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ARIDISOLS OF THE WORLD, OCCURRENCE AND POTENTIAL

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Aridisols of the World, occurrence and potential

by W.G. Sombroek*

ABSTRACT

Though there is no direct geographical equivalence between Aridisols and Arid Zone soils, it is useful to obtain an impression of the definition and extent of desertic regions. A comparison is made between the criteria used by Unesco in its "Arid Zone Research" programme; those used by Soil Taxonomy and Newhall-Van Wambeke as regards "aridic moisture regime"; and the ones of FAO in its "agro-ecological zones" project.

Soils in desertic areas, whether Aridisols or others, have commonly specific surficial features, which are described and denominated . The reasons for occurrence of Aridisols outside desertic areas are explained; then an estimate is given of the world distribution of Aridisols. The diagnostic features of the soils are given in synoptic form.

The potential of Aridisols and associated soils in desertic areas is discussed for rainfed arable cropping; irrigated agriculture; water harvesting; range management, and tourism.

A few questions are formulated on the usefulness of some of the criteria used at present for the classification of Aridisols.

DEFINITION OF ARIDISOLS

As stated by Nettleton and Peterson (1983) Aridisols are soils of dry places, commonly of arid regions, with one or more distinctive genetic horizons. Without irrigation, they cannot sustain mesophytic plant growth, and arable crop growth in particular, because the period of the year when

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both soil temperature and soil moisture conditions are suitable for such growth is less than three continous months.

More precisely they are soils with a physiologically aridic soil moisture regime which has expressed itself in:

a) very limited amount of organic matter in the topsoil (ochric epipedon)
b) some degree of soil formation in the subsurface horizon (cambic horizon or stronger)
c) a rearrangement in the soil profile of more or less soluble salts (chlorides, sulphates, carbonates, silicates), into weak or strong, soft or cemented forms (calcareous, calcic, petrocalcic, etc.)

The soils may, or may not, have a degree of pedogenic textural differentiation (argillic horizon).

Included are soils with relics of soil formation under former less arid conditions, but excluded are soils in presentday aridic climates that are either very young (Entisols), sandy (Psamments), peaty (Histosols), extremely strongly preweathered (Oxisols), or that have pronounced swell-shrink features (Vertisols). The above definition of Aridisols means that they occur commonly in arid to semi-arid climatic regions, but that far from all soils of these environments are Aridisols, and quite a few occur in subhumid environments.

OCCURRENCE OF DESERTIC REGIONS

Although there is no exact geographical equivalence between Aridisols and soils of arid regions, it is useful to give first a description of the definition and extent of arid regions (extremely arid, arid, and semi-arid environments). This because it is mainly the rainfall, or rather the lack of it, which determines the potential of the land concerned, in combination with the temperature. Some general references are Meigs (1953), Hills (1967), McGinnies and Goldman (1969), Cooke and Warren (1973), Goodall and Perry (1979), Heathcote (1983), and Campos-Lopez & Anderson (1983).

Many arid land studies refer back to Meigs (1953) as to the extent of deserts of the world. His maps are rather simplistic. A much better classification and delineation is given in Unesco's MAB Technical Note no. 7 (1977) with the accompanying map at 1:25M scale of the world distribution of arid regions. It is one of the products of Unesco's former "Arid Zone Research" programme. Since I have the impression that this map and its criteria are not too well known in soil science circles, a short description may be useful.

The Unesco map shows the following combinations of climatic conditions:

a) degree of bioclimatic aridity: established on the basis of the ratio P/Etp, in which P represents the average total annual rainfall and Etp the potential evapotranspiration, calculated according to Penman's formula. Distinguished are: hyperarid (P/Etp smaller than 0.03), arid (0.03-0.20), semi-arid (0.20-0.50) and subhumid (0.50-0.75). Data of approximately 6000 weather stations were analysed, and the boundary lines between zones of different degrees of aridity were then drawn by taking into consideration the local topography, soils and vegetation.

b) temperature regimes: In each of the aridity zones, the temperature, in degrees Celsius, of the coldest (winter) and the warmest (summer) month of the year were determined. All possible combinations were identified for respectively: winters that are either warm (20° to 30°C), mild (10-20°), cool (0-10°) or cold (less than 0°); and summers that are either very warm (more than 30°), warm (20-30°) or mild (10-20°).

c) lengths of drought periods: these were superimposed, not as geographical boundary lines but as coloured circles only, because the number of recording stations was less (approximately 1000 only). The number of dry months (less than 30 mm precipitation) is indicated by the size of the circle, and its colour indicates whether it concerns dominantly summer drought (with one or two rainy seasons), dominant winter drought (also with one or two rainy seasons), or transitional drought regions (regimes with both rainy seasons, one in summer and winter; or with occasional or unpredictable rains).

