EVOLUTION OF TROPICAL SOIL SCIENCE: PAST AND FUTURE

Workshop
Brussels, 6 March, 2002

Guest Editor: Georges Stoops

KAOW · ARSOM

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Welcome

by

Michel DELIENS*

For several years already, our Academy has been in contact with Portuguese institutions and two memoranda of cooperation have been established. The first one was signed on January 10, 1996 with the *Instituto de Investigação Científica Tropical* of Lisbon, which resulted in the organization of a successful exhibition at the Royal Library (Brussels) entitled: "The Adventures of Plants and the Portuguese Discoveries". The second one was signed on July 18, 1996 with the *Instituto de Higiene e Medicina Tropical.*

Profs. Drs. António Guerra Réffega and Rui Pinto Ricardo, members of the *Instituto de Investigação Científica Tropical,* who both had to read a paper today were unfortunately unable to come to Brussels. This is why our Colleague Professor Georges Stoops will, in his introduction, shortly summarize the topics which should have been developed by the Portuguese speakers. Their manuscripts, however, will be taken into consideration for publication in the Proceedings.

Our Academy is also closely linked with the *Académie des Sciences d'Outre-Mer de France.* This resulted in the organization of two joint sessions in Paris on 13th and 14th May, 1995. The theme of these meetings concerned problems dealing with cooperation for development.

Everybody is aware of the major importance of having a good knowledge of soils of which the exploitation is essential for the existence itself of human communities. Pedological problems are particularly crucial in the tropical regions with many vulnerable soils.

Our planet is undergoing drastic climatic changes that involve related phenomena such as an increase in temperature, a melting of ice bodies and a desertification of large areas, situated mainly in tropical countries.

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Also human factors have a negative impact on the quality of soils: the rapidly expanding demography, the intensive agriculture, the use of unsuitable farming systems, the extension of towns and infrastructures which may develop on rich agricultural soils, as well as pollution caused by industry, mining and domestic activities.

It is therefore essential to gain a trustworthy knowledge of soils, to develop a logical classification system and to follow systematically their evolution under different types of management, in order to come to a sustainable use of the available soils, and a conservation of the endangered sites.

This is the main purpose of our session.

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Introduction

by

Georges STOOPS*

The aim of this symposium is to bring together several persons who have played an important role in the development of tropical soil science and a few younger colleagues to give their vision on the present and future of tropical soil science. Moreover, this theme was an excellent occasion to illustrate the history and to co-operate with the *Instituto de Investigação Científica Tropical* in Lisbon and our sister academy in Paris. Both institutions sent a positive reply to our invitation, but much to our regret, our Portuguese colleagues, Prof. Rui Ricardo and Prof. António Réffega, were not able to join us. However, their paper will be included in the proceedings of this symposium. Prof. Alain Ruellan of the "Académie des Sciences d'Outre-Mer" in Paris will illustrate the contribution of the French researchers to soil science.

In the first half of the 20th century, tropical soils were investigated mainly by European scientists trained in soil science according to concepts based on the existing knowledge on temperate soils at that moment. The Dokuchaev principle of zonality still played an important role in soil classification and mapping (DUDAL 2003). Theoretical and practical problems caused by the use of this principle in tropical soil survey were already commented upon by VAGELER (1941). He stated also that soil surveys in Europe could map small, significant differences between soils, based on an interaction with the knowledge of local farmers, whereas in tropical areas, where much larger areas of soils have to be mapped, such feedback was hardly possible. Of course, ethnopedology, which is now strongly developed in Mexico (ORTIZ 2002), was not yet a topic.

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When discussing soils in the tropics, a clear distinction has to be made between those of the arid regions, those of the more humid tropics and those of the mountainous areas. Whereas the general characteristics of the first are essentially determined by climate and the drainage, this is not true for the typical soils of the humid tropics and their bordering regions. Here not only the present climate plays a role, but far more the past climates, and the fact that soils developed in a pre-weathered parent material (STOOPS 1989). In Africa, for example, a deep weathering mantle formed, often over a period of millions of years, as testified by the presence of Cretaceous land surfaces. For instance, the Plateau of the Bateke near Kinshasa existed already when in Europe the Alps were still forming. The cover of intensely weathered rock is besides much larger than the present climate suggests, due to climatic changes in the past, and shifting of the zone of maximum weathering as a result of continental drift (TARDY & ROQUIN 1998). This is in contrast with the temperate and boreal areas, where during the Ice Ages all former weathering products were removed by the glaciers or rivers, or covered by recent sediments, such as loess or moraines. Therefore, in temperate areas, especially in the northern hemisphere, the parent material is a relatively fresh, only slightly weathered rock. This is also partially the case for soils in the mountainous areas of the tropics, in young volcanic areas and recently formed landscapes such as flood plains and deltas.

If soil science had started in Central Africa, rather than in Russia, several concepts would perhaps have been formulated in another way. The first generation of soil scientists working in the tropics was therefore obliged to look critically to the theories they learned at their University or College, and forget about zonality (at least on a small scale) and the over-importance given to the climate. Soil scientists soon discovered that geomorphology and parent material were, on a regional scale, much more important than climate (RUELLAN 2003).

Although the first important contributions to tropical soil science date from the thirties (for instance VAGELER 1930, MOHR 1934-38, MOHR & VAN BAREN 1954), a real breakthrough came only in the fifties and the sixties of last century, when especially Belgium, France and Portugal founded in their colonies large research stations with a pedological section, supported by specialized research teams in Europe. The obvious merit was that not only technical, but also fundamental research, often on an interdisciplinary basis, was largely sponsored. In the Netherlands and UK attention was meanwhile mainly given to practical applications of soil studies in South and Southeast Asia. But this does not mean that Belgium, France or Portugal were less interested in applications. For instance, already in 1938, J. Baeyens published two volumes on the natural fertility of the soils of the Lower Congo, at that time a very progressive document. Several studies in the Belgian colonies concerned management and production capacities of soils in the tropics both on the scale of industrial companies and that of small farmers (SYS 2003).

With respect to arid soils especially the input of French pedologists in Northern Africa (RUELLAN 2003) has to be mentioned, for instance in Algeria and Morocco. Their studies on soil genesis in relation to the landscape were very innovative at that time.

As mentioned before, concepts of soil science from temperate regions were not readily applicable in Africa. Whereas a genetic soil profile in the temperate, and even in the Mediterranean zone, can be expressed over a depth of one, maximum two metres, this is not the case in the tropics, where typical "zonal" profiles are several metres deep, and polygenetic. The horizon designation was therefore a point of controversy. The presence of plinthite, and especially petroplinthite (laterite, lateritic gravel) in the profile is an example of a common feature observed in many soils of humid and semi-humid Africa, but unknown in the temperate regions. Different approaches are possible. One possibility is to ignore this material as a pedological formation, and to consider only the overlying cover as part of the soil, as was for instance recommended by KELLOGG & DAVOL (1949) for Congo. They suggested considering hard ferruginous crusts (laterite banks, crusts) as rock because they are inert for plant growth. This is a typical agronomic approach. Another possibility is to consider this material as a B-horizon of a deep weathering profile, a more naturalistic approach specially developed by Aubert from ORSTOM and promoted in the well-known handbook of DUCHAUFOUR (1960). Where the ferruginous (lateritic) gravel was present, the Belgian soil scientist (SYS 1960) considered it as a so-called "gravel layer" in the geological profile, formed in a specific period, and separating the layer of superficial deposits and the saprolite. In this geological profile the soil profile was developed and the gravel layer could be part of the epipedon, the argillic or the oxic horizon. The lateritic gravel layer gave rise to an extensive literature on stone-lines in tropical soil profiles, involving geomorphologists, as discussed in a special symposium of our Academy some years ago (ALEXANDRE & SYMOENS 1989). The role of termites in the formation of tropical soils still remains a point of discussion.

The relations between parent rock, saprolite and soil were studied in detail by many pedologists and geologists from ORSTOM, often in close collaboration with mineralogists and geochemists from the group of Millot in Strasbourg.

The importance given in the fifties to soil survey in Africa resulted automatically in a special interest in soil classification. One of the early problems was the confusion created by the use of the term laterite in different senses, as a red soil, a red material that hardens, or a hard iron-rich material (DUDAL 2003). In 1948 Bothelho da Costa proposed to restrict the use of the name laterite to materials rich in iron, and abandon it for soils (BOTHELO DA COSTA 1959). For the classification of the zonal soils of Central Africa new diagnostic criteria had to be developed and tested. An important one was the SiO_2/Al_2O_3 ratio, which should be less than 2 for ferralitic soils (RICARDO & REFFEGA 2003). Much emphasis was laid by the Belgian soil scientists, under the leadership of Sys, to characteristics easily recognizable in the field, such as the presence of pseudosands in the poor ferralsols, and the presence of shiny clay skins in the much richer ferrisols (SYS *et al.* 1961). Many of these criteria were later taken over in the international classification systems, such as Soil Taxonomy or the FAO legend (DECKERS *et al.* 2003). In those good old days soil mapping was still done in the field, based on a careful observation of the profile, with a minimum of simple analyses. Now it seems to me more a question of satellite images, computers, and especially very sophisticated, expensive analyses on small fractions of one horizon. Where is the soil in soil survey (NACHTERGAELE & VAN RANST 2003)?

Tropical soil science has also contributed in a more general way to soil science, or science in general. Let us mention the introduction of the Catena concept by Milne in 1935, which has since been widely used and misused throughout the world as an expression of the relation between soil and landscape.

Another universal concept, developed in the frame of tropical pedology, is that of biostasy and rhexistasy by ERHART (1956). In his book "La genèse des sols en tant que phénomène géologique. Esquisse d'une théorie géologique et géochimique. Biostasie et rhexistasie" he explains his theory developed as a result of his experience with tropical soils. During periods of biostasy deep soils develop in stable landscapes under forest. In such conditions rivers do not transport much clastic sediments in suspension, but mainly weathering products in solution. A very limited amount of clastic sediments in the sea, but enormous amounts of calcareous sediments, as for instance in Cretaceous times, reflect this. Periods of biostasy are followed by periods of rhexistasy, characterized by strong erosion, river incision and deposits of huge amounts of clastic sediments. Soil formation is then slower than erosion and therefore practically inexistent.

The preparation of a soil map of Africa by J. D'Hoore, under the auspices of the Interafrican Pedological Service, has been a strong stimulation in the evolution of tropical soil science (D'Hoore 2003). For the first time different classification systems and concepts of different origin and philosophy had to be compared and combined, prompting scientific discussions on classification and genesis of soils.

As a last point of this introduction I would like to emphasize the relation between tropical soil science and the Royal Academy of Overseas Sciences.

In Belgium the Royal Academy of Overseas Sciences has since long been the meeting-place by excellence of scientists working in the field of tropical soils. Many of the present members and corresponding members, such as J. D'Hoore, R. Dudal, C. Sys, and A. Van Wambeke, are worldwide considered as real pioneers of tropical soil classification and survey, together with others, such as the late R. Tavernier and R. Frankart, all members of this learned society. A new generation of Academy members is taking over these tasks. I mention our corresponding member H. Eswaran from USDA, specialized in soil classification, E. Van Ranst from Ghent University who is preparing a new soil map of Rwanda, B. Delvaux from Louvain-la-Neuve with his fundamental studies on the colloidal fraction of volcanic ash soils, and J. Shamshuddin from Malaysia studying the physico-chemical properties of soils in the tropics.

Whereas most other scientists working on overseas problems find a national meeting-place in one of our Federal Research Institutes, such as the Royal Museum of Central Africa in Tervuren or the Institute for Tropical Medicine in Antwerp, not such a centre exists for tropical soil scientists. By taking the initiative to organize the present meeting in the Academy, I hoped to emphasize the importance of the role and tradition of members of this Academy in this field of science. In discussions of a possible new structure of the Academy special attention should be given to the creation of a framework in which such "homeless" groups could acquire a more official status. It is therefore regrettable that, due to financial constraints, the Academy was not able to take over the important library and documentation centre of the former INEAC, which constitutes a wealth of documentation on tropical soils, survey reports and unachieved maps.

I hope that this symposium will contribute to a reflection on tropical soil science, at a moment when in-depth scientific research risks to be replaced by superficial profit-oriented research.

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Evolving Concepts in Tropical Soil Science: the Humid Tropics

by

Raoul DUDAL*

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KEYWORDS. — History of Soil Science; Soil Classification; Humid Tropics.

SUMMARY. — With the advent of soil science, at the end of the 19th century, when the location and characteristics of soils were associated with climate and vegetation zones, the soils of the humid tropics were recognized as a separate zonal entity called "Tropical forest lateritic soils". The term "lateritic" was derived from "Laterite" (from Latin, *later*, brick) coined to describe an iron-rich clay observed in Malabar, South India, which hardened upon exposure and was used as building material. In time "Laterite" was considered to be representative of soil formation in the humid tropics and the concept was progressively extended to soils with mottled clay, with iron concretions or an iron pan and to a wide range of red soils of different character. Initially 'Laterite' was defined in terms of molar ratios of silica and sesquioxides separating allites, siallites and ferrallites. Field investigations in Indonesia, early in the 20th century, led to a distinction between friable ("Roterde") and non-friable ("Rotlehm") soils combining physical properties with the chemically characterized stage of weathering. The intensification of soil surveys, in the

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1950s, allowed for more precise definitions of the strongly weathered soils of the humid tropics. The term "Lateritic soils" was replaced at first by a more narrowly defined "Latosol", characterized by a high degree of aggregate stability and a dominance of low activity clays and oxides of iron and aluminium. Concepts evolved further in the 1960s with the separation, in different systems of classification, of Oxisols, Kaolisols, Ferralsols and Ferrallitic soils. The presence of clay translocation in the strongly weathered soils of the humid tropics was recognized in the Ultisols, Ferrisols, Acrisols, Nitisols and *Sols ferrugineux tropicaux*. The term "Plinthite" (from Greek, *phinthos*, brick) substituted "Laterite" to name hardening iron-rich clay materials. The development of a World Reference Base for Soil Resources in the 1980s aimed at creating an internationally accepted means of communication and correlation. It was realized that soils of the humid tropics are the product of geogenesis as well as of pedogenesis and that they need to be defined on the basis of their characteristics rather than of the processes of their formation. Additional attention was given to human influence on soil properties. The question arises in how far the diagnostic criteria selected are relevant to the three major purposes of soil classification, namely taxonomy, the making of soil surveys and the interpretation for land use. It appears that soil classification, as currently conceived, cannot equally serve these three purposes and that concepts will need to further evolve in order to meet modern demands on soils, also in the humid tropics.

TREFWOORDEN. — Geschiedenis van de bodemkunde; Bodemclassificatie; Vochtige tropen.

SAMENVATTING. — *Ontwikkelende concepten in de tropische bodemkunde: de vochtige tropen.* — Toen op het einde van de 19de eeuw de bodemkunde zich tot een wetenschap ontwikkelde, werd tussen de spreiding en de eigenschappen van de bodem een verband gelegd met klimaat en vegetatiezones. Derhalve werden de bodems van de vochtige tropen als een afzonderlijke klasse erkend onder de naam „Lateritische bodems van de tropische bossen". De term „Lateritisch" was afgeleid van „Lateriet" (van het Latijn, *later*, baksteen), een naam die gegeven werd aan een ijzerrijke klei in Malabar, Zuid-India, die bij uitdroging verhardde en als bouwmateriaal gebruikt werd. Mettertijd werd 'Lateriet' beschouwd als kenmerkend voor de bodemvorming in de vochtige tropen en werd het concept geleidelijk uitgebreid tot bodems met gevlekte klei, met ijzerconcreties of een verharde ijzerlaag, en tot een brede waaier van rode gronden van zeer verscheidene aard. Oorspronkelijk werd „Lateriet" bepaald op grond van molaire verhoudingen van silica en sesquioxiden, waarbij een onderscheid gemaakt werd tussen alliten, sialliten en ferralliten. Veldonderzoek, dat in Indonesië bij het begin van de 20ste eeuw begon, leidde tot het onderscheid van kruimelige („Roterde") en niet-kruimelige („Rotlehm") rode gronden. Hierbij werden fysische eigenschappen verbonden met de scheikundig gekenmerkte graad van bodemverwering. De uitbreiding van de bodemkartering in de jaren vijftig bevorderde een meer nauwkeurige bepaling van de sterk verweerde bodems van de vochtige tropen. De term „Lateritische bodems" werd aanvankelijk vervangen door „Latosols" gekenmerkt door een hoge aggregaatstabiliteit en een overwegende aanwezigheid van kleien met een lage activiteit en van ijzer- en aluminiumoxiden. In de jaren zestig werd het concept verder ontwikkeld en was er in verschillende classificatiesystemen spraak van Oxisols, Kaolisols, Ferralsols en Ferrallitische bodems. Klei-aanrijking in de sterk verweerde bodems van de vochtige tropen werd onderscheiden in de Ultisols, Acrisols, Ferrisols, Nitisols en 'Sols ferrugineux tropicaux'. Voor de verhardende ijzerrijke kleien werd de term „Lateriet" vervangen door „Plinthiet" (van het Griekse *plinthos*, baksteen).

De ontwikkeling van een „World Reference Base for Soil Resources" (WRB) streeft, sinds de jaren tachtig, naar een internationaal erkend middel voor communicatie en correlatie. Daar de bodems van de vochtige tropen het product zijn van geogenese zowel als van bodemvorming is het duidelijk dat ze bepaald moeten worden op basis van hun kenmerken eerder dan op grond van de aard van hun vorming. Ruimere aandacht moet hierbij ook gegeven worden aan de menselijke invloed op de bodemeigenschappen. De vraag wordt gesteld of de diagnostische criteria die weerhouden worden relevant zijn voor de drie doelstellingen van een bodemclassificatie: taxonomie, bodemkartering en interpretatie voor bodemgebruik. Het blijkt dat bodemclassificatie, zoals ze heden opgevat wordt, deze drie doelstellingen niet gelijkwaardig kan vervullen en dat een verdere evolutie van concepten noodzakelijk is, ook voor de bodems van de vochtige tropen.

MOTS-CLES. — Histoire de la pédologie; Classification des sols; Tropiques humides.

RESUME. — *Evolution des concepts en pédologie tropicale: les tropiques humides.* — Lors de la constitution de la science du sol, à la fin du 19e siècle, il fut établi que la répartition et les propriétés des sols étaient liées aux zones de climat et de végétation. Par conséquent, les sols des tropiques humides furent classés séparément sous l'appellation de «sols latéritiques des forêts tropicales». Le terme «latéritique» était dérivé de «latérite» (du latin, *later*, brique), un nom donné à des argiles riches en fer, observées à Malabar, Inde méridionale, qui durcissaient par dessiccation et qui furent utilisées comme matériaux de construction. Peu à peu, la «latérite» fut considérée comme représentative de la formation des sols en région tropicale humide et le concept fut progressivement étendu aux sols à argile tachetée, à concrétions ou à carapace ferrugineuse, et à un ensemble de sols rouges de nature très diverse. A l'origine, la «latérite» fut définie sur base du rapport molaire de silice et de sesquioxides, séparant les allites, siallites et ferrallites. Les travaux de terrain, commencés en Indonésie au début du 20e siècle, suscitèrent une distinction entre les sols rouges friables («Roterde») et les sols rouges non friables («Rotlehm»), combinant ainsi des propriétés physiques aux caractères chimiques reflétant le degré d'altération. L'intensification de la cartographie dans les années 50 permit une définition plus précise des sols fortement altérés des tropiques humides. Le terme «sols latéritiques» fut remplacé par les «latosols» caractérisés par une forte stabilité des agrégats et par la dominance d'argiles à faible activité et d'oxydes de fer et d'alumine. Les concepts ont continué à évoluer dans les années 60 et ont mené à la distinction, dans différents systèmes de classification, entre oxisols, kaolisols, ferralsols et sols ferrallitiques. La présence d'une migration d'argile dans les sols fortement altérés fut identifiée dans les ultisols, acrisols, ferrisols, nitisols et les sols ferrugineux tropicaux. En ce qui concerne les argiles riches en fer indurées, le terme «latérite» fut remplacé par la «plinthite» (du grec, *plinthos*, brique).

La création, dès les années 80, d'une «Base de référence mondiale pour les ressources en sols» a pour but de fournir un moyen de communication et de corrélation internationalement reconnu. Vu que les sols fortement altérés des tropiques humides sont le produit de la géogenèse autant que de la pédogenèse, il est impératif

que ces sols soient définis sur base de leurs propriétés plutôt qu'en fonction des processus de leur formation. Aussi est-il apparu que l'influence humaine sur les propriétés des sols mérite une attention accrue. La question se pose si les critères diagnostiques choisis conviennent pour satisfaire les trois objectifs d'une classification des sols: la taxonomie, la cartographie et l'évaluation des sols. Il apparaît que la classification des sols, telle qu'elle est actuellement conçue, devra évoluer ultérieurement afin de répondre à la demande présente d'information sur les sols, aussi en ce qui concerne les tropiques humides.

The Diversity of the Tropics

The tropics are that region of the world that lies between the tropics of Cancer and Capricorn, 23°27' north and south of the equator. It covers 4,950 million hectares, that is 38 % of the global land mass. The tropics are the area where the sun shines overhead throughout the year, with the result that mean monthly temperatures, corrected to sea level, are above 18 °C and that the difference between mean winter and summer soil temperatures is minimal. Co-varying properties are the absence of seasonal soil freezing, except at very high elevation, and a constant length of daylight throughout the year. It should be realized that these temperature and radiation characteristics are the only ones that soils in the tropics have in common. Indeed they show considerable diversity as a result of major differences in moisture regime, lithology, age, degree of weathering of parent materials, relief and elevation above sea level (Van Wambeke & Dudal 1978). With regard to moisture regimes, annual rainfall in the tropical belt ranges from practically zero in the deserts of northern Chile or in Somalia, to several metres in the equatorial forests of the Amazon, Central Africa or Borneo. In fact the tropical belt is the one where all twelve orders of Soil Taxonomy (Soil Survey Staff 1999) occur, including the Gelisols on the snow-covered high mountains of the Andes and East Africa.

The first adjustment to be made to concepts in tropical soil science is that the previously held assumption, concerning a distinctive and exclusive pathway of pedogenesis peculiar to this climatic zone, can no longer be upheld. Hence the term "tropical soils", connotative of uniqueness, is not very meaningful. Its use has led to misleading generalizations that "tropical soils" are problem soils, are acid, infertile, fragile and prone to degradation. Misconceptions of soils of the tropics also affect certain approaches to research conducted on "mixed samples" or without any characterization of the soils other than that they are "tropical". The great variability of soils in the tropics needs to be fully recognized when determining production potentials and constraints, and in order to identify site specific management requirements.

While the concept of an exclusive tropical soil zonality cannot be maintained, it appears that dominant soils in the humid tropics show common properties other than temperature and radiation. Indeed high temperatures and rainfall seem to favour the development of deep, strongly weathered regoliths with low contents of weatherable minerals and with clays consisting mainly of kaolinite and oxides of iron and aluminium. In the humid tropics rainfall plus stored moisture are approximately equal to, or exceed the amount of evapotranspiration for 9 to 12 months per year, during which water moves through the soil. The humid tropics cover 1,190 million hectares, that is 9 % of the global land mass or 24 % of the tropical belt. It is estimated that nearly 70 % of the humid tropics are covered by strongly weathered soils with a dominant kaolinitic and oxidic mineralogy: Ferralsols, Nitisols, Acrisols, Plinthosols (FAO 1991). Still, over 30 % of the region are covered by Andosols, Arenosols, Fluvisols, Gleysols, Histosols and Podzols. On the other hand strongly weathered red soils also occur in the seasonally dry tropics, and even outside the tropics as remnants formed under previously warmer and humid conditions. The present paper, however, addresses mainly the strongly weathered soils which prevail in the humid tropics.

The map attached, figure 1 (FAO 1991), illustrates the diversity of the soil pattern in the tropics and shows that the "levelling effect of the tropical climate" is not an overriding factor of soil formation.

Laterite and Lateritic Soils

With the advent of soil science at the end of the 19th century, when V.V. DOKUCHAEV (1893) proclaimed that the location and characteristics of soils are associated with climate and vegetation zones, the soils of the humid tropics were recognized as a separate "zonal" entity called "Tropical forest lateritic soils" (SIBIRTZEV 1895, 1966). The term "Lateritic" was derived from "Laterite" (from Latin, *later*, brick) coined by BUCHANAN (1807) to describe an iron-rich clay observed in Malabar, South India, which hardened upon exposure and was used as building material. In time "Laterite" was considered to be representative of soil formation throughout the humid tropics even though Buchanan, who was a doctor of medicine, did not refer to a soil, but to a material and to its hardness but not to its colour. However, the concept was progressively extended to soils with mottled clay, to layers of iron concretions or to iron pans and in the broadest sense to all red soils of the tropics. Since then, pedology has laboured under great difficulties on

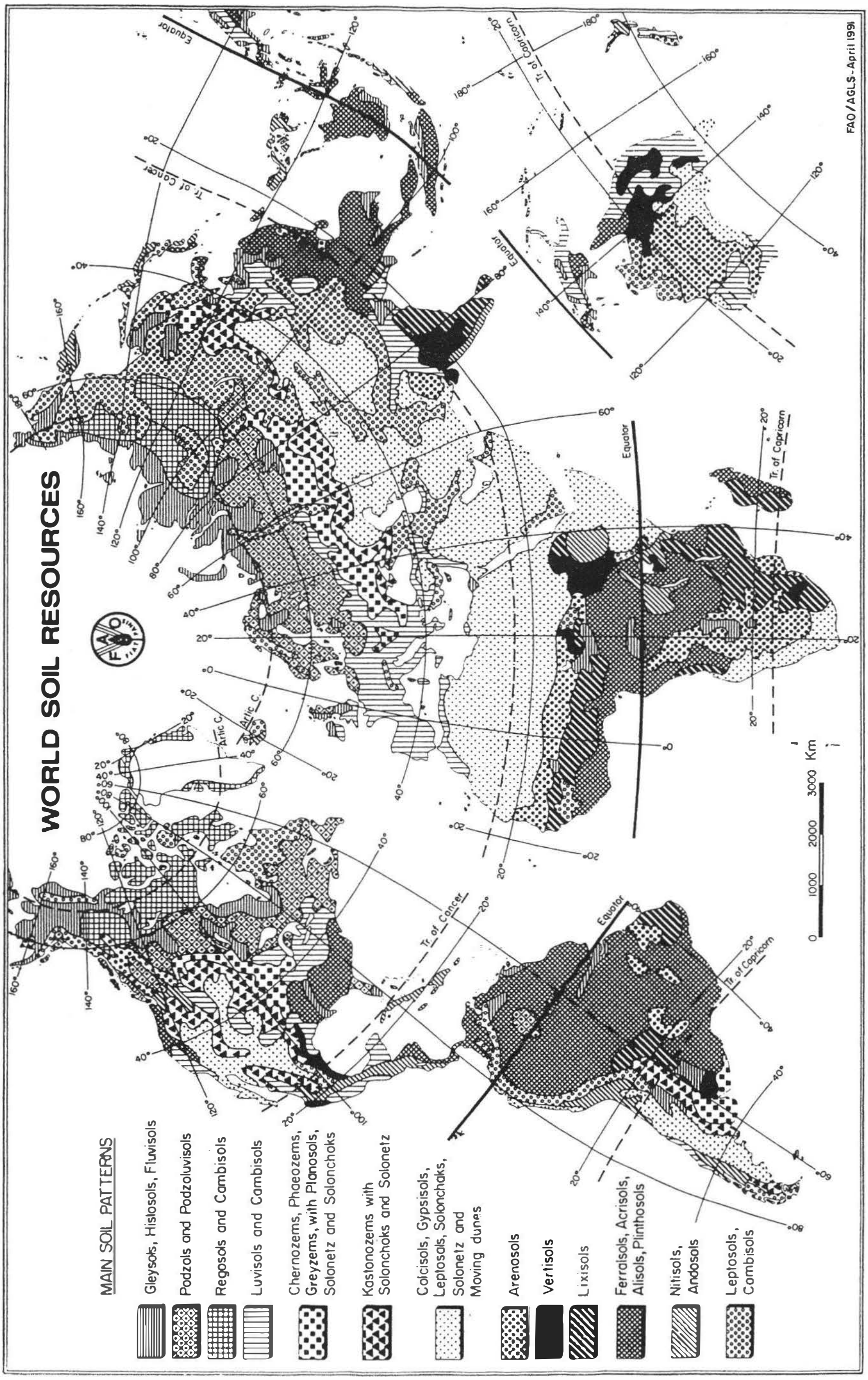

Fig. 1. — Diversity of the soil pattern in the tropics (*source*: Food and Agriculture Organization of the United Nations (FAO) 1991).

account of the loose use of the term "Laterite" and of its connotation with a wide range of red soils of very different character.

Early definitions of Laterite were made in terms of chemical properties. In French Equatorial Guinea, LACROIX (1913) characterized different types of Laterite according to their content of hydroxides: true Laterites containing more than 90 % hydroxides, silicate Laterites with 50 to 90 %, Lateritic clay with 10 to 50 %. HARRASSOWITZ (1926) and MARTIN & DOYNE (1927) defined Laterite as having a molar SiO_2/Al_2O_3 ratio of less than 1.33. HARRASSOWITZ (1926) further distinguished Allites and Siallites on the basis of their SiO_2 content, less than 12 % for the Allites and 12 % or more for the Siallites. Subsequently, ROBINSON (1949) introduced the molar ratio SiO_2/R_2O_3 to separate Ferrallites — replacing the Allites of Harrassowitz — and the Siallites, respectively having a ratio of less than 2 and 2 or more. He suggested, however, that the terms siallite, allite and ferrallite be used to describe materials rather than soils.

Field investigations of soils in the humid tropics started in 1905 with the creation of the Soil Research Institute in Bogor, Indonesia. In 1910 Mohr divided the soils of Java in six groups based on a combination of parent material, temperature, moisture regime and stage of weathering, the latter being assessed in terms of soil colours. This classification was further developed to serve a systematic agro-geological survey in Sumatra (SZEMIAN 1933). MOHR (1934-1938, 1944) published an elaborate study on the soils of the Netherlands East Indies classifying soils in terms of soil-forming factors with main emphasis on the mineralogy of the parent material. He distinguished young Lateritic soils, Lateritic loams and old Lateritic soils next to ash soils, marl soils, calcareous and quartzitic soils, peat soils and marine clays. Mohr followed a deductive approach which was not systematically translated into a characterization of actual pedons.

In 1930 Vageler, having worked in East Africa and in Indonesia, published the first manual on soils of the tropics. Reflecting on the formation of Laterites and Red soils he called attention to a major difference between "Roterde" (red earths) and "Rotlehm" (red loams). The former had a loose crumb structure while the latter showed a subsurface accumulation of clay and possibly a bleached surface horizon. This difference was also acknowledged by ROBINSON (1936) when he distinguished Friable and Non-friable Red soils which he correlated with sesquioxidic (allitic) and silicious (siallitic) soils respectively. He stated that the weathering complex of the non-friable soils was definitely of a clay character, which gave rise to plasticity and cohesiveness, while friable soils contained an excess of sesquioxides marked by a non-cohesive structure. The difference between "Erde" and

"Lehm" was further highlighted by KUBIENA (1948) whose micromorphological studies showed the friable soils to be formed by an agglomeration of soil particles by sesquioxides in contrast to the more plastic and mobile nature of the clay in the non-friable soils. This early differentiation within the red soils of the tropics was a most valid one and still persists in current soil classification systems.

