Working Paper and Preprint

No.84/6

SOILS OF THE HUMID TROPICS:
STATE OF KNOWLEDGE AND RESEARCH PRIORITIES

W.G. SOMBROEK

Presented at the 1° Simposio do Tropico Umido,
Belém. Para, Brazil, November 1984

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

1° Simposio do Tropico Umido, CPATU, Belém, Para, Brasil, November 1984

Soils of the Humid Tropics; state of knowledge and research priorities

by

W.G. Sombroek

Director, International Soil Reference and Information Centre (ISRIC),
Wageningen, the Netherlands

ABSTRACT

A review is given of past soil research activities in the three main regions of humid tropical lowland forest, viz. South-East Asia, Central Africa and the Amazon region of Latin America.

A number of national and international soil-related research programmes is nowadays in execution or under consideration, often as networks. An effort is made to identify major knowledge gaps and research priorities per subdiscipline of soil science (soil genesis, classification and cartography; soil mineralogy, physics and chemistry; soil biology, fertility and plant nutrition; soil technology and conservation). It is stressed that site selection for studies on soil-plant relationships should be done in relation to major soil geographic patterns, to ensure that the results can be extrapolated to large areas with similar soil conditions. New and existing sites should be studied and described very carefully and comprehensively as regards soil characteristics.

1. INTRODUCTION

For a thorough review of the state of knowledge on research on soils of the humid tropics one would need the space of a book. The present contribution is only meant to give an overview, an identification of major gaps in our knowledge, and an indication of priorities at soil research planning.

There have been, in recent years, several reviews on soil research in the tropics, directed either purely to specialists on the subject, or to broad-subject audiences such as the present symposium. One particularly useful reference is the book "Soils of the Humid Tropics" as compiled by an international committee on tropical soils with Dr. Matthew Drosdoff as chairman. It was published twelve years ago by the National Academy of Sciences of the USA (Drosdoff, 1972), just before the publication of the FAO-Unesco Soil Map of the World at 1:5,000,000 (FAO-Unesco, 1971-1982). It contains a comprehensive summary of the knowledge available at the time, and spells out a number of research priorities. Most of them remained priorities in the years since, and have been voiced again and again, for instance at the international "Soil-Related Constraints Conference" in Los Banos, Philippines in 1979 (Metz and Brady, 1980). That conference resulted - after four more years - in the formal establishment, in Townsville-Australia, of the IBSRAM organization. This acronym stands for International Board for Soil Research and Management (in the tropics and subtropics), with an ambitious research programme through the "networking" concept, but as yet very shaky financial basis.

Other interesting reviews are given in Unesco's publication on tropical forest ecosystems (Unesco, 1978); by Sanchez (1973) for Tropical Latin America, and by Sombroek (1984) for the Amazon region. Biologically oriented overviews annex research programme proposals are given by Swift (1984) and Lavelle (1984).

3. OVERVIEW OF AVAILABLE INFORMATION PER REGION

a) South-East Asia

In the early years of the twentieth century much soil research was carried out in Indonesia by Dutch scientists (see Mohr, Van Baren and Van Schuylenborgh, 1972). The present Centre for Soil Research in Bogor, Java was in fact founded by Prof. Mohr and is about to celebrate its centenary. Soil fertility in relation to parent materials was a major item of research in those early days. After World War II, FAO staff collected and compiled much field information on the South-East Asia region as a whole (Dudal and Moormann, 1964). At present, much new soil information - on genesis, classification, fertility, and management - is emanating from Malaysia and Thailand, its aggregation being stimulated by several regional soil conferences in recent years (e.g. Joseph, 1980).

b) Central Africa

After World War II a very significant effort on soil and vegetation mapping and soil research in general was carried out by Belgian scientists of the INEAC organization, in Zaire, Rwanda and Burundi, with Yangambi as scientific centre. Also in French and Portuguese speaking African countries there was an emphasis on soil genesis and mapping, through the activities of the ORSTOM and JIU organizations, based in Paris and Lisbon respectively. In English language African countries much attention was given to soil properties, and soil management under different forms of agricultural occupation (Muguga-Kenya; Kwadaso-Kumasi, Ghana; cf. Nye and Greenland, 1960).