It is interesting to compare this with the definitions of soil moisture and soil temperature regimes of Soil Taxonomy, published two years earlier (Soil Survey Staff, 1975), and with the distribution of aridic moisture regime as shown on maps prepared according to the Newhall Computation Model by Van Wambeke for South America, Africa and for N.W. Asia (1981, 1982, 1985 respectively).

The aridic or torric soil moisture regime is defined formally as: the soil is dry in all parts of the moisture control section for more than half the time (cumulative) that the soil temperature at a depth of 50 cm is above 5°C, and never moist in some or all parts for as long as 90 consecutive days when the soil temperature at a depth of 50 cm is above 8°C. "Dry" in this context is defined as the soil condition in which the moisture tension is 15 bars or more; "moisture control section" (MCS) as the soil layer between 30 and 90 cm if sandy, between 20 and 60 cm if coarse loamy, and between 10 and 30 cm if of heavier texture.

In practise, the actual soil moisture regime is rarely measured for an individual soil. Usually the atmospheric climatic data are taken as the starting point. Many soil classification specialists using Soil Taxonomy rely on the computational model of Newhall and the regional or continental maps prepared with that model by Van Wambeke. The Newhall model takes the Thornthwaite formula for calculating the potential evapotranspiration rather than Penman's. Not surprisingly, there are rather strong geographical differences between the distribution of hyperarid, arid, and semi-arid lands on the Unesco map and the distribution of aridic moisture regime on maps prepared with Newhall's model. In his 1985 publication, Van Wambeke makes a tentative subdivision of the aridic moisture regime into extremely aridic (the MCS being completely dry during the whole year); typic aridic (MCS is moist for 45 consecutive days or less), and weak aridic (MCS is moist for 45 to 90 consecutive days). No suggestion is given on how to use these and subdivisions of other moisture regimes (xeric, ustic and udic) in the soil taxonomic system. The implied message, however, is clear: use them at family level, and map of rainfall/evaporation conditions separate from mapping of taxonomic soil units. The use only at the family level, and replacement of the soil moisture regimes at the Suborder level by associated morphometric features, was already suggested by Sombroek (1985) during the fifth International Soil Classification Workshop in Sudan, 1982.

Another approach to measuring aridity in relation to rainfed crop production is applied by FAO (1978) in its Agro-ecological Zonification project published one year after the Unesco map and based on approximately 2000 long-term climatic data sets. It defines <u>length-of-growing-periods</u>: the length in consecutive days of the year when water and temperature permit crop growth. The beginning of the period is taken at the moment that the monthly precipitation is equal to or exceeds half of the monthly potential evapotranspiration, calculated with the Penman method (P more than 0.5 Etp). The end of the period is defined as the end of the time taken to evapotranspire 100 mm of soil-stored water after the moment that the monthly precipitation becomes again less than half of the potential evapotranspiration. Special criteria are used when two rainy seasons are involved (bimodal rainfall patterns are prevalent in large parts of eastern Africa). Where the length of the growing period is determined by both moisture and temperature constraints, the FAO model first quantifies the period of time when crop growth is limited by temperature, 14 major temperature regimes being considered. Subsequently these values are reduced till the periods when water is available for crop growth.

