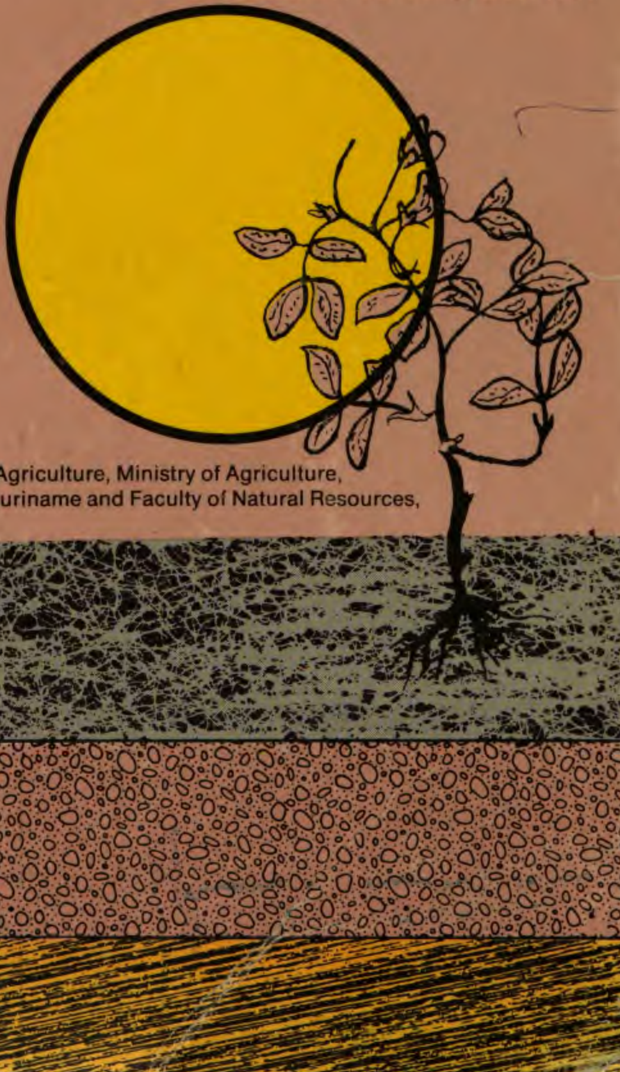
WORKSHOP ON THE

MANAGEMENT OF LOW FERTILITY ACID SOILS OF THE AMERICAN HUMID TROPICS

Paramaribo, Suriname, Nov. 1981



Inter-American Institute for Cooperation on Agriculture, Ministry of Agriculture, Animal Husbandry, Fisheries and Forestry, Suriname and Faculty of Natural Resources, versity of Suriname.

Management of Low Fertility Acid Soils of the American Humid Tropics

Proceedings of the Joint Workshop on

Management of Low Fertility Acid Soils of the American Humid Tropics

Paramaribo, Suriname, 23 - 26 November, 1981

Inter-American Institute for Cooperation on Agriculture, Ministry of Agriculture, Animal Husbandry, Fisheries & Forestry, Suriname and Faculty of Natural Resources, University of Suriname

Edited by:

J.F. Wienk
Centre for Agricultural Research
Paramaribo, Suriname

H.A. de Wit (eds)
Faculty of Natural Resources,
Paramaribo, Suriname

San José, Costa Rica
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FOREWORD

In compiling the proceedings of the Workshop, all the papers presented have been included as far as possible in their original form. Except for making reference to locations visited and other relevant aspects of the field day, no attempt has been made to provide other details.

The discussions that took place in the working groups, like their recommendations, have only been summarized.

Of those who have assisted in preparing the proceedings we would like to mention Mrs. L.C. de Bie - Bergval for her diligent typing, and Mr. H.R. Baarh for redoing all maps and graphs of the workshop papers.

The Editors

INTRODUCTION

The Workshop on "Management of Low Fertility Acid Soils of the American Humid Tropics" was the first scientific activity which IICA undertook in Suriname, following on its acquisition of membership of the Institute. The Workshop was jointly organized and sponsored by the Ministry of Agriculture, Animal Husbandry, Fisheries and Forestry, the Faculty of Natural Resources, University of Suriname, and IICA. It was a direct response to the concern expressed in May 1981, by Dr. A.H. van Dijk, Minister of Agriculture at the time, that Suriname lacked the information and know-how to facilitate the development and exploitation of the extensive area of low fertility acid soils in the country.

Since this area represented one of special interest in Suriname's medium term development, a consultation of experts in Latin America with knowledge and experience in the utilization of similar soil types in agricultural production would be advantageous, as this could be of considerable value to Suriname. It was, therefore, agreed that the Workshop should be designed to bring together scientists who have been actively engaged in the study of these soils and their exploitation. By this means, current knowledge would be reviewed, the need for additional investigation identified and a future course of action outlined.

Essentially, it is on this basis that the Workshop was conceived, planned and executed. The participation of the Republic of Guyana and French Guiana, where a considerable expanse of similar soils occurs, was seen as a logical consequence of this initiative.

The recommendations of the three working groups of the Workshop cover a considerable number of topics. These will now be studied in consultation with the countries and a plan of action will be developed and initiated.

R. Bazán
Workshop Coordinator

PROGRAMME

November 22

10:00 – 12:00	**Registration of Participants at the Krasnapolsky Hotel**

November 23

08:00 – 09:00	Registration at the Centre for Agricultural Research
09:00 – 10:00	Opening Ceremony
10:00 – 10:30	Coffee Break
	Session 1: The Importance of Acid Soils for Agricultural Production Country Reports Chairman: W. Forsythe
10:30 – 11:00	French Guiana
11:00 – 11:30	Guyana
11:30 – 12:00	Peru
12:00 – 12:30	Suriname
12:30 – 14:00	Lunch
14:00 – 14:30	Brazil
	Session 2: The Properties of Acid Soils Chairman: H.A. de Wit
14:30 – 15:15	Acid Soils of the Humid Tropics of South America with Special Reference to the Well Drained Soils on Old Alluvial Sediments – J. Bennema
20:00	Reception at Fort Zeelandia (Courtesy of the Minister of Agriculture, Animal Husbandry, Fisheries and Forestry)