Soil geographic information was aggregated into the 1:5 million Soil Map of Africa of CCTA (d'Hoore, 1960), which served as valuable precursor for the FAO-Unesco soils map of that continent. At present, Ibadan in Nigeria, Adiopodomé/Tai in Ivory Coast, and Nairobi/Kitale in Kenya are some of the centres producing much research data on the soils of the humid tropics in Africa.

c) Latin America, viz. the Amazon region

The Amazon region has been **terra incognita** until quite recently. Factual soils information started to be published in the early sixties, with this author having had the privilege to provide a part (Sombroek, 1966).

Complete small-scale geographical coverage, refuting many early guestimates, was obtained only afterwards, from the Brazilian radar-supported mapping project (Projeto Radam, 1972-1978; Ranzani, 1979), followed by similar programmes in Colombia (Botero, 1980 and others), Venezuela and Peru. The opening-up of Brazilian and Peruvian parts of the region by a network of highways, and the urge towards large-scale or small-holder agro-pastoral settlement gave impetus to soil management research in both the Brazilian part (CPATU, CEPLAC, etc.) and at the Yurimaguas research station in Peru (Sanchez and Buol, 1974, et seq.). Also soil-vegetation relationships with the ecosystem approach received attention, e.g. at INPA in Manaus (Chauvel, 1982; and others), at San Carlos de Rio Negro in Venezuela through Unesco's Man and the Biosphere Programme (Herrera, 1977; and others), in Surinam (Wienk and De Wit, 1982), and at Iquitos University in Peru. These centres are in full swing in the production of research data.

Moreover, international organizations such as CIAT in Colombia and CATIE in Costa Rica produce regional compilations, especially in the sphere of soil fertility and management (e.g. Sanchez, 1973; Bornemisza and Alvarado, 1975; Hecht, 1982).

3. SOIL RESEARCH NETWORKS

Several national and international networks of soil and soil-related research in the humid tropics are now in execution, or under active consideration.

Examples at national level are Indonesia, which is setting up regional centres on the various islands, and Brazil which has its very effective network of EMBRAPA agricultural research centres.

At international level, Unesco's MAB programme has a soil section which is comparing soil conditions in biosphere reserves and research sites in the tropics. FAO has, since many years, a loose network of projects in the sphere of soil research institution building, fertilizer use demonstration plots, and soil conservation training. It also hopes to update the FAO-Unesco Soil Map of the World, which is rapidly becoming out of date, especially on the humid tropics. UNEP is starting to propagate its World Soils Policy Plan-of-Action, including catchment management studies. Its Global Environmental Monitoring System (GEMS), which should include the soils element, is gradually taking shape.

The International Union of Biological Sciences (IUBS) wants to start a network on "soil biological processes and tropical soil fertility" (Swift, 1984), which may form part of the International Geosphere-Biosphere Programme as announced by the International Council of Scientific Unions (ICSU) at a "Global Change" Symposium in Ottawa, September 1984. The International Federation of Institutes for Advanced Study (IFEAS) has similar plans for a network of tropical soil research.

The "Tropsoils" programme of a consortium of US universities supports management-oriented research sites in Peru and Indonesia and is also looking for a study area in humid tropical Africa. For a number of years the US-Hawaii Benchmark Soils Project linked soil classification-oriented research in Brazil, Cameroon, Indonesia, and Philippines with those of Hawaii and Puerto Rico. Its successor project IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) is building up a more ample network of research on soil-weather-plantgrowth relationships, using modeling techniques. ORSTOM has widened its research from Africa to tropical Latin America and Asia. Dutch institutions are considering to initiate a network on tropical forest research called "Tropenbos", including a substantial soil research and land evaluation component.

The IBSRAM organization, mentioned earlier, is about to implement international research networks on Land Clearing and Development, on Acid Tropical Soils, and on Wetland soils. The South-East Asian countries cooperating in ASEAN have recently decided to cooperate in exchange of soils information and research, and there are similar plans by all countries that have a share in the Amazon region (REDINAA; PACTO AMAZONICO).

More, and more precise site characterization from all these network points is therefore being produced and becoming available for comparison at country, regional and global level. Nevertheless, such characterizations are often still incomplete; according to different methods of field study and laboratory methods; and worse, the siting may not be representative for natural subregions within the humid tropics. This brings us to the presentday research gaps and research priorities.