Higgins et al. (1981, in the Proceedings of the 3rd international Soil Classification Workshop, held in Syria and Lebanon) have compared this approach with the soil moisture and temperature regimes of Soil Taxonomy. In the context of the discussion of Aridisols the relevant agro-ecological zone of FAO is the one with less than 90 days length-of-growing-period (and less than 120 days in case of the warm subtropics with winter rainfall). This agrees rather well with the aridic/torric moisture regime of Soil Taxonomy, but with a number of exceptions. These exceptions are assumed to be related to the recognition or not of bimodal rainfall patterns, and to the difference in computation of the potential evapotranspiration (Penman versus Thornthwaite). Comparing the continental maps of agro-ecological zones at 1:5M of FAO with those of (soil) moisture regimes of Van Wambeke, a visual impression is obtained that the extent of aridic conditions - i.e. too dry for rainfed crops - is somewhat overestimated by Van Wambeke for most regions. This was exemplified in detail during the 1986 FAO/SMSS regional Soil Classification Workshop in Botswana (report in press) and by Isbell and Williams (1981) for the Queensland area of Australia.
It would be very interesting to note and explain the differences between the respective FAO and Unesco maps, too, but to my knowledge this has never been attempted.
Higgins' regional comparison leads to an estimation of aridic (soil) moisture regime as follows: Africa 50%, South-West Asia 80%, South-East Asia 12%, South America 13% and 37% for Australia. Nettleton and Peterson (1983) report only about 1% for North America - which seems very low. The extent in North East Asian region (China) is estimated to be 20% (Gong-zitong, this meeting).

Soils of arid lands have commonly specific surficial features (cf. Nettleton and Peterson, 1983; Souirji, 1987; Blume et al., 1984). They are:

- A surficial or near-surface crust.
- a pavement of embedded and loose pebbles, or of stones, with a black to reddish brown desert varnish.
- shrinkage polygons, locally with the appearance of slick spots (takyr), with cracks continuing to or into the B horizon, the cracks often being filled with sand.
- a thin platy surface horizon showing vesicular pores.
- presence of pitted and rounded quartz grains showing a matte surface, constituting and appreciable percentage (20% or more) of the sand fraction in the surface horizons.

These features, which together or individually may be designated "torric" or "yermic" surface features, have been put into a composite drawing by Alaily, who worked with Blume, Stahr, and other West German soil scientists on arid zone soils of Southern Egypt, Libya, Yemen and Sudan (Alaily et al., 1987).

OCCURRENCE OF ARIDISOLS

Aridisols make up only a part of the desert areas of the World. As a rough guess it is less than 50%. Aridisols in a desert environment are often geographically associated with Torripsamments (shifting dune sands or "ergs"), with Torriorthents (regosolic soils on hilly land with rocky substratum and soils on recent colluvial fans or on stable land surfaces in long-time extremely arid conditions), with Torrerts (cracking clay soils on plains), and Torrifluvents (stratified young sedimentary deposits in wide floodplains or "wadis"). Other soils in desert areas have rather strong development, either in the form of mollic epipedons or argillic horizons. They are Xerolls, Borolls, Ustolls, Xeralfs/Ustalfs, and Xerults/Ustults and predominate in transition zones from semi-arid to subhumid. Nettleton and Peterson (1983) give a review of their distribution, based in large part on the work of Dregne (1976;1983).

Aridisols outside climatically defined desert areas - or better said: areas with an aridic moisture regime based on atmospheric climatic conditions -

are not uncommon. This is related to a part of the definition of the Aridisol order: there should be an aridic soil moisture regime; plant growth is very strongly hampered by a lack of available moisture in the rootable layers of the soil. This can be for various reasons:

a) rainfall itself is very limited or very irregular: climate-induced aridic soil moisture regime.

b) the surface layer is capped or sealed to such an extent that most rainwater runs off, while there is no groundwater to compensate for it: surface-induced aridic soil moisture regime. Many of the older cover sands in the Sudan-Sahelian transition zone of West Africa have thin but strong surface sealing (Sombroek and Zonneveld, 1971).

c) the rootable layer is so thin that only a minor part of the rainwater can be stored, causing drought after a few weeks without rainfall: soil-depth-induced aridic soil moisture regime (soils in lithic subgroups or with shallow petrocalcic or petrogypsic horizons).

d) the soil solution has such a high degree of salinity that moisture cannot be taken up by plants: salinity-induced aridic soil moisture regime (Salorthids).