November 24

	Session 3 : Constraints in the Use of Acid Soils for Agriculture . Chairman : J. Bennema
09:00 – 09:45	Constraints in the Use and Management of Infertile Acid Soils in the Humid Tropics – J.R. Benítes and C.L. Valverde
09:45 – 10:15	Coffee Break
	Session 4: Agricultural Use of Acid Soils Chairman: E. Soe Agnie
10:15 – 11:00	Continuous Crop Cultivation in Acid Soils of

		the Amazon Basin of Peru – D.E. Bandy and P.A. Sanchez
	11:00 – 11:45	Sustained Timber Production in the Tropical Rainforest of Suriname – N.R. de Graaf
	11:45 – 12:30	The Role of Pastures in Acid Interfile Soils of the Humid Tropics in Latin America – J.M. Spain
	12:30 – 14:00	Lunch
		Session 5: Research Priorities
		Chairman: N. Ahmad
	14:00 – 14:45	Research Priorities on the Sandy Soils of Suriname – R. Bazán
	14:45 – 15:30	General Discussion
	15:30 – 16:00	Coffee Break
		Session 6: Working Groups
		Chairman : A.H. van Dijk
	16:00 – 16:30	Assignment of Topics and Organization of Working Groups
	16:30 – 17:00	General Announcements Working Group Discussions
	20:00	Cultural Evening (Courtesy of the Minister of Culture, Youth and Sports)
November 25		
	06:00 - 18:00	**Field Visits** to : Kabo Experimental Farm Forestry Experiments at Tonka Coebiti Experimental Farm Pine Tree Plantation in the Coesewijne Area
November 26		
		Session 6 (continued) : Working Groups at Nieuw Amsterdam
	08:00 – 08:15	Welcome by Mr. H.P. Wormer, District Commissioner of the Commewijne District
	08:15 – 09:30	Working Group Discussions
	09:30 – 10:00	Coffee Break
	10:00 – 12:00	Working Group Discussions
	12:00 – 13:00	Preparation of Group Reports, Conclusions and Recommendations
	13:00 – 13:15	Closing Remarks by Dr. J. Ruinard, Dean of the Faculty of Natural Resources, University of Suriname
	13:15 – 14:45	Lunch

ORGANIZING COMMITTEE

Chairman - A.H. van Dijk
R. Bazán
J. Edhart
C.J. Seales - Meye
E. Soe Agnie
E.C. Tjoe Awie
J.F. Wienk
H.A. de Wit

LIST OF PARTICIPANTS

Ahmad, N.	University of the West Indies Department of Soil Science St. Augustine Trinidad & Tobago
Bandy, D.E.	North Carolina State University Soil Science Department P.O. Box 5907 Raleigh, NC 27607 U.S.A.
Bazán, R.	IICA-OAS Apartado 55 2200 Coronado San José, Costa Rica
Benítes, J.R.	Estación Experimental "San Ramón" Yurimaguas, Loreto Peru
Bennema, J.	Agricultural University Department of Tropical Soil Science Duivendaal 10 Wageningen, The Netherlands
Boulet, R.	ORSTOM BP 165 97305 Cayenne, French Guiana
Boxman, O.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Brandon - Van Steijn, M.M.	University of Suriname Faculty of Natural Resources P.O. Box 1914 Paramaribo, Suriname

Bullen, C.	Ministry of Agriculture Central Agricultural Station Mon Repos, East Coast Demerara, Guyana
De Graaf, N.R.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Dė Wit, H.A.	University of Suriname Faculty of Natural Resources P.O. Box 1914 Paramaribo, Suriname
Dos Santos, R.D.	EMBRAPA Rua Prudente de Morais 1757 202 Rio de Janeiro Brazil
Dubois, J.	IICA-Tr6picos CP 2044 66000 Belem PA Brazil
Dulder, I.G.H.	Ministry of Agriculture Agricultural Experiment Station P.O. Box 160 Paramaribo, Suriname
Everaarts, A.P.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Fletcher, R.	CARDI 64 Middle Street Cummingsburg Georgetown, Guyana
Forsythe, W.	IICA P.O. Box 1318 Port of Spain Trinidad & Tobago

Fung Kon Sang, E.W.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Goense, D.	Centre for Agricultural Research P.O. Box 1914 Paramaribe, Suriname
Görlitz - Tjon, M.	Ministry of Agriculture Agricultural Experiment Station P.O. Bex 160 Paramaribe, Suriname
Granger, M.	Ministry of Agriculture Central Agricultural Station Mon Repos, East Coast Demerara, Guyana
Guman, S.A.	Ministry of Agriculture P.O. Box 160 Paramaribo, Suriname
Huiswoud, R.R.	Ministry of Agriculture Agricultural Experiment Station P.O. Box 160 Paramaribo, Suriname
Jairam, G.	Ministry of Agriculture Agricultural Experiment Station P.O. Box 160 Paramaribo, Suriname
Janssen, B.H.	Agricultural University Department of Soils and Fertilizers De Dreyen 3 Wageningen, The Netherlands
Jonkers, W.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Kerkhoff, P.	Ministry of Agriculture Agricultural Experiment Station P.O. Bex 160 Paramaribo, Suriname

Lucas, Y.	ORSTOM BP 165 97305 Cayenne, French Guiana
Neering, K.E.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Persaud, H.	Ministry of Agriculture Central Agricultural Station Mon Repos, East Coast Demerara, Guyana
Philips, R.	Ministry of Agriculture, Agricultural Experiment Station P.O. Box 160 Paramaribo, Suriname
Piggott, J.	Guyana National Service Broad Street Georgetown, Guyana
Poels, R.L.H.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Pretell, O.	OAS 4106 Military Road Washington DC, U.S.A.
Ruinard, J.	University of Suriname Faculty of Natural Resources P.O. Box 1914 Paramaribo, Suriname
Schmidt, P.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Simons, A.P.	University of Suriname Faculty of Natural Resources P.O. Box 1914 Paramaribo, Suriname

Soe Agnie, E.	Ministry of Agriculture Agricultural Experiment Station P.O. Box 160 Paramaribo, Suriname
Soerodimedjo, F.W.	Ministry of Agriculture Agricultural Experiment Station P.O. Box 160 Paramaribo, Suriname
Spain, J.M.	CIAT Apartado Aéreo 67-13 Cali, Colombia
Tjoe Awie, E.C.	Ministry of Development Department of Soil Survey Coppenamelaan Paramaribo, Suriname
Tjon Lim Sang, R.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Van Dijk, A.H.	University of Suriname Faculty of Natural Resources P.O. Box 1914 Paramaribo, Suriname
Van der Werff, P.A.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname
Villanueva, G.E.	IICA P.O. Box 1895 Paramaribo, Suriname
Walmsley, D.	CARDI University of the West Indies St. Augustine Trinidad & Tobago
Wienk, J.F.	Centre for Agricultural Research P.O. Box 1914 Paramaribo, Suriname