4. RESEARCH PRIORITIES FOR SOILS OF THE HUMID TROPICS

Following the traditional grouping of subdisciplines in soil science, the following priorities of soil research may be identified. Reference is made to the recent comprehensive overview of soil study needs in developing countries by Baumgardner et al. (1983) and by Craswell and Isbell (1984).

4.1 SOIL GENESIS, CLASSIFICATION AND CARTOGRAPHY

Relevancy of diagnostic soil horizons and features. Diagnostic horizons as defined nowadays in the US Soil Taxonomy system of classification and in the Legend of the FAO-Unesco Soil Map of the World turn out not to be relevant for many tropical soils. The concepts of "argillic" (B) horizon and "mollic" or "humic" (A) horizon as developed for soils in temperate region need to be modified and subdivided (for instance with a soil constituents parameter, organic matter distribution types, and degree of structure stability). Additional diagnostics may have to be introduced, such as the "horizonte plintico" of the Brazilian soil survey (EMBRAPA-SNLCS).

Correlation of soil classification systems. There are at least half a dozen soil classification systems in use in the tropics, each with its own structure, criteria and terminology. A uniform system, applicable to all situations and acceptable to all schools of thought, will be difficult to achieve, if only because soils are a continuum, at the contact between the dead geo- and the living bio-units. The current diversity of terminology is however a bewildering and repulsive jungle to pedologists, agronomists and ecologists alike. Perhaps the recent initiative of the International Society of Soil Science (ISSS) to devise an International Reference Base (IRB) for soil classification is a way out to terra firme.

Small-scale mapping. Many countries of the tropics are now working towards systematic small-scale soil resources inventories, usually at scale 1:1 million. The methodology - structure of legends, system of soil classification; quality and quantity of groundtruth; degree of incorporation of climatic and topographic aspects - varies however from country to country. There is an urgent need to correlate and incorporate all this new information, with one standardized legend, into an updated version of the existing 1:5 million FAO-Unesco Soil Map of the World and/or into a computer-assisted map at 1:1 million scale, possibly as part of UNEP's proposed Global Resources Information Base (GRID).

Soil data base development. Several tropical countries, e.g. Brazil with its SISSOLOS system, have started with a computerized data base of their soil and land resources. In this field, again, a situation may develop that the data bases of countries are not compatible, hampering international soil knowledge transfer. Good work is however being done by the international Working Group on Soil Information Systems of ISSS to remedy this situation.

Short-distance sequences. Side by side with small-scale mapping, there is a strong need for attention to short-distance variations in soil conditions, occurring either in a systematic pattern (catenary sequences) or haphazardly (for instance fossil termite mounds). Their identification is indispensable for a good understanding of local variations in forest and crop growth.

Selection of multidisciplinary research sites. As indicated before, pedologists should play a key role in the selection of sites for ecological research, be it on forest architecture, nutrient cycling/biomass production, agronomy trials, or other subjects. Only by making sure that new sites for integrated research on soil-plant/vegetation relationships are chosen in relation to major soil geographic patterns, the results can be extrapolated to large areas with similar conditions. At present, forest ecological studies tend to be concentrated on the poorest soils, and agronomic experiments on the best soils. A truly multidisciplinary ecological approach requires the elimination of this traditional antagonism between foresters and agronomists. In any case both existing and new sites should be studied and described very carefully and comprehensively as regards soil characterization and conditions.

4.2 SOIL MINERALOGY

Silicate minerals. Many soils of the humid tropics have nearly exclusively kaolinite as silicate mineral. The physico-chemical activity of this soil mineral varies however from nearby zero (CEC value of 1-2 meq/100 g) to very substantial (CEC around 16 meq). The reasons for this - due to size, crystallinity or surface roughness of the mineral, or else - need to be investigated.

Sesquioxides. The determination of the total amount of sesquioxides has all along been standard in tropical soils analysis. Little data is however available on the type of sesquioxide (goethite, Al-substituted goethite, hematite, maghemite, gibbsite, etc.), its degree of crystallinity and its reactivity. These minerals are often abundantly present in tropical soils, and this fact has been taken as index for their weathering state ("lateritisation"). The minerals may, or may not, be active agents in the formation and stabilization of the "porous massive" structure of such soils. Much depends on whether the sesquioxides are inert and coarsely aggregated (concretions), or finely divided and interacting with the silicate minerals, thereby co-determining the physico-chemical properties of the soils. Micromorphological and spectrometric studies may be helpful. At much larger scale than at present, relative contents have to be determined of "total" Fe and Al oxides (X-ray analysis, or boiling with concentrated acid) versus "free" amounts (extraction with citrate-dithionite) and "active/amorphous" amounts (extraction by ammonium oxalate). Such studies may establish if present classification criteria are valid, or need to be adapted.