In 1927 Marbut recognized Pedalfers and Pedocals at the highest level of generalization. The Pedalfers were characterized by the absence of calcium carbonate and by an accumulation of iron and aluminium, as in Laterites and Lateritic soils. The USDA yearbook, Soils and Men (BALDWIN *et al.* 1938) recognized "Lateritic soils of forested warm temperate and tropical regions" at sub-order level. They included the great groups Yellow Podzolic, Red Podzolic, Yellowish-brown Lateritic, Reddish-brown Lateritic and Laterite soils. The term "Laterite" was retained for deeply weathered soils with reticulately mottled parent materials. The term "Podzolic" made its first appearance with regard to soils of tropical regions on account of the occurrence of light coloured surface horizons linked to a subsurface accumulation of clay. It was realized that the processes involved were different from those which developed Podzols; however, the Podzolic name-giving was maintained and led to a long-lasting ambiguity (DUDAL 1970). The separation of "Lateritic Podzolic soils" (STEPHENS 1962, BENNEMA 1963) did not clarify the issue.

In 1933 the Belgian Government created the *Institut National pour l'Etude Agronomique au Congo* (INEAC). A first study of the soils of Central Africa was carried out in the framework of INEAC's Agrology Division (BAEYENS 1938). A soil suitability scale for different tropical crops was developed with special attention to soil fertility. Linking soil characteristics, both chemical and physical, to other production factors such as climate and management practices, added an important dimension to the classification of soils in the humid tropics.

In 1948 the Commonwealth Agricultural Bureaux convened an international Conference to review the state-of-the-art of soil classification, soil fertility and soil erosion in the tropics and sub-tropics. In addition to the forty-five delegates from the Commonwealth countries, soil scientists from Belgium, FAO, France, the Netherlands, Palestine and the United States were also invited. With regard to soil classification the Conference revealed the profound diversity of approaches to characterize and name soils in the tropics. The different meanings given to the terms Laterite, Lateritic and Podzolic resulted in a feeling of uncertainty to such an extent that the Conference concluded that "no recommendations be made by the Conference regarding the classification of tropical and sub-tropical soils" (Commonwealth Bureau of Soil Science, 1949).

Latosols and Oxisols

It was at the above conference that KELLOGG (1949) proposed the concept of "Latosol" on the basis of an exploratory study which he had just made in the Congo (KELLOGG & DAVOL 1949). The introduction of the Latosol was meant to mark a distinction between the Buchanan Laterite, that hardened upon drying, and well-structured red soils of the humid tropics.

The proposal was formalized at the 4th International Congress of Soil Science (ISSS), Amsterdam, 1950, in a lecture which KELLOGG (1950) devoted to "Tropical Soils". The dominant characteristics of the Latosol were associated with: a low silica/sesquioxide ratio of the clay fraction, medium to low cation exchange capacity, low content of weatherable minerals, low content of soluble material, relatively high degree of aggregate stability, red colour or reddish hues of other colours, no essential horizons of accumulation through additions, relatively thin organic surface layer, generally low content of silt. This definition combined chemical and morphological characteristics applicable to an entire pedon rather than to samples of soil material. No form of Laterite was regarded as an essential property for the Latosol sub-order. It was regarded diagnostic only in the "Intrazonal Groundwater Laterite". This distinction was shored up by D'HOORE (1954) who identified the relative and absolute accumulations of sesquioxides. The relative accumulation resulted from the exportation of non-sesquioxides out of the system, such as in the Latosols, while the absolute accumulation was produced by a selective importation of free sesquioxides such as in the Groundwater Laterites.

In the 1950s soil surveys were started in Congo and in a number of tropical countries. In addition to the Congo the Latosol concept was readily adopted in Southeast Asia (DUDAL & SOEPRAPTOHARDJO 1957), South America (BENNEMA 1956), and Hawaii (CLINE *et al.* 1955). In 1954, Congo hosted the 5th International Congress of Soil Science, the first one to be held in a tropical environment. The classification of soils in the tropics was amply discussed (AUBERT 1954) with special attention to the proposal of BOTELHO DA COSTA (1954) to use the term "Ferrallitic soils" in substitution of "Lateritic soils". The name "Latosol" was felt less suitable on account of its too wide scope and of its reminiscence of the term "Laterite". At the 6th ISSS Congress, in Paris in 1956, AUBERT & DUCHAUFOUR (1956) presented a system of soil classification in which the red soils of the humid tropics were labelled as *Sols ferrallitiques* and *Sols ferrugineux tropicaux* distinguished by a molar SiO_2/Al_2O_3 ratio of less than 2 and 2 or more respectively.

At the 7th ISSS Congress, in 1960 in Madison, USA, SMITH (1960) and the Soil Survey Staff of the United States Department of Agriculture (1960) presented the 7th approximation of "Soil classification: a comprehensive system". The soils of the humid tropics were accommodated in the Oxisols and Ultisols. Oxisols were characterized by an oxic horizon, the quantitative criteria of which remedied the broadly descriptive definition previously proposed for the Latosols. The Ultisols were defined as having an illuvial subsurface accumulation of clay, an argillic horizon, having a low base saturation. The "7th approximation" was a breakthrough in soil classification. It introduced a new soil nomenclature to resolve the confusion of "Lateritic" and "Podzolic" name-giving. It introduced named diagnostic horizons replacing the earlier ABC designations. This change was most opportune for soils in the humid tropics as no agreement could ever be reached, in the absence of an absolute accumulation and because of the importance of the weathering crust, whether the subsurface horizons of a Latosol were to be named B, (B) or C. The abandonment of ABC horizon designations throughout the system was particularly welcome since the different meanings ascribed to this rather simplistic alphabetical subdivisions had been a major constraint to effective communication. Soils were defined on the basis of their own properties, preferably quantified, observable and selected on the basis of their reflection of established genetic processes and on their significance for soil management. The term "Plinthite" (from Greek *plinthos*, brick) was coined to replace "Laterite". The definition of Plinthite covered only the soft iron-rich humus poor mixture of clay with quartz and other diluents. Indurated material, whether vesicular or pisolitic, was considered as a Petroferric contact. The "7th approximation" introduced soil temperature and soil moisture regimes as diagnostic criteria in soil classification, considered to be factors of soil formation and of importance to land use. The Udic moisture regime referred to the humid tropics and was diagnostic at sub-order level (*e.g.* Udox, Udult). The prefix "Trop" was used to identify soils of the intertropical belt characterized by minimal differences between mean winter and summer temperatures. "Trop" was diagnostic either at sub-order level (*e.g.* Tropepts) or at great group level (*e.g.* Tropudults). "Trop" did not apply to Oxisols which were considered to occur in the tropics only. In the second edition of Soil Taxonomy (Soil Survey Staff 1999) the "Trop" groups were abolished on account of the overlap with the temperature differentiae applied at soil family level.

Ferralsols, Nitisols and Acrisols

In order to ensure a more precise definition and a subdivision of the Latosols in Congo, the term "Kaolisols" was coined (SYS *et al.* 1961) to denote intertropical soils with a dominance of kaolinite in the clay fraction mixed with important quantities of free oxides. Kaolisols included Ferralsols and Ferrisols. The Ferralsols were characterized by a weak horizon differentiation, low or no reserve in weatherable minerals, absence of clay coatings and low silt content. Ferrisols had a similar mineralogical composition but showed clay coatings in what was called a "structural B horizon". The French soil classification retained a similar subdivision between its *Sols ferrallitiques* and the *Sols ferrugineux tropicaux* (CPCS 1967). No separations were foreseen in the highest categories for soils with subsurface clay accumulation. Both Ferrallitic and Ferruginous soils had *lessivé* units at soil group level. In Angola the Portuguese system of soil classification adopted a comparable separation between Ferrallitic and Paraferrallitic soils (BOTELHO DA COSTA 1959).

The Soil Map of Africa, scale 1:5,000,000 (D'HOORE 1964, 2003), published in 1964 in the framework of the CCTA (*Commission de Coopération Technique en Afrique*/Commission for Technical Cooperation in Africa), reflected a major effort of correlation between the various systems in use in different African countries. The red intertropical soils were accommodated in Ferrallitic soils, Ferrisols and Ferruginous tropical soils. In 1960 the 7th Congress of the ISSS, held in Madison, USA, recommended that a Soil Map of the World be prepared in a uniform legend, at scale 1:5,000,000, thus enabling the comparison of soils on a global scale and the transfer of experience between areas of similar environment. FAO and Unesco jointly undertook the project, in cooperation with the ISSS and under the guidance of an international advisory panel (DUDAL & BATISSE 1978). A major obstacle to a comparative study was the absence of an internationally agreed system of soil classification. A first draft of a uniform legend was prepared for the 9th ISSS Congress held in Adelaide, Australia, in 1968 (DUDAL 1968, 1969). The definitions of soil units were based on measurable or observable characteristics of the soils themselves, drawing largely upon the USDA's Comprehensive System of Soil Classification (Soil Survey Staff 1960). Soil names were taken, whenever possible from current soil literature. However, new names were coined to avoid the use of terms which had acquired conflicting meanings. With regard to the red intertropical soils the legend distinguished Ferralsols and Acrisols, broadly corresponding to the Oxisols and Ultisols of Soil Taxonomy. Provision was also made at the highest level for a unit of Nitisols (from Latin, *nitidus*, shiny; *campi nitidissimi*, productive fields), corresponding to the Ferrisols of Congo, to the Reddish-brown lateritic soils of the former USDA Soil Classification (BALDWIN *et al.* 1938), the *Terra roxa estruturada* of Brazil (BENNEMA 1963) and to the greater part of the "pale-" great groups of the Ultisols in Soil Taxonomy. Nitisols have diffuse horizon boundaries, a deeply stretched clay bulge, low clay activity, and show shiny ped faces. They occur on rejuvenated geomorphic surfaces and predominantly on basic parent materials. They are among the most productive soils in the humid tropics, which led to their recognition.

The legend of the FAO/Unesco Soil Map of the World was published in 1974 (FAO 1974) including Ferralsols, Acrisols and Nitisols, with the provision for plinthic groups. The legend did not retain soil temperature and soil moisture regimes. Instead "climatic variants" were envisaged to be applied as an overlay on the map rather than to be part of the soil classification.

The first edition of Soil Taxonomy was published in 1975 (Soil Survey Staff 1975). Recently the Chinese soil taxonomy (Inst. Soil Sci., Chinese Acad. of Sci., 2001) introduced Ferralsols and Ferrosols, defined on the basis of diagnostic horizons and properties, including Ferralsols, Acrisols and Nitisols. The Russian classification (ZONN 1986) comprises allitic, ferrallic and ferritic soils which, in the first instance, reflect the composition and properties of the crust of weathering rather than the morphology of pedons. The Australian soil classification (ISBELL 1996) includes Ferrosols, Kandosols and Kurosols at order level which partially correspond to the Ferralsols, Nitisols and Acrisols. They replace the earlier Australian Red Earths, Krasnozems and Lateritic podzolic soils (STACE *et al.* 1968).

During the 1960-70s the realm of "Laterite" and "Lateritic soils" faded away, at least in the soil science community. It survives in the domains of geology and geography where efforts are also being made to correlate "Laterization" and the many meanings of "Laterite" both at international and interdisciplinary level (MCFARLANE & SOMBROEK 1986). However, Laterite appears to still have a tenacious grip on environmentalists and decision-makers. Some of them hold that "a problem characteristic of all tropical lands is when jungle areas are cleared, the land turns into cement after only a few years" (Science Policy Research Division 1977). The changing concepts in the classification of soils should stress that plinthite and hardened petroferric layers only cover a fraction of the humid tropics and that most indurated layers are fossil features rather than the result of current land use.

The FAO/Unesco Soil Map of the World was completed in 1981 (FAO 1971-1981). Although its legend adequately served an inventory of the world's soil resources, it was realized that it had been biased by the area extent of soils that could be shown on a small scale map. A further effort was required toward an internationally agreed means of correlation and communication. A work programme was started at the initiative of FAO in cooperation with Unesco, UNEP and the ISSS. In 1980 a group of soil scientists, representative of the major soil classification schools in Belgium, France, Germany, Russia and the USA, met in Sofia, at the N. Poushkarov Institute for Soil Science. The group initiated the preparation of an International Reference Base for Soil Classification (IRB). At the start of the programme 26 units were recognized at the highest level of generalization, including Ferralic soils, clay differentiated Ferralic soils and structured Ferralic soils, broadly corresponding to the Ferralsols, Acrisols and Nitisols of the FAO/Unesco legend for the Soil Map of the World (FAO/Unesco/UNEP/ISSS 1980). This legend was further used as the basis for the development of the IRB. The programme was adopted by the ISSS at its 12th Congress in New Delhi, India, in 1982. Successive approximations, prepared with the cooperation of soil scientists throughout the world, culminated in the endorsement of the World Reference Base for Soil Resources (WRB) (FAO 1998, ISSS 1998) by the 16th Congress of the ISSS, held in Montpellier, France, in 1998. The WRB accommodates the strongly weathered soils of the humid tropics in the Ferralsols, Nitisols, Acrisols and Plinthosols. The latter group was added on to the previous FAO/Unesco legend to cater for those soils in which a plinthic or a petroplinthic horizon are diagnostic. It is worth noting that the successive stages in the classification of the strongly weathered soils of the humid tropics consistently reflect the separation between Laterite and the Friable and Non-friable soils of ROBINSON (1936) or the "Roterde" and "Rotlehm" of VAGELER (1930).

Kandic, Argillic and Argic Horizons

With continuing fieldwork and the progress of analytical techniques the knowledge and insights on the classification of soils evolve. All systems remain in a flux of change and needs for updating are regularly perceived (VAN WAMBEKE 1989). One of the questions which arose was the adequacy of the argillic horizon as a diagnostic criterion for defining Ultisols. By definition the argillic horizon results from clay accumulation by illuviation which is marked by the presence of clay coatings on structural ped faces. This concept was developed mainly in temperate areas and subsequently extrapolated to the tropics. It appeared, however, that the recognition of an argillic horizon proved to be difficult in soils dominated by low activity clays. Some of these soils either have no clay increase but show clay skins or the reverse, show a clay bulge in the absence of clay skins. Furthermore, the accessory properties that are attributed to argillic horizons, structural stability, nutrient content, enhanced air-water relationships (SMITH 1986), do not, or to a much lesser extent, apply to soils with low activity clays. Classification of soils in the humid tropics has been fraught with difficulties over the identification of an argillic horizon and over its relevance as a defining diagnostic horizon in the highest category. These issues were reviewed in depth by ESWARAN & SYS (1979) and by VAN WAMBEKE (1989). In order to overcome these difficulties, Soil Taxonomy, in its second edition (Soil Survey Staff 1999), introduced the kandic horizon. It is a subsurface horizon that has a significantly higher percentage of clay than the overlying horizon(s) and has the low cation exchange capacity inherent to a clay fraction composed predominantly of kaolinite and varying amounts of hydroxides of iron and aluminium (MOORMANN 1985). The clay increase in the kandic horizon may be the result of illuviation, but also of clay destruction, selective erosion, sedimentation or lithological discontinuities. The definitions of the argillic and kandic horizons actually overlap. The kandic horizon is used as a defining diagnostic feature at great soil group level both in Ultisols and in Oxisols (*e.g.* Kandiudults, Kandiudox), in the latter case only when the surface layer contains less than 40 % clay. This important change in definitions overcomes the difficulties to identify argillic horizons in materials dominated by low activity clays but implies that the use of non-mutually exclusive diagnostic horizons complicates identification procedures (BEINROTH & ESWARAN 2003). The kandic horizon compromise leaves a considerable uncertainty as to which diagnostic properties should be the overriding ones, low activity of the colloidal fraction or the textural differentiation. It has been pointed out (ESWARAN 1990) that for the purposes of use and management the chemical and mineralogical properties of the soils in humid tropics present greater constraints than the apparent advantage of a clay increase with depth. The Australian, French and Russian soil classifications actually give priority to the ferrallic properties at order level, while textural differentiation is diagnostic only at a second level.

In WRB the argillic horizon of Soil Taxonomy has been substituted by the argic horizon which is connotative of a fine textured subsurface horizon which is not necessarily caused by clay illuviation but may also result from other processes. Hence the presence of clay coatings is no longer required; however, when they are not present, the textural differentiation needs to be more pronounced to qualify for an argic horizon. The fine textured subsurface is used at the highest level to separate Acrisols from Ferralsols; however, deeply stretched textural differentiation combined with low cation exchange capacity and a nutty structure with shiny ped surfaces are distinguished as Nitisols. The latter correspond to many of the "kandi" Oxisols or Ultisols in Soil Taxonomy.

A weak point in Soil Taxonomy and in WRB is the separation of different soils with an argillic or argic horizon on account of their base saturation. Ultisols and Alfisols in Soil Taxonomy or Acrisols and Lixisols in WRB are distinct by their base saturation being respectively lower or equal and higher than 50 % in or below their fine textured subsurface horizon. This differentiation, based uniquely on analytical data, can hardly be detected in the field. For a separation in the highest category this diagnostic feature is most unsatisfactory. Furthermore, for soils with low activity clays, a difference in base saturation is not very meaningful.

Anthrosols

An aspect which has not received sufficient attention in the classification of soils, especially in the tropics, is the human factor of soil formation (DUDAL *et al.* 2002). Deforestation, the levelling of termite hills, the construction of mounds for tuber cultivation (SYS 2003), the uneven spread of ashes with slash-and-burn practices, terracing, liming, fertilization and land-clearing techniques, have markedly influenced soil characteristics, especially of the surface layers. In Southeast Asia large areas have been terraced for the cultivation of irrigated rice. As a result of long-term saturation with water, iron and manganese migrate from the upper horizons of freely drained soils, such as Ferralsols and Nitisols, and accumulate at 20-60 cm below the surface, at times forming a hardpan. "Anthrosols" have recently been introduced in most soil classification systems to identify soils which have been strongly modified through human interference. The so-called "Padi soils" have been separated as "anthraquic" subgroups in Southeast Asia (DUDAL & MOORMANN 1964), as "hydragric anthrosols" in WRB, as "Fe-accumulic-stagnic anthrosols" in China. In Southeast Asia they occupy an important part of the agricultural area.

Another expression of human influence on soil formation in the humid tropics are the anthropogenic black earths in the Amazon region (SOMBROEK *et al.* 2002). They are locally known as *Terra Preta do Indio* and are apparently kitchen middens of pre-Columbian Amerindian settlements that have transformed the original soils, Ferralsols and Acrisols, into Fimic Anthrosols with approximately double the amount of soil organic matter and higher amounts of phosphorus and calcium. They do not occupy extensive areas, in dispersed patches of 5 to 300 ha, but are a strongly expressed mark of the anthropogenic factor of soil formation.

The evolution of soil classification concepts has mainly addressed the macrovariability of soils in the humid tropics. Equally important attention will need to be devoted to microvariability which is often reflected by considerable unevenness of crop growth over short distances. The causes are mainly human influence, as mentioned above, but also the uneven location of mound-building termites, the influence of termite activity on chemical and mineralogical soil characteristics, differences in depth and thickness of a stone line, lateral variations of the regolith, the uneven depth at which plinthite occurs. Microvariability belies the generally held opinion that soils in the tropics are homogeneous over large areas. This variability has to be taken into account in determining management practices, designing field experiments, recommending balanced fertilization and selecting suitable cropping patterns.

How Good is our Soil Classification?

The pathway from Buchanan's Laterite to the Plinthic Ferralsol of WRB or the Petroferric Kandiudox of Soil Taxonomy has been a protracted one. Did it lead to a "good classification"? An assessment of the adequacy of a classification system has to be made in terms of the purposes for which it has been designed. Soil classifications are generally meant to establish a taxonomy, make soil surveys and serve as a tool for interpretation. Can a single system effectively meet these different objectives? "In any system of classification, groups about which the greatest number, most precise and most important statements can be made for the objective serve the purpose best. As the things important for one objective are seldom important for another, a single system will rarely serve two objectives equally well" (CLINE 1949).

Taxonomy is about identification, recognition and the establishment of a hierarchy of classes which allows an orderly overview of the diversity of the object concerned. It is now generally recognized that "genesis" as such is no longer an adequate basis to classify soils. The concept was borrowed from biosciences, the phylogenetic relationships of which do not apply to soils. However, soil formation is still taken into account for selecting morphological differentiae for separating classes. One may wonder though in how far this approach is relevant to the strongly weathered soils of the humid tropics. The tropical belt has been subjected to considerable climatic fluctuations. The old stable landscapes on which soils were formed may date back to mid-tertiary (De Heinzelin 1954). Although weathering crusts were not scraped away by icecaps, they underwent pluvial and interpluvial cycles entailing erosion and sedimentation. The presence of stonelines in many of the strongly weathered soils are witness of a considerable translocation of materials and of the biological activity of termites that have influenced soil formation since the Pleistocene (Stoops 1967). Hence, strongly weathered and deep regoliths are the products of successive geomorphological cycles and are the result of geogenesis rather than pedogenesis (Kovda 1964). Earlier conditions may have left a stronger imprint than present climatic and hydrobiological factors. This polygenetic process is difficult to reconstruct and one may even wonder about the nature of soil formation which is currently prevailing in the humid tropics. The emphasis on a morpho-driven soil classification is particularly justified when considering that hypotheses on genesis include a large element of conjecture. It is against this background that the validity of the currently adopted hierarchy has to be evaluated.

The branching sequence of organisms has evolution as an objective basis. For soils, however, the hierarchy is a matter of opinion (Swanson 1993). Correlations were made by Sys (1967), Aubert & Tavernier (1972) and Deckers *et al.* (2003). There is a growing convergence as to which properties and horizons are diagnostic for strongly weathered soils in the humid tropics: cation exchange capacity linked to mineralogy, textural differentiation in the form of argic, argillic or kandic horizons, the presence of shiny ped faces, the molar ratio of SiO_2/R_2O_3, the presence of plinthite or of hardened petroferric or petroplinthic horizons, base saturation and colour. However, the limits of these diagnostic properties differ between the various classification systems, as well as the combinations in which they have been applied and the precedence they have been given at different categorical levels. The establishment of equivalents remains arduous. WRB is an attempt to overcome heterogeneous separations by reducing the classification to two categories, the 30 major reference groups subdivided at second level by qualifiers without hierarchical ranking (Nachtergaele *et al.* 2002).

With regard to making soil surveys it should be noted that soil surveys started well prior to the creation of soil taxonomies. Most present-day soil surveys are based on mapping units which are pragmatic and are geared toward the specific purpose of the survey. It is realized that the use of taxa in the higher categories of the classification sacrifices information because of the broad scope of their definitions. Furthermore, the alleged three-dimensional nature of soil is barely reflected by a ten square metre pedon. Soils are characterized not only by a vertical succession of horizons but also by spatial variations of their properties due to lateral movements at the surface and within the soil. The leaching and accumulation processes in the solum have their equivalent in discharge and recharge flows in the landscape. The emphasis on the use of taxa in soil surveys, carrying precise criteria for separating them, has reduced the awareness of the lateral and gradual links within a three-dimensional soil cover. An alternative approach to more comprehensive representation of the soil pattern, the soil catena, was advocated as early as 1935 by Milne. A move toward a structural analysis of the landscape is advocated by RUELLAN (2003) as a basis for the separation of more meaningful mapping units.

Soil classification has traditionally been considered as a means to optimize land use and to transfer technology between comparable soils in different areas. This assumption may be valid for broad assessments provided that other production factors such as climate, relief, hydrology, socio-economic conditions are also taken into account. For more specific interpretations soil taxa seldom suffice. Their class differentiae are preferably chosen to be stable subsoil characteristics while transient properties of the surface layers, which vary with soil management practices, are generally avoided. It is striking also that parameters of soil hydraulics are given little consideration in soil classification even though they are of prime importance for land use. Information on the specific impact of class differentiae on soil production capacity is scarce and the value of the numerous changes introduced in soil classification systems is seldom measured. Taxonomic endeavours seem to run ahead of field experience and of ascertaining the relevance of differentiating criteria.

It appears that soil classification, as currently conceived, cannot equally serve a taxonomy, the making of soil surveys and the interpretation for land-use purposes (DUDAL 2002). A future approach could inspire itself from plant sciences which clearly distinguish plant taxonomy, phytosociology and phytotechnology. Plant taxonomy aims at producing a system of classification which best reflects the totality of similarities and differences between plants. Phytosociology handles the distribution of plant communities, reflecting the interdependence of species and the environmental relationships which influence their distribution. Phytotechnology classifies plants in function of their utilitarian differentiae (cereals, tubers, fibre, fruits, oil crops, etc.) across taxonomic boundaries.

With regard to soil classification, a taxonomy allows for an overview of soil resources at regional and global level. Soil survey should give additional attention to soil landscapes, highlighting temporal and spatial dynamics, rather than to single taxa. Interpretation of soil characteristics would need to address specific land-use requirements and to be combined with other important production factors such as climate, relief and socio-economic conditions.

Our soil classification has served us well up to now. However, modern demands on soils call for a further review of concepts and applications, also with regard to the soils of the humid tropics.

Classification of Soils in the Humid Tropics
Chronology

1807	Buchanan	Laterite of Malabar
1895	Sibirtzev	Tropical forest lateritic soils
1913	Lacroix	Laterite and Lateritic clay
1926	Harrassowitz	Allite and Siallite
1927	Marbut	Pedalfer, Lateritic soils
1930	Vageler	Laterite, Roterde, Rotlehm
1934	Mohr	Young Lateritic soils, Lateritic loams, Old Lateritic soils
1936	Robinson	Laterite, Friable and Non-friable soils
1938	Baldwin et al., USDA	Lateritic soils, Red-yellow Podzolic soils, Reddish-brown Lateritic soils
1938	Baeyens, INEAC	Soil fertility scale of soils of Central Africa
1949	Robinson	Ferrallite, Siallite
1950	Kellogg	Latosols
1954	Botelho da Costa	Ferrallitic soils
1954	5th Congress ISSS, Congo	First ISSS Congress in the tropics
1954	Aubert, ORSTOM	Lateritic soils
1956	Aubert and Duchaufour	*Sols Ferrallitiques, Sols Ferrugineux tropicaux*

1960	Smith, G.D. USDA Soil Survey Staff	Soil classification: a comprehensive system Oxisols, Ultisols, Plinthite
1961	Sys et al., INEAC	Kaolisols, Ferralsols, Ferrisols
1964	D'Hoore, CCTA	Soil Map of Africa, Ferrallitic soils, Ferrisols, Ferruginous tropical soils
1968	Dudal, FAO	Definitions of soil units for the Soil Map of the World, Ferralsols, Acrisols, Nitisols with Plinthic groups
1974	FAO	Legend FAO/Unesco Soil Map of the World, Ferralsols, Acrisols, Nitisols with Plinthic groups
1975	USDA Soil Survey Staff	Soil Taxonomy (1st edition), Oxisols, Ultisols, with 'Trop' and Plinthic groups
1980	FAO/Unesco/UNEP/ISSS	International Reference Base for Soil Classification, Ferrallitic soils, clay differentiated Ferrallitic soils, structured Ferrallitic soils
1985	Moormann, SMSS	Kandic horizon
1998	FAO/ISRIC/ISSS	World Reference Base for Soil Resources, Ferralsols, Nitisols, Acrisols, Plinthosols
1999	USDA Soil Survey Staff	Soil Taxonomy (2nd edition), Oxisols, Ultisols with Kandic groups; 'Trop' groups abolished
2002	Royal Academy of Overseas Sciences	Evolution of Tropical Soil Science: Past and Future

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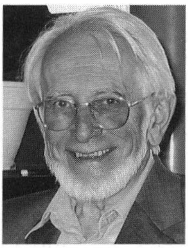
pp. 39-47 (2003)

The Contribution of Intertropical Pedology to the Development of Soil Science. The Contribution of French Pedologists

by

Alain RUELLAN *



Prof. Emer. Alain Ruellan (France, 1931) obtained in 1954 the degree of Agricultural Engineer at the "Ecole Nationale d'Agriculture de Rennes" and in 1970 the degree of "Docteur ès Sciences Naturelles" at the University of Strasbourg on a thesis entitled "Les sols à profil calcaire différencié des regions méditerranéennes". He started his scientific career at ORSTOM as researcher in Morocco and Senegal; in 1972, he became Full Professor of Soil Science at the "Ecole Nationale d'Agriculture de Rennes", but returned in 1982 to ORSTOM as its General Director, till 1987. Hereafter he was subsequently Technical Adviser of the General Director of the Ministry of Agriculture, Director of the "Centre National d'Etudes Agronomiques des Régions Chaudes" in Montpellier and Director of the Environmental Programme of the CNRS. Since the eighties he has been especially involved in soil research and education in Brazil. Alain Ruellan played a leading role in several national and international scientific societies, such as INQUA, ISSS, AFES and CNRS. Since 1990 he is a member of the Academy of Overseas Sciences of France. Apart from his scientific career he was also very active in a number of national and international socio-cultural associations, especially focusing development in the Third World. Alain Ruellan is author or co-author of over 250 scientific papers and reports in the field of soil science, geomorphology, paleopedology and development, including handbooks and didactic materials.

KEYWORDS. — French Intertropical Pedology; Soil Cover; Soil System.

SUMMARY. — Since the end of the Second World War an important progress has been made in the study of the soils of the intertropical regions. French pedologists have largely contributed to this progress. These studies have contributed not only to the knowledge of the intertropical environments but also to the evolution of general soil science, particularly 1. the demonstration of the existence of lateral

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* Prof. emer.; Member of the Académie des Sciences d'Outre-Mer de France; Former President of the International Union of Soil Sciences.

differentiations, of transformation fronts and of the time factor to explain the pedological systems, their distribution and their dynamics; 2. the inventory and cartography of soil types, then of pedological systems; 3. the conditions of land use (fertility evaluation of the soil cover).

MOTS-CLES. — Pédologie intertropicale française; Couverture pédologique; Système pédologique.

RESUME. — *Les apports de la pédologie intertropicale au développement de la science du sol. La contribution des pédologues français.* — Les études pédologiques des régions intertropicales se sont beaucoup développées depuis la fin de la Seconde Guerre mondiale. Les pédologues français y ont largement participé. Ces études ont non seulement fait avancer la connaissance des milieux intertropicaux, mais ont aussi contribué à faire évoluer la science du sol dans son ensemble. En particulier: 1. la mise en évidence des différenciations latérales, des fronts de transformation et du facteur temps pour expliquer les systèmes pédologiques, leurs répartitions et leurs dynamiques; 2. l'inventaire et la cartographie des types de sols, puis des systèmes pédologiques; 3. les conditions d'utilisation des sols (approche de la fertilité des couvertures pédologiques).

TREFWOORDEN. — Franse Intertropische Bodemkunde; Bodembedekking; Bodemsysteem.