LIST OF CHAIRPERSONS

N. Ahmad
Professor of Soil Science,
University of the West Indies,
St. Augustine, Trinidad & Tobago

J. Bennema
Professor of Soil Science,
Agricultural University,
Wageningen, The Netherlands

A.H. van Dijk
Associate Lecturer Horticultural Science,
University of Suriname,
Paramaribo, Suriname

W. Forsythe
Director IICA Office,
Port of Spain, Trinidad & Tobago

E. Soe Agnie
Director of Agricultural Research,
Ministry of Agriculture, Animal Husbandry, Fisheries and Forestry,
Paramaribo, Suriname

H.A. de Wit
Lecturer Soil Science,
University of Suriname,
Paramaribo, Suriname

LIST OF ABBREVIATIONS

CARDI	Caribbean Agricultural Research and Development Institute
CELOS	Centre for Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical
CPAC	Centro de Pesquisa Agropecuária do Cerrado
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
FAO	Food and Agricultural Organization
ICA	Instituto Colombiano Agropecuario
IICA	Inter-American Institute for Cooperation on Agriculture
IFDC	International Fertilizer Development Center
INIPA	Instituto Nacional de Investigación y Promoción Agraria
INRA	Institut National de Recherches Agronomiques
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières
IRRI	International Rice Research Institute
NCSU	North Carolina State University
OAS	Organization of American States
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer
SNCLS	Serviço Nacional de Levantamento e Conservação de Solos
UNESCO	United Nations Educational Social and Cultural Organization

OPENING CEREMONY

WELCOME ADDRESS BY THE CHAIRMAN OF THE ORGANIZING COMMITTEE

A.H. van Dijk

Honourable Minister of Agriculture, Animal Husbandry, Fisheries and Forestry, Honourable Minister of Development, Honourable Minister of Culture, Youth and Sports, Representatives of the Inter-American Institute for Cooperation on Agriculture, Invited Speakers, Country Delegates, Ladies and Gentlemen. It is a great honour and pleasure to say a few words to you and to welcome you on behalf of the Organizing Committee at this opening session of the Workshop on the Management of Low Fertility Acid Soils of the American Humid Tropics.

A special word of welcome and appreciation to our Ministers present. We appreciate that you have taken time out to be with us here this morning and as so to underline with your presence the importance of this workshop.

As you know, this workshop, which is about to be opened by the Minister of Agriculture, Animal Husbandry, Fisheries and Forestry, is a joint event sponsored by the Ministry of Agriculture, the Inter-American Institute for Cooperation on Agriculture (IICA) and the University of Suriname, or to be more specific, the Faculty of Natural Resources of our University. It was indirectly initiated by the Faculty of Natural Resources and it will be the first event on the programme of this faculty celebrating its 5th anniversary.

This workshop was made possible by many organizations who gave us both financial and technical support. First of all we must say that we regret it very much that Dr. Araujo, Director General of IICA could not be with us today. We would like to ask Mr. Villanueva, representative if IICA in Suriname, to extend to Dr. Araujo our sincere appreciation for his support. From this place we would also like to thank the Foundation for Experimental Agriculture (SEL), the agricultural division of H.J. de Vries, Surinam Sky Farmers, the Agricultural Bank, the Parbo brewery, the Surinam Alcohol Company (SAB), and all others that made this workshop possible. A special word of appreciation goes to the Minister of Culture, Youth and Sports for the support that we are receiving from his Ministry.

Fellow Delegates and Invited Speakers, we are about to begin discussions on one of the major problem soils of the world identified by a very low chemical fertility, a high acidity, a high aluminium and a low phosphate content. With the aid of IICA we were able to bring together scientists from all over the world in an effort to concentrate on these problem soils. Each of you has something to contribute to the solution of the problems we are faced with in the management of these soils or to make us more aware of the limitations that we have to accept. We as initiators of this workshop do not pretend to present all the answers in the proceedings of this workshop, but we hope that we will make a considerable contribution and that we may continue to seek solutions for the problems we could not solve.

Ladies and Gentlemen, I am sure we will have very fruitful discussions and I wish you a very pleasant stay in our country.

Thank you.

ADDRESS BY THE DIRECTOR OF THE IICA OFFICE IN SURINAME

G.E. Villanueva

Honourable Ministers of Cabinet, Mr. Chairman, Distinguished Delegates, Ladies and Gentlemen. It is quite unfortunate indeed that Dr. José Emilio G. Araujo, IICA's Director General, could not be present at this ceremony and participate in the workshop as he would have liked to do so, since he and Dr. Van Dijk initially developed the idea of having a technical event in Suriname, focussing on some relevant problems affecting agricultural development in the country. The utilization of the Zanderij soils came then into the picture. And now, here are we all, coming from various places and countries, to join our colleagues from Suriname in a scientific event which may help increase our knowledge on the use and management of the Zanderij soils, which, as we know, cover an impertant area in the country. On behalf of Dr. Araujo I feel pleased to welcome you all.

On the other hand, I should express how honoured I feel to be present at this occasion and to participate in the implementation of this event, as the very first activity of the new IICA office in Suriname, of which I feel pleased to be its representative.

Agricultural development in the Latin-American countries as well as in the Caribbean is the main goal of IICA, and as such I will do my best in assisting this country to find out the means to identify and to tackle problems in the agricultural sector. This is not an easy task unless appropriate support and collaboration is provided by local and national institutions.

It is undoubtedly that population growth in our countries and the needs for food, fibers and energy production would stimulate migration to new areas and expansion of the agricultural frontier. History shows that in the absence of adequate plans for development of such new areas, land utilization turns into traditional systems such as shifting cultivation, rather than into more productive and sustained systems, which may also help to improve the welfare of the rural poor.

The development of such systems requires careful planning, not only along the line of agricultural techniques, but also in social and economical aspects of real concern to farmers. Therefore, there is a need to prevent risks against the introduction of unproductive agricultural systems, or of inadequate land use systems, but also inadequate for the socio-economical development of the region.