Specific surface areas. A good indication of the reactivity of the soil mass, in dependence of type and form of the silicate and sesquioxide clay minerals, can be obtained by determining its specific surface. The total of microsurface area per gram of soil or clay, after all, determines to a large extent the chemical properties (cation and anion exchange capacities) and the physical properties (e.g. moisture holding capacities, degree of swelling and shrinking).

First determinations of these surface areas, as carried out by for instance IITA in Nigeria, EMBRAPA-SNLCS in Brazil, the Lincoln Federal Laboratory in the USA, and at ISRIC in the Netherlands indicate that such values may be a useful additional diagnostic feature of tropical soils.

Aeolic admixtures. Detailed studies of the assemblage and forms of the minerals in the sand and silt fraction of selected soil samples may throw light on the influence of airborne materials on the process of soil formation and the origin or maintenance of nutrient levels. Volcanic ash and desert dust, even if deposited in tiny quantities far away from their source, may exert a relatively strong influence, because of the high degree of weathering of the local parent materials.

4.3 SOIL PHYSICS

Effective moisture storage capacities. There are indications that the effective storage capacity in many tropical soils are quite small, making shallow rooting plants subject to drought stress even if only a few "dry" months occur. Data on full moisture retention (pF) curves, and associated measurements of micro and macro porosity, on undisturbed samples of representative soil types, are badly needed to substantiate this.

Structure stabilities. Early assumptions that all soils of the humid tropics have stable structures, making them little sensitive to compaction and erosion, are nowadays challenged, especially for soils relatively poor in sesquioxides. Precise data, including the effects of soil mesofauna and of tillage practices on the structure, are however lacking. Measurements of "water-dispersable clay", if well calibrated, may be helpful. There is also a need for adapted standardized criteria for description of the structures of tropical soils in the field.

Bulk densities. There is very little data on bulk densities, determined on undisturbed samples, of well identified soil types, as a means to establish the occurrence of compact soil layers. Such layers can have a very strong influence on structure and stability of the forest vegetation which they support.

Rheological properties. The behaviour of the major tropical soils under mechanical stress, e.g. through the use of heavy machinery at land clearing, is a neglected area of research (see El-Swaify and Lal's contributions on Physical and Mechanical properties of Alfisols, Ultisols and Oxisols; in Theng, 1980).

4.4 SOIL CHEMISTRY

Organic matter: composition and distribution patterns. The varying composition of the organic matter in tropical soils - in relation to soil type, (soil) climatic conditions (altitude!) and type of forestcover or land use - has been little studied. Most laboratory analysis for soil survey and classification purposes is confined to C and N determinations, after combustion. Non-destructive analysis of humic acids-fulvic acids-humins is rarely done.

The relative amounts of aliphatic C, aromatic C, aromaticity, carboxyls, carbohydrates and proteins can now be determined in one go (Preston and Schnitzer, 1984). Also, direct measurement of the cation and anion exchange capacities of these components and of the whole organic matter fraction will be needed, to determine its relative importance viz-à-viz the mineral fraction. Model-supported calculations on C and N turn-over can be helpful in assessing the amount of young and active, consumable organic matter versus stable humus (Paul, 1984). Systematic comparison of the vertical distribution patterns of the (stable) humus per major soil type can be useful in soil classification (Bennema, 1982) and may provide indications which of these soil types are particularly sensitive to degradation upon mechanical clearing.

Chemical charge characteristics. By and large, the routine determination of the cation exchange capacity of tropical soils is still carried out at pH 7.0 or pH 8.2, though it is accepted that this in many cases gives unrealistic figures of the exchange capacity at field conditions (Theng, 1980). Systematic determination of permanent and pH dependent charges, and determination of effective cation exchange capacity (at the pH of the soils in the field) should be stimulated. The same applies to levels of exchangeable aluminium, which are often proving to be toxic. Standardization of such adapted methods will be required, and a machinery should be developed to have new laboratory methods and procedures of proven relevance and reliability readily accepted at all soil characterization laboratories in the tropics (Van Reeuwijk, 1982).

