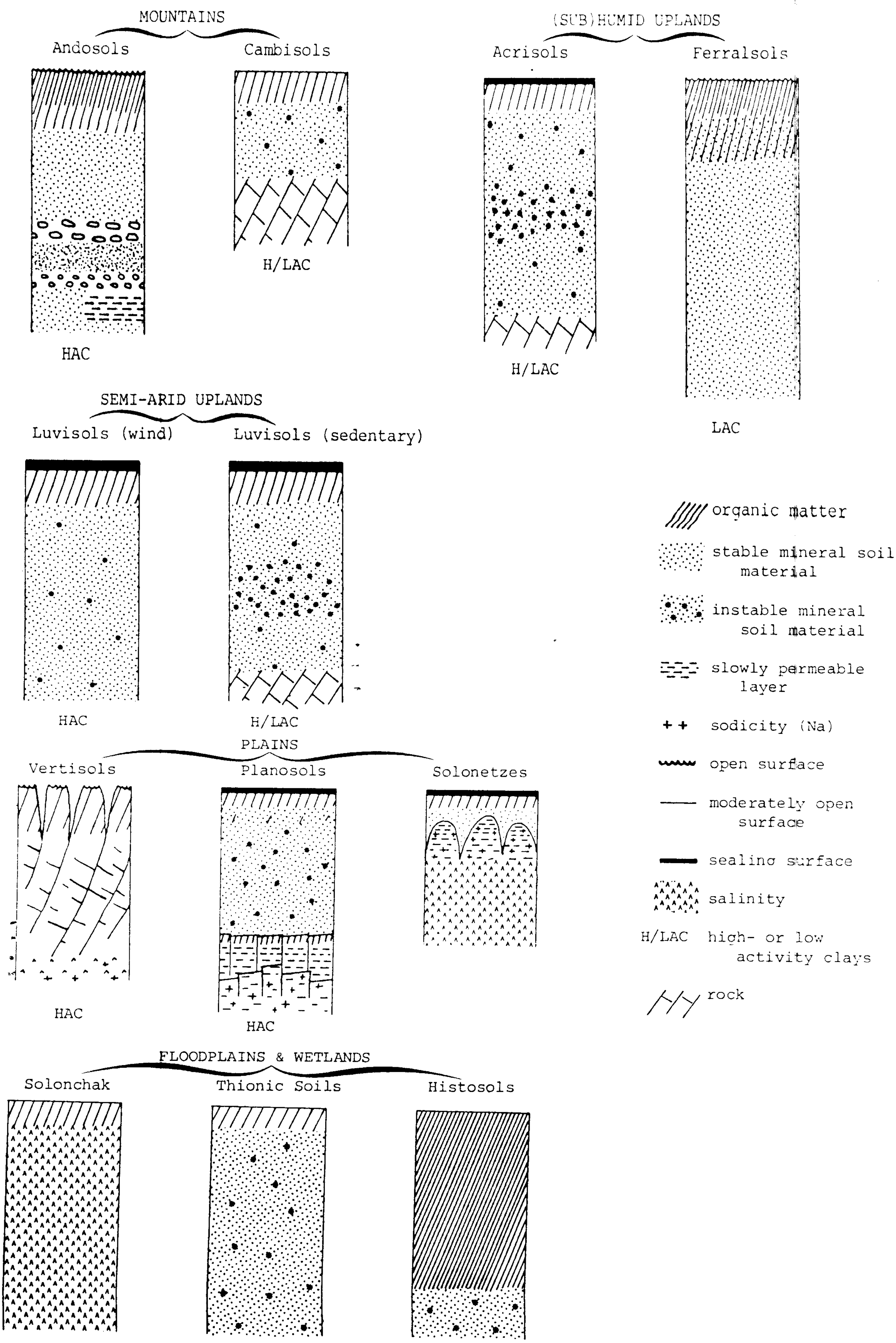
6. POORLY DRAINED SOILS OF FLOODPLAINS AND WETLANDS

The soils of tropical Floodplains vary strongly in their inherent properties (Fluvisols, Gleysols, gleyic or plinthic subunits of other soils: all expressions of varying texture and texture differentiation, humus content, acidity etc.). Their actual use is strongly conditioned by the type of flooding or submergence. Once empoldered and/or drained they are often highly productive - e.g. the "varzea" lands along the lower Amazon river - but may then also show or develop management problems because of extremely heavy texture (like Vertisols), development of claypans (like Planosols), sodic pans (like Solonetzes), or high salinity (like Solonchaks).

The patterns of occurrence of these different soils are often very intricate, requiring adapted lay-outs of irrigation and drainage systems on the basis of detailed topographic, soil and substratum mapping and evaluation. A sound knowledge of the geomorphological - climatological - sedimentological history of such floodplains can be very helpful at this (e.g. for the "fadama" areas of the Sudan-Sahelian zone of West Africa, including the interior delta of the Niger river in Mali).

Research needs:

- A comprehensive and practical system of classification of inundation regimes, as a major element in land evaluation for the areas concerned, whether to be empoldered or to be used for wet-foot crops. Depth; duration; flow force; regularity; quality of the water (pH, sediment load, salt content); period of the year in relation to the growing season), are all elements to be taken into account at devising such a system.


MOUNTAINS
Andosols
Cambisols
HAC
H/LAC
(SUB)HUMID UPLANDS
Acrisols
Ferralsols
H/LAC
LAC
SEMI-ARID UPLANDS
Luvisols (wind)
Luvisols (sedentary)
HAC
H/LAC
PLAINS
Vertisols
Planosols
Solonetzes
HAC
HAC
FLOODPLAINS & WETLANDS
Solonchak
Thionic Soils
Histosols
organic matter
stable mineral soil material
instable mineral soil material
slowly permeable layer
sodicity (Na)
open surface
moderately open surface
sealing surface
salinity
H/LAC high- or low activity clays
rock