With this purpose in mind, we all should give our best to make of this event not only a friendly gathering, but also an event that at its end may leave to our colleagues of Suriname some guidelines which may help them to plan adequately the development of the proposed area, as well as others in the country.

Finally, I wish to congratulate the Organizing Committee of the workshop, who have devoted plenty of their valuable time and efforts to make of this event a very fruitful one. Please let us help them to achieve such success.

Thank you.

OPENING ADDRESS BY THE MINISTER OF AGRICULTURE, ANIMAL HUSBANDRY, FISHERIES AND FORESTRY

F.E. Vreden

Mr. Chairman, Distinguished Delegates, Ladies and Gentlemen. I feel privileged and honoured to have the opportunity of addressing this outstanding forum on the occasion of the workshop on "The Management of Low Fertility Acid Soils of the American Humid Tropics". May I, on behalf of the Revolutionary Gevernment of Suriname, whom I have the honour to represent, commence by conveying a warm welcome and friendly greetings to the foreign delegates. I may proceed, Mr. Chairman, by conveying congratulations to the Organizing Committee of this meeting.

Ladies and Gentlemen. Our Policy Centre and the Suriname Government have introduced their new policy for national development. This new policy has been based on the principle that a fundamental condition to permanently eradicate poverty, hunger and malnutrition, can be attained exclusively by an adequate political order as a conditio sine qua non for a socio-economic system aimed at eliminating the conditions that generate poverty, unemployment and hunger. With regard to this new development policy it was considerod essential that existing profitable investment options in forestry, agriculture and fisheries be utilized more intensively and be realized more significantly and consistently than had shown to be possible to date. Increase of the national production must be based on the development of the sectors which I have just mentioned, as a consequence of the nature of our country. While it is true that we can implement agricultural development to foster national socio-economic conditions, it is also true that we must be careful and rational to preserve the land as a basis for renewable resources. In order to do so, to implement rational land use, it is essential to have a clear insight and a clear understanding of the land characteristics, being attributes of land that can be measured or estimated, such as slope, rainfall, soil texture, biomass of the vegetation.

It is clear that rational land use is an indispensable step to proper agricultural development in Suriname. Taking into account that more or less 80 percent of the area of Suriname consists of the so-called low fertility acid soils, it is clear that this international workshop is of paramount interest for agricultural development.

Mr. Chairman, the soils to be discussed at this workshop cannot simply be designated as easily utilizable natural resources. However, they have to be considered as an important potential natural resource that should be used in a joint effort in which we will have to adapt the environment to our needs. When considering, for instance, that the peoples of the Middle East have succeeded in converting deserts into arable land, it must be possible to utilize these low fertility soils. The challenge is, however, that we must be able to obtain a sustained agricultural production against the lowest possible investment. That means that we have to sustain the production capacity of the soil. Management of these soils therefore means being aware of their susceptibilities such as a) compaction (especially during landclearing and tillage), b) acidification, c) podzolization.

Despite the opportunities in the past to gain sufficient experience in the management of these soils, very little of the available data could be directly utilized for a better understanding of their behaviour under management. The land use practiced, based on the available data was not so successful as anticipated. In 1958, 5 000 ha of heterogeneous tropical forest were converted into a homogeneous conifer forest plantation. Due to lack of information, not only on land characteristics but also on the species grown, this was not successful. Regarding pine plantations, besides the limited possibilities for utilization there also exists the lack of perspective for their continuous production on these acid soils. Since there is no time nor money left for any further basic research the existing pine plantations shall only be considered for scientific purposes, and it will not be superfluous to state here that expansion of this activity will not be considerod for the time being.

In 1970, the Experiment Station of the Ministry of Agriculture started at Coebiti to examine the agricultural potentialities of low fertility acid soils, while in 1978 a new experiment started near Kabo in the charge of the Centre for Agricultural Research, to examine some other aspects. The results obtained in the two aforementioned experiments will be presented, hopefully, during this meeting.

The task, however, is broader. Not only do we have to achieve a proper land classification, we have to manage our soils in perpetuity. Permit me therefore, Mr. Chairman, to add one indispensible word to the general objective of the workshop, which is, to my mind "sustained". The general objective therefore will be stated as: To increase the knowledge and experience in the management of acid soils for sustained agricultural production. In order to achieve the aforementioned, much scientific research has to be done. Research to formulate the exact criteria for productivity of several crops. Some of these criteria can be summarized as follows: moisture availability, workability of the land, resistance to soil erosion, conservation of the organic material in the topsoil during clearing activities. One should, however, bear in mind that the individual criteria, being in fact land qualities, should not be examined separately; their interrelation is of paramount importance.

A great deal of this research has to be done either in our country, or has already been carried out in our neighbouring countries. And if good neighbourliness is not only meant to be a matter of words but is also meant to be transformed into actions, then this seminar is an outstanding occasion to demonstrate regional solidarity. This, Mr. Chairman, should be included as one of the specific objectives of your seminar.

As stated before, low fertility acid soils simply do not form a great asset to the nation. Low fertility generally means a low amount of nutrients, thus causing low crop yields. But even on these soils there is natural vegetation which can show production capabilities for some crops under certain conditions. Nature, most of the time, is the simplest and the most reliable guide. Forestry therefore will have to play an important role in the management of low fertility acid soils, most of which, therefore, will remain under forest. However, the need for increased food production will necessitate the conversion of some forest areas for agricultural use. Research into clearing methods is therefore urgently required in order to prevent soil deterioration.

The lack of population pressure in Suriname, could appear as a factor against an intensive land use. However, the low level of accessibility and therefore the need for concentration areas for economic reasons forces us to an efficient use of the land. The effective use of land therefore does not allow for a widely distributed and uncontrolled system of shifting cultivation. The efficient use of land, and I can safely say, the efficient use of low fertility acid land, will therefore also have to have an impact on our inland population. The agricultural extension service is therefore waiting impatiently for well defined and simply formulated instructions to be given to the agricultural and forestry users of the acid soils, primarily to move the inland population towards a more continuous system of crop cultivation. For they too, will have to contribute to the national development in a sustained way and to the best of their abilities.