Therefore, one may have side by side, in the same semi-arid to subhumid atmospheric climatic conditions, shallowly rootable soils that are Aridisols and deep ones, without any pan, that are Xeric or Ustic. The same holds for stony or coarse loamy versus fine loamy or clayey soils, and soils with high bulk density versus those with low bulk density. Also, low-activity- clay soils can store less available moisture per unit volume of soil than high-activity-clay soils. Low-activity-clay soils are not uncommon in subhumid areas, either because of the lithology of the parent material (e.g. kaolinitic sandstones in West Africa) or because of very old and stable land surfaces that have undergone strong weathering in previous humid periods (e.g. oxic or kandic soils in Australia and northeastern Kenya).

The tendency to rely on calculations from atmospheric climatic data rather than on actual measurement of the soil moisture regime permits Aridisols of subhumid regions to remain hidden in soil surveys of the reconnaissance type. Systematic surveys in semi-arid, and especially arid regions are still few, even at very small scale. The ones that have been carried out recently in Arab countries show a surprisingly strong variation in occurence of Soil Orders and Suborders/Great Groups. There has been no systematic effort to compile the existing information at world level on any meaningful scale, say 1:1M, using Soil Taxonomy. The only project thus far on worldwide compilation was completed some fifteen years ago by FAO, resulting in the 1:5M FAO/Unesco Soil Map of the World. Its Xerosols and Yermosols are roughly equivalent to the Aridisols, though there is separate identification of the strongly saline and alkaline ones as Solonchaks and Solonetzes, and of the strongly texturally differentiated ones as Planosols.

The area of the Yermosols plus Xerosols by continent is as follows (Purnell, personal communication): Africa 459 million ha (16%), Southwest Asia 131 m ha (34%), South America 8.4 m ha (5%), Central America 32 m ha (12%), South-east Asia 43 m ha (5%), North-central Asia and USSR 247 m ha (7%), Europe without USSR 19 m ha (4%), North America 105 m ha (5.5%), and Australia 213 m ha (25%). The world figures therefore are 1791 m ha or 13.8% of the land surface. For the United States itself, Nettleton and Peterson (1983) report a total of 107 m ha of Aridisols proper (11.6%).

In the context of the next paper (progress report on ICOMID by A. Osman) it may be interesting to note that in the new FAO Soil Legend Terminology (FAO, 1987) the "aridic moisture regime" as a requirement for Xerosols and Yermosols, and the weak ochric versus very weak ochric A horizon to differentiate between the two, will be deleted; Calcisols and Gypsisols will partially replace them, and desertic surface features will be used to denote "yermic" phases of these and other soils.

DIAGNOSTIC FEATURES OF ARIDISOLS

The morphology of Aridisols has been comprehensively described elewhere. Therefore only a synopsis is given in this introductory paper. Notable features are the following (listed in order of occurrence from the surface downwards):

- "yermic" soil surface features as described earlier in this paper.
- ochric epipedon that is not hard and massive when dry, with organic carbon contents of only a few tenths of a percent (the hard and massive exclusion being intended to keep the "hard-setting" soils aridic-xeric transition zone of California and of the Australian desert out of the Aridisol order; Smith 1986, pages 123 and 162).

- cambic horizon, as a pedogenetically altered, eluviated, or weakly illuvial subsurface horizon; showing obliteration of stratification by mixing, relatively high chroma, or some degree of structure development. In low-carbonate parent materials it is commonly the only diagnostic feature of Aridisols in addition to the ochric epipedon.
- an argillic horizon that is moderately thin and shallow. It normally does not have oriented clay coatings on ped surfaces and pore walls, but these are prominent on sand grains and pebbles. Strongly developed and deep argillic horizons are considered to be an inheritance from past, more humid climates.
- a natric horizon, that is an argillic horizon with high exchangeable sodium percentage, commonly with columnar structure and rather strong textural differentiation in relation to the overlying material. It is assumed that this stronger development of argillic horizon features is related to easier clay illuviation because of Na-induced dispersion in the presence of some organic matter. The natric horizon in Aridisols is often thin and shallow in lowland situations; in uplands they may be quite thick and deep, and then it may concern relict argillic horizons recharged with exchangeable sodium of aeolian origin.
- a horizon of pedogenic calcium carbonate accumulation, which may engulf a good part of the argillic horizon if present.
- a horizon of gypsum accumulation.
- a horizon of easily soluble salt accumulation.