4.5 SOIL BIOLOGY

Mesofauna studies. Quantitative studies on the composition of the soil mesofauna population are quite rare for the humid tropics region. All ecologists agree that the effects of termites, leaf cutting ants, cicades, etc. on the maintenance of a porous structure of these soils and on the homogenization of the soil profile are very substantial. Measurements on quantity and depth of soil transport per soil type, under forest or some form of cultivation (e.g. Wielemaker, 1984), will however be needed to substantiate the claim that the deeply weathered soils of relatively low iron content (e.g. the xanthic Ferralsols of western Amazonia) depend very strongly on ample mesofauna activity to maintain their favourable structure as found under forest coverage.

Microbiological studies. Data on taxonomy and population of fungi and bacteria are also sparse, and often lacking in precise tagging as regards the type of soil and its vegetation/land use history.

Soil-rhizosphere interactions. More and more indications appear that many of the tree species of the tropical forest need specific mycorrhiza's to ensure sufficient nutrient intake, especially phosphorus, in their early stages of development. The degree of soil type specificity of these organisms is however largely unknown; the same holds for N-fixation effectivity of rhizobia. With reforestation projects increasingly becoming stipulated follow-up activities of large scale logging or ranching, this is a research area of high priority.

Rooting patterns. Forest architectural studies are being increasingly undertaken (Hallé et al., 1978), but their natural counterpart, i.e. the establishment of rooting patterns/mosaics, is receiving scant attention, also because the measurement techniques are quite elaborate. A good understanding of the differences in forest structure and forest regeneration requires an insight in how far tree root development is hampered by the occurrence of dense, hydromorphic, or toxic subsoil layers.

4.6 SOIL FERTILITY AND PLANT NUTRITION

Soil fertility testing. Short distance variation of topsoil fertility, both under primary forest vegetation and after clearing can be considerable. Therefore, compound sampling over a sizeable surface area (100 m^2) and to a standard depth (30 cm) should be adhered to. Fertility testing in the laboratory is far from standardized, though the North Carolina type of testing, as used in the so-called Soil Fertility Capability Classification (Buol and Couto, 1980) is rapidly gaining ground.

Nutrient cycling. Theoretical histograms of biomass production are more and more being substantiated by measurements of annual nutrient inputs to the forest floor, nutrient capital in the living biomass, and reserves in the soil. There are now about 15 study sites in South-East Asia, 10 in Africa, 10 in South America and 5 in Central America and the Caribbean (Bruynzeel, pers. comm.). The type of information gathered per site varies substantially; measurements of inputs from atmospheric and substratum sources and losses via percolation and leaching are scanty. In this field of research close contact with pedologists is necessary, not only for precise description and classification of the soil once the studies are under way, but especially for the selection of a site in the first place. The impression prevails that some of the present sites are not representative for major soil geographic regions, being located on exceptionally poor soils. Overstatement of the perils of deforestation on the productive capacity of the land may be the result. The biomass production on well-drained, relatively young soils, especially those on basic parent materials (like the Terra Roxa Estruturada of Brazil or some of the Andosols of Java) can stand a much higher degree of human interference than that on the poorly drained Podzols of San Carlos de Rio Negro - and there is a whole range of situations in-between!

Micro-element deficiencies and toxicities. At occupation of forest land for permanent cropping or cattle herding the micro-element situation in the soil often turns out to be of critical importance. Instead of expensive analysis of hosts of soil or tissue samples, one may try to establish relationships with type of soil parent material and the degree of weathering through physiographic field studies. Analysis of drainage waters can be helpful, too.

Phosphorus behaviour. Phosphate fixation and release are intimately linked with the physico-chemical characteristics of tropical soils, as determined by the assemblage of silicate minerals and sesquioxides and their reactivity. Indications are that the residual efficiency of phosphate fertilizers varies strongly with the taxonomic soil unit (Roche et al., 1980; Fox and Li, 1983). The systematic determination of P sorption-desorption curves as a means to predict P fertilizer requirements over the years may be useful.