Mr. Chairman, one of your specific objectives says, and I quote "to define research priorities as a main basis for the development of agricultural projects in the area". I can fully support this objective, because research priorities must bo set. I hope, however, that it is understood that these research priorities and research items will be formulated such that they provide information of practical value to our farmers. Governments of developing countries always have very limited funds available for basic research. Consequently, strict and serious timetables should be scheduled to meet the nation's needs towards an accelerated agricultural development.

Recently a new land-reform policy was formulated in order to prevent land speculation as occurred in the past. This audience, Mr. Chairman, is here to investigate and evaluate the complete knowledge on the management of the acid soils of our country and to transform this knowledge into instructions, to the best of their abilities. As far as

Suriname is concerned we can safely state that the achievement of your workshop will serve all the Suriname people who have long waited for ways to develop their country for using all available knowledge. I am convinced, Mr. Chairman, that this workshop will turn out to be a highly successful one for every delegate and I would take this opportunity to suggest that regular workshops on land use can become a feature of regional co-operation.

Mr. Chairman, Distinguished Delegates, I thank you.

COUNTRY REPORTS

ACID SOILS OF FRENCH GUIANA

Y. Lucas and R. Boulet
ORSTOM, French Guiana

A. Domeny
Direction Départementale de l'Agriculture, French Guiana

INTRODUCTION

This report presents the main types of acid soils of French Guiana that have been surveyed and on which crops have been cultivated so far. These soils mainly occur along the coast, as the sparsely populated interior is not at present included in the development plans.

Although the knowledge on the morphology and other profile characteristics of the soils of this coastal strip is quite advanced, little is known as yet about their agricultural potential. The morphology and variability of the different soil mantles in this area will be described, followed by a brief account of the climate. The agricultural uses will then be discussed along with the main agronomic problems that slow further development.

SOIL TYPES, THEIR EXTENT AND PROPERTIES

The acid soils on sandy to sandy clay, sedimentary formations that have been surveyed so far in French Guiana, are found on the Zanderij formation, the Lelydorp formation and the sandy formations on recent coastal ridges.

Soils of the Zanderij formation

The Zanderij formation, known in French Guiana as the Detrital Basement Series, is found in the northwest of the country. Its present known extent as shown in Figure 1, covers over 53 000 ha. Figure 2 shows the position of the Zanderij formation relative to the surrounding formations. This formation rests unconformably on the crystalline basement rock. It is located between the basement and the formations of the old coastal plain, covering areas ranging from stretches of a few hectares to plateaus of over 5 000 ha.

Morphological observations made in the field during soil surveys have enabled us to reconstruct in great lines the pedological history of the area since the Zanderij formation was formed. This history will be briefly discussed as it explains the distribution of the soils, the types of profile development and the soil forming processes encounterod. It may

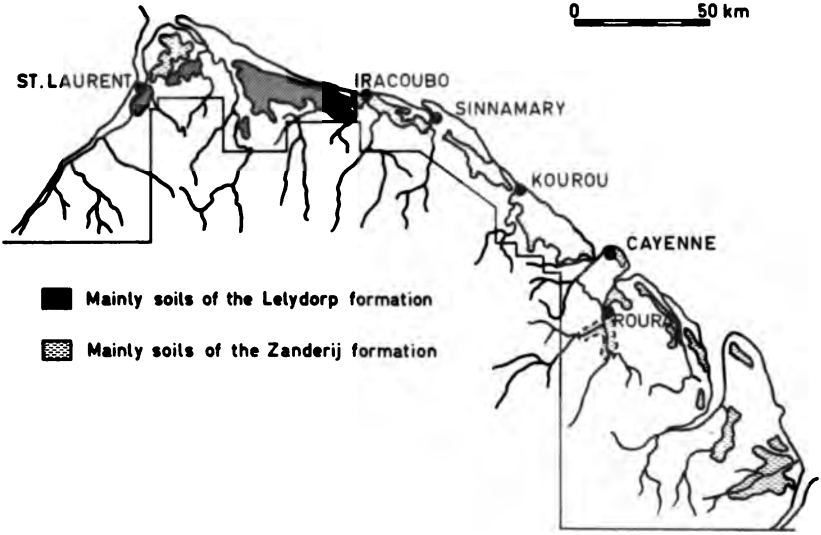


Fig. 1. Extent of Lelydorp and Zanderij formations in French Guiana.

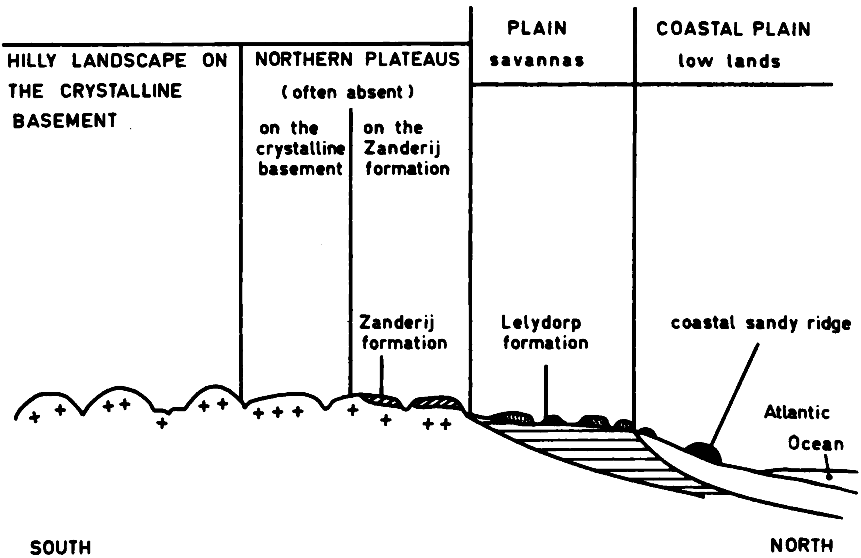


Fig. 2. Location of the sand and sandy clay sedimentary deposits relative to the crystalline basement.

be divided into four stages, outlined in Figure 3.

1) Initial formation, on the crystalline basement rock, of a soil mantle with the same horizon differentiation as presently found in soils on this rock.
2) During an undetermined period - most probably antequaternary - truncation of this soil mantle as a result of increased erosion.
3) Simultaneously, or a little later, deposition of sedimentary material of what is now called the Zanderij formation. From what we know of present-day sediments, it most probably is a matter of continental spreading related to shifting rivers. The base of these sediments is consistently marked by a thin bed (5 cm) of smooth quartz pebbles. Thicker beds mark the position of larger water courses.