The accumulations in these three horizons may be weak or strong. In the latter case the horizon is denoted as calcic, gypsic or salic horizons when soft; as petrocalcic (calcrete, kunkar, caliche), petrogypsic, or (rarely) petrosalic when continuously cemented or indurated.

The three accumulative horizons of salts in order of increasing solubility occur in downward vertical sequence in upland situations, where the source of the salts ($CaCO_3$ or $MgCO_3$, $CaSO_4.2H_2O$, NaCl etc.) is aeolian, and there is a degree of leaching by occasional heavy rainstorms - even if these do occur only once in many years. In lowland situations, where the source of the salts is from shallow groundwater, the sequence is often upwards, because of a regular upward movement of soil moisture through capillary rise and evaporation and evapotranspiration. In case both soil forming conditions are or have been present, complex sequences may occur. This holds in particular for the petric forms, since they are often the resistant relicts of former conditions of landscape and climate.

- duripan horizon (silcrete or duricrust). This silica-cemented horizon is a less common variant of petric horizons. It occurs in areas with parent materials containing readily weatherable glass from pyroclastic rocks or volcanic ash (the latter as thick deposits or as occasional thin layers). The cementing agents are opal and chalcedony, often with calcium carbonate as an accessory. Discontinuous or weakly cemented silica accumulations are distinguished as durinodes.

There is increasing evidence that pedogenic palygorskite, albeit in small percentages, is a rather characteristic clay mineral for Aridisols, if the parent material is calcareous and the soil temperature not too low.

The way in which the various surface and subsurface horizons, as described above, are or should be combined in the taxonomic subdivision of the Aridisol order will be dealt with in subsequent papers.

A detailed summary of soil-genesis research for Aridisols of the US is given by Gile and Grossman (1979) in "The Desert Project Soil Monograph", with follow-up discussions by Nettleton & Peterson (1983). There are many other accounts on soil genesis for the Middle East situation (for instance Blume et al, 1984, Yaalon 1982, Rohdenburg, 1987), for the Sahara region (for instance Aubert, 1962; Ruellan, Fauck and other ORSTOM scientists), and for Australia (Isbell and Williams, 1981).

POTENTIAL OF ARIDISOLS

Arid land use in general is described in many monographs (for instance Stamp 1961; Hall et al. 1979). By definition, the potential of Aridisols and other arid zone soils for rainfed arable crops is nil. Special dry-farming techniques have however been developed for areas where the rainfall is not extremely low; they maximize the storage and use of the scarce moisture, the rainfall of two years or two seasons to be used for one crop.

Recent advances in the breeding of drought-resistent and salinity-tolerant cultivars of grain crops and pulses, and the shortening of their growing periods, are gradually shifting the geographic boundary of arable cropping further into semi-desertic areas. It is not only the breeding of new cultivars that opens possibilities. The propagation, by cultivation or protection, of useful herbaceous or shrubby plants native in an arid area and their transfer to other areas is a neglected but promising undertaking (Vietmeyer, 1987). Some interesting species, often of multipurpose use, are the "chaya" vegetable (*Cnidoscolus* spp.), the "tuna" fruits and the forage of the pricklypear cactus (*Opuntia* spp.), and the "tepary" beans (*Phaseolus acutifolius*) of arid Central America; the nuts and forage of the "ye-eb" (*Cordeauxia edulis*) of the Horn of Africa; the "marama" bean (*Bauhinia esculenta*) of the Kalahari desert; the gum and fodder of the "dhaincha" (*Sesbania bispinosa*) of the Indian subcontinent.

In many cases it is not the average total annual, or rather seasonal, rainfall that is limiting the growing of drought-resistant crops, but the irregularity of the rainfall over the years. In Kenya and large parts of Eastern Africa in general, the analysis of the reliability of the two rainfall seasons ("long rains" and "short rains"), on their own or in combination, is a more important aspect of land evaluation than the total yearly rainfall, or even the soil conditions.
It is a point of much debate whether the reliability of rains in marginal areas (starting date; total rain per season) is remaining constant over the years, or gradually becoming less or more erratic because of overuse of the land, resulting in "desertification" (Meckelein 1980, Van Baren 1981).