4.7 SOIL TECHNOLOGY

Land Clearing Methods. Considerable ad-hoc research has been carried out in land clearing by mechanical or traditional means (Surinam, Jari in Brazil, IITA in Nigeria, Yurimaguas in Peru, etc.). The lack of precise characterization of the soils concerned, and the correlation with soil and climatic conditions elsewhere in the humid tropics, has led to unnecessary acronimous debate on the merits of any particular method. Fortunately the new IBSRAM organization is promoting networking research in Land Clearing and Development, at which the soils component will receive ample attention.

Tillage studies. As a sequel to the above, adapted methods of land tillage after clearing may have to be developed per type of soil, accompanied by quantitative assessments of the "tilth" situation of topsoils under various forms of management. Perhaps a return to Atterberg value determinations is worthwhile (Theng, 1980).

Engineering properties. With the advance of road building in tropical forest regions, the need for soil geography-based data on suitability of the land for road construction and maintainance is ever increasing. There is far too little contact between soil materials specialists and pedologists, resulting not only in overlap of laboratory testing but also in unnecessarily expensive engineering works.

4.8 SOIL CONSERVATION AND ENVIRONMENT

Rates of soil formation. Data on the rate of soil formation in relation to the type of parent rock or sediment is scanty. This is not only of theoretical interest: one needs such data to establish the levels of erosion that are still "permissible" in relation to neo-formation of soil material in the tropics. Laboratory experiments may be of some help, but much more insight in the geographic pattern can be gained by systematic field studies on age and stability of landforms on which specific soils occur.

With the propagation of "comprehensive" taxonomic systems of soil classification, land form - parent material - soil type relational studies tend to be neglected these days.

Soil degradation after clearing. Assessment of the types and rates of soil degradation, after clearing with different methods and establishment of different forms of agricultural land use, is as yet largely speculative (Fearnside, 1980). Measurements in surface crusting, land gullying, sediment transport, subsoil compaction and hardening, and loss or redistribution of organic matter are needed on a variety of soils of the humid tropics. This should comprise not only experimental erosion study plots, but also long-term monitoring on farmers' fields. Comparison with plots on the same soil and land units under forest vegetation - where "hidden" soil erosion may take place, too - are a necessary base-line complement to such studies.

Integrated watershed studies. Studies on whole hydrographic catchment areas are needed, too, if only to predict and quantify any effects on downstream areas of accumulation. In such cases careful consideration has to be given to the erodibility of the different soil and land units that make up the catchment area - thereby providing gauges for extrapolation to other areas.

5. TOOLS AND EXPERTISE

It may be obvious that we are only at the beginning of a whole range of new studies on the soils of the humid tropics. There is however a number of new tools available that allows us to speed up such studies, both in width and depth.

As regards mapping, there is now a lot of remote sensing imagery, including side-looking-airborne-radar images, for a number of the countries concerned. Interactive graphical systems of digitized mapping are in development, complemented by computer-stored soil profile data bases, which can speed up soil cartography over large areas. It also opens the way to small-scale (say 1:1 million) soil inventory and land evaluation of the whole of the humid tropics with a unified system - as well as its regular updating as new groundtruth data becomes available.

For better characterization of the soils there is new clay mineral analysis apparatus (X-ray analysis; Mössbauer Spectroscopy; BET-Nitrogen or EGME specific surface area measurement) and new micromorphological equipment (SEM-EDAX; Quantimet) supported by standardization of measurement criteria. Neutron probes are available for soil moisture testing, and ion-tracing apparatus for nutrient cycling studies. Also advanced humus analysis apparatus, using nuclear magnetic resonance, has been developed.

However, much of this equipment is very expensive in acquisition and maintenance, and only available in advanced soil laboratories in industrialized countries. One would wish that such laboratories use some of their expertise to develop simple and sturdy apparatus that can be used in the field. For instance, the design of portable equipment to measure reliably soil moisture retention characteristics (pF curves), and a device for field measuring the effective CEC of the soil, would be of great help for soil surveyors working in the tropics.

To carry out all soil and land evaluation studies as touched upon in the above, the cadre of tropical soil specialists has to be much enlarged. The provision of experts by international and bilateral technical assistance agencies can be only of temporary soulace. Training facilities for local soil scientists, both at international centres of excellence, and at local universities and institutes have to be strongly enlarged, especially in tropical African countries. Network programmes, as mentioned in chapter 3, have to give ample attention to the training of local scientific staff.