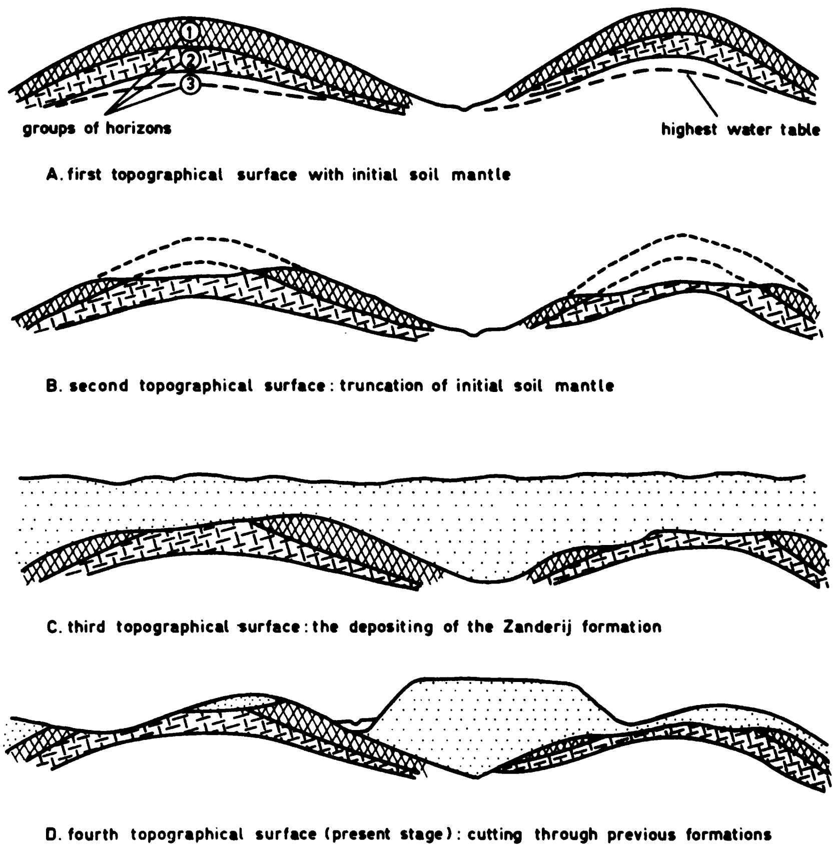


Fig. 3. The different stages of landscape and soil formation in the French Guiana Zanderij formation.

4) During the Quaternary, erosion lowerod the surface of this sedimentary formation, sometimes reaching the base.

It is therefore the intersection of three seemingly independent, topographical surfaces which determines the complex distribution of the various soil materials. This complexity (see Fig. 3) has the important consequence that it is impossible to predict the distribution of materials from a limited number of observations made in particular sites. Instead, a systematic survey has to be made in these regions at a scale depending on the precision requirod.

In fact, it is essential that one should be able to differentiate between soils on sufficiently thick Zanderij formation, soils on a shallow Zanderij formation overlying horizons derived from weathering products of the crystalline basement rock, and soils directly formed from this rock. If certain horizon types that were formed on the basement rock (e.g. horizon groups 2 and 3 in Fig. 3) are present near the surface (about 1 metre deep), the water flow in the soil is essentially superficial and lateral, contrary to soils with a deep percolation. This difference in water movement is of great agronomic importance and should therefore be used as a criterion in soil surveys.

Where the Zanderij formation is sufficiently thick, the soils are either brightly coloured or white sandy or a combination of both. The brightly coloured soils represent the least weathered part of the Zanderij formation. These soils have a strong brown colour (7.5YR 5/6-5/8); their texture below 20 cm varies from sandy loam to sandy clay loam. The clay content increases with depth reaching a maximum of 30 to 40 percent at 110 cm depth. This clay content remains constant at about 30 percent in a thick, strong brown horizon with a massive, microaggregated structure (aggregate diameter about 0.2 mm). These soils may represent variations in the eluviation process and the decolourizing of the surface horizons. The A horizon overlies a brown to yellowish brown, sandy horizon (10YR 5/4-5/3), with a distinct transition between 30 and 80 cm depth, to strong brown, more clayey horizons. In such cases, between 40 and 60 cm a horizon of greater bulk density may be present which is associated with a temporary perched water table during the rainy season.

The white sands represent the most strongly weathered soils of the Zanderij formation. The profiles have a dark grey surface horizon which gradually changes into white sand at 30 cm depth. The texture is very sandy, clay content being less than 1 percent. Water infiltrates rapidly, and is not retained because of the soil's very low water-holding capacity. This water feeds a water table which fluctuates rapidly and, in places, reaches the surface either at the foot of a slope or in the centre of a plateau.