SAMENVATTING. — *De bijdrage van de intertropische pedologie tot de ontwikkeling van de bodemkunde. De inbreng van de Franse pedologen.* — Sedert het einde van de Tweede Wereldoorlog werd aanzienlijke vooruitgang geboekt in de studie van de bodems van de intertropische gebieden. Franse pedologen hebben hier een belangrijke inbreng gehad. Deze studies hebben niet enkel bijgedragen tot de kennis van de intertropische milieus maar ook tot de evolutie van de bodemkunde in het algemeen, en meer bepaald 1. het aantonen van het bestaan van laterale differenciatie- en transformatiefronten en de factor tijd om de bodemkundige systemen, hun verspreiding en dynamiek te verklaren; 2. de inventarisatie en cartografie van de bodemtypes, vervolgens van pedologische systemen; 3. de voorwaarden voor bodemgebruik (vruchtbaarheidsevalutatie van de bodembedekking).

1. Introduction

Pedological studies of intertropical regions have progressed considerably since the end of the Second World War in 1945 (PEDRO & KILIAN 1986). French soil scientists, working with their African, Latin-American and Asiatic colleagues, have largely contributed to this progress. Mainly in the framework of ORSTOM [1]* and of several technical institutes (today regrouped in CIRAD [2]), they have since 1945 first discovered, then studied in detail the soil covers of nearly seventy Mediterranean and tropical countries, mainly in Africa, later in Latin America, and also in

* The numbers in brackets [ ] refer to the notes p. 47.

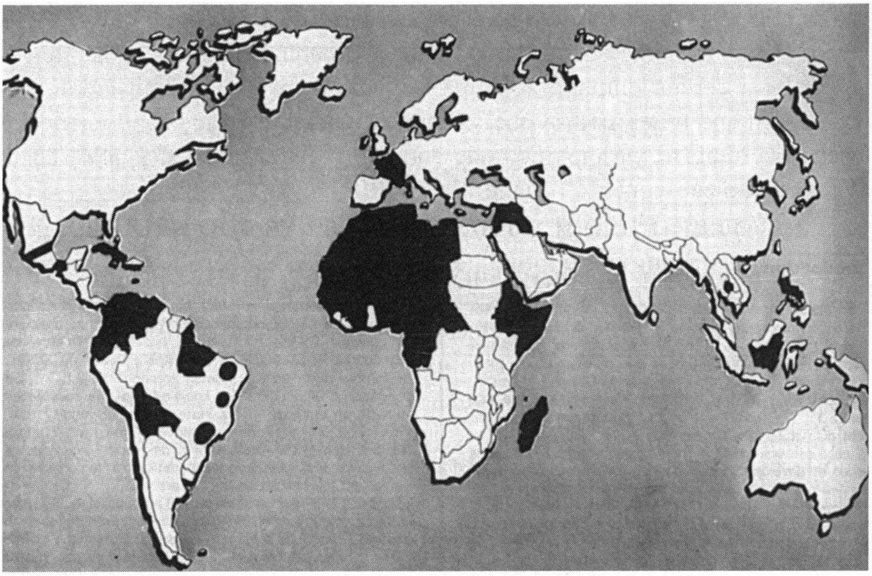

Fig. 1. — Intertropical regions where French pedologists have worked (1945-1984) (PEDRO & KILIAN 1986).

Asia, the Pacific, Australia, etc. (fig. 1). These pedological studies have contributed not only to the knowledge of the intertropical environments, but also to the evolution of soil science in general. This evolution concerns the concept of soil: what it is and, consequently, how it has to be studied; what its place and role are in the world ecosystem, as well as the condition of its use. These original contributions are presented in this paper.

2. The Two Stages of Progress

2.1. THE FIRST STAGE

The first stage of the studies and discoveries made by French pedologists and their colleagues during the period 1945-1960, has been that of wide inventory journeys, on the continental scale, and that of small-scale cartography (RUELLAN & DOSSO 1993). It was the time of Georges Aubert and his first young colleagues, who travelled mainly in Mediterranean and tropical Africa. It was a time of discovery, without any reference except the concept of climatic soil zonality, mainly elaborated in Russia. It was the time of exploration, based on the study of profile pits, whose localization was facilitated by the existence of big monotonous, apparently homogeneous, territories, by a certain climatic zonality, obvious thanks to its translation into vegetation and relief, and by the vicinity of vast virgin lands and territories used according to various methods and for different aims that allowed to compare the consequence of land use on different soil types.

It was during this first stage that the main characteristics and geographical distributions (continental and regional) of the main intertropical pedological units were recognized. Some of the relationships between pedological cover and main landscape features were established: climatic soil zonality, soil variation in relation to natural vegetation (for example on contact with forest and savannah), soil variation in relation to parent material and to the main relief types (*e.g.*, the relations between soils and terraces). Moreover, the specificity of soil behaviour, of soil fertility and of soil fragility was emphasized during this stage, but without being really understood and, consequently without being adequately controlled.

2.2. The Second Stage

The second stage starting early in the sixties is characterized by more detailed studies, on larger scales. The aim was a better understanding of the organization of the soil cover and a better response to the needs of those involved in land management projects.

2.2.1. Two Important Hypotheses

These very carefully made detailed cartographies have rapidly revealed the complexity of intertropical soil covers: the apparent homogeneity and zonal distribution are true only on a small scale. Detailed cartography has shown that climatic soil zonality and soil distribution in relation to rocks, are strongly modified by soil distribution in relation to relief. To explain this, two important hypotheses were elaborated.

2.2.1.1. The First Hypothesis

The existence of lateral differentiation: soils do not form only vertically, by vertical migration of solution and material, but also by lateral differentiation, resulting from lateral movement of solution and material in the soil.

2.2.1.2. The Second Hypothesis

The importance of the time factor and of the history of soil and landscape: in a landscape or watershed soils have diverse ages which explain part of soil diversity and distribution.

2.2.2. Two Scales

These new results being obtained and these new hypotheses being put forward, it was again necessary to change the study scale and methodology. Two scales were progressively privileged.

2.2.2.1. Elementary Watershed Scale

Elementary watershed scale, where one analyses vertical and lateral distribution of morphological characteristics, of constituents, of physico-chemical properties, of behaviours, etc., in order to study in detail the pedological horizon distribution and the morphological and dynamic relationships that exist between these horizons.

2.2.2.2. Microstructure Scale

Microstructure scale allows the use of a petrological approach. Indeed, the use of soil thin sections permits:

- On one side to discover the organization of microsystems, whose knowledge and understanding are particularly necessary for a better use of the soil.
- On the other side to reveal the chronology of formation of the different soil constituents and soil structures (*e.g.* aggregates, nodules, horizons, etc.). This is important for the understanding of soil history which is necessary for the prevision of the soil future permitting to anticipate soil evolution in function of various possibilities of land use.

3. The Pedogenic Interpretations

The pedogenic interpretations of these detailed studies were confronted each other during the years 1960-1990; but they progressively evolved.

3.1. History

After the zonal and actualistic view of the years 1945-1960, it has been the tendency for some years to attribute to geomorphology and to past climates the main role in soil differentiation: erosion, reworking, soil truncation, buried soils, lithologic discontinuities, paleosoils, etc. have thus been at the root of many interpretations on soil genesis and distribution. This debate is still going on today.

3.2. New Approaches

Refinement of soil structural studies, on various scales, as well as progressive development of observations, measurements, experiments concerning the actual functioning of the soil (water and solution dynamics, transfer of particles and of mineral and organic constituents, biological activity, etc.) and concerning soil behaviour in relation to the soil management technology, have progressively revealed the existence of **two types of dynamics** that many pedologists now consider as fundamental to understand the pedological covers.

3.2.1. The Strictly Pedological Mechanisms

The first dynamics for the formation of soil covers, is the strictly pedological mechanisms: desegregation and dissolution of rocks and minerals; transfer of solid, liquid, gaseous material; aggregation of constituents; genesis of constituents and aggregates by biological activities; genesis of porosity by biological and mechanical processes; concentration of constituents, etc. All these mechanisms are active for a longer or shorter time: to understand the soil cover it is necessary to know how to take into account this time factor. All these mechanisms are sufficient to explain the majority of soil covers in the world.

3.2.2. Transformation Phenomena

To be more precise, all these strictly pedological mechanisms lead to transformation phenomena, which affect soil constituents and structures. These transformations cause the succession, on the same site, by self-development or by variation of external factors, of different soil horizons, and of "soil types" considered as very different one from another. On the scale of the watershed this succession gives rise to different soil covers. This is illustrated with three examples.

3.2.2.1. Pioneer Works of Gérard Bocquier, in Chad

Bocquier (1971) demonstrated that very different soils, like leached soils, solonetz and vertisols, are in fact dynamically associated in space, from upstream to downstream, and in time: vertisols succeeds to solonetz that succeeds to leached soils. Real **transformation fronts** of constituents and structures exist between horizons that constitute this topochronosequence.

3.2.2.2. Works of René Boulet and Colleagues, in French Guiana

BOULET *et al.* (1982) demonstrated the dynamic association between ferralic soils and giant podzols (podzols replacing ferralic soils). It is not possible to map and to manage these soils if this history is not taken into account. This sequence is very frequent and still frequent in the humid tropical and equatorial world: Amazonia, Africa, Asia.

3.2.2.3. Works of Alain Ruellan, in Morocco

RUELLAN (1970) demonstrated the landscape and historical relationships between the diverse forms of calcareous accumulation in soil, from diffuse and nodular accumulation to thick crusts and slabs. In the soil covers all these horizons of calcium carbonate accumulation occur always in the same order, vertically, laterally, historically.

3.2.3. Pedological Systems

Progressively the reality of pedological systems and the artificiality of soil types defined by the single vertical profile appears. A pedological system is, on the scale of the landscape, a set of soil volumes, that is essentially a set of horizons which are related by a common evolutive dynamics. A pedological system is therefore defined by:

- Its horizons;
- The relationships existing between the horizons, *i.e.* by the transformation fronts existing between them;
- The stage of development of the system, knowing that in a landscape the different stages of one, or more pedological systems (fig. 2), generally coexist.

4. Conclusions

Three main points should be emphasized:

1. All the studies summarized above prompted to rethink the relationships between soil covers and other constituents of the environment. It was shown that the internal transformations of the pedological cover have impor-

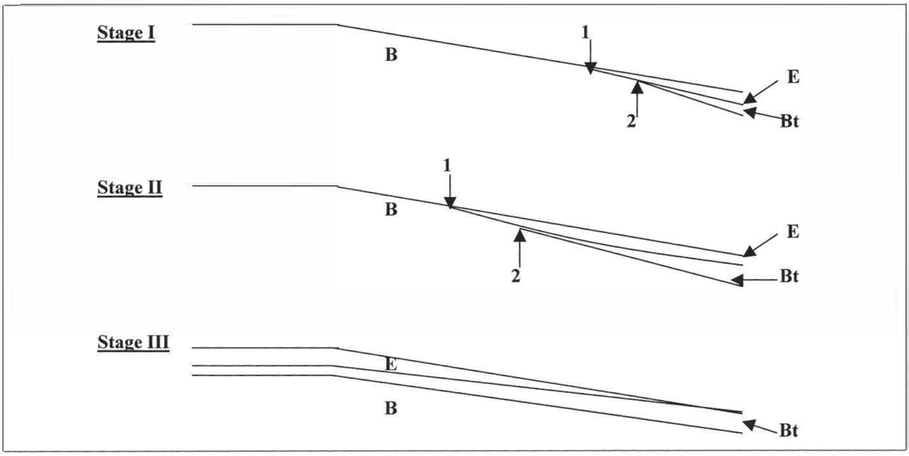

Fig. 2. — Schematic representation of three stages of development of a pedological system, associating a ferralic horizon, an eluvial horizon and an argic horizon. The three stages can be present in the same landscape (RUELLAN 2002); **E** = eluvial horizon, **Bt** = argic horizon, **B** = ferralic horizon. The point **1** is the beginning of the **transformation front** between horizons **B** (ferralic) and **E** (eluvial): the eluvial horizon transforms the ferralic horizon. The point **2** is the beginning of the **transformation front** between horizons **B** (ferralic) and **Bt** (argic): the argic horizon transforms the ferralic horizon. Vertical scale: 1 centimetre # 1 metre, horizontal scale: 1 centimetre # 10 metres.

tant repercussions on relief, water, vegetation and the ecosystem as a whole, including human activity. As a consequence, one goes progressively from the concept of soil evolving under the action of external factors (relief, vegetation, water run-off, human activity, etc.) to the concept of a pedological cover deeply influencing functioning and transformations of ecosystem, including human activities as an integral part of ecosystem.

2. The soil covers are strongly structured and strongly differentiated both vertically and laterally. They are the place of vertical and lateral transfers and of rapid and important structure modifications, in space and time. All this leads to rethink the soil fertility approach as it is no more possible to define soil fertility from the single characteristics of a vertical soil profile. Fertility has to be defined from the characteristics of a much larger pedological unity, in which it is necessary to take the time to study vertical, lateral and temporal variations. Moreover, to know the fertility it is necessary to take into account, as a priority, the detailed morphological characteristics and their relations with other soil characteristics.

3. All the studies summarized before have led to rethink the approaches to soil cartography and soil classification. It is no longer possible to be satisfied

with the classification and cartography only of soil types that are artificially delimited units. It is now necessary to develop the inventory, cartography and classification of pedological systems. This work has been undertaken (RUELLAN 2002) but very much remains to be done.

NOTES

[1] ORSTOM, Office de la Recherche Scientifique et Technique Outre-Mer, then Institut Français de Recherche Scientifique pour le Développement en Coopération, then IRD, Institut de Recherche pour le Développement — 213 rue La Fayette, 75480 Paris Cedex 10.

[2] CIRAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement — 42 rue Scheffer, 75116 Paris.

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Contribution portugaise au développement de la science du sol tropicale

par

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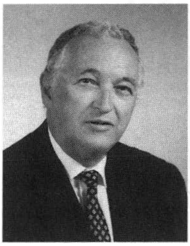

Prof. António Augusto GUERRA REFFEGA (Portugal, 1935) est ingénieur agronome. Après avoir été assistant et maître de conférences à l'Université de Luanda (Angola), il devint directeur et président du Comité d'Installation de l'Institut Polytechnique de Vila Real (Portugal). Depuis 1979, il est professeur titulaire de chaire à l'Université Nova de Lisbonne. Il a travaillé dans différents domaines, tels que la genèse, l'évolution, la taxonomie et la cartographie des sols. En tant que vice-président de l'Instituto de Investigação Científica Tropical (depuis 1984), le prof. Réffega est responsable de plusieurs projets dans des domaines distincts tels que la sécurité alimentaire, la cartographie agro-écologique et de la végétation, l'environnement. Il est représentant de l'Enseignement Supérieur Agricole portugais dans l'OCDE, représentant de la recherche nationale dans les programmes STD et $INCO_2$ de l'Union Européenne, et membre du groupe de travail du Programme d'Action national de la Convention des Nations Unies de Lutte contre la Désertification. Il a publié plusieurs travaux sur la préservation des écosystèmes tropicaux et sur les problèmes de l'éducation.

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MOTS-CLES. — Science du sol tropicale; Pédologie; Angola; Mozambique; Latérites.

RESUME. — Les études des sols effectuées dans les régions tropicales par les pédologues portugais ont commencé en août 1946 par une reconnaissance préliminaire des sols sur le plateau central d'Angola. Les études systématiques des sols tropicaux ont été étendues ultérieurement aux autres territoires d'outre-mer sous administration portugaise: Cap-Vert, Guinée-Bissau, São Tomé et Príncipe, Mozambique, Etat portugais de l'Inde (Goa, Damon, Diu), Macao et Timor. Les études effectuées se rapportent surtout aux domaines suivants: caractérisation des sols, y compris leur micromorphologie, classification et cartographie des sols, physique, chimie et minéralogie du sol, fertilité du sol et nutrition des plantes, technologie de la fertilisation. En outre, elles comprennent secondairement la pédogenèse, la dégradation, la conservation et la récupération des sols, la technologie générale du sol et les latérites. Les recherches développées sur toutes ces matières ont contribué à une meilleure connaissance des sols tropicaux.

KEYWORDS. — Tropical Soil Science; Pedology; Angola; Mozambique; Laterites.

SUMMARY. — *Portuguese Contribution to the Development of Tropical Soil Science.* — The study by Portuguese pedologists of soils in tropical areas started in August 1946, as a preliminary soil survey in the central plateau region of Angola. The systematic soil survey was later extended to the other overseas regions under Portuguese administration: Cape Verde, Guinea-Bissau, São Tomé and Principe, Mozambique, Portuguese State of India (Goa, Daman, Diu), Macao and East Timor. The studies conducted in those regions, mainly dealt with the following domains: characterization of soils, including their micromorphology, soil classification and cartography, soil physics, chemistry and mineralogy, soil fertility and plant nutrition, soil fertilization technology. Additionally, pedogenesis, soil degradation, conservation and reclamation, general soil technology and laterites were taken into account. Research in these different topics forms an important contribution to the knowledge of tropical soils.

TREFWOORDEN. — Tropische bodemkunde; Pedologie; Angola; Mozambique; Laterieten.

SAMENVATTING. — *Portugese bijdrage tot de ontwikkeling van de tropische bodemkunde.* — Bodemkundige studies ondernomen door Portugese bodemkundigen namen een aanvang in augustus 1946 bij de verkenning van de bodems van het centraal plateau van Angola. Later werd het systematisch onderzoek van tropische bodems uitgebreid tot de andere overzeese gebieden onder Portugees beheer: Kaapverdische Eilanden, Guinee-Bissau, San Tomé en Principe, Mozambique, Portugees India (Goa, Damon, Diu), Macau en Timor. De uitgevoerde studies betroffen in hoofdzaak volgende domeinen: bodemkarakterisatie, met inbegrip van hun micromorfologie, bodemclassificatie en kartering, bodemfysica, -chemie en -mineralogie, bodemvruchtbaarheid, plantenvoeding en bemestingstechnologie. Bovendien omvatten zij verder de bodemvorming, degradatie, conservatie en recuperatie, de algemene bodemtechnologie en de laterieten. Onderzoek in al deze gebieden heeft bijgedragen tot een beter begrip van de tropische bodems.

PALAVRAS-CHAVE. — Ciência do solo tropical; Pedologia; Angola; Moçambique; Laterites.

RESUMO. — *Contribuição portuguesa para o desenvolvimento da ciência do solo tropical.* — O estudo sistemático dos solos nas regiões tropicais pelos pedologistas portugueses começou em Agosto de 1946, com o reconhecimento preliminar dos solos do planalto central da ex-colónia de Angola. Estendeu-se depois a todos os outros territórios ultramarinos sob a administração de Portugal: Cabo Verde, Guiné Portuguesa, São Tomé e Príncipe, Moçambique, Estado Português da India (Goa, Damão e Diu), Macau e Timor. Os estudos efectuados respeitaram sobretudo aos seguintes domínios: caracterização dos solos, incluindo a sua micromorfologia; classificação e cartografia de solos; física e química do solo; mineralogia do solo; fertilidade do solo e nutrição das plantas; e tecnologia da fertilização. Eles ocorreram igualmente, embora de forma secundária, nos domínios da pedogénese, de degradação, conservação e recuperação dos solos, da tecnologia geral do solo e das laterites. A investigação desenvolvida em todas as matérias especificadas contribuiu de forma efectiva para um melhor conhecimento dos solos tropicais.

Introduction

Dès la création des Services agricoles dans les ex-colonies portugaises, à la fin du 19[e] siècle (1878), des laboratoires destinés à l'étude des sols sont apparus, soit pour donner de l'assistance technique aux colons, soit pour orienter l'agriculture indigène.

Bien qu'on puisse considérer 1878 comme l'année à partir de laquelle les techniciens portugais ont commencé à s'intéresser aux sols tropicaux, les premiers écrits effleurant le sujet datent seulement de 1909 (MONTEIRO 1909a, b; DORIA 1912). Toutefois, jusqu'à la fin du 19[e] siècle, les explorateurs portugais qui ont voyagé à travers le Continent africain — en particulier Serpa Pinto (PINTO 1881), Capelo and Ivens (CAPELO & IVENS 1881, 1886), Paiva Couceiro (COUCEIRO 1890, 1892) et Artur de Paiva (PAIVA 1892) — ont toujours fait dans leurs rapports de voyage de nombreuses références aux sols qu'ils ont observés, même s'il s'agissait de références de nature rudimentaire. Malgré cela, le premier travail réel sur des sols d'un territoire tropical sous administration portugaise ne date que de 1914, et encore est-il dû à un étranger (HOLMES 1914).

Après ces années initiales, au cours desquelles les sols furent abordés d'une manière fragmentaire et limitative, on passe à une période (de 1914 à 1945) d'études déjà objectives, quoique peu nombreuses — soit des études portant exclusivement sur les sols, soit des études générales mais contenant des éléments précis de nature pédologique (par exemple: ALMEIDA 1920; MAYER 1925; QUEIROZ 1930; SOUSA 1930, 1931; BARRADAS 1943; VELHO 1943).

L'année 1946 est considérée comme le début de la recherche proprement dite de la science du sol dans les ex-colonies portugaises. En effet, au cours de cette année-là, la reconnaissance préliminaire des sols du plateau central d'Angola fut réalisée par J.V. Botelho da Costa et Ario L. Azevedo intégrés dans une «Missão Agrológica» organisée par la «Junta de Exportação dos Cereais das Colonias» (COSTA & AZEVEDO 1947). C'est ainsi qu'ont commencé les études systématiques des sols tropicaux par des chercheurs portugais, études qui, depuis 1951, ont été poursuivies en Angola sous l'égide de la «Junta de Investigações do Ultramar» (JIU).

Organismes de recherche

La JIU a d'abord financé pour l'Angola une «Brigada de Estudos de Pedologia Tropical» (1951) et une «Missão de Estudos de Hidráulica Agrícola» (1952); puis, en 1953, elle a créé la «Missão de Pedologia de Angola» («Missão de Pedologia de Angola e Moçambique» depuis 1964), ainsi que, en 1960, le «Centro de Estudos de Pedologia Tropical» qui est devenu en 1983 le «Centro de Estudos de Pedologia» en absorbant cette mission. Pour l'Angola il y eut encore deux autres institutions se consacrant à l'étude des sols, localisées sur le territoire même de l'ex-colonie, tandis que les organismes précédents étaient établis à Lisbonne (à l'«Instituto Superior de Agronomia» de l'«Universidade Técnica de Lisboa»). Les deux autres institutions, fondées en 1962, sont la «Secção de Pedologia» de la «Faculdade de Agronomia» de l'«Universidade de Luanda» et le «Departamento de Solos e Fertilidade» de l' «Instituto de Investigação Agronómica de Angola».

En ce qui concerne le Mozambique, le début de l'activité de la recherche systématique dans le domaine de la science du sol s'est confirmé en 1947 avec la reconnaissance cotonnière projetée par le «Centro de Investigação Científica Algodoeira» créé dans l'ex-colonie en 1944 et dépendant de la «Junta de Exportação do Algodão». Dans le même temps, la section des sols des anciens Services agricoles de l'ex-colonie s'est mise à développer également, de manière intensive, l'étude des sols. Plus tard, en 1961, on a fondé sur le territoire l'«Instituto de Investigação Agronómica», avec un département de sols auquel on a attribué tout le patrimoine des sols et l'activité de recherche pédologique appartenant aux structures antérieures. En outre, en 1963, a été fondée l' «Universidade de Lourenço Marques» qui, dans la «Secção de Pedologia» de sa «Faculdade de Agronomia», a effectué également des études de sols.

Dans les autres ex-colonies — Cap-Vert, Guinée-Bissau, São Tomé et Príncipe, Etat portugais de l'Inde (Goa, Damon, Diu), Macao et Timor —, les études des sols se sont déroulées également sous l'égide de la JIU, par l'intermédiaire toutefois d'une «Missão de Estudos Agronómicos do Ultramar» qui a été créée avec l'objectif général de la recherche agronomique. En Guinée-Bissau, d'ailleurs, la «Junta de Exportação do Algodão» a effectué également des études pédologiques importantes visant la culture du cotonnier dans le territoire.

Domaines et lignes de recherche

Les études de sols effectuées dans les différentes ex-colonies portugaises se rapportent surtout aux domaines suivants: caractérisation des sols (y compris leur micromorphologie), classification et cartographie des sols, physique, chimie et minéralogie du sol, fertilité du sol et nutrition des plantes, et technologie de la fertilisation. Il y a encore, secondairement, des autres domaines de recherche tels que la pédogenèse, la dégradation, la conservation et la récupération des sols, la technologie générale du sol, et les latérites.

Les études concernant la caractérisation, la classification et la cartographie des sols ont été fréquemment associées dans les mêmes projets de recherche, et ce sont celles qui ont eu le plus grand développement au Portugal. Elles se sont étendues aux territoires de toutes les ex-colonies portugaises, impliquant l'activité de nombreux pédologues parmi lesquels se sont distingués: J.V. Botelho da Costa, Ario L. Azevedo, E.P. Cardoso Franco, R. Pinto Ricardo, J. Carvalho Cardoso, D. Godinho Gouveia, A.J. da Silva Teixeira, E.M. Silva da Câmara, J. Sacadura Garcia, A.T. Constantino, A. Castanheira Diniz, A. Sá e Melo Marques, F. Xavier de Faria, J. Faustino Fernandes et J.F. Casimiro. Il reste à inclure dans cette liste le nom de Luis Bramão qui, bien que n'ayant jamais été attaché aux ex-colonies portugaises, a travaillé activement dans les régions tropicales au service de la FAO.

Déjà en 1948, une étude sur les caractéristiques et la répartition de divers groupes de sols d'Angola (incluant une contribution importante à la taxonomie des sols tropicaux), présentée par J.V. Botelho da Costa et Ario L. Azevedo à l'occasion de la Conférence africaine des Sols (COSTA & AZEVEDO 1948), a été bien reçue et a bénéficié d'une appréciable renommée internationale.

En 1953 paraissait le livre «Solos de Angola. Contribuição para o seu estudo», traitant les caractéristiques (et des considérations de nature taxonomique) des principaux types de sols observés par la «Missão Agrológica» de 1946 (Costa *et al.* 1953). Ce livre a été fort apprécié et fréquemment cité dans la bibliographie scientifique internationale. Il a mérité de Van Baren, par exemple (*Tropical Abstracts*, vol. X, p. 646, 1955), une ample évaluation critique qui commence par les mots suivants: «The treatise gives a clear and systematic account of the results of a soil survey of Angola, carried out between 1946 and 1952, and for the date obtained in subsequent laboratory investigations. As one of the reasons for executing such an elaborate and strenuous task the authors assert that the failure of many European Agricultural enterprises in the tropics may be ascribed to the wrong choice of soils. A second reason lies in the urgent need to work out a sound soil conservation system which will fit in and can be adapted to native agriculture».

Dans les années qui ont suivi, de nombreuses études ont été réalisées sur les caractéristiques et les propriétés de divers types de sols tropicaux, dont quelques-unes ont fait l'objet de communications dans les congrès internationaux. Ces études concernent, par exemple, les sols ferrallitiques et fersiallitiques (Costa & Povoas 1959, Souto 1963, Franco 1964), les sols de régions sèches (Gouveia & Azevedo 1954b; Ricardo & Franco 1958; Costa *et al.* 1959a, b; Gouveia & Gouveia 1959; Cardoso 1975), les sols halomorphes (Vaz 1964, Marques 1972) et les vertisols (Azevedo & Costa 1954, Gouveia 1968).

Une des méthodes pour caractériser les sols qui a particulièrement intéressé les pédologues portugais est la micromorphologie du sol. Mettons en évidence dans ce domaine les chercheurs António A.G. Réffega et Edgar C. Sousa qui ont atteint une grande spécialisation en la matière (Reffega 1972a, Benayas & Reffega 1974, Eswaran & Sousa 1975, Eswaran *et al.* 1975). Dans ce contexte, on doit encore faire référence aux travaux ponctuels d'autres pédologues sur la micromorphologie des sols (Condado 1969, Benayas & Ricardo 1973).

Les études pédologiques développées sous l'égide de la JIU ont contribué d'une façon remarquable au progrès de la taxonomie des sols tropicaux, depuis la seconde moitié des années 40. Jusque-là, il existait une grande confusion dans l'emploi des termes latérite et latéritique. L'idée que la particularité des formations cimentées formées par une accumulation de sesquioxydes libres, typiques du milieu tropical, ne serait pas une caractéristique essentielle des sols tropicaux appelés latérites et sols latéritiques, a constitué en effet une évolution très significative. Dans cette évolution, les pédologues portugais ont joué un rôle important. En effet, J.V. Botelho da Costa (en collaboration avec C.G. Trapnell et J. Van Garderen) a présenté à la Conférence africaine des Sols (*Bulletin Agricole du Congo Belge*, XL (1), p. 1042, 1949, Bruxelles) la proposition suivante: «Considering that whatever the original meaning of laterite, this term is now in general use in Africa in the sense of Du Preez's definition (DU PREEZ 1948), this Conference agreed to recommend restriction in future of the use of this term to this definition. Having regard to the importance of the composition of the inorganic colloïds of the soil, both from the pedological and the agronomic point of view, it is also agreed that as a provisional measure and pending further research, Martin and Doyne's distinction of soils by the SiO_2/Al_2O_3 ratio of the colloidal fraction be recognized for the present as one of the criterions in soil classification, but that the soils termed: laterite and lateritic by these authors (SiO_2/Al_2O_3 less than 1.33 or between 1.33 to 2) be known henceforth as allite and allitic respectively».

Plus tard, au cours de la Deuxième Conférence interafricaine des Sols (Léopoldville, 9-14 août 1954), J.V. Botelho da Costa a soutenu l'adoption du terme ferrallitique pour désigner divers groupes de sols des régions tropicales et subtropicales qui se caractérisent essentiellement par une fraction argileuse avec basses valeurs de leurs rapports moléculaires silice-sesquioxydes, et dans lesquels la latérite (selon le sens donné par DU PREEZ 1948) ne représente pas un caractère essentiel (COSTA 1954b). Par la suite, ce terme a été soutenu et adopté par AUBERT (1954) lors de la conférence générale qu'il a prononcée au Cinquième Congrès international de la Science du Sol (Léopoldville, 16-21 août 1954): «Ne pourrait-on pas utiliser pour les Sols Latéritiques eux-mêmes, un terme qui s'éloigne un peu plus du terme primitif que celui de Latosol, proposé par C.E. Kellog et le 'Soil Survey' des U.S.A.? Ne pourrait-on, pour cet ensemble qui correspond, semble-t-il, à tout un Sous-Ordre de sols, prendre le terme de 'ferallite' déjà proposé par d'autres, en particulier par le regretté Professeur G.W. Robinson, et tout récemment encore, lors de la Conférence interafricaine des Sols, par J.V. Botelho da Costa, et laisser aux éléments latéritiques en voie de durcissement les noms de carapace et de cuirasse latéritiques?»

C'est alors que la désignation de sols ferrallitiques est entrée dans la nomenclature taxonomique des sols tropicaux. Selon CHATELIN (1972), «sans mésestimer les recherches d'autres écoles, on peut avancer que l'étude des sols ferrallitiques, qu'ils soient désignés par le vocable ferrallitique ou par un autre, est dominée pendant la période moderne par les équipes animées par Aubert (ORSTOM), Sys (INEAC), Botelho da Costa (JIU), et par l'équipe du Soil Survey Staff U.S. La place prééminente prise par les quatre organismes en question dans l'étude des sols ferrallitiques, ou *ferralíticos*, ou kaolisols, ou oxisols, se traduit par le fait que ce sont leurs terminologies et classifications qui sont le plus employées».