Training is however only one of the incentives. There should be more facilities for publication of research findings, both at national level and in international periodicals and book series, for soil scientists indigenous of the countries with humid tropical conditions. Right now, much valuable research data of Latin American soil scientists does not reach the international circuit, by being published only in Spanish or Portuguese. National governments and international agencies alike should be prepared to fund also more basic research, in addition to the development oriented type. In fact, much of the basic research going on is cloaked in a "development jacket". This is often frustrating for both the scientists and the funding agencies, and may unduly influence the results, consciously or accidentally.

Most important of all, financial and social incentives should be generated for local soil scientists to stay working under humic tropical field conditions for more than a few years in the early stages of their professional carreer.

REFERENCES

Baumgardner, M., P.R. Crosson, H. Dregne, M. Drosdoff and F.C. Weston, 1983: "Soils". In: Conant, F. et al. (eds.) 1983: "Resource Inventory & Baseline Study Methods for Developing Countries". American Association for the Advancement of Science, Publ. 83-3, ASSS, Washington DC, U.S.A.

Bennema, J., 1982: "Acid Soils of the humid tropics of South America, with special reference to the well drained soils on old alluvial sediments". p. 105-126, In: Wienk, J.F. and H.A. de Wit, 1982 (see below).

Bornemisza, E. and A. Alvarado (eds.), 1975: "Soil Management in Tropical America". Proceedings of a Seminar at CIAT, Cali-Colombia. Soil Science Dept., N.C. State Univ., Raleigh NC, U.S.A.

Botero, P.J., 1980: "Caracteristicas geo-morfopedologicas de los paisages entre los rios Putumayo y Caqueta - Amazonia Colombiana. Revista CIAF, Bogota, Colombia 5: 127-150.

Buol, S.W. and W. Couto, 1980: "Soil fertility capability assessment for use in the humid tropics". In: D.J. Greenland (ed.): "Characterization of soils in relation to their classification and management for crop production: examples from some areas of the humid tropics". Oxford University Press.

Drosdoff, M. (ed.), 1972: "Soils of the Humid Tropics". Committee on Tropical Soils, Agric. Board, Natural Research Council, National Academy of Sciences, Washington DC, U.S.A.

Chauvel, A., 1982: "Os latossolos amarelos, alicos, argilosos dentro dos ecosistemas das bacias experimentais do INPA e da regiao vizinha". Supl. Acta Amazonica 12(3):47-60.

Craswell E.T. and R.F. Isbell, 1984: "Proceedings of the International Workshop on Soils; research to resolve selected problems of soils in the tropics". ACIAR, Canberra.

Dudal, R. and F.R. Moormann, 1964: "Major Soils of South-east Asia". Journal of Tropical Geography 18:54-80. Universities of Singapore and Malaysia, Singapore.

FAO-Unesco, 1971-1982: Soil Map of the World at 1:5,000,000. Unesco, Paris.

Fearnside, Ph.M., 1980: "Os efeitos das pastagens sobre a fertilidade do solo na Amazonia Brasileira: consequencias para a sustentabilidade de produçao bovina. Acta Amazonica 10(1):119-132.

Fox, R.L. and Li, Xue-yuan, 1983: "Phosphate-fertilizer Requirements of Weathered Soils and Residual Phosphate Fertilizer Efficiency as Indicated by Phosphate Sorption Curves". Proceedings International Symposium on Red Soils, Nov. 1983, Nanjing, P.R. of China (in press).

Hallé, F., R.A.A. Oldeman and P.B. Tomlinson, 1978: "Tropical trees and forests; an architectural analysis". Springer Verlag, Berlin, pp 440.

Hecht, S.B. (ed.), 1982: "Amazonia, Agriculture and Land Use Research". CIAT, Cali, Colombia, Series 03E-3(82), pp. 428.

Herrera, R., 1977: "Soils and terrain conditions in the International Amazon Project at San Carlos de Rio Negro, Venezuela; correlation with vegetation types". Trans. Intern. MAB-IUFRO Workshop, Hamburg-Reinbeck, 182-188.

d'Hoore, J., 1960: "The soils map of Africa south of the Sahara (1:5,000,000)". Trans. Inter-Congr. Soil Sci. Congr. VII, Madison, USA, 1960. Vol. 4:11-19.

Joseph, K.T. (ed.), 1980: "Proceedings of the Conference on Classification and Management of Tropical Soils 1977". Malaysian Society of Soil Science, Kuala Lumpur.