The strong brown coloured soils and the white sands are the

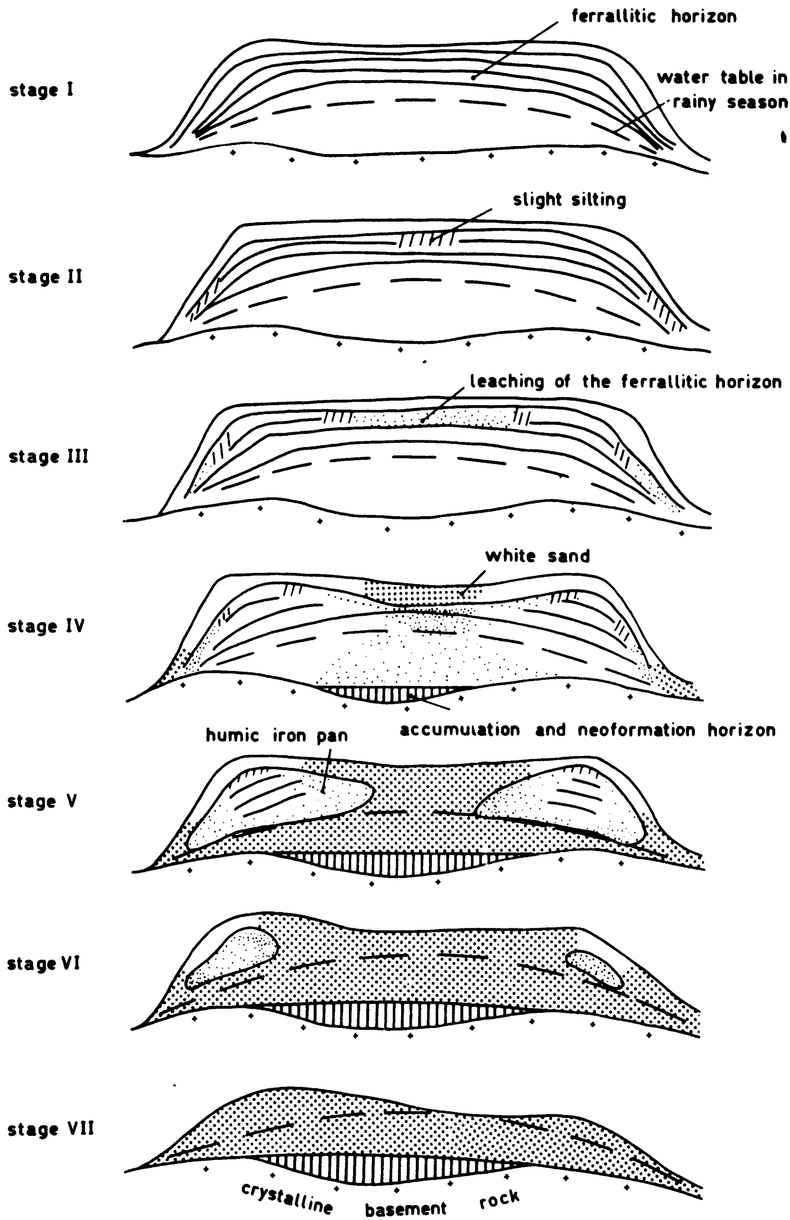


Fig. 4. Schematized stages of transformation from a sandy clay mantle of the Zanderij formation into a white sand mantle.

extremes in the process of soil formation. Turenne (1975) and Boulet et al. (1979) studied these systems on the basis of many observations in the field. The various weathering stages are outlined in Figure 4. The clay fraction gradually disappears from the centre and from the boundaries of the landscape units - which may cover a few kilometres - without decolourizing the soil. When the clay content becomes less than 3 percent, the sandy material becomes white, a phenomenon which is frequently associated with the presence of horizons with an accumulation of organic matter and iron (Bhir). These horizons are situated at the interface between the upper and lower weathering fronts. This weathering process, which in fact is a podzolization process, will continue until only white sand remains.

The strong brown coloured, least weatherod soils of the Zanderij formation are among the soils of the Fronch Guiana uplands with the least limitations. They are therefore the first to be surveyed. At present the Iracoubo - Saut Sabbat region is being studied.

Soils of the Lelydorp formation

The Lelydorp formation also has varied soils that constitute a weathering sequence. This formation was originally deposited as offshore ridges which run more or less parallel to the coast. These ridges are 1 to 10 m high, 200 m long, 5 to 800 m wide. At present they are found in the coastal plain, up to about 20 kilometres inland. Their distribution is shown in Figure 1; they cover an area of about 100 000 ha and are associated with the Para formation.

On these ridges the least weathered soils have sandy textures and brown colours near the surface, changing into strong brown sandy loamy to loamy fine sand (grain diameter less than 0.1 mm; 20 percent clay) below 40 cm depth, while also some violet-roddish spots or nodules occur. The thickness of the profile depends on the depth at which the Para clay is found. The most weathered stage has a white sand profile abruptly overlying Para clay. Intermediate stages occur between these two extremes. The sand becomes white if the clay content of the surface horizons of these intergrades has decreased to a value of 3 - 5 percent, a stage which is accompanied by a temporary and discontinuous Bhir horizon. This weathering pattern is both centripetal, i.e. beginning at the centre of the ridges, and centrifugal, i.e. beginning at their boundaries.

Soils of recent coastal ridges

The recent coastal ridges with medium to coarse sand, can also be differentiated in yellow sandy well-drained soils and white sands that have a water table near the surface during the rainy season. These soils are limited to narrow strips parallel to the coast.

Acid soils on material from the crystalline basement rock

Certain soils on the crystalline basement rock have properties and a morphology that closely resemble those of the least weathered soils of the Zanderij formation. They occur immediately south of the Zanderij formation. Their profile is conformable with the topography. Underneath brown to yellow-brown surface horizons, a thick (over 1 m), yellow-red clay to sandy clay horizon occurs which is porous, containing numerous microaggregates and changing into a more compact redder horizon at lower depths. Rainwater passes vertically through the whole profile. These soils are called "free vertical drainage" soils. They also are an initial stage of a weathering sequence, but one that differs considerably from the Zanderij formation sequence.

Various studies have shown that this weathering sequence was initiated by a relative subsidence of the base level. The topographical surface then lowered which caused originally deeper horizons to appear higher in the soil profile. This entire process was due to a tectonic lifting of French Guiana between two subsident, sedimentary basins, i.e. Guyana-Suriname to the northwest and the Amazon basin to the southeast.

Where the compact red horizon or the deeper horizons appoar near the surface, i.e. within about 1 metre, they cause the water flow to become essentially superficial and lateral. These soils are called "blocked vertical drainage" soils. This differentiation of the water flow is at present an important limitation for agricultural development and use. Technology must be developed to eliminate these drawbacks as these soils cover considerable areas of the uplands.

CLIMATIC CONDITIONS (Godon, 1980)

The equatorial climate of French Guiana is marked by two seasons, i.e. a dry season from mid-August to mid-November, and a rainy season from mid-November to mid-August. The rainy season can be divided into two intensive rainy periods, the 1st and 2nd crop cycles, with - between these two - a period with statistically less rain, the so-called "little March summer". The rainfall regime is dependent on the intertropical convergence zone. The amount of annual rainfall varies considerably but there also is considerable variation in the monthly averages, as shown in Figure 5. Average annual rainfall can vary by 100 percent, e.g. extreme values for Cayenne are 1 500 and 4 200 mm.

Rains are sometimes heavy and of long duration. Rainfall decreases towards the interior and to the coast.

The annual mean temperature is high, i.e. 25.5°C at Rochambeau. Relative humidity is high all year round and wind speeds are low.

Variations in daily sunshine are considerable. Potential evapotranspiration is high.