En ce qui concerne les Sols et Argiles Noirs Tropicaux et Subtropicaux — actuellement désignés par Vertisols — Ario L. Azevedo et J.V. Botelho da Costa ont distingué, dans une communication présentée à l'occasion du Cinquième Congrès international de la Science du Sol, des sols dérivés de formations rocheuses et des sols de plaines alluvionnaires (AZEVEDO & COSTA 1954). Pour D'HOORE (1955), «cette subdivision nous semble intéressante, surtout que la plupart des terres noires signalées en Afrique semblent pouvoir être assimilées à l'une ou l'autre de ces catégories». Pour cette raison, il a adopté cette distinction dans les cartes des sols d'Afrique (D'HOORE 1960, 1964).

Une autre proposition de J.V. Botelho da Costa (COSTA 1954b), présentée lors de la Deuxième Conférence interafricaine des Sols, à propos des systèmes de nomenclature généralement en usage, consistait à modifier ces systèmes relativement aux points suivants:

— Récuser les désignations de grands groupes de sols (ou d'unités de catégorie taxonomique supérieure) qui ne seraient pas fondées sur les caractéristiques essentielles des sols concernés;
— Remplacer les désignations de grands groupes de sols constituées par des termes appuyés exclusivement sur la couleur des sols;
— Préférer des termes recouvrant plus d'une caractéristique essentielle;
— Préférer des termes dérivés du latin et du grec.

Il a d'ailleurs obtenu sur ce dernier point l'approbation toute particulière de C.E. Kellog qui a même fait savoir qu'un tel critère était à l'étude dans son pays.

Une autre contribution également importante des pédologues portugais à la taxonomie des sols tropicaux, est l'adoption des rapports moléculaires SiO_2/Al_2O_3 et SiO_2/R_2O_3 de la fraction argileuse comme indice pour la distinction des sols à un niveau élevé — sols ferrallitiques, fersiallitiques et siallitiques, dont l'argile possède des caractères respectivement ferrallitique, fersiallitique et siallitique (COSTA *et al.* 1953, COSTA 1959, COSTA *et al.* 1959d). Ces caractères sont les suivants:

Argile		Rapports moléculaires	
		SiO_2/Al_2O_3*	SiO_2/R_2O_3*
Ferrallitique	Faiblement ferrallitique	2,0 – 1,7	< 2,0
	Moyennement ferrallitique	1,6 – 1,4	< 2,0
	Fortement ferrallitique	⩽ 1,3	< 2,0
Fersiallitique		> 2,0	< 2,0
Siallitique	Faiblement siallitique	2,0 – 2,4	> 2,0
	Fortement siallitique	2,5 – 3,4	> 2,0
	Très fortement siallitique	⩾ 3,5	> 2,0

* La silice dont il est question ici est la silice à l'état combiné (silicates et silico-aluminates).

Relativement au domaine de la taxonomie pédologique, nous devons indiquer encore, à titre d'exemple, les références suivantes: COSTA (1954a), COSTA *et al.* (1956b), COSTA & AZEVEDO (1957), AZEVEDO & CARDOSO (1962), CARDOSO (1962), COSTA & FRANCO (1965).

La cartographie des sols comporte la réalisation soit de cartes pédologiques, soit de cartes de classement des terres ainsi que d'autres cartes d'interprétation dérivées de la carte pédologique, et ceci à toutes les échelles (petites, moyennes et grandes échelles), permettant ainsi d'obtenir des cartes générales ou généralisées, cartes de reconnaissance, cartes semi-détaillées ou très détaillées. Associée au document cartographique, une notice explicative donne, entre autres, des renseignements précieux sur la typologie des sols et leur classification.

La cartographie pédologique a été réalisée dans tous les territoires sous administration portugaise, ce qui représente plusieurs centaines de cartes publiées. A titre d'exemple, nous présentons de suite quelques références sur le sujet, qu'elles soient des travaux se rapportant exclusivement au thème en question ou qu'elles soient des travaux généraux contenant des éléments de nature cartographique sur les sols de la région concernée: pour l'Angola: COSTA (1951), AZEVEDO (1954b), GUERRA *et al.* (1956), COSTA *et al.* (1956b,1959), DINIZ *et al.* (1957), COSTA *et al.* (1959c, d), COSTA & AZEVEDO (1960), COSTA *et al.* (1964), MPAM & CEPT (1968), CONSTANTINO (1974a), CEP (1985, 1995, 1997, 2002); pour le Cap-Vert: NUNES (1962), FARIA (1970, 1987); pour l'Etat portugais de l'Inde: GARCIA (1961), GARCIA & CARDOSO (1964); pour la Guinée-Bissau: TEIXEIRA (1959, 1962), FERNANDES (1960); pour Macao: GARCIA (1963); pour le Mozambique: GOUVEIA & AZEVEDO (1950, 1954a, 1955), COSTA *et al.* (1954a), CASIMIRO (1968b), MARQUES (1970), SOUTO (1973), Gouveia & Marques (1973); pour São Tomé et Príncipe: Garcia & Cardoso (1961), Cardoso & Garcia (1962), Mariano (1968); et enfin pour le Timor: Garcia *et al.* (1963), Garcia & Cardoso (1978).

A l'égard de la «Generalized Soil Map of Angola» (Costa & Azevedo 1960), présentée lors du Septième Congrès international de la Science du Sol (Madison, 15-23 août 1960), V.A. Kovda (Costa & Azevedo 1960) a émis l'opinion suivante: «The new soil map of Angola is very important for our knowledge of the soils of Africa. The published part of the soil map and text are very useful and impressive. It is to be hoped that important survey and publication will be completed».

Sans aucun doute, on peut dire que le travail de cartographie pédologique effectué en détail par les pédologues portugais a permis d'obtenir une vaste information sur les sols tropicaux, laquelle a entraîné une collaboration importante dans différents projets internationaux, par exemple dans la Carte des Sols d'Afrique (D'Hoore 1960, 1964) et dans la «Soil Map of the World» (FAO-Unesco 1970-1981). La Carte des Sols d'Afrique a été réalisée sous la coordination générale de J.L. D'Hoore qui a pu compter pour son exécution sur la collaboration de divers scientifiques parmi lesquels les Portugais suivants: J.V. Botelho da Costa, qui est intervenu dans l'établissement de la Légende générale respective et dans les travaux concernant l'Angola, avec la participation de Ario L. Azevedo, R. Pinto Ricardo, E.P. Cardoso Franco et E.M. Silva da Câmara; A.J. da Silva Teixeira, en ce qui concerne la Guinée-Bissau; D.H. Godinho Gouveia et Ario L. Azevedo pour le Mozambique.

Quant à la «Soil Map of the World» (FAO-Unesco 1974, 1976), la coordination du projet fut confiée à Luis Bramão (pédologue portugais) dans la période 1961-1968, qui a également intégré le Conseil consultatif dudit projet. Parmi les scientifiques participant à ce projet figurent les pédologues portugais de la «Junta de Investigações do Ultramar» (JIU) et de l'«Instituto de Investigação Agronómica de Moçambique», avec au premier plan J.V. Botelho da Costa, Ario L. Azevedo, R. Pinto Ricardo et E.P. Cardoso Franco (Angola), A.J. da Silva Teixeira (Guinée-Bissau), D.H. Godinho Gouveia et Ario L. Azevedo (Mozambique) et J. Carvalho Cardoso (São Tomé et Príncipe).

Fréquemment la cartographie pédologique fut suivie par la réalisation de cartes d'interprétation visant des objectifs agricoles précis ou des objectifs simples de nature agraire générale ou, alors, une finalité plus large de l'établissement de plans de développement territorial. En plusieurs occasions, toutefois, il n'y a pas eu véritablement d'élaboration de ces cartes mais des unités pédologiques qui furent interprétées et redéfinies en tenant compte de l'aspect pratique recherché.

Toujours sur la base des cartes pédologiques, on a établi des cartes d'interprétation, en partant des unités pédologiques respectives et en les interprétant dans un sens utilitaire déterminé — ou alors, comme alternative, seule la classification utilitaire des unités pédologiques a été effectuée sans l'expression cartographique correspondante —, avec une tendance à orienter ce travail surtout dans les domaines suivants: aptitude culturale (par exemple pour les cultures du riz, du blé, du maïs, des arbres fruitiers, du cacaoyer, du caféier, du cocotier, de la canne à sucre, du bananier, du cotonnier, de la plante à thé, etc.), aptitude pour les cultures irriguées, capacité d'utilisation agricole, capacité productive de la terre, vocation agraire et forestière, etc. Il est évident que ces cartes ont toujours exigé un travail préliminaire de classification et de caractérisation des unités-terre respectives établies selon leur vocation, aptitude, capacité de production, etc., relativement à certaine culture (ou certaines cultures), domaine agraire ou quelque autre finalité.

Comme les cartes pédologiques, les cartes d'interprétation de la carte pédologique existent en assez grand nombre et concernent toutes les ex-colonies. Donnons ici quelques exemples: sur l'aptitude culturale: SILVA (1956, 1960), COSTA *et al.* (1956a, 1959e), SOUTO (1968), GASPAR *et al.* (1969), CONSTANTINO (1973a, 1974b), CARDOSO (1974); en ce qui concerne l'aptitude pour l'irrigation: COSTA *et al.* (1951), COSTA & AZEVEDO (1954), COSTA *et al.* (1954), RAMOS (1963), DINIZ (1965), FARIA (1968), FERNANDES (1969), CONSTANTINO (1971); relativement au classement des terres, à la capacité productive de la terre ou à la capacité d'utilisation agricole: CICA (1955), SILVA (1958a), CONSTANTINO (1964, 1973b), CASIMIRO (1969), MPAM (1974), DINIZ (1991), DINIZ & MATOS (1986), DINIZ & AGUIAR (1998); en correspondance avec la vocation agraire et forestière: CONSTANTINO (1970).

En ce qui concerne la physique du sol, les études ont été principalement dirigées sur les chapitres de la structure et de l'eau, tant au point de vue scientifique pur que sur leurs relations avec les plantes cultivées. Citons dans ce domaine les recherches surtout effectuées et orientées par J.V. Botelho da Costa, J.F. Casimiro et A. Antunes da Silva; voici quelques références: COSTA & MACEDO (1955), SILVA (1958b), FERRINHO (1960), ALMEIDA (1961), SOUSA (1961), COSTA & SOUSA (1961, 1962), LEITAO (1964), SILVA (1967, 1969, 1971), CASIMIRO (1971), SERRANO (1972) et FRANCO (1982).

Parmi les travaux de chimie du sol se distinguent ceux relatifs à deux lignes principales de recherche: une portant sur la matière organique du sol et l'autre sur le phosphore du sol; on citera aussi des études sur les oligo-éléments, l'azote, le potassium et le soufre. Dans le domaine de la chimie se sont distingués L.A. Valente Almeida, R. Pinto Ricardo, J. Bastos Macedo, E.P. Cardoso Franco et J. Montalvão Marques.

Une ligne de recherche concernant la matière organique des sols tropicaux a été initiée en 1950 par R. Pinto Ricardo (citons: RICARDO 1951, 1961, 1968a, b; ALMEIDA & RICARDO 1954; FRANCO *et al.* 1998) portant surtout sur le fractionnement et la caractérisation de la matière organique de divers types de sols, en particulier des sols ferrallitiques; elle incluait également l'étude de la fraction des acides humiques de quelques-uns des principaux types de sols d'Angola, et particulièrement sur les aspects suivants: propriétés optiques, composition élémentaire, capacité d'échange cationique, divers paramètres physiques et susceptibilité à la floculation. Ces études ont eu un impact très grand dans l'approfondissement des connaissances sur ce type de constituant des sols, comme on peut justement en conclure des nombreuses références faites dans la bibliographie pédologique.

Les études concernant le phosphore du sol ont porté sur les thèmes suivants: les méthodes de dosage du phosphore total et assimilable, le fractionnement du phosphore du sol, le rôle du phosphore dans les sols, les mécanismes de sa rétention par les oxydes de fer et d'aluminium du sol. Exemples de références: ALMEIDA & MIRANDA (1954), MACEDO (1955, 1960, 1964, 1968), COSTA (1957), AZEVEDO & GOUVEIA (1957), ALMEIDA *et al.* (1958), FRANCO & POVOAS (1959), REFFEGA (1960), RODRIGUES (1961), VICENTE & CARDOSO (1975).

La recherche sur les oligo-éléments a commencé en 1956 dans les sols d'Angola (FRAGOSO 1959). Malheureusement, cette ligne n'a eu qu'un développement très limité (PINHEIRO 1970, SILVA 1974). Quelques études ont été effectuées pour l'azote et le potassium — par exemple: MARQUES (1965), CASIMIRO (1967), COELHO (1968), ALMEIDA *et al.* (1968, 1969), MARQUES (1969, 1973-1974), GONCALVES (1972b) et GAMA (1974).

L'étude de la minéralogie du sol — ligne de recherche introduite au Portugal par J. Bastos Macedo, et qui a eu comme autres chercheurs principaux A.F.A. Sanches Furtado, António A.G. Réffega et J.C. Soveral Dias — a porté principalement sur les méthodes de caractérisation minéralogique des sols, la minéralogie des fractions d'argile, de limons et des sables, le rôle physico-chimique de l'argile dans le sol, la genèse des minéraux constitutifs de l'argile et la minéralogie des sols *versus* l'altération des roches. Citons par exemple: MACEDO (1948), DIAS (1959), DIAS *et al.* (1959b), POVOAS & MACEDO (1959a, b), PACHECO (1962), FURTADO & PORTAS (1964), PORTAS &

Furtado (1964a, b), Pissara *et al.* (1965), Furtado (1965, 1968a, b, 1973, 1974), Reffega (1971, 1973), Pinilla & Reffega (1972), Fernandes & Reffega (1973) et Pascual & Reffega (1973a, b).

On doit rapporter, à propos de la minéralogie du sol, que le travail de J. Bastos Macedo, présenté à la Conférence africaine des Sols (Macedo 1948), a eu un certain caractère de pionnier: il est question d'une étude de la composition de l'argile des sols d'Angola selon une méthode qui, jusque-là, n'avait jamais été appliquée aux sols du territoire africain. Les scientifiques de l'INEAC, J. L. D'Hoore et J. Fripiat (*Bulletin Agricole du Congo Belge*, XL (1), p. 1026, 1949, Bruxelles) ont salué cette innovation en affirmant que «les méthodes employées se révèlent intéressantes» et ont manifesté personnellement à J.V. Botelho da Costa leur intention d'étudier l'application de la même méthode aux sols de l'ex-Congo belge.

Par ailleurs, Ario L. Azevedo et J.V. Botelho da Costa (Azevedo & Costa 1954) sont parmi les premiers scientifiques à signaler la présence de la montmorillonite dans les Sols et Argiles Noirs Tropicaux et Subtropicaux d'Afrique, dans les études qu'ils ont effectuées sur les terres noires d'Angola. Ces mêmes études ont également montré que la répartition des terres noires en Angola était bien différente de celle décrite par Marbut (Shantz & Marbut 1923) dans sa Carte des Sols d'Afrique (première carte des sols de ce continent). D'ailleurs, on a vérifié semblable situation à propos de la carte de sols de Schokalsky (1944).

De plus, les travaux de L.A.Valente Almeida et R. Pinto Ricardo (Almeida & Ricardo 1954), ainsi que de J. Bastos Macedo et collaborateurs (Dias *et al.* 1959a), ont conduit à la conclusion que les Sols et Argiles Noirs Tropicaux et Subtropicaux étaient très pauvres en matière organique, ce qui impliquait que la couleur foncée ne pouvait résulter de la quantité de matière organique mais plutôt de leur nature liée à d'autres causes, en particulier les quantités et les formes du fer et du manganèse présents dans les sols.

Quant aux domaines de nutrition des plantes, fertilité du sol et leur amélioration (fertilisation), les lignes principales de recherche développées par les pédologues portugais surtout en rapport avec les sols ferrallitiques, paraferrallitiques et fersiallitiques tropicaux ont été les suivantes: questions générales de la fertilité du sol (par exemple: Dias 1962; Moreira 1964; Cardoso 1967, 1969; Cardoso *et al.* 1974, 1981), prospection de carences ou d'excès de plusieurs éléments minéraux par l'entremise de diverses techniques de diagnostic, en particulier les essais en pot et les tests microbiologiques (par exemple:

CONTREIRAS *et al.* 1960; MOREIRA 1963; XABREGAS 1966; FREMOND 1967; CARDOSO & MARIANO 1968c; CARDOSO *et al.* 1968d; CARDOSO *et al.* 1970; GOUVEIA 1970; GONCALVES *et al.* 1972, 1980; GONCALVES & CARDOSO 1979a, b; GONCALVES *et al.* 1979c; CARDOSO 1981), sélection et étalonnage de méthodes pour le dosage des formes assimilables des éléments nutritifs (par exemple: COSTA 1957, AZEVEDO & GOUVEIA 1957, CUNHA & LOPES 1960, CASIMIRO 1967, COELHO 1968, GONCALVES 1972b), dynamiques du phosphore et du potassium dans le sol (par exemple: SANTOS 1967, HENRIQUES & CARDOSO 1969, SANTOS & VICENTE 1975), problèmes de la nutrition minérale et de la fertilisation de différentes cultures — caféier, cacaoyer, canne à sucre, bananier, riz, maïs, blé, etc. — relatifs surtout au diagnostic de l'état de nutrition des plantes et à leur rapport avec la fertilité et autres caractéristiques du sol, au rythme d'absorption des éléments nutritifs et au niveau d'éléments nutritifs minéraux et organiques en divers types de sols (par exemple: BARBOSA 1949; AZEVEDO 1952; CONTREIRAS *et al.* 1959; ALMEIDA & BALBINO 1960; CARDOSO & BOROUGHS 1960; CARDOSO 1961, 1966; MILHEIRO 1964; MARIANO 1965; CARDOSO & MARIANO 1968a, b; MARQUES 1969, 1970, 1971; DIAS 1971; GONCALVES *et al.* 1978, 1983; GONCALVES & CARDOSO 1980). Les chercheurs principaux dans ces domaines ont été A.P. Silva Cardoso, J.C. Soveral Dias, Tomaz J.S. Moreira, M. Mayer Gonçalves et Domingos B. Mariano.

Quelques travaux également importants ont été réalisés dans des domaines moins étudiés que les précédents: ceux de la pédogenèse (par exemple: MACEDO 1954, FRANCO 1968, CASIMIRO 1968a, REFFEGA 1972b, BENAYAS & REFFEGA 1973, RICARDO *et al.* 1974, SOUSA 1976, RICARDO *et al.* 1980), de la dégradation, la conservation et la récupération des sols (par exemple: COSTA 1950; CASTRO 1951; AZEVEDO 1953; SALBANY 1953, 1959; HENRIQUES 1954; COSTA *et al.* 1954b; RAMOS 1964; GRILO 1970), de la technologie générale du sol (par exemple: COUTINHO 1948, AZEVEDO 1954a, GONCALVES 1972a) et des latérites (par exemple: COSTA 1954d, CARVALHO 1961, FURTADO & MARQUES 1968, MARQUES 1974).

Rapportons à ce propos que dans le traité «An African Survey revised 1956» (HAILEY 1957), il y a des références aux problèmes de conservation du sol en Angola, tenant compte du travail d'Ario L. Azevedo sur le sujet (AZEVEDO 1953). Dans ce même ouvrage, d'autre part, on trouve l'affirmation que «Portuguese soil scientists also have done much work recently in Angola and Mozambique especially in relation to the possibilities of irrigation».

Pour terminer, nous devons affirmer que, parmi les pédologues portugais, l'un d'entre eux s'est particulièrement distingué: J.V. Botelho da Costa, à qui nous rendons hommage. Le mérite de J.V. Botelho da Costa avait d'ailleurs été reconnu très tôt par la communauté scientifique internationale, puisque lors du Quatrième Congrès international de la Science du Sol (Amsterdam, 24 juillet – 1er août 1950) l'Assemblée générale de l'Association internationale de la Science du Sol l'a nommé Vice-Président de la Commission VI (Technologie du Sol) pour la période 1950-1954, puis lors du Cinquième Congrès (Léopoldville, 16-23 août 1954), Président de cette même Commission pour la période 1954-1956. Il a par ailleurs été choisi comme un des vice-présidents d'honneur de ce même Congrès et invité à prononcer l'une des conférences générales: «Aspects des relations sol-eau-plante» (COSTA 1954c). Ces distinctions sont en même temps la reconnaissance, par la communauté scientifique internationale, de l'activité scientifique développée jusque-là par les Portugais dans les domaines des sols tropicaux.

J.V. Botelho da Costa, à juste titre, doit être regardé comme l'introducteur au Portugal de la Science Pédologique, grâce à son travail présenté en 1932 sur «Os novos conceitos da ciência do solo e o seu valor para a agronomia» (COSTA 1932), dans lequel le sol était considéré pour la première fois au Portugal d'après les principes établis par Dokuchaiev. De la même façon, il doit être vu comme le père de la Science du Sol Tropicale Portugaise, puisqu'il a été l'initiateur dans le pays de l'étude systématique et approfondie des sols tropicaux avec sa «Missão Agrológica» en Angola au cours de l'année 1946.

Nous ne pouvons que déplorer son décès prématuré en 1965 (il n'avait que 55 ans), alors qu'il aurait pu encore contribuer énormément au progrès de la Science du Sol en général, et de la Science du Sol Tropicale en particulier.

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Tropical Soils in the Classification Systems of USDA, FAO and WRB

by

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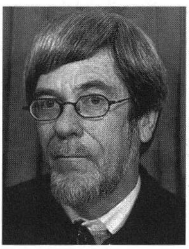

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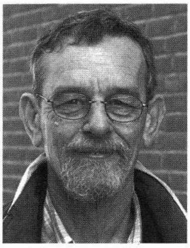

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KEYWORDS. — WRB; Tropics; Soil Classification; Soil Taxonomy; FAO.

SUMMARY. — This contribution aims at providing insight in the classification of soils in the tropics in the three most commonly used classification systems: USDA–Soil Taxonomy, the Legend of the FAO Soil map of the world, and World Reference Base for Soil Resources (WRB). The historical evolution of the three systems in highlighted to explain parallels and differences in the classification approach, with particular attention to soils in the tropics. An attempt is finally made to correlate Soil Taxonomy with FAO-WRB.

TREFWOORDEN. — WRB; Tropen; Bodemclassificatie; *Soil Taxonomy*; FAO.

SAMENVATTING. — *Tropische bodems in de classificatiesystemen van USDA, FAO en WRB.* — Deze bijdrage beoogt inzicht te geven in de classificatie van bodems in de tropen in de drie meest gebruikelijke bodemclassificatiesystemen; USDA-*Soil Taxonomy*, de Legende van de FAO-Wereldbodemkaart, en de *World Reference Base for Soil Resources (WRB)*. De historische evolutie van de drie systemen wordt toegelicht om gelijkenissen en verschillen te verklaren, met speciale aandacht voor bodems in de tropen. Tot slot wordt er gepoogd een correlatie te maken tussen *Soil Taxonomy* en FAO-WRB.

MOTS-CLES. — WRB; Tropiques; Classification du sol; *Soil Taxonomy*; FAO.

RESUME. — *Sols tropicaux dans les systèmes de classification USDA, FAO et WRB.* — Cette contribution a pour but de comprendre la classification des sols sous les tropiques dans les trois systèmes de classification des sols les plus utilisés: USDA-*Soil Taxonomy*, la Légende de la mappe du monde du sol de la FAO et la *World Reference Base for Soil Resources (WRB)*. L'évolution historique de ces trois systèmes est expliquée afin d'éclaircir les ressemblances et les différences, en mettant l'accent sur les sols sous les tropiques. Pour terminer, une tentative de corrélation entre *Soil Taxonomy* et FAO-WRB sera établie.

1. Introduction

Soil is a three-dimensional body with properties that reflect the impact of (1) climate, (2) vegetation, fauna, man, (3) relief, and (4) parent material over a variable (5) time span. The nature and relative importance of each of these five "soil-forming factors" vary in time and in space. With few exceptions, soils are still in a process of change; their "soil profile" shows signs of differentiation or alteration of the soil material incurred in a process of soil formation or "pedogenesis" (FAO *et al.* 2001).

The many soil classification schemes developed over the years reflect different views held on concepts of soil formation and mirror differences of opinion about the criteria to be used for classification. In the 1950s, international communications intensified while the number of soil surveys increased sharply both in temperate regions and in the tropics. The experience gained in those years and the exchange of data between scientists rekindled interest in (the dynamics of) the world's soil cover. Classification systems were developed, which aimed at embracing the full spectrum of the soil continuum. In addition, emphasis shifted away from the genetic approach, which often contained an element of conjecture, to the use of soil properties as differentiating criteria. By and large, consensus evolved as to the major soil bodies, which needed to be distinguished in broad-level soil classification although differences in definitions and terminology remained.

In 1998, the International Union of Soil Sciences (IUSS) adopted the "World Reference Base for Soil Resources" (WRB) as the Union's system for soil correlation. The structure, concepts and definitions of the WRB are strongly influenced by the legend of the FAO-Unesco 1/5,000,000 Soil Map of the World (FAO 1974; FAO-Unesco-ISRIC 1988, 1990), which in turn borrowed the diagnostic horizons and properties approach from USDA Soil Taxonomy (Soil Survey Staff 1999). At the time of its inception, the WRB proposed 30 "Soil Reference Groups" accommodating more than 200 (second-level) "Soil Units".

The purpose of this paper is to reflect on differences and highlight parallels between WRB and Soil Taxonomy in their present state-of-the-art with special emphasis on soils in the tropics.

2. Historical Perspective

2.1. Soil Taxonomy (Soil Survey Staff 1999)

A first major milestone for Soil Taxonomy in the tropics was the 5th ISSS World Soil Congress in Leopoldville, in 1954, where the 3rd Approximation was launched. That same year European scientists had their input in Soil Taxonomy in Ghent, hosted by the late prof. R. Tavernier, and the 4th Approximation took shape. Two years later, in 1956, the 5th Approximation was presented at the 6th ISSS Congress in Paris. In 1957 the 6th Approximation was elaborated upon in Ghent (Belgium) with strong involvement of Belgian soil scientists. Among other scientists R. Tavernier and V. Leemans contributed considerably to the linguistic aspects of Soil Taxonomy. At the 7th ISSS World Soil Congress in Madison, in 1960, a finalized fully fledged and tested Soil Taxonomy was launched as the so-called Seventh Approximation. Since then, Soil Taxonomy has further been tested and elaborated upon through the action of a number of international committees (ICOM's). The following ICOM's were dealing with soils of the tropics: low activity clays (ICOMLAC) (supervision Frank Moorman); Oxisols (ICOMOX) (Stan Buol); Vertisols (ICOMERT) (Juan Gomerma); Aridisols (ICOMID) (Ahmed Osman); Andisols (ICOMAND) (Mike Leamy); Aguic Moisture Regimes (ICOMOD) (supervision Johan Bouma). Based on the recommendations of the ICOM's, Soil Taxonomy was subject to regular revisions which were published as the well-known "Keys to Soil Taxonomy" by the Soil Survey Staff (Soil Survey Staff 1999).

A major challenge for Soil Taxonomy in the tropics was to come to grips with all the work Belgian soil scientists were doing in Central Africa (D'Hoore 1965, Sys 1960, Van Wambeke *et al.* 1956, D'Hoore 2003). The Belgian team working under INEAC developed their own legend for the soil maps, the insights of which were at the base of diagnostic horizon adopted in Soil Taxonomy and in WRB to accommodate soils of the tropics. For example, the Ferrisols were taken up on Kandiudults in Soil Taxonomy and as Nitisols in WRB.

2.2. World Reference Base (FAO *et al.* 1998)

World Reference Base is the successor of the International Reference Base for Soil Classification (IRB), an initiative of FAO, supported by the United Nations Environment Programme (UNEP) and the International Society of Soil Science (ISSS), dating back to 1980. The intention of the IRB project was to work towards the establishment of a framework through which existing soil classification systems could be correlated and through which ongoing soil classification work could be harmonized (DUDAL 1996). An important consultation on IRB was convened in Montpellier, France, in 1992, in order to take stock of the current status of the IRB in the light of the discussions held at the 14th ISSS Congress of Kyoto (1990) (FAO *et al.* 1994). The wise decision was taken that the IRB should adopt FAO's Revised Legend for its future activities. It would be IRB's task to apply its principles of definitions and soil relationships to the existing FAO units, providing greater depth and background. The merger of the two efforts was launched under the name: "World Reference for Soil Resources", undertaken by ISSS, FAO and ISRIC.

A draft document of the WRB soil correlation system was published at the 15th World Congress of Soil Science in Acapulco, Mexico, in 1994 (FAO *et al.* 1994). In 1998, the finalized WRB soil correlation system was presented at the 16th ISSS Congress as the World Soil Resources Report no. 84 (FAO *et al.* 1998). WRB was adopted by the congress as its system for international soil correlation. Now WRB has been translated and is used in 10 languages. At the 17th World Congress of Soil Science, a new publication "The Major Soils of the World" (FAO *et al.* 2001), was presented along with the CD ROM on WRB (FAO *et al.* 2002). Both publications are targeted for students in soil science and provide background information on the 30 Reference Groups of WRB over the world.

3. Definition of the "Tropics"

WRB and USDA Soil Taxonomy follow different definitions of the "Tropics". One of the principles of WRB is to avoid the use of climatic criteria in soil classification, so strictly speaking there are no tropics or other climatic zones recognized in WRB. However, it is suggested by WRB to use the principles of the FAO agro-ecological zones project (FAO 1979) for climatic zonification. According to this method, the tropics are those areas where mean temperatures adjusted at sea level of all months are more than 18 °C.

Soil Taxonomy classifies soil climates, that is temperature and soil moisture at a depth of 50 cm. In Soil Taxonomy soil temperatures are considered as tropical when the difference between mean summer and winter temperatures at 50 cm depth is less than 5 °C, the so-called ISO thermal regimes. As for most places on earth, soil temperatures are not available, the isolines of 7 °C difference between mean summer and mean winter air temperatures are taken to calculate the tropics.