Aridisols and associated soils with a suitable topography can be used for *irrigated agriculture* (Yaron et.al., 1973), provided good-quality water is available. Small-scale traditional irrigation is a stable feature of many areas with Aridisols and settled populations, because these populations have learned through century-long practise how to avoid salinization and sodification. Large-scale irrigation schemes, in hitherto non-populated desertic areas, government-initiated and often financially backed by international donor or lending organisations, are quite spectacular at the start. More often than not they fail after a number of years because of undisciplined management, insufficient knowledge about local soil conditions, and lack of information on the substratum layers - which should permit deep drainage towards an outlet to prevent salinization or sodification in the long run. Such large schemes often bulldozer away any small scale irrigation practises because those are termed "outdated", "primitive", or "non-economic".

A special form of land degradation due to irrigation may occur in areas with gypsum accumulation. Local subsidence and collapse holes through the gradual solution of gypsum not only causes irregularities in once level fields, but whole irrigation structures may suddenly break down.

One way to overcome problems of maintenance of irrigation structures, and to conserve precious irrigation water until it actually reaches the field, is the traditional "ghanat" system of underground water conducting (Iran, Northern China). It is however very laborious, and quite unsavoury for the maintenance personnel.

A special case of traditional irrigated agriculture, with more prospects, is formed by the age-old water-harvesting technique as practised in the Negev (Bruins, 1986) and in Yemen. Rainwater from barren sloping terrain, often with crusted soils and purposely kept free of vegetation, is guided towards lower terrain and there used for localized irrigation; the number of successive fields to be used per year depending on the annual water yield, sometimes with storage in sandy subsoils for use in the next year. This practise is little known in Africa south of the Sahara, but there are certainly many sites where it can be introduced there with relatively little effort.

By far the main use of Aridisols and associated desert soils is for range management. Only in hyper-arid regions is the land surface completely bare, with some short-lived (ephemeral) plant species cropping up immediately after the rare rainstorm. Elsewhere, the native vegetation consists of scattered xerophylic shrubs or low trees (for instance Acacia tortilis and Commiphora spp. in large parts of semi-arid Africa), dwarf shrubs, succulents, and annual or perennial grasses.

Many of these plants, not only the grasses, are utilized for grazing or browsing by cattle, sheep, goats or camels, often in a complementary way (Thalen, 1979). Each of these groups of animals have different requirements. Arid lands with a stony desert pavement that is completely unsuitable for cattle, may still be fair grazing for camels. The occurrence, and even cultivation of some succulents, for instance Opuntia spp, may serve as survival feed in extremely dry years (northeastern Brazil).

The structure of the vegetative cover and the spacing of the individual components is largely dependent on the atmospheric climatic conditions, but the floristic composition within a given aridic zone depends more on the soil conditions. Through careful observation and mapping, many close relationships between plant species occurrence and soil type can be established (Van Wijngaarden, 1985). Nevertheless, many range management specialists look only at the vegetative cover for establishing "range condition and trend". It is a challenge to soil scientists to convince them that there is considerable merit in looking at the soil conditions as well. This may require somewhat less attention to the fine-tuning of a taxonomic soil classification and more attention to the soil surface and terrain features, including the mapping of the nature and frequency of spots with natural surface water storage (watering points, or "waterholes").
The grazing on arid or semi-arid land may be in the form of large fenced individual farms, as group ranches, or nomadic. The latter may take place within a relatively small area (from uplands in the rainy season to floodplains in the dry season, and back). Or it may take place over large distances in annual treks from subhumid to arid zones or vice-versa, following the seasonal rains ("transhumance" in the Sudan-Sahelian zone of West Africa). Efforts to settle nomadic groups around new deep wells should be undertaken with great care as regards their spacing to avoid acute desertification in large circular areas around such wells. The negative effects are not only through overgrazing, but also through excessive use of the woody vegetation for domestic fuel.