Lavelle, P., 1984: "The Soil System in the Humid Tropics". Paper presented at the ICSU/UNDP Symposium "Savanna and Woodland Ecosystems in America and Africa: a Comparison", Brasilia, Oct. 1983. Biology International 9, IUBS, Paris, France.

Metz, J.F. and N.C. Brady (eds.), 1980: "Priorities for Alleviating Soil-related Constraints to Food Production in the Tropics", pp. 468, IRRI, Los Banos, Philippines.

Mohr, E.C.J., F.A. van Baren and J. van Schuylenborgh, 1972: "Tropical Soils, a comprehensive study of their genesis". Third, revised and enlarged edition. Mouton-Ichtiar Baru-Van Hoeve, the Hague-Paris-Djakarta.

Nye, P.H. and D.J. Greenland, 1960: "The soil under shifting cultivation". Comm. Bur. Soil Techn. Commun. 51.

Paul, E.A., 1984: "Dynamics of organic matter in soils". In: Tinsley, J. and J.F. Darbyshire (eds.): "Biological processes and soil fertility". Developments in Plant & Soil Sciences 11:275-286.

Preston, C.M. and M. Schnitzer, 1984: "Effects of Chemical Modification and Extractants on the Carbon-13 MNR Spectra of Humic Materials". Soil Sci. Soc. Am. Proc. 48(2):305-311.

Projeto Radam (or Radam Brasil), 1972-1978: "Levantamento de Recursos Naturais". Vol. 1 to 15. Ministerio das Minas e Energia, Departamento Nacional da Produçao Mineral, Rio de Janeiro, Brazil.

Ranzani, G., 1979: "Recursos pedologicos da Amazônia". Supl. Acta Amazônica 9(4):23-35, Manaus.

Ranzani, G., 1980: "Identificaçao e caracterizaçao de alguns solos da Estaçao Experimental de Silvicultura Tropical do INPA". Acta Amazônica 10(1):7-42.

Roche, P., L. Grière et al., 1980: "Phosphorus in Tropical Soils: Assessing Deficiency Levels and Phosphorus Requirements". IMPHOS-World Phosphate Institute, Sc. Publ. 2, Paris, France.

Sanchez, P.A. (ed.), 1973: "A Review of Soils Research in Tropical Latin America". Soil Science Department, North Carolina State University Tech. Bull. 219, pp. 195, Raleigh, NC, U.S.A.

Sanchez, P.A. & S.W. Buol, 1974: "Properties of Some Soils of the Upper Amazon Basin of Peru". Soil Sci. Soc. Amer. Proc. 38(1):117-121.

Sombroek, W.G., 1966: "Amazon Soils, a Reconnaissance of the Soils of the Brazilian Amazon Region". PUDOC, Wageningen, pp. 300.

Sombroek, W.G., 1984: "Soils of the Amazon Region", Chapter 20 in Sioli, H. (ed.) 1984: The Amazon; limnology and landscape ecology of a mighty tropical river and its basin. Monographiae Biologicae 56. Dr. W. Junk Publishers, Dordrecht, the Netherlands.

Swift, M.J., 1984: "Soil Biological Processes and Tropical Soil Fertility; a proposal for a collaborative programme of research". Biology International Special Issue 5, IUBS, Paris, France.

Theng, B.K.G. (ed.), 1980: "Soils with variable charge". New Zealand Society of Soil Science, Lower Hutt, New Zealand, pp. 448.

Unesco, 1978: "Tropical Forest Ecosystems". Natural Resources Research 14, Unesco, Paris, France, pp. 800.

Van Reeuwijk, L.P., 1982: "Laboratory Methods and Data Exchange Program for Soil Characterization; a report on the pilot round". Technical Paper 6, ISRIC, Wageningen, Holland.

Wielemaker, W.G., 1984: "Soil Formation by Termites; a study in the Kisii area, Kenya". Dept. of Soil Science and Geology, Agricultural University, Wageningen.

Wienk, J.F. and H.A. de Wit (eds.), 1982: "Management of Low Fertility Acid Soils of the American Humid Tropics". Proceedings of a joint workshop IICA-Surinam in Paramaribo, 23-26 Nov. 1981, pp. 220, Series Ponencias, Resultados y Recomendaciones de Eventos Técnicos 266, IICA, San José, Costa Rica.