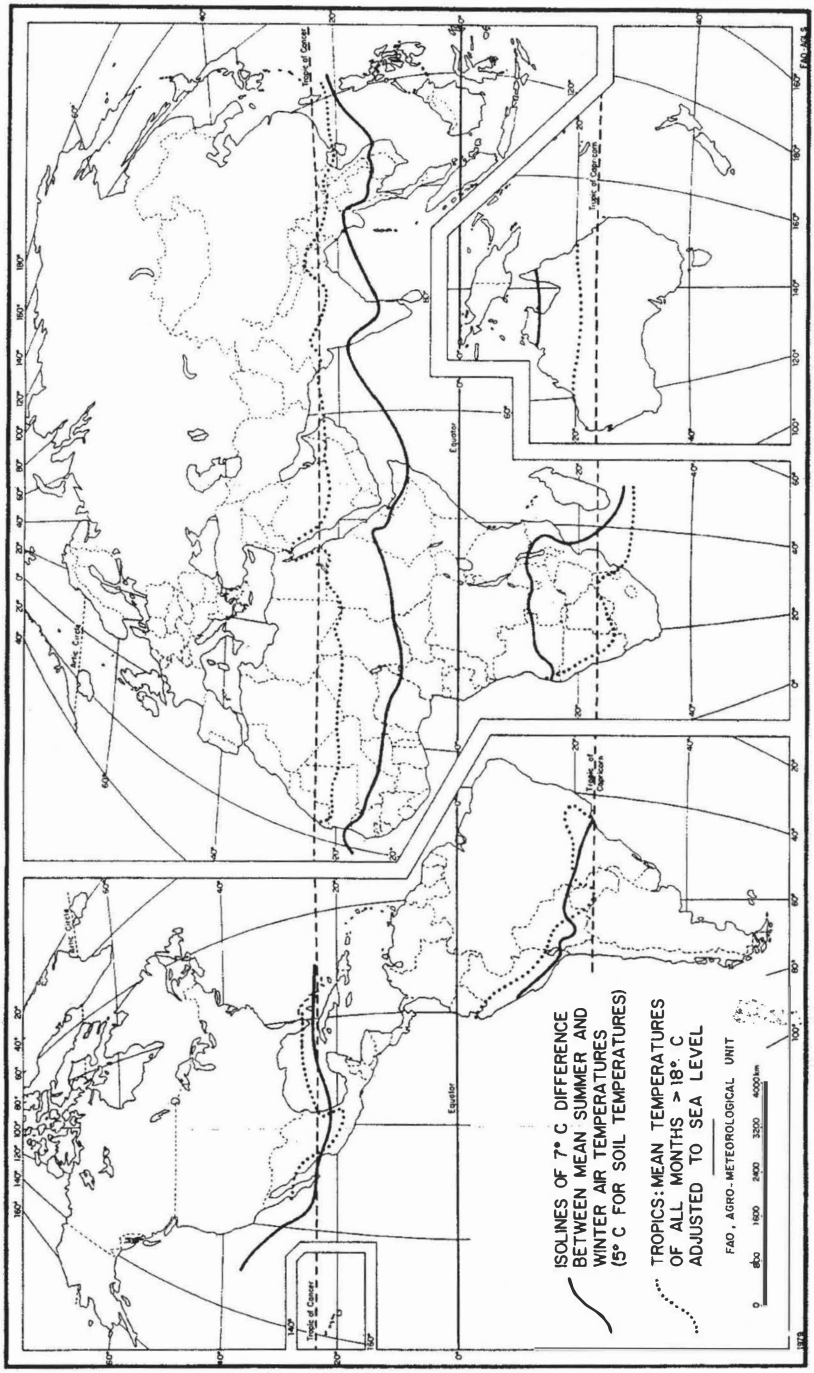

Fig. 1. — Characterization of the tropical environment according to isotemperatures or mean monthly temperatures.

Figure 1 compares the extent of the tropics according to FAO and Soil Taxonomy. It can be concluded that Soil Taxonomy is more stringent in its definition of the tropics, resulting in a much larger area considered as tropical in FAO terms especially in Africa, Asia and Australia. The correlation between both systems is fairly good in Central and South America.

4. Diagnoses used in WRB and Soil Taxonomy

The taxonomic units of the WRB and Soil Taxonomy are defined in terms of measurable and observable "diagnostic horizons", the basic identifiers in soil classification. Diagnostic horizons are defined by (combinations of) characteristic "soil properties" and/or "soil materials".

Soil characteristics are single parameters which are observable or measurable in the field, laboratory, or can be analysed by using microscope techniques. They include characteristics such as colour, texture and structure of the soil, features of biological activity, arrangement of voids and pedogenetic concentrations (mottles, cutans, nodules, ...) as well as analytical determinations (soil reaction, particle-size distribution, cation-exchange capacity, exchangeable cations, amount and nature of soluble salts, ...).

Soil properties are combinations ("assemblages") of soil characteristics which are known to occur in soils which are considered to be indicative of present or past soil-forming processes (*e.g.* vertic properties are a combination of heavy texture, smectitic clay mineralogy, gilgai, slikensides, hard consistency when dry, sticky consistency when wet, shrinking when dry and swelling when wet).

Soil horizons are three-dimensional pedological bodies which are more or less parallel to the earth's surface. Each horizon is characterized by one or more properties, occurring over a certain depth, with a certain degree of expression.

Reference Groups are defined by a vertical combination of horizons within a defined depth, or by the lack of them.

For the sake of example, diagnostic horizons, properties and materials and a selection of qualifiers that are used to differentiate between Reference Soil Groups in WRB are summarized in tables 1, 2, 3 and 4.

Note that the generalized descriptions of diagnostic horizons, properties and soil materials given in tables 2, 3 and 4 are solely meant as an introduction to WRB terminology. For exact concepts and full definitions reference is made to FAO Soil Resources Reports no. 84 (FAO/ISRIC/ISSS 1998).

Table 1

A Sample of Diagnostic Horizons in WRB

Surface horizons	
Anthropogenic horizons	surface and subsurface horizons resulting from long-continued "anthropedogenic processes", notably deep working, intensive fertilization, addition of earthy materials, irrigation or wet cultivation.
Histic horizon	(peaty) surface horizon, or subsurface horizon occurring at shallow depth, consisting of organic soil material.
Umbric horizon	well-structured, dark surface horizon with low base saturation and moderate to high organic matter content.
Yermic horizon	surface horizon of rock fragments ("desert pavement") usually, but not always, embedded in a vesicular crust and covered by a thin aeolian sand or loess layer.
Subsurface horizons	
Cryic horizon	perennially frozen horizon in mineral or organic soil materials.
Duric horizon	subsurface horizon with weakly cemented to indurated nodules cemented by silica (SiO_2) known as "durinodes".
Fragic horizon	dense, non-cemented subsurface horizon that can only be penetrated by roots and water along natural cracks and streaks.
Vertic horizon	subsurface horizon rich in expanding clays and having polished and grooved ped surfaces ("slickensides"), or wedge-shaped or parallelepiped structural aggregates formed upon repeated swelling and shrinking.

Table 2

Descriptive Summary of Sample Diagnostic Properties in WRB

Albeluvic tonguing	iron-depleted material penetrating into an argic horizon along ped surfaces.
Alic properties	very acid soil material with a high level of exchangeable aluminium.
Permafrost	indicates that the soil temperature is perennial at or below 0 °C for at least two consecutive years.
Stagnic properties	visible evidence of prolonged waterlogging by a perched water table.

Table 3

Descriptive Summary of Sample Diagnostic Materials in WRB

Anthropogenic soil material	unconsolidated mineral or organic material produced largely by human activities and not significantly altered by pedogenetic processes.
Organic soil material	organic debris, which accumulate at the surface and in which the mineral component does not significantly influence soil properties.
Sulfidic soil material	waterlogged deposit containing sulphur, mostly sulphides, and not more than moderate amounts of calcium carbonate.
Tephric soil material	unconsolidated, non or only slightly weathered products of volcanic eruptions, with or without admixtures of material from other sources.

Table 4
Sample of WRB Qualifiers and their Definitions

Examples of unique qualifier definitions:	
Carbi-	having a cemented *spodic* horizon which does not contain enough amorphous iron to turn redder on ignition *(in Podzols only).*
Carbonati-	having a soil solution with pH > 8.5 (1:1 in water) and $HCO_3 > SO_4 > Cl$ *(in Solonchaks only).*
Chloridi-	having a soil solution (1:1 in water) with $Cl > SO_4 > HCO_3$ *(in Solonchaks only).*
Cryi-	having a *cryic* horizon within 100 cm of the soil surface.

5. Key to the Reference Groups (WRB) and to the Orders (Soil Taxonomy)

As shown in tables 5 and 6, both WRB and Soil Taxonomy classification systems are making use of a key to classify the soils of the universum. WRB comprises 30 Reference Soil Units whereas in Soil Taxonomy the key counts 12 Soil Orders. In WRB the idea is to reflect the major soils of the world at the highest level in the Reference Groups, whereas the 12 Soil Orders of Soil Taxonomy represent the major soil regions of the USA.

The tropical environment is covered in WRB by the following Reference Groups, although these groups do not always exclusively occur in the tropics: Histosols, Vertisols, Solonchaks, Gleysols, Andosols, Plinthosols, Ferralsols, Solonetz, Planosols, Gypsisols, Durisols, Calcisols, Alisols, Nitisols, Acrisols, Lixisols, Arenosols and Regosols. Tropical soils in Soil Taxonomy comprise: Histosols, Andisols, Oxisols, Vertisols, Aridisols, Ultisols and Alfisols. By comparing these lists it becomes clear that some of the Soil Orders in Soil Taxonomy encompass several Reference Groups of WRB, *e.g.* the Aridisols in Soil Taxonomy correlate with the Solonchaks, Solonetz, Gypsisols, Calcisols, Durisols, Arenosols and Regosols in WRB.

6. Lower Categorical Levels in WRB and in Soil Taxonomy

6.1. WRB

The WRB comprises two tiers of detail (Nachtergaele *et al.* 2000):

— The "Reference Base", which is limited to the first (highest) level, having 30 Reference Soil Groups;

Table 5
Simplified Key to the WRB Reference Groups

1	Organic matter > 40 cm deep	yes →	HISTOSOLS
2	Cyric horizon at < 100 cm depth	yes →	CRYOSOLS
3	Human modifications	yes →	ANTHROSOLS
4	Depth < 25 cm	yes →	LEPTOSOLS
5	> 35% clay vertic horizon	yes →	VERTISOLS
6	Fluvic materials	yes →	FLUVISOLS
7	Salic horizon	yes →	SOLONCHAKS
8	Gleyic properties	yes →	GLEYSOLS
9	Andic or vitric horizon	yes →	ANDOSOLS
10	Spodic horizon	yes →	PODZOLS
11	Plinthite or petroplinthite within 50 cm	yes →	PLINTHOSOLS
12	Ferralic horizon	yes →	FERRALSOLS
13	Natric horizon	yes →	SOLONETZ
14	Abrupt textural change	yes →	PLANOSOLS
15	Chernic or blackish mollic horizon	yes →	CHERNOZEMS
16	Brownish mollic horizon and secondary $CaCO_3$	yes →	KASTANOZEMS
17	Mollic horizon	yes →	PHAEOZEMS
18	Gypsic or petrogypsic horizon	yes →	GYPSISOLS
19	Duric or petroduric horizon	yes →	DURISOLS
20	Calcic or petrocalcic horizon	yes →	CALCISOLS
21	Argic horizon and albeluvic tonguing	yes →	ALBELUVISOLS
22	Argic horizon with $CEC_c > 24$, $Al_{sat} > 60\%$	yes →	ALISOLS
23	Argic and nitic horizons	yes →	NITISOLS
24	Argic horizon with $CEC_c < 24$, $BS < 50\%$	yes →	ACRISOLS
25	Argic horizon with $CEC_c > 24$, $BS > 50\%$	yes →	LUVISOLS
26	Argic horizon with $CEC_c < 24$, $BS > 50\%$	yes →	LIXISOLS
27	Umbric horizon	yes →	UMBRISOLS
28	Cambic horizon	yes →	CAMBISOLS
29	Coarse texture > 100 cm	yes →	ARENOSOLS
30	Other soils	→	REGOSOLS

(Each step 1–29: ↓ no → next step)

Table 6
USDA Soil Taxonomy — Key to the Soil Orders

1.	Gelisols	Frost within 1 m
2.	Histosols	Organic soils
3.	Spodosols	Spodic horizon
4.	Andisols	Volcanic materials
5.	Oxisols	Extreme weathering: oxic horizon
6.	Vertisols	Swell-shrink
7.	Aridisols	Arid moisture regime
8.	Ultisols	Argillic horizon and low-base status
9.	Mollisols	Mollic epipedon
10.	Alfisols	Argillic horizon and high-base status
11.	Inceptisols	Initial stage of profile development
12.	Entisols	Young soils

— The "WRB Classification System" suggesting combinations of adjectives to the Reference Soil Groups, which allows precise characterization and classification of individual soil profiles.

The most important innovation in the World Reference Base is the building-block approach. The building blocks are the uniquely defined qualifiers as described above. There are 121 of these, which compares favourably with the 152 different soil units in the Revised Legend of the FAO Soil Map of the World. A sample of qualifiers and their definitions is given in table 4.

Once the Reference Group is identified, the building blocks assembled as in the Ferralsol example below are used to define individual Soil Units.

To classify a Ferralsol one would go down the list of qualifiers (tab. 7) and note that qualifier #2 applies. Therefore, the soil is classified as a Geric Ferralsol. On the basis of available information on clay distribution (clay increase meets minimum specifications of an argic horizon) and base saturation (less than 50 % in at least part of the ferralic B horizon is available) (qualifier #9), one would further classify this soil as an Acri-Geric Ferralsol. If more than two qualifiers apply, these can be added between brackets behind the standard name. If, for instance, the Ferralsol discussed also features "strongly humic properties" (qualifier #14) and a dark red colour (qualifier #20), the soil would be named an Acri-Geric Ferralsol (Humic, Rhodic).

In addition to the unique qualifiers, an opportunity is created to indicate depth (from shallow to deep: Epi, Endo, Bathi) and intensity (from weak to strong: Proto, Para, Hypo, Ortho and Hyper) of features, which is important for management interpretations. In a Vertisol, one may indicate the occurrence of the calcic horizon within 50 cm from the surface by classifying the soil as Epicalcic Vertisol. In cases of polysequential soil profiles, the qualifiers Cumuli or Thapto can be used to indicate accumulation or burial.

For each Reference Soil Group a defined list of which qualifier is available, which suggests qualifier rankings as in the example given above. For a comprehensive list of the qualifiers reference is made to the FAO *et al.* 1998.

Table 7

Example of WRB Qualifier Use to Key out a Ferralsol

In Ferralsols the following qualifiers have been recognized so far (in ranking order):		
Strong expression qualifiers:		
1.	Gibbsic	having gibbsite layer within 100 cm
2.	Geric	having geric properties within 100 cm
3.	Posic	having a positive charge within 100 cm
Intergrade qualifiers (in the order of the key):		
4.	Histic	intergrade with Histosols reference soil group
5.	Gleyic	intergrade with Gleysols reference group
6.	Andic	intergrade with Andosols reference group
7.	Plinthic	intergrade with Plinthosols
8.	Mollic	intergrade with Phaeozems
9.	Acric	intergrade with Acrisols
10.	Lixic	intergrade with Lixisols
11.	Umbric	intergrade with Umbrisols
12.	Arenic	intergrade with Arenosols
Secondary characteristics – qualifiers directly related to diagnostic horizons, properties or soil materials:		
13.	Endostagnic	stagnic properties between 50 and 100 cm
14.	Humic	strongly humic properties
15.	Ferric	presence of a ferric horizon within 100 cm
Secondary characteristics – qualifiers not directly related to defined diagnostic horizons, properties or soil materials		
16.	Vertic	$ECEC_{clay}$ of less than 6 cmolc/kg
17.	Alumic	Al saturation (ECEC) of 50 % or more
18.	Hypereutric	having a base saturation of 80 % or more
19.	Hyperdystric	having a base saturation of less than 50 % in all parts between 20 and 100 cm and less than 20 % in some parts
Qualifiers related to soil colours:		
20.	Rhodic	ferralic horizon with hue redder than 5YR, etc.
21.	Xanthic	ferralic horizon with hue of 7.5YR or yellower, etc.
"Remaining characteristics" qualifier:		
22.	Haplic	other ferralic horizons

6.2. USDA Soil Taxonomy

USDA Soil Taxonomy is built up of 6 categorical levels as shown in table 8, which allow a very precise classification of a pedon, provided all the data are available which are referred to in the keys to the various classification tiers.

For tropical soils it is usually no problem to key out the soil order which in most cases is based on straightforward use of the diagnoses as explained for WRB. However, even at Soil Order level, soil moisture data are prompted for example to classify soils from arid tropical zones into the Aridisols. As from Suborder downward more climatological data are required which may present problems in those areas where weather data are scanty.

Table 8
USDA Soil Taxonomy Categorical Levels

1.	Order:	Originating from geographical soil region in the USA — diagnostic horizons *e.g. Alfisol from Pedalfer in SE USA*
2.	Suborder:	Commonly reflecting temperature and moisture regime *e.g. Aquox; Torrox; Ustox; Torrox* or reflecting other diagnoses: *e.g. Humus: Humult* *Texture: Psamment*
3.	Great Group:	Other diagnostic horizons *e.g. Kandic horizon: Kandiudox*
4.	Subgroup:	Inter- and extragrades *e.g. Intergrades: Kandiudalfic Eutroperox* *Extragrades: Rhodic Eutroperox*
5.	Family:	Texture class, mineralogy, temperature regime *e.g. Fine kaolinitic member of Isothermic Kandiudalfic Eutroperox*
6.	Series:	Place names

7. Match between WRB and Soil Taxonomy for Soils in the Tropics

As the approach to soil classification in WRB is different from Soil Taxonomy, it is logical that in the tropics a near-perfect correlation between the two systems is true for a few reference groups only: Histosols, Vertisols and Andosols (tab. 9). The match for the other tropical soils is only partly true (*pro parte*), *e.g.* the Nitisols of WRB may key out as Kandiudox or as Kandiudults depending on the CEC of the clay in the Kandic horizon.

Even though one could conclude from table 9 that international consensus on soil naming is growing, the match between WRB and Soil Taxonomy can only be partial for several reasons:

— In Soil Taxonomy, climatic factors are used to differentiate at Soil Order level (*e.g.* Gelisols, Aridisols) as indicated by "pp." (*pro parte*) in table 9. WRB avoids climatic criteria and argues that an overlay with precise climatic information (as result of modelling) may result into a more accurate analysis for the purpose of land evaluation.
— Another reason for the less than complete match between Soil Taxonomy and the WRB is that the WRB distinguishes 30 Reference Soil Groups at the highest categorical level whereas Soil Taxonomy differentiates between 12 Soil Orders. For instance the Mollisols of Soil Taxonomy cover the WRB Reference Soil Groups of the Chernozems, Phaeozems and Kastanozems, in addition to some of the Luvisols, Planosols and Solonetz.
— WRB uses only two categorical levels whereas Soil Taxonomy comprises 6 levels.
— WRB uses more diagnostic horizons, properties and materials than Soil Taxonomy.
— Though there is great similarity between names of diagnostic horizons in Soil Taxonomy and WRB, the differences are sometimes large (*e.g.* argic and salic horizons). WRB has made a special effort to simplify analytical requirements to classify soils. It should also be noted that WRB recognizes at the highest level processes such as prolonged hydromorphy or intense man-made changes, whereas these are recognized at second level in Soil Taxonomy.

Table 9

Match between WRB and Soil Taxonomy for Soils in the Tropics

Near-perfect match:

WRB (1998)	Soil Taxonomy (1998)
Histosols	Histosols
Vertisols	Vertisols
Andosols	Andisols

***Pro-parte* match:**

WRB (1998)	Soil Taxonomy (1998)
Ferralsols	Oxisols pp.
Nitisols	Oxisols – Kandiudox pp., Ultisols – Oxisols –
Plinthosols	Plinthaquox pp., Ultisols – Plinthudults pp.
Lixisols	Alfisols – Ustalfs pp., Udalfs pp.
Acrisols	Ultisols – Udults pp., Ustults pp.,
Alisols	Ultisols – Udults pp.
Gleysols	Inceptisols – Aquepts pp., Entisols – Aquents pp.
Planosols	Alfisols – Abruptic Albaqualf pp.
Solonchaks	Aridisols – Salorthids pp.
Solonetz	Aridisols – Natrargids pp.
Gypsisols	Aridisols – Gypsids pp.
Durisols	Aridisols – Durids pp.
Calcisols	Aridisols – Calcids pp.
Arenosols	Aridisols – Psamments pp.
Regosols	Entisols pp.

8. Conclusions

— Soils are keyed out in Soil Taxonomy and WRB based on objective diagnoses (horizons, properties, materials, etc.), resulting in reliable soil correlation.
— The match between Soil Taxonomy and WRB is only *pro-parte* as the two systems start from different classification strategies.
— Since 1998, FAO has adopted WRB as its system for the Soil Map of the World and the IUSS as its reference system for international soil correlation.
— Soil Taxonomy allows a rather precise wording of the taxa in a rigorous categorical system down to family level with climatic criteria at order and sub-order level.
— With its two-tier approach, WRB reaches a considerable level of accuracy. However, at most detailed level, there is a need to develop family criteria based on soil texture.
— As soil climate is imbedded in the highest levels of Soil Taxonomy, its application in many tropical countries is cumbersome for lack of data.
— WRB avoids climate as much as possible to differentiate soil taxa. Climate is used as overly to support applications of the soil maps.

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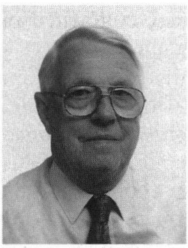
The Soil Map of Africa (1/5,000,000). Joint Project CCTA no. 11

by

Jules D'HOORE*



Prof. Jules D'Hoore (1917) began his overseas career in 1946 as a research assistant at the Agrology Division of INEAC in Yangambi (Belgian Congo). In 1949 he spent two months as a free researcher at the University of Madison (Wisconsin, USA) and in 1951 he took part in an extended West African Survey of laterization phenomena. In 1953 he obtained a PhD degree (Ghent University) with a thesis entitled: "The accumulation of free sesquioxides in tropical soils". In 1953 he was appointed Director of the Interafrican Pedological Service. He made frequent journeys throughout Africa and also travelled through tropical South America. In 1962 he was appointed Professor at the Catholic University of Leuven (Belgium) where he taught general soil science, soil genesis and soil geography. He also took part in a few evaluation missions in Africa and South East Asia. He was invited to several meetings and working sessions of NASA, ESA and EURATOM on the practicability of remote sensing for the identification and mapping of soils.

KEYWORDS. — Africa; CCTA; INEAC; Pedology; Soil Mapping.
SUMMARY. — The second Interafrican Soil Conference (Leopoldville, August 1954) made the Interafrican Pedological Service (IPS) responsible for the co-ordination of a new generalized soil map of Africa. The second meeting of the Administrative Council of IPS (Yangambi, November 1955) suggested a scale of 1/5,000,000. After intensification of contacts with possible collaborators the latter were asked to draw new generalized soil maps of the territories in which they were active. Parallel to this, IPS collected updated information on so-called soil-forming factors (lithology, geomorphology, climate, vegetation, age) and a hypothetical map was drawn of their presumed distribution. Concurrent with the acquisition of new data, this hypothetical map was corrected and gradually dressed up with the incoming new soil data. A first draft, covering Belgian Congo, Ruanda-Urundi, French Equatorial Africa and Cameroon, contiguous territories, was used in March

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1959 as a basic document in order to bring together the classification systems and map legends of ORSTOM and INEAC. Properly amended as a result of these discussions, this document was then extrapolated towards the West, the East and the South and resulted in a first Approximation of the new generalized map. It covered about the two thirds of the continent south of 20 ° northern latitude. A second and a third Approximation followed in quick succession after consultation with British, Portuguese, Rhodesian and South-African colleagues. The third Approximation was presented at the 7th International Soil Science Congress (Madison, Wisc., USA) in August 1960. July 1960 was rather difficult for the IPS. As a result of the disturbances following the independence of the Congo, the Research Centre of Yangambi, where IPS had its offices, was abandoned and the precious basic documentation of the map became inaccessible. In late September 1960 the IPS could resume part of its activities in Ghent and with the help of its correspondents it was possible to recompose the essential documents. In September 1961 a fourth Approximation was ready for evaluation. Definitions were refined, some units added in order to include soils situated to the north of the Sahara and a fifth and final version, completed in 1963, was published in 1964, together with an explanatory monograph.

TREFWOORDEN. — Afrika; CCTA; INEAC-NILCO; Pedologie; Bodemkartering.

SAMENVATTING. — *De bodemkaart van Afrika (1/5 000 000). Gezamenlijk project CCTA nr. 11.* — De tweede Interafrikaanse Bodemconferentie (Leopoldstad, augustus 1954) belastte de „Service Pédologique Interafricain" (SPI) met de coördinatie van een nieuwe veralgemeende bodemkaart van Afrika, en de Beheerraad van de SPI (Yangambi, november 1955) stelde een schaal van 1/5 000 000 voor. Eerst werd nader contact opgenomen met potentiële medewerkers en werd hen gevraagd nieuwe veralgemeende bodemkaarten te tekenen van de gebieden waar ze werkzaam waren. Tegelijkertijd verzamelde de SPI gegevens betreffende de zgn. bodemvormende factoren (lithologie, geomorfologie, klimaat, vegetatie, ouderdom van de afzettingen) teneinde een zeer hypothetische distributiekaart van deze factoren te schetsen. Deze kaart, voortdurend bijgewerkt naarmate nieuwe gegevens binnenkwamen, en aangekleed met bodemkundige gegevens, veranderde gaandeweg in een bodemkaart. Een eerste schets betrof de aaneenliggende gebieden Ruanda-Urundi, Belgisch Kongo, Frans Equatoriaal Afrika en Cameroun. Ze werd gebruikt als basisdocument op een werkvergadering te Brazzaville (maart 1959) waar gestreefd werd naar een correlatie tussen het Franse (ORSTOM) en het Belgische (INEAC) bodemclassificatiesysteem. Het resultaat was een geamendeerde bodemkaart die dan werd uitgebreid naar het westen, het oosten en het zuiden. Dit werd onze eerste Approximatie. Zij omvatte zowat de twee derden van het continent ten zuiden van de 20ste noordelijke breedtegraad. Deze eerste Approximatie werd vlug gevolgd door een tweede en een derde na grondig overleg met Engelse, Portugese, Rhodesische en Zuid-Afrikaanse collega's. De derde Approximatie werd voorgedragen op het 7de Internationaal Bodemkundig Congres te Madison (Wisconsin, USA) (augustus 1960). Juli 1960 was voor de SPI een zeer moeilijke periode. Ten gevolge van de ongeregeldheden waarmede de onafhankelijkheid van Congo gepaard ging, moest het Onderzoekscentrum van het INEAC te Yangambi, waar SPI gevestigd was, worden geëvacueerd en werd heel onze kostbare basisdocumentatie ontoegankelijk. Toch kon SPI vanaf eind september 1960 zijn werkzaamheden gedeeltelijk hervatten te Gent en dankzij de bereidheid van zijn correspondenten kon het essentiële van onze basisdocumentatie weer worden samengesteld. Eind september 1961 kwam een vierde Approximatie klaar, enkele definities werden bijgeschaafd, enkele eenheden toegevoegd om ook de bodems ten noorden van de Sahara op de kaart te kunnen zetten, en de 5de Approximatie, de definitieve, kon in 1964, samen met een uitgebreide, verklarende nota worden gepubliceerd.

MOT-CLES. — Afrique; CCTA; INEAC; Pédologie; Cartographie des sols.

RESUME. — *La carte des sols d'Afrique (1/5 000 000). Projet conjoint CCTA n° 11.* — La deuxième Conférence Inter-africaine des Sols (Léopoldville, août 1954) chargea le Service Pédologique Interafricain (SPI) d'entreprendre des travaux de coordination en vue d'établir une nouvelle carte généralisée des sols d'Afrique, et la deuxième réunion du Conseil d'Administration du SPI (Yangambi, novembre 1955) recommanda sa réalisation à l'échelle du 1/5 000 000. Après intensification des contacts avec ses futurs collaborateurs, le SPI leur demanda de dresser de nouvelles cartes des territoires où ils étaient actifs. Parallèlement, le SPI rassemblait des données récentes concernant les soi-disant facteurs pédogénétiques (lithologie, géomorphologie, végétation, climat, âge des recouvrements) en vue de dresser une carte hypothétique de leur distribution. Cette carte fut progressivement habillée de données pédologiques, nous parvenant avec les nouvelles cartes de sols. Une première esquisse de carte pédologique couvrait le Ruanda-Urundi, le Congo belge, l'Afrique-Equatoriale française et le Cameroun. Elle fut soumise comme document de travail en mars 1959 à une réunion tenue à Brazzaville en vue d'accorder les classifications belges et françaises (INEAC et ORSTOM). Le document amendé qui en résulta fut extrapolé ensuite vers l'ouest, l'est et le sud et devint la première Approximation de notre carte. Elle couvrait environ les deux tiers du continent au sud du 20^e parallèle nord. Elle fut rapidement suivie par une deuxième et une troisième Approximation après consultation avec nos collègues anglais, portugais, rhodésiens et sud-africains. La troisième Approximation fut présentée au 7^e Congrès international de la Science du Sol (août 1960) à Madison (Wisconsin, USA). Le mois de juillet 1960 fut très difficile pour le SPI. Le Centre de Recherches de Yangambi, où il était installé, fut évacué, suite aux troubles graves accompagnant l'accession du Congo à l'indépendance. Fin septembre 1960, le SPI put néanmoins reprendre certaines de ses activités grâce à l'hospitalité que lui accordait l'Université de Gand et à la diligence de ses correspondants qui lui permirent de reconstituer l'essentiel de sa documentation de base. Fin septembre 1961, une quatrième Approximation put être soumise pour avis; quelques définitions furent revisées, quelques unités ajoutées afin d'inclure les sols situés au nord du Sahara et la 5^e Approximation, définitive, fut achevée en 1963. En 1964, elle fut publiée, accompagnée d'un mémoire explicatif.

1. Introduction

This new generalized Soil Map of Africa, based more on surveyed facts than on theoretical deduction, was conceived in 1953 and published in 1964 (CCTA 1964a, b).

In these pre-satellite days several generalized thematic maps on various subjects were in preparation, all fitting well within the geopolitical framework prevailing at the time. The peculiarity of our project originated mainly from the fact that it embraced an entire large continent — 30 million km^2 — straddling the Equator and extending 35° of latitude both to the North and to the South. Moreover, it could take advantage of the substantial progress made during the previous decennium in matters of tropical and subtropical soil science. And last but not least, it was backed by an international organization (*Commission de Coopération Technique en Afrique*, CCTA) and could rely on the scientific and technical support of national and local agencies.

2. Geopolitical Context

We may refer here to the Conference of San Francisco (April-June 1945) at which the United Nations Organisation (UNO) was founded and its charter unanimously adopted by the then 50 member nations. Article 73 of Chapter IX of this Charter is headed by the following declaration: "Members of the United Nations which have or assume responsibilities for the administration of territories whose peoples have not yet attained a full measure of self-government recognise the principle that the interests of the inhabitants of these territories are paramount and accept as a sacred trust the obligation to promote to the utmost, within the system of international peace and security established by the present Charter, the well-being of the inhabitants of these territories".

And in paragraph d) of this same article it is further specified that the aforesaid members should to this end: "promote constructive measures of development, encourage research, cooperate with one another and, when and where appropriate, with specialised international bodies with a view to the practical achievement of the social, economic and scientific purposes set forth in this article".

This Charter, enforced in October 1945, gave soon rise to an increased solidarity between the European Nations involved in Africa, most of whom had already research facilities and expert personnel on the spot, whereas international bodies such as FAO were not yet operational. It should be noted that formal contacts concerning these co-operation matters already existed in 1945 between Great Britain and France and that in 1947 Belgium, Portugal, the Rhodesias and the Union of South Africa were included in their consultations.

Consequently, various interafrican co-operation projects were initiated, first modestly between adjacent countries, later on a larger scale and on specific subjects such as geology, climatology, phytogeography, medicine, agriculture, and soon the need arose for a co-ordinating body, the Scientific Council for Africa (*Conseil Scientifique Africain*, CSA). In 1950 all these activities were grouped under the auspices of an international organization, the Commission for Technical Co-operation in Africa (CCTA) which supervised Joint Projects, organized meetings, published documents and provided technical and financial assistance where needed. Its Headquarters were in London, its Secretary General being seconded by the French government.