Some desertic areas are good for tourism, because of their often spectacular scenery, the surprising variation in plant growth and its ingenious adaptation to aridic conditions, or the relative abundance of wildlife (for instance the Tsavo ecosystem in Kenya). Game cropping is carried out in some countries, but it is rarely an economic undertaking on its own.
Barren desert land is sometimes used for military training and testing purposes, or for motor rallies such as the annual Paris-Dakar event, but from the ecological point of view this can hardly be described as good use.

SOME QUERIES ON ARIDISOL CLASSIFICATION

The Guy Smith interviews on the rationale for concepts in Soil Taxonomy (Smith, 1986) are a convenient basis for some queries as to the usefulness of some of the criteria for classification of arid zone soils in the Soil Taxonomy system. From personal experience as a soil surveyor in northern Nigeria and northern Kenya, occasional visits to desertic areas elsewhere, and comparison with other classification systems, I am putting the following questions:

- Is the use of an 'aridic soil moisture" regime adequate to distinguish soils with strong moisture stress from other soils? Is it wise to continue the propagation of the Newhall computation techniques to determine moisture regimes? Is the soil moisture control section not too thin from the plant-ecological point of view in semi-arid situations? Should one not include infiltration and run-off measurements, or surface crust characterization, as a main element in assessing an aridic soil moisture regime?
- Is it realistic to exclude soils with hard-setting surfaces from Aridisols, in view of the fact that so many other arid zone soils have a surface crusts or polygonal elements instead of being soft? Alternatively: can it be useful to exclude all low-activity-clay soils (CEC clay below 16 or 24 meq) from Aridisols, and include them with the Alfisols or Ultisols with a suffix of 'aridic' or 'yermic' at the subgroup level, in recognition of the fact that these torric soils were largely formed in former more humid climates?
- Is it useful to make the presence or absence of thin and shallow argillic horizons with hardly any clayskins a distinguishing feature at the suborder level? Would it be better to exclude soils with abrupt textural change, and soils with well developed salic or natric horizons from the Aridisols (as done in the FAO soil legend)?
- Is it really necessary to have over 180 subgroups in the Aridisol order, as proposed in ICOMID circular letter no.5, each with very precisely defined boundary values? Is one not making the system too rigid and too detailed for worldwide application, also in view of the fact that so many desertic areas have not yet been inventoried, pedologically and ecologically?

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Publications - December 1987

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8. Ferric Luvisol (Oxic Paleustalf), Nigeria, in prep.

Technical Papers

1. Procedures for the collection and preservation of soil profiles, 1979
2. The photography of soils and associated landscapes, 1981
3. A new suction apparatus for mounting clay specimens on small-size porous plates for X-ray diffraction, 1979 (exhausted, superseded by TP 11)
4. Field extract of "Soil Taxonomy", 1980, 3rd printing 1983
5. The flat wetlands of the world, 1982
6. Laboratory methods and data exchange program for soil characterization. A Report on the pilot round. Part I: CEC and Texture, 1982, 3rd printing 1984
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9. Procedures for soil analysis, 1986; 2nd edition, 1987
10. Aspects of the exhibition of soil monoliths and relevant information (provisional edition, 1985)
11. A simplified new suction apparatus for the preparation of small-size porous plate clay specimens for X-ray diffraction, 1986
12. Problem soils: their reclamation and management (copied from ILRI Publication 27, 1980, pp. 43-72), 1986
13. Proceedings of an International Workshop on the Laboratory Methods and Data Exchange Programme: 25-29 August 1986, Wageningen, The Netherlands, 1987
14. Guidelines for the Description and Coding of Soil Data, 1987
15. ISRIC Soil Information System - User and Technical Manuals, 1987 (provisional edition)
16. Comparative classification of some deep, well-drained red clay soils of Mozambique, 1987

Monographs

1. Podzols and podzolization in temperate regions, 1982
   with wall chart: Podzols and related soils, 1983
2. Clay mineralogy and chemistry of Andisols and related soils from diverse climatic regions, in prep.
3. Ferralsols and similar soils; characteristics, classification and limitations for land use, in prep.

Wall charts

1. Podzols and Related Soils, 1983 (97x67 cm) (see Monograph 1)
2. Soils of the World, Elsevier/ISRIC, in cooperation with FAO and Unesco, 1987 (135x85 cm)

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