3. Pedology: Interafrican Co-operation

The Belgian government took the initiative in matters of agriculture in which it had some renown. INEAC (*Institut National pour l'Etude Agronomique au Congo Belge*), its national institute for agricultural studies in the Belgian Congo, founded in 1933, was managing some twelve regional experimental stations, several plantations, and the well-known Research Centre of Yangambi. It had a staff of more than hundred European agents, half of them with university degrees. In February 1947 an "Agricultural week" was convened in Yangambi which was attended by representatives from almost every territory south of the Sahara. This rather successful convention was followed next year by the First Interafrican Soil Conference in Goma and at this Conference three Recommendations were formulated that would affect the future elaboration of our map (INEAC 1948).

The first recommended the founding of an interafrican information bureau on matters concerning the conservation and the utilization of African soils (BIS). It was installed in Paris in 1950, edited a newsletter and later a periodical bulletin, entitled *Sols Africains — African Soils.*

A second recommendation proposed the creation of a research unit, an Interafrican Pedological Service (*Service Pédologique Interafricain*, SPI) devoted to the characterization, classification and cartography of African soils. It was installed at the Yangambi Research Centre in 1953 and the author of this paper was entrusted with its direction.

And thirdly it was proposed to organize four Regional Committees for the Conservation and Utilization of Soils for the central, eastern, southern and western parts of the Continent and named CRACCUS (*Comité Régional de l'Afrique Centrale pour la Conservation et l'Utilisation des Sols*), EARCCUS (East African Regional Committee for the Conservation and Utilization of the Soils), SARCCUS (Southern African Regional Committee for the Conservation and Utilization of the Soils), and CROACCUS (*Comité Régional Ouest-africain pour la Conservation et l'Utilisation des Sols*).

These committees, which met at regular intervals, were started between 1953 and 1956 and became the essential links for BIS and SPI with the African agricultural reality.

4. Elaboration of the Map

The drafting of a new generalized soil map based on surveyed data was on the agenda of the inaugural Meeting of SPI's administrative Council in 1953. Though at first considered as a long-term proposal it gradually gained in importance due to the rapid development of tropical soil science at the time. Indeed the following year, at the second Interafrican Soil Conference (Leopoldville, August 1954), the SPI was asked to undertake the general co-ordination in order to establish such a map (CCTA 1954). At the second meeting of the SPI Council (November 1955) it was decided to start the work, at a scale of 1/5,000,000, in close collaboration with the Regional Committees.

4.1. Procedure

Before 1953 the Division of Agrology of INEAC, with which the IPS was closely connected, had already collected some soil maps of tropical regions, African and others. There were of course the generalized soil maps of Africa by Shantz & Marbut (1923) and Schokalskaya (1944), each at a scale of approximately 1/30,000,000. Both maps were rather theoretical, relying strongly on hypothetical climate distribution, and for our purpose their practicability was rather limited. Most of the other documents were land-use maps, several years old, covering rather small areas. Units were poorly defined according to very different criteria and common terms did not have everywhere the same significance. New partial maps were therefore most urgently needed.

SPI's first concern was to establish personal contacts with future collaborators and their institutions. Indeed most of the new information was to come to us through the authority of the latter, and more particularly through the French *Office de la Recherche Scientifique et Technique Outre-Mer* (ORSTOM), the "East African Agricultural and Forestry Research Organisation" (EAAFRO), the *Junta de Investigaçoes do Ultramar* (Pinto Ricardo & Reffega 2003), diverse Departments of Agriculture and INEAC.

As was mentioned before, our first objective was to promote the drafting of new generalized partial maps, preferably of entire territories. Our visits, which generally coincided with Meetings of Regional Committees and often included field excursions, enabled us to discuss the general pattern of the future map and the way we intended to proceed. Few suggestions were made as to the choice of mapping units, as we were almost sure that their agreement would be better than that on earlier maps. This was indeed confirmed though major differences did persist.

When field work can start with a legend composed of clearly defined units it is relatively easy to identify, to list, to delineate homogeneous areas and to transfer them to a map. We were of course not able to provide our collaborators with a general legend valid for the whole continent. On the contrary, our intention was to deduce such a legend from their partial maps. Our co-ordination role was to maintain an evolutive compromise between different cartographic classification systems, themselves often evolving in their own successive approximations. Moreover, this evolutive compromise had to take into account the fundamental theme of the Map, had to have a solid pedogenetic backing, though not entirely ignoring the economic potential of the soils. It had to be based primarily on the effects of soil-forming factors observable in the profiles.

In order to materialize the latter proposition, to visualize the concept, we drew a very hypothetical sketch of the geographical distribution of these soil-forming factors, and more especially of the presumed distribution of parent materials. Reminders of this preliminary sketch can still be recognized on the final draft: raw mineral soils, weakly developed soils, etc. Even the limit Savannah-Tropical rain forest has been recorded.

As a means to establish this presumed distribution, data on lithological rather than structural geology, data on geomorphologic elements that took account of the relative age of the "surfaces", and climatological and phytogeographical documents were assembled, the most recent at the time but undoubtedly all carrying some bold extrapolations. This hypothetical distribution map of soil-forming factors was to serve as a theoretical framework, as a background screen, that would gradually be amended and dressed up with incoming new soil data and thus transformed into a proto-soil map.

As could be expected, the juxtaposition of soil maps of different origins and their superposition on our hypothetical framework brought to light some incompatibilities. Some of these could easily be corrected such as the extension of alluvial deposits, but others, especially those due to terminology or unit definition, were more difficult to settle. Arbitrage generally led to revised definitions and to additional mapping units. And this had often its effect on other areas of the general map and led to major redesign. The promotion of agreements on definitions and the recurrent actualization of the map certainly were the most delicate and the most arduous portions of our task.

4.2. First Approximations

Towards the end of 1957, after two years of incubation, our project seemed sufficiently ripe to risk a first soil distribution sketch of some dimension. It covered the Belgian Congo, Ruanda-Urundi, French Equatorial Africa and Cameroon, adjoining territories of which we had good recent soil maps. The proposed legend listed 15 mapping units that were rather broadly defined. It was submitted as a working document at a meeting convened by the Regional Committee for Central Africa in Brazzaville in May 1958. A rather good correlation could be established between the French (ORSTOM) and Belgian (INEAC) legends and the result was an amended sketch with a legend comprising 21 units. This sketch was sent for critical review to the soil scientists who took part in the Brazzaville meeting.

From now onwards the scope of our project was expanded considerably. The area covered by the Brazzaville sketch extended from the southern border of the Sahara (Chad) to beyond the humid Congo basin to the South, and from the low Atlantic coast in the West to the mountainous centre of the continent. One could therefore assume that, allowing for some modifications and additions, the legend would be applicable to a much larger area. Taking into consideration the few new soil maps of adjoining areas that had become available in the meantime, a new sketch featuring 23 mapping units was drawn up, which covered some two thirds of the continent south of the 20th parallel north. It had been extended to French West Africa, Nigeria, Ghana, Sudan, Uganda, Kenya, Tanzania, Angola, Mozambique, Madagascar, The Rhodesias and the Union of South Africa. This was the first Approximation of our map.

Inevitably, due to its origin, this rather bold endeavour reflected more the French and Belgian concepts than those of British, Portuguese and South African soil scientists. Some fundamental discussions were therefore deemed essential and these took place at meetings organized by the Eastern and Southern African Committee in May 1959 in Kampala and in Pretoria. The constructive criticisms collected at these meetings, led to a number of corrections and additions, both to the legend and the spatial extension of the units. All this, added to the several new documents meanwhile received, amply justified a new design, the second Approximation of the map.

This map, whose legend now comprised 35 units, was submitted, together with a provisional explanatory notice, at the third and last Interafrican Soil Conference, convened by CCTA in Dalaba (Guinea) in November 1959 (CCTA 1959). In the course of this Conference, four working sessions were devoted to the elaboration of a third provisional legend that was extended to 45 units and was to be used for the establishment of a third Approximation. This increasingly detailed document was drafted at the SPI office in Yangambi during the months of January-February 1960. It was to be exhibited at the 7th International Soil Science Congress in Madison, Wisconsin, USA, in August 1960 (D'HOORE 1960a). At this same congress the US Department of Agriculture presented its "Soil Classification: a comprehensive system, 7th Approximation" (Soil Survey Staff 1960), a document that would have some impact on the future development of our legend.

All documents mentioned in this paragraph — texts as well as maps — were manuscripts. All were left behind in Yangambi when the research station was abandoned (see 4.3) with the exception of the third Approximation. Of the latter a simplified version (35 units, scale 1/25,000) was published (D'HOORE 1960b) and also some additional comments (D'HOORE 1960c).

4.3. Further Development and Completion

Departing for his triennial leave in Europe, and with the intent of presenting the third Approximation of the map at the Madison Congress, the SPI's Director took the original draft with him, ignoring that in doing this, he saved the precious document. Indeed the month of July 1960 was very difficult for the SPI, due to the grave disturbances following the accession of the Belgian Congo to its independence. Mr T.H. Paton, the recently arrived joint Director, installed in Yangambi only since January 1960 and who had been most helpful in the drafting of the 3rd Approximation of the map, had to be evacuated together with his family. Moreover, the Research Centre of Yangambi was abandoned and our precious basic documentation became inaccessible.

At the end of September 1960 the Director was able to take up his activities again, be it on a much reduced scale and confined essentially to the completion of the map, thanks to the hospitality of Ghent University. The diligence of SPI's correspondents allowed part of the documentation to be re-established, even additional new documents were acquired, and soon a fourth Approximation with a legend of 52 units could be prepared. It was presented at a meeting of soil scientists convened by CCTA at the BIS office in Paris in September 1961. This Approximation covered almost the whole continent south of the Sahara. At this meeting it was proposed to extend the map to the entire continent.

There were good maps available for Mauritania, Morocco, Tunisia, Spanish Guinea and Algeria. For the territories formerly under Italian administration we had some documents dating from before 1940. For Egypt we had the extent of the Nile alluvia and for the desertic parts we could rely on geological data. The legend had to be extended to 63 units and the map was redrafted at the University of Leuven (Belgium), the SPI having terminated by now its brief existence.

This fifth Approximation was submitted to a meeting convened by CCTA and FAO in May 1963, at the University of Lovanium (Kinshasa), and after some minor corrections and additions it was considered as definitive. The ex-Director of SPI was asked to write out the Explanatory Monograph and to produce the map. The latter, very technical portion of the task, was carried out in close co-operation with specialists of the Military Geographical Institute of Brussels. Finally the map, together with its Explanatory Monograph, in English and in French (CCTA 1964A, 1964b), was published in 1964 by CCTA (Lagos) which by then had become incorporated into the Scientific, Technical and Research Commission of the Organisation of African Unity (OAU). This publication was made possible by a grant from the U.S.A.I.D.

We also prepared a simplified version of the final draft for the Oxford regional Economic Atlas of Africa (D'HOORE 1965).

5. Epilogue

Our pragmatic approach, the only practicable in the given circumstances, certainly had its benefits. It was based on a profusion of survey data, not only of superficial characteristics, as can now be recorded by satellites, but also of profile characteristics. Even analytical data on selected horizons were available. Moreover, during the crucial period (1955-1960) when the new maps were prepared, most of sub-Saharan Africa was orderly and peaceful and field work could proceed in complete safety, and most institutions engaged in pedology had well-directed and well-equipped survey teams supported by reliable logistics.

Data communication and correlation on the other hand was subject to serious handicaps. The Research Centre of Yangambi where the SPI was residing had no telephone link with the outer world nor did many of our correspondents. All our communication had to be done, either by telegraph or through a weekly postal service. Most of the indispensable exchange of information had to be made through visits on the spot, which were generally most effective but involved long voyages and took much time.

The first satellite devoted to the observation of the terrestrial surface and available for civilian use — NASA's ERTS A — was put on orbit in July 1972. We never had the opportunity to utilize its multispectral images that could have been most useful, were it only to correct our theoretical frame or to back up certain extrapolations. Paradoxically however, the interaction occurred the other way round. Multispectral images from space were frequently compared with our map as many contrasting areas detected on these images coincided well with features we had recorded. Which certainly signifies that our collaborators had delivered a good piece of work! (D'HOORE 1976).

This brings me to reiterate my thanks to all who contributed in their various ways to the realization of the map. The legend printed on the map and prefacing the explanatory monograph lists some hundred names. Without their dedicated efforts throughout the varying fortunes and vicissitudes of the project, the final result could never have been attained.

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Qualitative and Quantitative Aspects of Soil Databases in Tropical Countries

by

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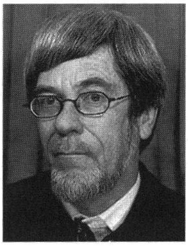

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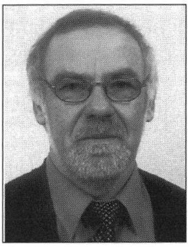

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KEYWORDS. — Soil Survey; Soil Databases; Quality of Soil Data; Quantity of Soil Data; Tropical Countries.

SUMMARY. — Over the last several years, pessimistic views have been expressed about the future of soil survey. Some of the reasons put forward are external to soil survey and strongly influenced by the general economic situation. Inappropriate presentation and the poor accuracy of soil information, together with high survey costs, are often to blame. The worldwide crisis in collecting primary field data in general may also partly be blamed by the over-reliance on the use of satellite imagery as the ideal tool to carry out natural resources inventories. While in Western Europe most national soil survey institutes have closed down or were privatized, in the developing world there are still relatively strong soil institutes in most countries backed by, albeit insufficient, government funds. Funds for classical soil surveys are difficult to obtain, but the demand for digital soil information obtained from different sources is increasing. Although many soil institutes over the whole world have adopted useful innovations, such as soil and geographic information systems and automated data collection, technology has not, by itself, provided enormous improvements in the way soil information can be used. Indeed, the over-enthusiastic, uncritical or hasty use of modern electronic tools can lead to inappropriate results and unwise decisions. Soil surveys must move with the times and be able to offer up-to-date, quantitative information about soil and how soil changes in both space and time. In this paper the evolution and availability of geographic soil databases in tropical countries, which depict soil information of areas in classical paper maps or as polygon information stored in geographical information systems, are discussed. The discussion includes also georeferenced point data, giving morphologically described and chemically and physically analysed soil profile information, and a comparison to the global situation is made. The quality and quantity of the soil data available in tropical countries are assessed and the problems for further development of such databases are reviewed and possible solutions given to remove some of the obstacles.

TREFWOORDEN. — Bodemkartering; Bodemdatabanken; Kwaliteit van bodemgegevens; Kwantiteit van bodemgegevens; Tropische landen.

SAMENVATTING. — *Kwalitatieve en kwantitatieve aspecten van bodemdatabanken in tropische landen.* — Gedurende de laatste paar jaar wordt de toekomst van de bodemkartering pessimistisch ingeschat. Een aantal redenen die hiervoor naar voren worden geschoven houden geen rechtstreeks verband met de bodemsurvey, maar zijn sterk beïnvloed door de algemene economische situatie. Een te weinig toegankelijke weergave en de geringe nauwkeurigheid van bodeminformatie, samen met de hoge onkosten verbonden aan bodemsurvey, zijn dikwijls de boosdoener. De wereldwijde crisis in het verzamelen van primaire veldgegevens kan tot op zekere hoogte ook worden toegeschreven aan een te groot vertrouwen in het gebruik van satellietbeelden als het ideale middel om natuurlijke hulpbronnen te inventariseren. Terwijl in West-Europa de meeste nationale instellingen voor bodemsurvey gesloten of geprivatiseerd werden, zijn er in de ontwikkelingslanden nog steeds relatief sterke instellingen voor bodemkunde aanwezig die, hoewel onvoldoende, door de overheid financieel gesteund worden. Financiële middelen voor klassieke bodemsurveys zijn moeilijk te bekomen, maar de vraag naar digitale bodeminformatie uit verschillende bronnen stijgt. Alhoewel vele instellingen nuttige technische vernieuwingen hebben doorgevoerd, zoals het invoeren van bodem- en geografische informatiesystemen en geautomatiseerde datacollectie, heeft deze technologie op zichzelf geen grote verbeteringen teweeggebracht qua bodeminterpretatie. Inderdaad, het overenthousiaste, niet-kritische of overhaast gebruik van moderne elektronische hulpmiddelen kan leiden tot niet gepaste resultaten en verkeerde beslissingen. Bodemkarteringen moeten meegaan met de tijd en in staat zijn eigentijdse kwantitatieve informatie te geven over de bodem en hoe de bodem verandert zowel in tijd als in ruimte. In dit artikel worden de evolutie en beschikbaarheid besproken van geografische bodemdatabanken in tropische landen, die bodeminformatie weergeven als oppervlaktes op klassieke papieren kaarten of als polygooninformatie opgeslagen in geografische informatiesystemen. De discussie omvat tevens geo-gerefereerde puntgegevens met informatie als de morfologische beschrijving en chemische en fysische analysegegevens van het bodemprofiel. Een vergelijking wordt gemaakt met de situatie wereldwijd. De kwaliteit en de hoeveelheid aan bodemgegevens die beschikbaar zijn in tropische landen worden geëvalueerd en de problemen voor de verdere ontwikkeling van dergelijke databanken worden onder de loep genomen. Mogelijke oplossingen om sommige van de hindernissen op te ruimen worden gegeven.

MOTS-CLES. — Cartographie des sols; Bases de données pédologiques; Qualité des données pédologiques; Quantité des données pédologiques; Pays tropicaux.

RESUME. — *Aspects qualitatifs et quantitatifs des bases de données pédologiques dans les pays tropicaux.* — Depuis plusieurs années, l'avenir de la cartographie des sols est considéré sous un aspect pessimiste. Certaines des raisons évoquées sont externes à la cartographie des sols elle-même et fortement influencées par la situation économique générale. Une présentation inadéquate et la faible précision de l'information relative au sol, auxquelles s'ajoutent les coûts élevés de l'investigation sur le terrain, sont souvent à blâmer. La crise mondiale qui atteint la collecte sur le terrain de données de base est due en général à une trop grande confiance en l'utilisation des images satellitaires en tant qu'outil idéal pour effectuer l'inventaire des ressources naturelles. Tandis que, dans les pays occidentaux, la plupart des instituts nationaux de cartographie des sols ont fermé ou ont été privatisés, dans le Tiers-Monde, il subsiste encore relativement de puissants instituts de pédologie dans la plupart des pays soutenus par des fonds gouvernementaux, quoique insuffisants. Les fonds sont difficiles à obtenir pour les études de cartographie des sols classique mais la demande de données pédologiques digitales obtenues par différentes sources augmente. Bien que beaucoup d'instituts de science du sol à travers le monde aient adopté les nouvelles techniques plus utiles, telles que les systèmes d'information géographique et pédologique ainsi que la collecte de données automatisée, la technologie n'a pas, par elle-même, apporté d'énormes améliorations dans la manière dont l'information pédologique peut être utilisée. En effet, l'utilisation trop enthousiaste, non critique et hâtive des outils électroniques modernes peut conduire à des résultats inadéquats et à des décisions irréfléchies. La cartographie des sols doit évoluer avec le temps et être capable d'offrir une mise à jour des informations quantitatives sur le sol et sur la façon dont ce dernier change dans l'espace et dans le temps. Dans cet article, seront discutées l'évolution et la disponibilité des bases de données géographiques du sol dans les pays tropicaux. Ces bases de données décrivent l'information pédologique du terrain soit dans les cartes classiques sur support de papier, soit comme attribut de polygone stocké dans les systèmes d'information géographique. En outre, la discussion concernera, d'une part, les données ponctuelles géoréférencées qui fournissent des informations descriptives morphologiques ainsi que des données analytiques chimiques et physiques des profils pédologiques, d'autre part, une comparaison avec la situation globale. La qualité et la quantité des données pédologiques disponibles dans les pays tropicaux sont évaluées et les problèmes en vue d'un développement futur pour ce type de bases de données sont revus et quelques solutions possibles sont apportées afin d'éliminer certains obstacles.

1. Introduction

Soil databases take various forms and have evolved quite rapidly recently. While ten years ago most soil data were produced as paper soil maps accompanied by a soil survey report, which usually contained thick annexes with soil profile descriptions and laboratory data, nowadays soil information is most likely to come stored in a Geographical Information System (GIS) and accompanied by a digital database containing the soil profile information linked as point data to the corresponding soil mapping unit polygon. The whole would be contained in a slim diskette or CD-ROM. More recently, some soil maps and data have even become directly accessible from the Internet.

While this technological revolution is in no way a guarantee for enhanced quality of the data itself, it has assured that presentation of soil data has become more accessible to potential users and decision-makers. This is true regardless of the geographic location, as computers and GIS software are nowadays to be found in all but the most remote situations. Fast Internet access, on the other hand, remains still largely limited to the developed world although developing countries are fast catching up.

Soil survey is at a crossroads. Over the last several years, pessimistic views have been expressed about its future. Some of the reasons put forward are external to soil survey and strongly influenced by the general economic situation. Inappropriate presentation and the poor accuracy of soil information, together with high survey costs, are often to blame. The worldwide crisis in collecting primary field data in general may also partly be blamed by the over-reliance on the use of satellite imagery as the ideal tool to carry out natural resources inventories. Although satellite imagery is an extremely useful tool to assist surveys even at the highest resolution, it limits observation to land cover. The actual land use and underlying soil layers are simply invisible to the satellite's sharpest lenses.

Another factor responsible for this field data crisis, is political and is particularly true for the collection of soil data in Western Europe where most national soil survey institutes have closed down or were privatized and have all abandoned systematic soil mapping. This is particularly critical for a region which, with few exceptions (Belgium, the Netherlands, Denmark, United Kingdom), had a scant soil information system before privatization, compared, to say, with Eastern Europe and the United States.

The situation in tropical countries, or in the developing world in general, is more varied in this respect, as overall there are still relatively strong soil institutes in most countries backed by, albeit insufficient, government funds. Systematic surveys are limited but still continue in most countries and have resulted in national maps and databases which, with regard to detail of scale and number of available soil profiles, can easily compete with those of countries in the industrialized world. Curiously, the so-called recession in carrying out soil surveys thus appears to have affected developing countries less than developed ones (HODGSON 1991). However, when data concerning the European Community (LEE 1991) are compared to those of less advanced countries (ZINCK 1990), the differences in soil survey status are less than might be initially expected. This is because there is renewed interest at the EC level as a whole (Soil Protection law in Germany, new national soil mapping programme in Italy, etc.). Nowadays, inequalities between developing and developed countries appear to be deepening rather than shrinking.

A last introductory remark concerns the problem of information access, which is not unique for soil data but applies for many other research data (climate, geology, topography, etc.) as well. The problem appears to be most acute in Europe, but recent developments point to an increase of data access problem in Africa and Asia as well.

In Europe, several phenomena have accelerated data access problems. The first event was the privatization process that started in the late seventies and resulted in national soil institutes being no longer subsidized as was the case in the past. The only valuable money source present in these institutes, apart from human resources, appeared to be the data and maps that had been compiled over the years. These were consequently marketed and commercialized and seen as an extra source of income. Strict copyright rules were put in place to avoid misuse and illegal reproduction of the data.

Another, less well documented phenomenon causing data access problems, appears to be the accelerated regionalization within the EU in which the power of some regions within countries (particularly in Germany, but also in Italy, France and Belgium) have become much more expressed. These countries have legally limited the data access that national institutes are allowed to extend to interested researchers or commercial companies. As international organizations can only discuss data availability with national entities, the problem becomes more difficult to solve.

The approach of UN agencies such as FAO is that data should be made available at their production and maintenance costs only.

2. Global and Regional Soil Databases

At the global level the 1:5 M scale FAO-UNESCO Soil Map of the World (FAO 1971-1981) is still, 20 years after his finalization, the only worldwide, consistent, harmonized soil inventory that is readily available in digital format and comes with a set of estimated soil properties for each mapping unit.

The project originated by a motion of the ISSS at the Wisconsin congress in 1960, started in 1961 and was completed over a span of twenty years. The first draft of the Soil Map of the World was presented to the Ninth Congress of the ISSS, in Adelaide, Australia, in 1968. The first sheets, those covering South America, were issued in 1971. The last and final map sheet for Europe appeared in 1981 (FAO 1971-1981).

With the rapidly advancing computer technology and the expansion of geographical information systems during the 1980s, the Soil Map of the World was first digitized by ESRI (1984) in vector format. In 1984 a first rasterized version of the soil map was prepared by Zöbler using the ESRI map as a base and using 1° x 1° grid cells. Only the dominant FAO soil unit in each cell was indicated. This digital product gained popularity because of its simplicity and ease of use, particularly in the United States, but should no longer be used.

FAO (1995) produced its own raster version which had the finest resolution with a 5' x 5' cell size (9 km x 9 km at the equator) and contained a full database corresponding with the information in the paper map in terms of composition of the soil units, topsoil texture, slope class and soil phase in each of the more than 5,000 mapping units. In addition to the vector and raster maps discussed above, the CD-ROM contains a large number of databases and digital maps based on statistically derived soil properties (pH, OC, C/N, soil moisture storage capacity, soil depth, etc.).The CD-ROM also contains interpretation by country on the extent of specific problem soils, the fertility capability classification results by country and corresponding maps. More information: http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGL/lwdms.htm

In the early 1990s, FAO recognized that a rapid update of the Soil Map of the World would be a feasible option if the original map scale of 1:5 M was retained, and started, together with UNEP, to fund national updates at 1:5 M scale of soil maps in Latin America and Northern Asia.

At the same time, FAO tested the physiographic SOTER approach in Asia (Van Lynden 1994), Africa (Eschweiler 1993), Latin America (Wen 1993), and the CIS, the Baltic States and Mongolia (Stolbovoy 1996), based on ideas developed at ISRIC by Wim Sombroek (1984) who supported an original approach based on land systems to re-inventory global land resources (the SOTER — SOil and TERrain database — approach) (UNEP *et al.* 1995).

These parallel programmes of ISRIC, UNEP and FAO merged together in mid-1995, when at a meeting in Rome the three major partners agreed to join the concerned resources and work towards a common world SOTER approach covering the globe at 1:5 M scale by the 17th IUSS Congress of 2002 to be held in Thailand. Since then, other international organizations have shown support and collaborated to develop SOTER databases for specific regions. This is for instance the case for Northern and Central Eurasia where the International Institute for Applied System Analysis (IIASA) joined FAO and the national institutes involved, and for the European Soil Bureau (ESB) in the countries of the European Union. The ongoing and planned activities are summarized in table 1 and figure 1.

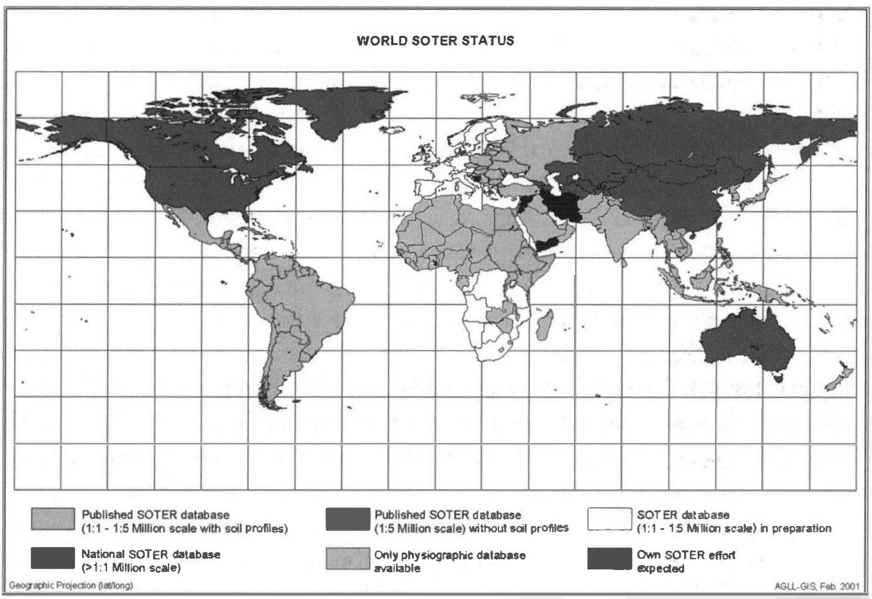

Fig. 1. — World SOTER status (October, 2001).

Table 1
Operational Plan for a World SOTER: 1995-2007

Regions	**Status**	**Main Agencies Involved**	**Published Dates**
Latin America and the Caribbean	Published	ISRIC, UNEP, FAO, CIAT, National Soil Institutes	1998
North-eastern Africa	Published	FAO-IGAD	1998
South and Central Africa	Ongoing	FAO-ISRIC-National Inst.	2001
Northern Africa	Ongoing	ESB-FAO-National Inst.	2003
North and Central Eurasia	Published	IIASA, Dokuchaev Institute, Academia Sinica, FAO, National Inst.	1999
Central and Eastern Europe	Published	FAO-ISRIC-Dutch Government-National Inst.	2000
Western Europe	Ongoing	ESB-FAO-National Inst.	2002
West Africa	Proposal submitted	Awaits funding (ISRIC, IITA)	
Southeast Asia	Proposal discussed	Awaits funding	
USA and Canada	-do-	FAO/ISRIC/Circumpolar Group of the ISSS	2004
Australia	-do-	CSIRO	Undecided

It should be noted that although the information is collected according to the same SOTER methodology, the specific level of information in each region results in a variable scale of the end products presented. The soils and terrain database for north-eastern Africa, for instance, contain information at equivalent scales between 1:1 M and 1:2 M, but the soil profile information is not fully georeferenced. For north and central Eurasia, profile information contained in the CD-ROM is very limited (FAO/IIASA/DOKUCHAIEV/ACADEMIA SINICA 1999). Fully comprehensive SOTER information is available for South and Central America and the Caribbean (FAO *et al.* 1998) and includes more than eighteen hundred georeferenced soil profiles. The data are downloadable from http://www.isric.nl/SOTER/LACData.zip and viewable using a viewer program at http://www.isric.nl/SOTER/Viewer102b.exe). The SOTER database for Central and Eastern Europe (1:2.5 million scale) contains more than 600 georeferenced soil profiles, as well as files of derived soil properties, and the results are available on CD-ROM (http://www.fao.org/catalog/book_review/giii/x8322-e.htm).

The SOTER status and the operational plan for completing the full update are given in figure 1 and table 1 respectively.

At present, less than half the world has a complete, systematic published 1:1 M scale soil map. The figures indicated by FAO in 1991 have not changed much (tab. 2).

Table 2 needs some interpretation: many small countries have been mapped, whereas the larger ones have not. Nevertheless, they do illustrate how far the world is from having even a 1:1 M soil scale map.

Table 2
World Soil Map Coverage, 1:1 M Scale or larger

	Countries		Area		Population	
	Number	%	km^2 x 10^3	%	10^9	%
Complete	109	68	42,261	31	2.1	39
Not complete	49	32	94,783	69	3.3	61
Total	158	100	137,044	100	5.4	100

3. Regional Soil Profile Databases

Several soil profile databases exist which contain georeferenced soil profile morphological and/or analytical information. These databases are of major importance for the development of pedotransfer functions which deduce non-measured soil characteristics from measured ones. If used unstratified and outside their natural context, they may cause extremely misleading statements and conclusions.

A particular problem with the soil profile databases is that no accepted standard for the storage of these data exists. Although generally the FAO Guidelines for Soil Profile Description (FAO 1991) or the USDA Soil Survey Manual (USDA 1999) are well-accepted guidelines internationally, each country has developed local variants (linguistic or otherwise). This in turn has hampered the development of a universal framework to store these data. Software was originally developed that fully followed the FAO guidelines (FAO/ISRIC/CSIC 1995). This is currently made available in a multilingual version (SDBm = Soil Data Base multilingual version), but is still not able to cater for all user requirements.

The ISRIC Soil Information System stores data of the global soil reference collection and contains about 700 soil profile descriptions and analytical soil data from more than seventy countries, but uses its own system (ISIS) to store the data.

At the global level, the WISE data set collected by ISRIC is the most comprehensive one (fig. 2). It contains now more than 6,000 soil profiles, a large part of which is thoroughly checked on internal analytical contradiction and soil classification. A statistical analysis of the soil characteristics by FAO soil taxonomic unit was undertaken and results can be linked to the Soil Map of the World (section 1), or to regional soil and terrain (SOTER) databases (FISCHER *et al.* 2000). A subset of this database, giving average soil property values by soil unit, is also contained in the CD-ROM release of the digital soil map of the world (FAO 1995).

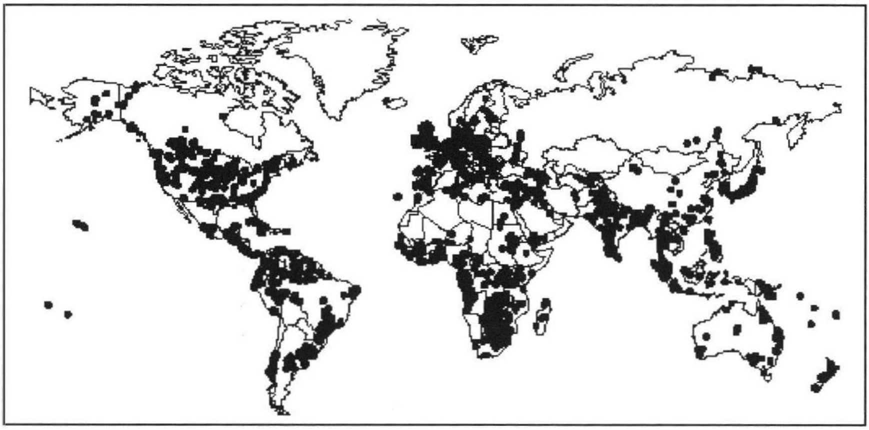

Fig. 2. — Distribution of soil profiles in the WISE database (after BATJES *et al.* 1997).

As mentioned earlier, each of the SOTER regional studies contains its own soil profile information set, with only parameters considered relevant for surveys at 1:1 M scale or smaller.

The Global Pedon Database, which is an extract of the WISE database and was created by ISRIC for IGBP on the basis of information received from the National Resources Conservation Service of the USDA, from FAO and from ISRIC, has been extensively tested on internal consistency and contains about 1,100 profiles. Table 3 gives the composition by region of the WISE and the data set compiled by the International Biosphere and Geosphere programme (IGBP) (IGBP-DIS/CSIRO/USDA/FAO/ISRIC 1999).

Two other soil data sets are worth mentioning in this respect, as they store mainly analytical data and not soil morphological data. One is built up by the European Union and is linked with the 1:1 million soil map of Europe (ESB 1999) and contains polygon-referenced analytical soil information. The other, developed by ZINKE *et al.* (1984), concentrates on georeferenced data of carbon and nitrogen, and is rather thin on other parameters, which makes its use difficult for more general applications.

Table 3
The Global Pedon Database (IGBP-DIS/CSIRO/USDA/FAO/ISRIC 1999)

Broad Geographic Regions	In WISE	In Homogenized Database (Int. set)			
		FAO[1]	NRCS[2]	ISIS[3]	Total
Africa	1,799	93	204	18	315
S., W. and Northern Asia	522	24	44	0	68
China, India, Indonesia, Philippines	553	45	129	106	280
Australia and Pacific Islands	122	28	27	0	55
Europe	492	5	2	0	7
North America	266	14	144	0	158
Latin America and the Caribbean	599	41	114	86	241
Total	4,353	250	664	210	1,124

[1] FAO: Food and Agriculture Organization of the United Nations.
[2] NRCS: National Resources Conservation Service of the US Department of Agriculture.
[3] ISIS: ISRIC Soil Information System (ISRIC, Wageningen).

One cannot escape the conclusion that the status of regional and global soil profile databases is unsatisfactory given the relative limited quantity of data present. Because of the emphasis on analytical laboratory data rather than morphological descriptors, many soil profile databases fail to reflect soil reality, and are often aimed at a single specific field of application.

4. National Soil Maps and Soil Profile Databases

Most countries have updated their soil information since the publication of the soil map of the world. In fact, many tropical countries have now produced national soil maps that in scale and level of information can easily compete with those developed in the industrialized world. Botswana, Kenya, Rwanda, Ghana, Tunisia are but a few examples of countries that have gone to great lengths to fully inventory their soils and document them.

As an example in Rwanda, the soil survey started in 1981 and was finalized in 1994. The semi-detailed soil survey was based on extensive use of aerial photographs and fieldwork. As such, 43 soil maps at scale 1:50,000 were produced, covering the whole of Rwanda and the 1,834 soil profiles, corresponding to 176 different soil series had been described and analysed. Spatial, descriptive and analytical data were discussed and summarized in the explanatory notes developed for each soil map. From 1989 onwards, the soil maps and all observation points with their corresponding data were stored in a master database using GIS and database software. The soil data were digitized as a polygon theme, representing the soil mapping units drawn on the topographical base maps, and as a point theme indicating each observation. Soil analytical data were organized in a relational database which contains the general soil profile data, physical and chemical analysis data of the horizons, graphs showing correlations between these parameters, and the soil map explanatory reports. The labels of each soil mapping unit, forming the skeleton of the final soil database, were then related to the tabular database containing essential soil properties, to form an integrated soil coverage, comprising both spatial and descriptive data (IMERZOUKENE & VAN RANST 2001). A schematic representation of the integrated national soil map and soil profile database of Rwanda is shown in figure 3. The maps and the database are available in the Laboratory of Soil Science of Ghent University and in the Ministry of Agriculture in Kigali.

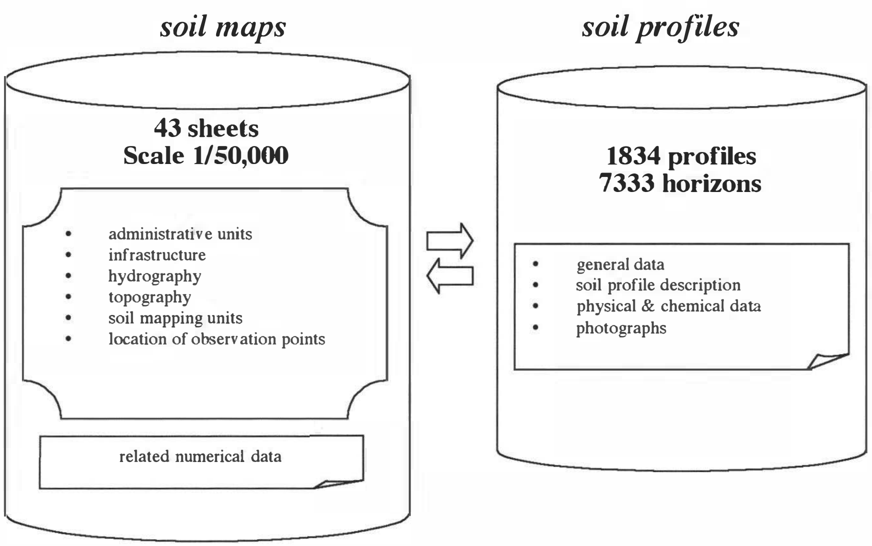

Fig. 3. — Schematic representation of the integrated national soil map and soil profile database of Rwanda.

A number of countries still have large gaps in their information and have hardly gone beyond the 1:5 M scale information contained in the soil map of the world. The Democratic Republic of Congo, Somalia, Algeria, Burma are examples in the developing world. Sweden and Finland are more surprising examples in the industrialized world. As an example, in Cameroon there is a complete soil map coverage at exploratory scales (1:1 M and smaller). Although some progress has been made in detailed reconnaissance mapping at 1:200,000 scale (30 % of the territory covered, fig. 4a), much work remains to be done, especially in detailed mapping, which until recently covered only 1 % (fig. 4b) of the country (VAN RANST & VANMECHELEN 1995).

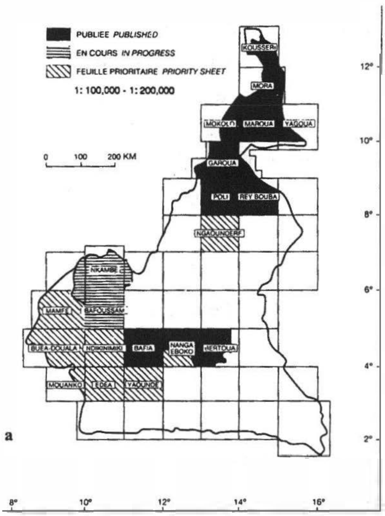

Fig. 4a. — Detailed reconnaissance (1:100,000-1:200,000) soil map coverage in Cameroon.

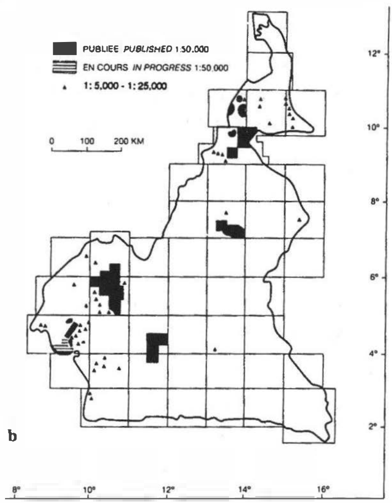

Fig. 4b. — (Semi-)detailed (1:50,000-1:5,000) soil map coverage in Cameroon.

Based on answers from 48 countries form Central and South America (12), Africa (21) and the Middle and Far East (15), the following general conclusions can be drawn as to the soil map coverage status (table 4):

— Many countries have some kind of general map on very small scale, usually substantially smaller than 1:250,000;
— Cartographic coverage for regional master planning of scales between 1:100,000 and 1:250,000 is largely incomplete, making it difficult to identify high-potential areas or, conversely, critical problem areas and their priority for more detailed inventories;
— Soil maps appropriate for project planning on scales around 1:25,000 cover a very small percentage of the countries;
— Soil maps suitable for operational planning, usually on scales larger than 1:25,000, are seldom mentioned.

Table 4
National Soil Survey Coverage (ZINCK 1995, updated)

		Small scale 1:500,000 - ±100,000 (%)	Medium scale 1:100,000 - ±50,000 (%)	Large scale ≤ 1:25,000 (%)
CENTRAL AND SOUTH AMERICA	Argentina	100	10	-
	Belize	100	35	-
	Brazil	35	5	5
	Colombia	85	5	5
	Costa Rica	100	20	5
	Jamaica	-	100	100
	Mexico	75	40	-
	Panama	50	-	-
	Peru	50	-	-
	Trinidad-Tobago	-	-	100
	Venezuela	90	5	2
	Uruguay	20	20	-
AFRICA	Algeria	-	5	5
	Benin	100	10	2
	Botswana	40	5	-
	Burkina Faso	100	25	-
	Burundi	100	-	-
	Cameroon	30	5	1
	Congo	10	5	-
	Egypt	100	10	10
	Gabon	30	-	-
	Gambia	100	-	100
	Ghana	95	-	-
	Kenya	100	25	-
	Mali	50	-	-
	Morocco	-	40	20
	Nigeria	70	35	-
	Rwanda	100	100	-
	South Africa	70	-	-
	Swaziland	100	10	5
	Tanzania	50	-	-
	Togo	80	20	-
	Uganda	100	-	-
ASIA	Bangladesh	95	-	-
	China	100	100	-
	India	80	-	-
	Indonesia	40	10	-
	Iran	-	10	10
	Japan	-	100	-
	South Korea	-	-	100
	Malaysia	100	10	-
	Myanmar (Burma)	100	20	2
	Pakistan	85	3	-
	Papua-New Guinea	5	10	-
	Philippines	100	10	-
	Sri Lanka	100	10	2
	Thailand	-	100	20
	Vietnam	-	40	30

This shortage results in a demand for medium- and large-scale maps virtually everywhere. These are precisely the scales to which the contribution of soil information to land-use planning and problem solving is most directly effective (ZINCK 1995).

In general, most developing countries have scattered soil surveys only partly correlated with one another and of variable age and quality, but tracking the coverage and quality of the many *ad hoc* surveys is not easy. Perhaps a compilation of the information would be a worthwhile contribution to the advance of soil survey, but the difficulty of achieving it should not be underestimated. It is noticeable that CABI publishes abstracts of a large proportion of all published papers on soils, but there is no equivalent for maps.

An overview of the state of the soil inventory in terms of scale and soil classification used in tropical countries is given in ftp://ftp.fao.org/agl/agll/docs/smw1.doc.

Many of these maps are accompanied by national soil profile data sets. The most important set in number of profiles stored is the one held by the National Resources Conservation Service (NRCS) of the United States with more than 20,000 profiles. Other countries also have important soil data sets, such as Botswana (more than 2,500 profiles), Rwanda (1,834 soil profiles), Namibia (more than 1,000 soil profiles), Denmark (850 profiles) and Mali (600 profiles), to name only a few of them.

Two specific issues related to the maps and the soil profile data merit more highlighting, the soil classification used which largely determines the units identified on the map and second, the quantity and quality of soil profile information which determines often the applicability of the map itself.

4.1. SOIL CLASSIFICATION ISSUE

Unlike most subjects of other natural sciences, "soil bodies" are not discrete and well-defined entities, and their naming and classification is after more than 100 years of soil science, still a matter of dispute. Until very recently, at an international level two different reference classification systems were generally accepted. One, the USDA Soil Taxonomy (USDA 1999), a soil classification system developed in the US in the early 1960s (more info on URL: http://www.nhq.nrcs.usda.gov/WSR/, and the FAO Legend for the Soil Map of the World (FAO 1974)) (URL: http://www.fao.org/waicent/FaoInfo/Agricult/AGL/agll/key2soil.HTM), a simplification of Soil Taxonomy, developed by soil scientists worldwide. Most countries in Africa and Europe have adopted the FAO legend for soil correlation on an international scale, while the Americas and most countries in the Near East adopted the USDA Soil Taxonomy. The situation in Asia is mixed with Soil Taxonomy prevailing in most countries. Other soil classification systems that have a large impact are for instance the French classification system (CPCS 1967) adapted by some countries in French-speaking West Africa, and the Russian soil classification system used to name soils in the former USSR (Rozov & Ivanova 1967).

After years of debating the problem, the International Union of Soil Science (IUSS) proposed in 1998 a new international soil correlation system: the World Reference Base for Soil Resources (IUSS/FAO/ISRIC 1998, Driessen *et al.* 2001). This system was officially endorsed at the last IUSS congress in Montpellier in 1998.

It is hoped that this recent development of this unique international soil correlation system endorsed by all soil scientists, has now solved this particular problem, although it will probably take years for the system to be fully adapted everywhere (Deckers *et al.* 2001, Nachtergaele *et al.* 2002). The only stumbling-block for developing countries will be the still requested sophisticated analyses (*e.g.* volcanic glass content, total reserve in bases) required to identify certain diagnostic horizons (*e.g.* andic) and properties (*e.g.* alic) and to classify the soils accurately. Developing countries very often lack trained resource personnel and the available equipment is insufficient or inadequate, and as a result the reliability of data is low. Even when modern technology is affordable, staff training is a problem.

4.2. The Quantity and Quality of Soil Profile Information

As far as soil profile information is concerned, the various international efforts to come to a homogenized soil profile data set have led to a number of conclusions that may be summarized as follows:

- The number of "controlled" georeferenced soil profiles in the public domain is extremely limited (1,100), while the total number of verified georeferenced soil profiles (more than 6,000) shows many gaps in terms of soil types for which this information is available, as well as geographically.
- The quality of the available information is very uneven in every respect: most soil profile databases have focused on analytical information, rather than on morphological aspects, while what is measured often responds to traditional soil survey and agricultural questions only. Soil characteristics of interest to environmental issues are often not measured.
- The methods for soil chemical and physical analysis vary worldwide and results obtained are often difficult to correlate. For instance, most of

eastern Europe, the former USSR and China use analytical methods different from those in other countries, making it difficult to compare, for example, soil texture or organic matter contents.
— Many analytical methods show a wide variability within and between laboratories, often more important than the expected change in value over time, making monitoring of such soil properties extremely uncertain.
— Modelling with soil data has many perspectives. Logical, empirical and mathematical models can be implemented. One main limitation derives from scale incompatibilities between the input data provided by soil survey, the selected model and the process to be modelled.
— As soil profile information is scale-independent, access to the data is often strictly regulated: ISRIC, for instance, insists on being associated with any study making use of the full WISE data, while the European Soil Bureau only leases the soil map and soil profile data year by year, under stringent copyright laws.

5. Conclusions and Recommendations

5.1. Conclusions

— Global soil resource information exists at 1:5 M scale in paper map and digital format in the digital FAO/UNESCO Soil Map of the World, and is currently being updated through the Global SOTER programme. The soil information provided relates to mapping units (polygons), for which a large number of statistically and expert-derived soil properties are available.
— Georeferenced and quality-controlled soil profile information is limited to about 6,000 profiles worldwide.
— The quality and quantity of the soil information gathered vary greatly from country to country but it is not necessarily worse in tropical countries.
— There is a problem of free access to soil information which hampers research and is counterproductive. The problem is particularly serious in Europe but is quickly spreading to tropical countries.
— There is a demand for relevant and reliable and more timely information about soils. This can be provided within reasonable costs, only by making full use of the existing data while applying new technology, and by updating them with the new survey methods.

5.2. Recommendations

— Support is needed to accelerate the finalization of a global soil and terrain database. A particular effort is needed to complete the information in West Africa and Southeast Asia.
— Quality-controlled, georeferenced soil profile information collection should be vastly expanded particularly in areas where none or very little of this information has become available (China, former Soviet Union).
— Problems of data access should be tackled by international political agreements such as those that can be arbitrated by the World Trade Organization and guarantee intellectual property.
— Most methodological problems could be overcome by making the decisions of a single body (most logically IUSS) binding for all organizations involved with soil classification, mapping and soil analytical methods.
— Interpretations of soil data need to be improved. They must be more accessible and intelligible to non-soil scientists. Clear language free of jargon does not come easily to soil surveyors, but soil survey reports are of no value if not read.
— Logical, empirical and mathematical models must be adapted to available data and not the other way round.
— The bottom line is that more resources should be made available for field-based soil investigations to exploit fully the enormous technological progress made by satellites and computers.

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Influence of Climate and Soil on Traditional Agriculture in Tropical Africa

by

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Carolus Sys is Agricultural Engineer, Doctor in Agricultural Sciences, Emer. Prof. Ghent University. Started his career in 1949 as soil scientist at I.N.E.A.C. (*Institut National pour l'Etude Agronomique au Congo Belge*). Participated in regional soil surveys in different parts of the Belgian Congo and Burundi. In 1956, appointed as *Chef du Groupe Cartographie et Prospection de la Division d'Agrologie*, he was in charge of the supervision and co-ordination of soil survey work in the Belgian Congo. In co-operation with his team the I.N.E.A.C. soil classification system was developed and a general soil map of the Belgian Congo was prepared. In 1960, integrated in the soil survey of Belgium, under Prof. Dr. R. Tavernier, he supervised soil survey work. In 1963, he joined the University of Ghent in charge of teaching tropical soils and research. Initially his research was oriented to the study of soil-forming process of tropical and arid soils but since the 1970s his interest has been mainly concentrated on land evaluation. In Africa, he realized soil survey and land evaluation projects in Morocco, Egypt, Senegal, Burkina Faso, Ethiopia, Chad, Ivory Coast, Togo, Benin, Cameroon, Democratic Republic of Congo, Rwanda, Burundi, Tanzania and Zambia. In Nicaragua, he planned and supervised the soil survey of the *Costa Atlántica* between the *Río Grande de Matagalpa* and the *Río Escondido*. In Asia he participated in soil research and soil survey work in Lebanon, Saudi Arabia, Iraq, Iran, Thailand, Malaysia, Indonesia and China.

KEYWORDS. — Agro-ecological Conditions; Charge Characteristics; Crop Pattern; Farmers; Land Use; Length of Growing Season; Market; Socio-economic Conditions; Soil Fertility; Soil Physical Conditions; Traditional Farming.

SUMMARY. — Traditional farming in tropical Africa consists of a primitive management of natural resources. This contribution examines in how far farmers take eco-climatic and soil conditions into account. At the origin the forest areas were almost

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exclusively the home of pygmees who practised a gathering system which gradually changed into a cultivable stage. In a first stage, crops which propagated vegetatively (Musa sp., Discorea alata) were cultivated for the supply of carbohydrates; proteins and flat were obtained by hunting. It was in the drier Sahel area that man learned to cultivate the species that propagate from seed: millet and sorghum. People coming from the Sahel, under the influence of population pressure, occupied progressively the forest areas and turned them into savannah. The crops present in the traditional agriculture, more or less stabilized with the colonial period, were mainly introduced from South America and Asia, by the Portuguese between the 15th and 18th century, supplemented by an Arabian way from Asia to East Africa. With regard to climate and agro-ecological conditions, the length of the growing season and temperature, as related to altitude, define the main crop pattern. Crop patterns and yield results in function of length of growing season illustrate this statement. Considering soil, attention is drawn to the evolution of physical and physico-chemical soil properties in function of the evolution stages of the soil and their effect on water, air, and nutrient supply. Nutrient supply as related to the fundamental principle of charge characteristics is discussed. One examines how these parameters (pH, Al-toxicity, cation balance, organic matter content, phosphorus fixation capacity) are taken into account in traditional, primitive, agriculture. Socio-economic conditions associated with primitive agriculture are mainly influenced by transactions at the local market. They are considered with regard to the production capacity and nutritional value of farm products.

TREFWOORDEN. — Agro-ecologische voorwaarden; Ladingseigenschappen; Vruchtwisseling; Landbouwers; Bodemgebruik; Duur van de groeitijd; Markt; Socio-economische toestand; Bodemvruchtbaarheid; Bodemfysische eigenschappen; Traditionele landbouw.

SAMENVATTING. — *De invloed van het klimaat en de bodem op de traditionele landbouw in tropisch Afrika.* — Oorspronkelijk werden de tropische regenwouden enkel bewoond door pygmeeën, die leefden van jacht en vruchtenverzameling. Bij de evolutie naar verbouwde gewassen gebruikte men in een eerste fase planten die zich vegetatief vermenigvuldigden (Musa sp., Discorea alata). Deze waren de bron van zetmeel. Eiwitten en vetten werden bekomen door de jacht. Het was in de droge Sahel dat de bevolking leerde gewassen telen die zich met zaad voortplanten, zoals gierst en sorghum. Onder een te hoge bevolkingsdruk zal de Sahelbevolking geleidelijk de beboste zones binnendringen en ze omvormen tot savanne. De gewassen thans verbouwd in de traditionele landbouw werden ingevoerd vanuit Latijns-Amerika en Azië gedurende de Portugese handelsreizen van de 15de tot de 18de eeuw, aangevuld met een Arabische weg van Azië tot Oost-Afrika. De verspreiding van de onderscheiden gewassen en de opbrengsten worden onderzocht in functie van de lengte van het groeiseizoen en de temperatuur (hoogteligging). De evolutie van de bodem is bepalend voor de fysische en fysico-chemische eigenschappen die verantwoordelijk zijn voor water, lucht en voedselvoorziening. De voedselvoorziening wordt toegelicht in functie van de fundamentele ladingseigenschappen. Men onderzocht hoe belangrijke parameters (pH, kationenbalans, organische stof, fosforfixatie) in acht genomen worden bij een reeks traditionele landbouwpraktijken. De sociaal-economische toestand, gekoppeld aan de primitieve landbouw, wordt essentieel bepaald door de omzet op de lokale markt; hij wordt toegelicht in het kader van de productiecapaciteit en de voedingswaarden van de hoeveproducten.

MOTS-CLES. — Conditions agro-écologiques; Caractéristiques de charge; Modèle de culture; Fermiers; Utilisation du sol; Durée de la saison culturale; Marché; Conditions socio-économiques; Fertilité du sol; Conditions physiques du sol; Agriculture traditionnelle.

RESUME. — *L'influence du climat et des sols sur l'agriculture traditionnelle en Afrique tropicale.* — L'agriculture traditionnelle en Afrique tropicale consiste en une gestion primitive des ressources naturelles. Cette contribution expose dans quelle mesure les fermiers ont été guidés par les conditions éco-climatiques et pédologiques. A l'origine, les zones forestières étaient presque exclusivement peuplées de pygmées pratiquant un système de cueillette qui s'est progressivement transformé en culture. Dans un premier stade, l'homme apprit à planter des espèces à reproduction végétative (Musa balbisiana, Discorea alata). Ces plantes fournissaient des hydrates de carbone. La chasse et la pêche procuraient les protéines et les graisses animales. C'est au Sahel que l'homme apprit à cultiver des espèces qui se multipliaient par graines. Des populations, concentrées au Sahel, sous l'influence d'une pression démographique, occupèrent progressivement les régions forestières et les transformèrent en savanne. Les cultures traditionnelles, plus au moins stabilisées avec la colonisation européenne, furent davantage importées d'Amérique latine et d'Asie, par les voies portugaises, du 15^e^ au 18^e^ siècle, auxquelles s'ajoute une voie arabe à partir de l'Asie vers l'Afrique de l'Est. Considérant le climat et les conditions agro-écologiques, c'est la durée de la saison culturale et la température qui déterminent le type de cultures et les rendements. En ce qui concerne les sols, on attire l'attention sur l'importance de l'évolution génétique des sols sur les conditions physiques et physico-chimiques qui règlent l'approvisionnement en eau, l'aération et la fertilité. On commente la libération d'éléments fertilisants en fonction des caractéristiques de charge. On examine comment ces paramètres (pH, toxicité-Al, balance cationique, matière organique, fixation de phosphore) sont considérés dans diverses technologies dans l'agriculture traditionnelle. Les conditions socio-économiques, associées à l'agriculture primitive, sont essentiellement influencées par les transactions sur le marché local; elles sont considérées en fonction de la capacité de production et la valeur nutritive des produits agricoles.

1. Traditional Agriculture

African traditional farming is a primitive type of shifting cultivation. It developed from the gathering and garnering of wild plants. From books and reports we learned that itinerant agriculture includes pseudo-rotations. One grows a succession of plants or a group of crops on the same plot. After 2-3 years the fields are abandoned for regeneration. It is often said that the distribution of the associated crops, on the same plot, has no particular order and the best farmers have an empirical knowledge for the best place of certain plants in their pseudo-rotation (AUBREVILLE 1949; DUMONT 1961; PORTIERES 1949, 1951, 1952).

We should like to draw attention to "no particular order" and "empirical knowledge" because, from our personal field experience for more than forty years, we have learned, indeed, that there is a particular order and that the choice of the best place for each crop is based not on empirical but on experimental knowledge. This experimental knowledge coincides, for the farmer, with unknown scientific rules.

Traditional farming is a management of natural resources: climate and soil; it guarantees the need in food and fibre and attempts to obtain a surplus for the local market.

This paper is an attempt to show how primitive farming takes into account the natural resources in the use of their land and how it initiates the first stage of socio-economic development.

2. The Farmers

At the origin the forest areas were almost exclusively the home of pygmees who practised a gathering system. The reflux of Black people from the north is thought to be due to the drying-up of the Sahara, the action of the Garamantes and, at the beginning of our era, to their exorcization by the Berbers. It is assumed that these features are at the origin of a concentration of Black people in the Sahel areas. JURION & HENRI (1969) outlined a general review on the migration and settling of African farmers. They reported that the first concentration of Black people was thought to be the southern limit of the Sahara, between the Atlantic Ocean and the Nile.

As a result of population pressure the migration to the south existed for several millennia. This migration to the south happened in a succession of large waves, like the Mongo, sometimes as warrior bands enslaving others. This population occupied progressively Central and Southern Africa, with the rainforest remaining intact in the centre.

With the voyages of Portuguese navigators between the 15th and 18th centuries, the introduction of new useful plants (cassava, sweet potatoes, maize, a.o.) made it easier to penetrate the forest. Losing their cattle, through tryponosomiasis, and some of their crops; these new crops facilitated the penetration into the rainforest. JURION *et al.* (1969) described how from the 16th century a series of tribes had penetrated the forest. Some from the north-east entered the forest from the south after a flanking movement through Nyassaland, Zambia, Shaba (Congo) and Angola.

The stabilization of this migration with the European colonization explains the basic common features of traditional African agriculture: population, crops, livestock, agricultural practices, mental attitudes to the land, to work and to society.

3. The Crops

Very few crops in tropical Africa have their cradle on the continent. Before the 15th century crops propagated vegetatively, derived from the domestication of Musa sp. and Discorea alata and esculenta, species occurring in the rainforest area. In the dry Sahel area the two most important plants domesticated include finger millet and *Sorghum arundinaceum.*

From 15th to 18th century Portuguese navigators introduced a great number of new crops. From South America they brought cassava, sweet potatoes, coco-yam, kidney beans, tobacco and cotton to West-Africa. The Portuguese brought from India *Oriza sativa* to East Africa and to South America and from there to west Africa. Through the Arabian way *Oriza sativa* and bananas were introduced to East Africa from Asia. This resulted in a crop pattern of different origins.

Among a broad series the most important food crops are:

— African origin: yam, vuandzeia, millet, sorghum, oil palm;
— South American origin: cassava, sweet potatoes, maize, beans;
— Asian origin: banana, rice, soya, sesame.

In addition, chickens and pigs were introduced from Asia.

Important in traditional farming is the surface area that can be managed by a smallholder. Agriculture is itinerant: a plot of land is cultivated for a certain number of years and then left in fallow for the regeneration of the soil. In such a system the working capacity of farmers and the labour requirement of the crops are important. The surface area cultivated by one family lies around 1 acre.

Some labour requirements under stabilized traditional farming have been estimated as follows (Smeyers, personal communication; corresponding to mean values of data collected by the author in Benin, Cameroon, Democratic Republic of Congo, Ivory Coast and Senegal):

— Association of cassava, rice (or beans), maize and banana: 200 days/ha;
— Sweet potato: 240 days/ha;
— Maize: 140 days/ha;
— Beans: 150 days/ha.

4. Natural Resources

Agricultural productivity can be analysed as an input/output system. Such an analysis attempts to examine the relationship between biological (crops) and physical (climate and soil) parameters. For normal development a crop requires: water, correct temperature, air and nutrients. Water and temperature are related to climatic conditions. Availability of nutrients and aeration are important land qualities depending on soil conditions.

4.1. Climate

Present knowledge may not allow a full understanding of all the agronomic consequences of climate. However, we can ascertain that climate is the main factor regulating the regional distribution of crops and that the yields obtained, free from soil and agro-climatic constraints, are closely related to climate. Temperature and water are the major climatic factors that define the distribution and yield of crops.

As the basis of the assessment of climatic resources, FAO (1978) used the growing period. The growing period as such is that part of the year (in days) during which precipitation exceeds half the potential evapotranspiration, plus a period required to evapotranspire an assumed 100 mm of water from excess precipitation. As such it is determined by the temperature and water availability. With regard to temperature a growing period should have a daily mean temperature above 6.5 °C. African high mountain areas where mean daily temperature is below 6.5 °C are very restricted and are taken out of consideration in this discussion. Most of the continent has a mean annual temperature above 20 °C. With regard to rainfall the growing period depends on the latitudinal situation.

FAO (1978) defined the growing period "as the period (in days) during a year when precipitation exceeds half of potential evaporation, plus a period required to evaporate an assumed 100 mm of water from excess precipitation (or less if not available) stored in the soil profile". According to the length of the growing period, agro-climatic zones have been defined having a specific pattern of traditional food crops.

The northern Sahel is a desert area with less than 60 days' growing season; fixed agriculture cannot be practised without irrigation. The land is used by nomadic cattle raisers, travelling with their camels, sheep and goats. During their drive they may sow millet on lower slopes and in depressions, the product will be harvested by other tribe members passing there at ripening.

The southern Sahel is a traditional area, *ca.* 400 km, wide from the Atlantic Ocean to the Nile where it turns southwards to embrace North-Eastern Kenya. The growing season is about 60 to 110/120 days. The main crops are millet in the north while sorghum is cultivated on lower slopes catching run-off water and in the south. Niebe comes in and groundnut is cultivated with local vegetables in the home gardens. Traditional agriculture is associated with cattle raising.

The Sudan zone with 110/120 to 270 days' growing period includes the Sudanese Acacia savannah in the North and the Miombo woodlands of Zambian type in the south. Main traditional crops are sorghum, maize, cassava, sweet potato and groundnuts. A series of fruit trees are cultivated in the home gardens.

The Guinean savannah has a growing season of 270 to 330 days. These large high grass savannahs scattered with trees are interrupted with forest galleries in main river valleys. Traditional crops are maize, cassava, sweet potato, yam, banana and groundnuts. Oil palm associated with fruit trees and vegetables is common in the home gardens.

The forest zone has a growing season of more than 330 days. The most important food crop pattern consists of rice, cassava, maize and banana. Oil palm, fruit trees, groundnuts and vegetables are cultivated in the home garden.

Table 1 illustrates calculated yields for some grain crops. The figures do not take into account constraints related to soil limitations or plant diseases.

Table 1

Yields (kg/ha) by Length of Growing Season for Millet, Sorghum and Maize

Crop	Agro-ecological Zone	Length of Growing Season (days)	Yields (kg/ha) Climatic Potential[1]
Millet	Southern Sahel	75-89	450 (300-600)
		90-129	1,300 (460-2,500)
	Sudan Zone	130-179	2,200 (600-3,900)
Sorghum	Southern Sahel	80-109	1,000 (200-1,800)
	Sudan Zone	110-149	2,100 (400-3,900)
		150-209	3,000 (900-5,100)
Maize	Sudan Zone	120-179	3,000 (700-5,400)
		180-219	4,100 (1,200-5,000)
		219-269	2,050 (700-3,400)
	Guinean Savannah	270-350	1,550 (700-2,400)

[1] Calculated biomass yields considering climatic constraints, not considering soil limitations (figures between brackets: lowest and highest yield respectively related to shortest and longest growing season class length and irregular rainfall figures).

In the mountain areas with an annual temperature lower than 20 °C the geographic distribution of temperature zones is related to altitude. This can be illustrated with one example among a series of others. If we follow an altitudinal line on the equator, in the Democratic Republic of Congo, we realize that at the altitude of 1,600 to 1,700 m, with a mean annual temperature just below 20 °C (Butembo), cassava, banana, sweet potatoes, beans and maize are still the main traditional crops. Above 1,800 m cassava, banana and sweet potatoes disappear gradually from the crop pattern and above 2,000 m, in the Lubero area at 2,100 m and a mean temperature of 15 °C, the traditional crops are beans, maize, white potato and wheat.

4.2. Soil

For practical land use the soil is an important natural resource and any farmer is acquainted with the influence of land suitability on the results of his material and human input.

Soil conditions regulate water availability, aeration and fertility conditions. The evaluation of these conditions requires an understanding of the relation between soil morphological properties, which can be observed in the field, and the soil-forming processes. This relation should be at the basis of any soil classification. But the African smallholder has to make a choice of his land based on his experience and natural vegetation is often a guideline. However, his choice is guided unconsciously by the scientific features unknown to him. Therefore, it seems useful to comment some soil-forming processes and their relation with observable field characteristics and physico-chemical parameters. With this information in mind it will be easier to comment the choice of cultivated land and to understand some traditional farm practices.

4.2.1. Soil Parent Materials and Choice of Cultivated Land

4.2.1.1. Tropical Saprolite

The African basement complex (paleozoic-metamorphic, igneous) and sometimes areas on mesozoic rocks are generally characterized by old peneplained landscapes alternating with residual zones (fig. 1). The weathering zones on mid and end tertiary peneplaines are often more than 20 m thick and of the ferrallitic or fersiallitic type (Botelho da Costa 1959). In the most humid equatorial part, the weathering type is ferrallitic; a SiO_2/Al_2O_3 ratio in the clay fraction lower than 2 suggests a clay of the kaolinitic type and gibbsite, iron oxides are goethite and/or hematite, the base saturation is low. In the drier areas, weathering is less aggressive, no gibbsite occurs, kaolinite can be associated with 2/1 clay minerals, the iron oxides are hematite and/or goethite, the clay fraction has a SiO_2/Al_2O_3 > 2 and a

$SiO_2/R_2O_3 < 2$, and the base saturation is higher. The transformation in the saprolite, from bedrock to the surface, shows a clear evolution of the colour from brown, reddish brown chroma Munsel values of 4 or less to higher red or yellow chroma values. We note an increase in the clay content, a decrease in the silt content, a decrease in the mobility in the clay expressed by a vanishing and final disappearance of the clay skins, a remarkable increase in soft iron oxide nodules (plinthite); near to the surface dehydrated iron nodules harden irreversibly to petro-plinthite (Sys 1968) and may cement together to a superficial laterite crust.

Such a deep saprolite can be subdivided into three parts:

— A recent stage of weathering, near the bedrock, with rotten rock fragments and if drainage is slow presence of 2/1 clay minerals associated with kaolinite;
— An intermediary stage of weathering with dominance of kaolinite, a high silt/clay ratio, an angular to subangular blocky structure with clay skins on the peds;
— An ultimate stage of weathering with a low silt/clay ratio, immobilization of clays by iron oxides that results in a fine granular structure and a flowery loose consistency; this stage occurs below the hardened surface laterite crust.

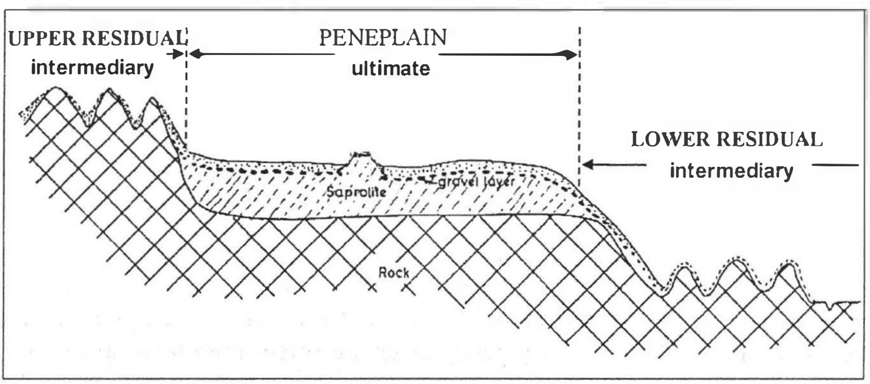

Fig. 1. — Peneplained landscape.

• The Geological Profile

In the present landscape these deep saprolites are still present as local higher reference hills capped with laterite above the main land surface (fig. 1). More generally, they have been dismantled as a result of the successive erosion processes. The erosion products are deposited on the present landscape. Their composition will depend on the erosion process. As a result, the present geological profile is built up by a series of layers:

— Superficial deposits of fine earth of various thickness;
— Gravel layer with iron oxide nodules sometimes associated with quartz fragments;
— The remaining part of the saprolite.

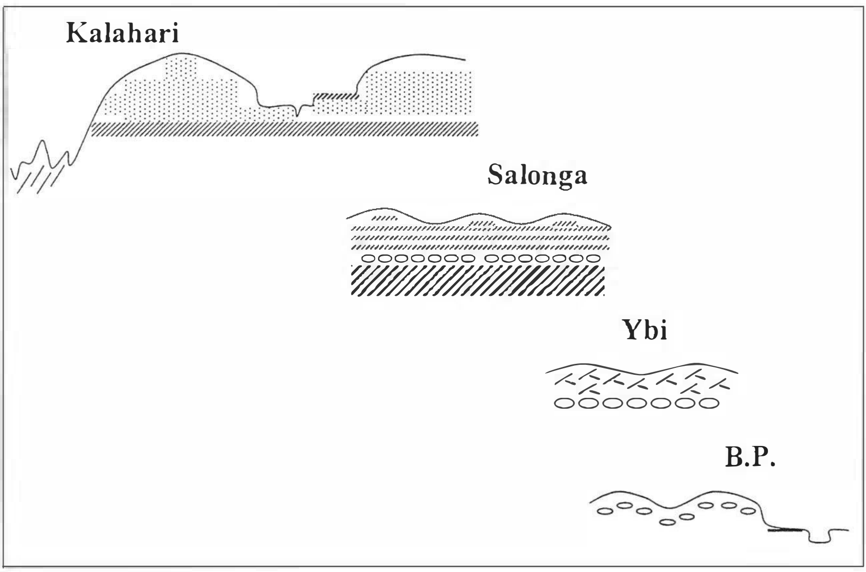

Fig. 2. — Plateau areas.

• The Soil Profile

The soil profile is developed in the superficial deposits but often the gravel layer appears within a depth of 2 m. According to its situation in the landscape, it is developed in a recent material, in a material at an intermediary or at the ultimate stage of weathering.

On and nearby rock outcrops the stony material presents an A-C profile; classification and agricultural value will depend on the thickness of the humiferous topsoil and on the base saturation.

Pleistocene residual landscapes are covered by soil material at the intermediary stage of weathering in a hilly topography (fig. 1). The A-B-C profile presents B horizons with angular or subangular blocky structure and the shining ped faces suggest the presence of clay skins. On heavy textured materials no textural differentiation can be observed, whereas on medium and coarse textured material there is often a clear textural differentiation. According to the case, the B horizon can be considered as cambic (Bw) or argillic (Bt). Classification and agricultural value will depend on texture, the nature or the humiferous topsoil (epipedon) and on the base saturation.

The old peneplain landscapes present soils at the ultimate stage of weathering. The A-B-C-D profile has B horizons with weak subangular blocky structure. The upper B or sub-surface horizon has a somewhat hard consistency; below the subangular blocks break under slight pressure into fine granules with a flowery feeling; in many cases clay nodules are present. This typical oxic B occurs in profiles with little textural differentiation on fine textured materials. On medium and coarse materials a textural differentiation can be noted (kandic B).

In those areas where peneplains alternate with residual landscapes around rock outcrops above the peneplain level, or residual erosion incisions below, one may observe a population concentration in the residual landscape while the peneplains are scarcely populated.

4.2.1.2. Plateau Areas

In great parts of Central and West Africa Tertiary and more recent Pleistocene, a thick mantle of cover sands buries erosion levels.

Up to 1960 the major part of geologists considered these cover sands as eolian deposits (Delhaye & Bourgniez 1948, Beugnies 1950, de Heinzelin 1952, Mortelmans 1956). However, there is a more recent tendency to abandon the traditional opinion of eolian origin. Jongen & Jamagne (1960) attributed a fluvio-lacuster origin to the low plateaus of the central Congo basin. Savory (1965), studying some sand mantles in Zambia, showed that their origin is not eolian. De Ploey *et al.* (1968), on the basis of a sedimentological study, abandoned the eolian origin of Kalahari sands.

Whatever their origin, we know that, on a geomorphological basis, these accumulation plateaus of the Congo basin occur on successive steps of lower and lower lying erosion surfaces (fig. 2). They can be subdivided into 4 groups.

— Kalahari sands;
— Plateaus of the Salonga type;
— Yangambi plateaus;
— Central Congo basin low plateaus.

• Kalahari Sands

The Kalahari sands of the southern Congo basin are loamy sands with a kaolinitic clay fraction that contains an appreciable amount of gibbsite. Under rainforest a bleached eluvial horizon appears below the topsoil with depth (more than 150 cm), local red accumulation spots are present with a composition similar to that of a spodic horizon. Southwards, under Miombo woodland, a dark-coloured humiferous horizon, 50 to 60 cm thick, passes gradually to a non-differentiated sand.

Soils have a low pH, a low base status and are occupied by a thinly scattered population concentrated on more humiferous terrace levels along the so called *vallées en auge.*

• Salonga Plateaus

The Salonga plateaus have a various clay content, their kaolinitic clay contains often some gibbsite; under the thin A horizon appears an eluvial horizon that presents bleached sand spots; the oxic B horizon below has a weak structure that breaks to fine granular in a flowery mass. The agricultural value of these acid soils depends on their clay content. Population is scarce and concentrated on more clayey places if a water source is available.

• Yangambi Plateaus

The Yangambi plateaus are characterized by a textural catena (De Leenheer et al. 1952). The texture ranges from sandy clay on the top over sandy clay loam on the slope to loamy sand on the lower slope; the clay fraction is kaolinitic, and no gibbsite is present. Clay content increases gradually with depth but rarely meets the definition of an argillic horizon. The parent material at the ultimate stage of weathering presents a profile with an oxic B of which the upper 30-40 cm has a hard consistency, but below the loose flowery material has a weak subangular block structure that breaks easily up to a fine granular structure. Base saturation is low and the natural fertility is ensured by the amount of nutrients immobilized in the forest vegetation and the humiferous topsoil. Population is mostly concentrated on lower slopes near the river water but the fields are somewhat higher behind the villages on the sandy clay loam soils, sometimes on sandy clays.

• Central Congo Basin Low Plateaus

These plateaus are fingering in a network of forested marshland determined by the Congo and Tchuapa rivers and their dense network of tributaries. The soils have a various texture with a clay content of 20 to 45 % of kaolinitic nature. The profile development is similar to that of the Yangambi plateaus, but the soils are less acid with base saturation from 35 to 50 %. Population is concentrated near the marshland and cultivation is preferentially practised on the most clayey soils.

4.2.1.3. Alluvial Soils

The alluvial soils along the river system consist of small levees and poorly drained marshland. The medium or lighter textured levee soils are in a recent stage of weathering and have an A-C profile or an A-Bw-C profile with cambic horizon. They are fertile and densely occupied. The poorly drained, clayey, sandy or organic marshes are not cultivated.

4.2.1.4. Volcanic Ash Soils

The recent volcanic ashes of East and Central Africa's mountain areas are Andosols, mostly with a high base saturation and a thick humiferous topsoil. These areas are densely populated.

4.2.2. Agricultural Practises and Soil Characteristics

Little is known about the standards applied in choosing the land for cultivation (JURION & HENRI 1969). Therefore we believe it is useful to comment some soil characteristics in relation to land-use practices in primitive farming.

4.2.2.1. Physical Soil Characteristics

Waterholding capacity and infiltration rate, as well as soil structure and workability, are important. Heavy textured Vertisols are never used by African smallholders, because their workability, together with their very low infiltration rate, are unfavourable. The land cannot be worked with a hoe and after heavy rains water does not penetrate into the soil so that the land remains flooded for several days. Even cultivation on ridges or hillocks is not practised because of the severe workability limitation.

Too sandy upland soils with good permeability and easy to be worked are avoided because of their low waterholding capacity and sensitivity to drought. Within the group of soils developed from a same parent rock and presenting a favourable texture, the waterholding capacity and infiltration rate are related to the stage of weathering. Recent soils around rock outcrops are often cultivated as they accumulate run-off water from the rocky hills and they have a satisfactory waterholding capacity due to their higher silt content.

The good waterholding capacity of materials in the intermediary stage of weathering on sloping lands in residual landscapes, explains why these slopes are more often used for cultivation as compared with the flat topography of the old erosion surfaces. On these sloping lands people plant on ridges always made in line with the slope. In the case of heavy rain, the sterile subsoil rather than the humiferous ridges will be eroded and removed, giving rise to quite spectacular erosion. Ridging along the contour lines remains unacceptable as long as African women remain the real farmers as it is an impossible work with a child on the back. Soils in the ultimate stage of weathering on the old erosion surfaces have a low waterholding capacity because of their very low silt content and their permeability is somewhat limited due to a subangular blocky subsurface horizon with hard consistency that overlies the granular very loose oxic subsoil.

4.2.2.2. Physico-chemical Characteristics

The capacity to retain nutrients and the charge characteristics of tropical soils are defined by: the silicate-clay minerals, the organic matter and the sesquioxides. Silicate clays have normally a negative charge; for kaolinite it is positive in the low pH-range and becomes slightly negative above pH 5.5. Organic matter has a negative charge that increases with increasing pH. It is generally accepted that the retention capacity of organic matter has a value of 260 meq/100 g. at pH 7 and decreases to 35 meq/100 g at pH 4.5. Organic matter is most often the only source of nutrients in tropical soils. In the rainforest the annual production of organic matter, which feeds the litter, is 15 tons dry material per ha, which participates in soil formation. It contains about 200 kg nitrogen and 250 kg mineral salts. A tropical rainforest immobilizes *ca.* 300 tons dry material per ha containing 1,100 kg N, 110 kg P, 85 kg K, 1,890 kg Ca and 290 kg Mg (LAUDELOUT & MEYER 1954, NYE & GREENLAND 1960). The annual production of organic matter in a savannah varies from 5 to 10 tons/ha dry material, with a mean of 20 kg N and 80-100 kg mineral salts (NYE & GREENLAND 1960). This illustrates the importance of the vegetation type and organic matter status when making a choice of the land.

The pH variable (+) charges in tropical soils are connected with oxide systems of iron, aluminium and allophane. Most often they form a stable coating around the clay minerals. These charge characteristics, responsible for the P-fixation capacity, may help to explain some agricultural practices in primitive farming.

4.2.2.3. Burning

Burning is the favourite method after clearing the forest or savannah just before cultivation begins. Burning produces ashes that, when mixed with the topsoil, improve the cation balance and increase the pH, resulting in an increase in the negative charges of the organic matter and a decrease in the positive charges of the oxide systems, and therefore decreasing the P-fixation capacity of the soil.

After the fire has done its work, nothing further is done in the forest to prepare the seedbed, whereas in the savannah preparations of various degrees of intensity are carried out.

4.2.2.4. Cultivation on Ridges and Hillocks

The superficially humiferous topsoil enriched with ash from the burned savannah vegetation is heaped up in a continuous ridge or a hillock on which the crops, particularly tubers, are planted. Doing so, one accumulates the fertility of the whole plot on nearly 50 % of the land. The enriched soil in the ridge benefits from the processes associated with the increase in pH and organic matter.

4.2.2.5. Bapende System

This system is practised by the Bapende (Kwango, R.D. Congo). On sandy soils, all the herbaceous vegetation is turned into the earth before setting fire. In such a case one saves part of the vegetation rests for gradual mineralization whereas the ash from what is fired will increase the pH, improving the cation balance as well as increasing the negative charges of the organic matter. Mainly food crops, such as cassava, are grown here.

4.2.2.6. Shitemene System

This is a particularly widespread and destructive form of itinerant agriculture, which is found in the wooded savannah and Miombo woodlands of Zambia and South Shaba (Dem. Rep. of Congo). In order to enrich their fields for annual crops, the farmers cut down all the bushes over an area ten to fifteen times greater than the area to be cultivated, and burn the trunks and branches. The ashes remain on the area to be seeded. This practise increases the effects of burning described above.

4.2.2.7. Eco-buage

"Eco-buage" is a method whereby advantage is taken of the partial burning of organic matter in the ridges, where the dense grass vegetation cover and the acid litter are mixed with the mineral soil.

It is often used on poorly to very poorly drained acid soils with high organic matter content and accumulation of an acid litter. The system is used for cultivation of dry season crops on soils saturated with water in the rainy season. In Burundi the system is used for dry season crops, mainly sweet potatoes or maize. When the land is dried superficially the ridges are built, a watertable that remains at 60-100 cm in the dry season provides the required water for dry-season cropping.

4.2.2.8. $CaCO_3$

In tropical Africa $CaCO_3$ is not a normal soil component, but if present it will improve the cation balance and increase the pH. As a consequence, one increases the negative charges of the organic matter and decreases the positive charges of the sesquioxides resulting in a decrease in the P-fixation capacity of the soil.

$CaCO_3$ has been described, in concretionary form, in termite mounds of the drier Sandano-Zambesian area. Another source of $CaCO_3$, in West Africa, is the inblow of calcareous dust from the Sahara. The inblow zone is characterized by topsoils with a pH of 5.6 to 5.8 and a sub-soil remaining acid (pH 5.0-5.2). These enriched soils, without Al-toxicity, represent a favourable land site for the cultivation of food crops. This feature was even at the origin of the classification of the cocoa soil in Ghana, where Charter (1954) introduced the Forest Ochrosoils and the Forest Oxysols.

5. Land Use, Marketing and Socio-economic System

From an analysis of the land use in different African countries we may conclude that it remains difficult to recognize a crop rotation in the real sense of the term. If African farmers have not discovered rotation systems as practised in Europe, it appears however that they have a good experimental knowledge of how to select the right place for cultivation of crops in association on a single plot of land.

This can be illustrated by the simplest form of crop association practised in the Congo forest area. After clearing and burning the forest, the land is occupied for 2 to 3 years by a pseudo-association: cassava, rice, maize and banana. Rice and cassava, resistant to Al-toxicity, occupy nearly the whole field where pH remains lower than 5.4; on places where burning of a concentration of branches gave more ash, the pH can reach 5.4-5.5 and maize is sown. Finally bananas are found on spots where larger trees have provided even more ashes and pH can reach 5.6 or somewhat higher. The land use of a typical smallholding (own observations in the 1950s; VAN MOERSIEKE 1929, BAPTIST 1951, GEORTANY 1956) consists of two units: a residential garden and a field plot. In the residential garden, 0.1 to 0.2 ha in size, one cultivates fruit trees (agrumen, avocado, ramboutan, safoutier, a few groundnuts, pineapple, piments, some banana and oil palm trees). The field plots, estimated at 0.4 ha, include the pseudo-rotation described above. Yields (tab. 2) and energetic balance (tab. 3) permit to estimate the product available for marketing (tab. 4).

Table 2

Yields (kg/ha) on Yangambi Series (Y1) on Traditional Smallholdings

Crop	**Reference yield* (kg/ha)**	**Yield (kg/ha) on Yangambi series**	**Consumable yield (kg/ha)**
Rice	1,400	728	626
Maize	1,800	954	859
Cassava	24,000	18,960	17,064
Banana	22,000	13,200	11,880
Fruits and vegetables	estimation (1 year)		720
Oil palm	5 trees x 18 kg (1 year)		90

* GEORTAY 1956. Reference yield: yields obtained on soils with land indice 100
- Land indice Y1 (Yangambi series): 52
- Land indice Y2 series: 40
- Land indice Y3: 26

Table 3

Energetic Balance (Y1 — Yangambi Series)

Residual plot		**Kcal**
Fruit and vegetables	720 kg x 400	288,000
Oil palm	90 kg x 8,840	795,600
	Sub-total	1,083,600
Field crops		**Kcal**
Rice	0.36 ha x 626 = 225 kg x 2,340	526,500
Maize	0.04 ha x 859 = 34 kg x 3,270	111,180
Cassava	2/3 (0.32 ha x 17,064 = 3,640 kg x 1,090	3,967,600
Banana	0.08 ha x 11,880 = 950 kg x 700	665,000
	Sub-total	5,270,280
	TOTAL	6,353,880
	DAILY	17,408
	Number of rations of 2,220 Kcal	7.8
Result for:	Y2 series: 6.4 rations of 2.200 Kcal	
	Y3 series: 5.1 rations of 2.200 Kcal	

Table 4
Marketing Part of Production Component

Soil Series	(1) Weekly production kg	(2) Weekly nutrition value no. of rations	(3) Weekly nutrition need no. of rations	(4) Remains for marketing no. of rations	(1) x (4) / (2) marketing part kg/week
Y1	108	54	35	19.6	38.7
Y2	84	45	35	10	18
Y3	59	36	35	1	1.6

The yields and energetic balance are given for the results obtained on the best plateau soil of the region (YAGAMBI SERIES, Y1), and were recalculated for Y2 and Y3 series. The results for these soils are also available. As the Y2 soils have the most important geographic distribution, one may estimate that most foodcrops are cultivated on these soils. The quantity of foodcrops available for the farmer to commercialize at the weekly market can vary from 1.6 to 38.7 kg according to the suitability of his land. To these vegetable products one may add some eggs, sometimes a chicken and very often smoked meat resulting from hunting or obtained from pygmees by exchange for agricultural products at farm level.

If the production centre of traditional farming is the smallholding, the centre of socio-economic activity is the market. Most villages have a weekly market visited by nearly the whole population of the area. Some people walk more than 15 km to reach the market.

The women travelling to the market carry a large basket on their head filled up sometimes to a weight of nearby 50 kg.

BAPTIST (1951) checked the weight transported by 5 women, on their way to the market: they carried loadings of respectively 48, 44, 37, 37 and 42 kg; at this check-point, most of the transported products were smoked meat and chikwange. The meat was a product of hunting, which indicates that, if the woman is the real farmer, the man contributes a lot as a result of his hunting.

The people present at the market are the smallholders to sell their farm and hunting products: chikwange (a cassava preparate), cassava, bananas, rice, groundnuts, oil palm, fruits as citrus, ramboutan, pili-pili, meat, etc. At the other hand there are merchants to buy farm products and to sell everyday wear: salt, lances, machetes, cigars, cigarettes, several ornaments and decoration such as strings and pearls.

As such the local markets are the centre of socio-economic life. They create purchasing power, stimulate social contacts and exchange of mental attitudes. People discuss land, work and life, farm practices, business, pests and diseases, drought and flooding, weather conditions, and finally socialize.

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Conclusions

par

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Parmi les actions scientifiques de la Belgique dans les territoires d'outre-mer, il en est une qui doit être mise en évidence, c'est celle liée aux sciences de la terre, et plus particulièrement à la science du sol: la pédologie tropicale.

La journée d'étude qui lui a été consacrée par l'Académie Royale des Sciences d'Outre-Mer permet de retracer l'œuvre et l'influence des pédologues belges d'abord dans les anciennes colonies mais aussi, par après, dans les autres pays tropicaux, que ce soit en Afrique, en Asie ou en Amérique latine. Cette réunion a donné la parole à des pédologues belges, pionniers de la pédologie au Congo, mais qui ont aussi œuvré dans de nombreux pays tropicaux, souvent dans le cadre des activités de la F.A.O. Il faut aussi souligner la présence du Professeur A. Ruellan, représentant l'Ecole française, et la contribution de nos collègues portugais excusés. A regretter cependant l'absence des collègues belges francophones qui, eux aussi, ont participé et participent encore au développement de la science du sol sous les tropiques.

Avant toute chose, il me faut rappeler le rôle primordial de l'Ecole du Professeur R. Tavernier de l'Université de Gand dans le développement et l'enseignement de la pédologie tant en Belgique qu'outre-mer.

C'est donc dans l'ex-Congo belge, comme l'a souligné J. D'Hoore, au Centre de Cartographie de l'INEAC à Yangambi, qu'a été conçue, en 1959, la première carte pédologique au 1:5 000 000 couvrant les territoires du Congo belge, du Ruanda-Urundi, mais aussi de l'A.E.F. et du Cameroun. Cette carte, qui alliait les données géologiques, géomorphologiques, climatiques et de végétation aux données de terrain, fut un exemple pour l'Afrique.

Et J. D'Hoore de conclure que lorsque les premières données satellitaires sont arrivées en 1972 et comparées à la carte pédologique d'Afrique, la

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concordance était parfaite, signifiant ainsi, *a posteriori*, l'excellence des observations des cartographes de Yangambi.

C. Sys, issu comme J. D'Hoore de l'Ecole de Gand, a débuté sa carrière en 1949 à Yangambi et a participé de façon active à la cartographie des sols dans les anciennes colonies belges.

Il démontre la coïncidence entre le choix «empirique» des cultures par les fermiers traditionnels et la connaissance scientifique du climat et du sol, et souligne combien les sociétés primitives prennent en compte les ressources naturelles pour leur développement socio-économique.

En prenant comme exemple la cuvette congolaise, son climat, ses sols et les pratiques culturales traditionnelles, il montre comment les populations sont arrivées non seulement à la sécurité alimentaire, mais comment elles peuvent participer au circuit économique et, par l'intermédiaire des échanges, aux contacts sociaux.

A. Ruellan rappelle également que, depuis les années 50, les pédologues français ont, eux aussi, collaboré à la pédologie intertropicale dans les divers continents. Il insiste sur l'étude de la structure du sol qui résulte du passé et de la dynamique actuelle, permettant ainsi de prévoir le comportement futur du sol et sa fertilité.

Il développe surtout l'importance de la morphopédologie, et plus particulièrement la notion du bassin-versant, et insiste sur le fait que la géomorphologie et la pédologie sont indissociables pour la compréhension du sol, sans cependant négliger les influences anthropiques dans la transformation des sols.

Nos collègues portugais montrent aussi que c'est par l'étude des sols en Angola par Costa et Azevedo (1946) que la cartographie pédologique a débuté pour se développer ensuite dans les autres colonies portugaises. Eux aussi ont collaboré à la Conférence interafricaine des Sols. A souligner que c'est à leur école que l'on doit la distinction entre sols latéritiques et latérite et à l'introduction du terme «ferrallitique».

R. Dudal insiste sur la grande diversité des pédogenèses et donc des sols en région tropicale et il s'élève contre la notion globalisante de «sol tropical». Il rappelle la proposition de Costa (1954) d'utiliser le terme ferrallitique au lieu de sol latéritique. Il traite enfin de l'évolution de la terminologie en pédologie tropicale.

La classification des sols tropicaux est complexe et Deckers compare les trois systèmes existants: USDA, FAO et WRB. Il rappelle que les propriétés des sols sont influencées par le climat, la végétation, la faune, l'homme, le relief, la roche-mère et le temps. En proposant pour les différents systèmes de classification, des clés de référence et des tableaux de comparaison, il permet de clarifier une situation fort complexe.

Enfin, F. Nachtergaele et E. Van Ranst évoquent les difficultés rencontrées pour la cartographie des sols, notamment leur faible précision et le coût élevé des investigations sur le terrain. Par ailleurs, l'imagerie satellitaire, si elle peut donner une vue globale et indirecte des sols, ne peut pas apporter une information pédologique suffisante sur le terrain.

Personnellement, je pense que l'avenir de la pédologie tropicale se trouve dans une meilleure compréhension de la géomorphopédologie dans le cadre du bassin-versant.

Par ailleurs, il ne faut pas négliger, dans le futur, l'apport des données G.P.S. insérées dans un système d'information géographique afin d'arriver à une agriculture de précision et ainsi à une rationalisation de certaines pratiques culturales.