From an agro-climatic point of view the following can be noted:

- The long rainy season favours perennial crops or crops with a long growing cycle (over 10 months).
- Annual crops with a short growing cycle, i.e. a few months, could be grewn twice a year. However, there are restrictions. During the first period difficulties with ripening and harvesting (occasional dry February) and during the second period, difficulties with tillage and sowing - with risks of water excess in May and June - may be encountered.

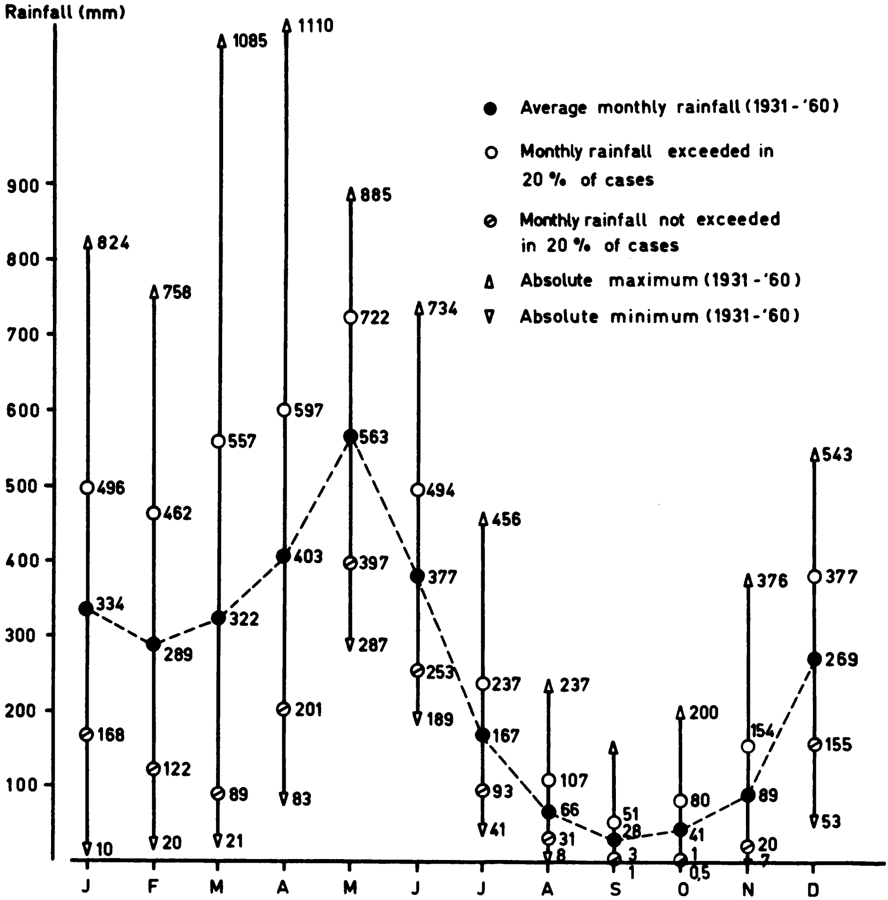
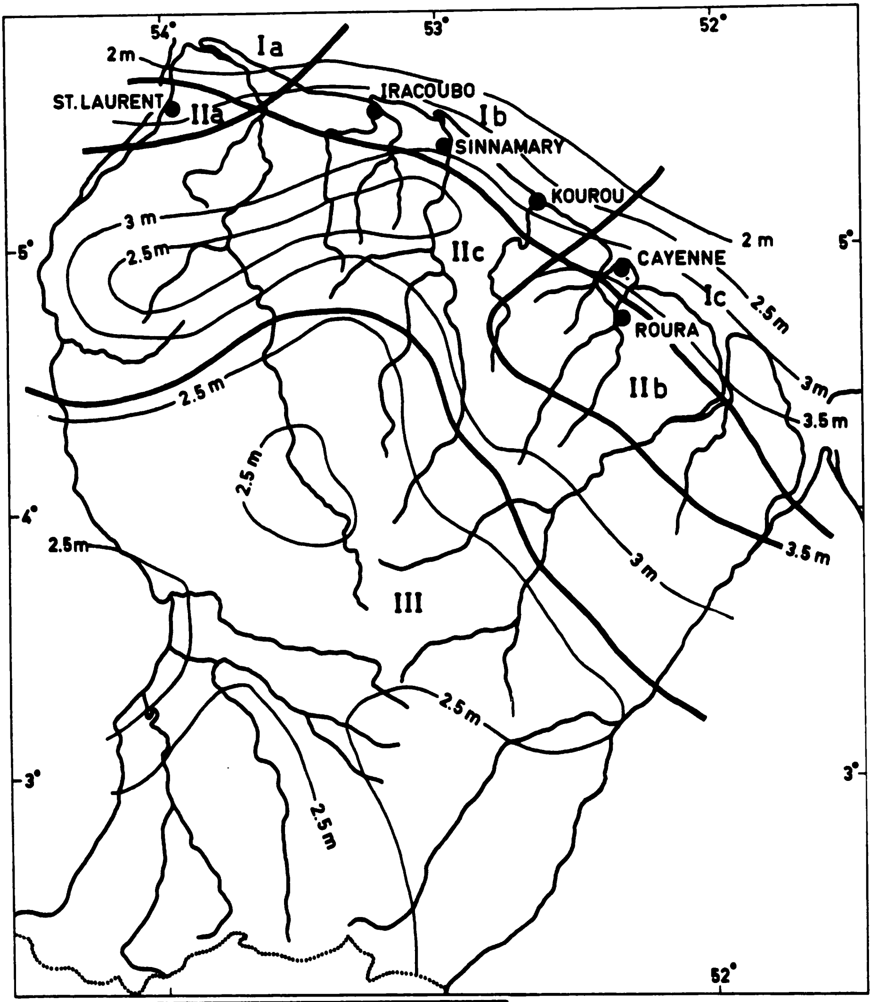


Fig. 5. Distribution of monthly rainfall for Cayenne, French Guiana. Source: Godon (1980).



	annual rainfall (1956-'75)	length of dry season	ratio rainfall/ pot. evapotransp. in March
	m	weeks	
Ia	< 2	18	< 1.5
Ib	2.5 — 3	16 — 17	1.5 — 2
Ic	3 — 3.5	15 — 17	2.5 — 3
IIa	2.5	14	1.5
IIb	> 3.5	14 — 15	> 2.5
IIc	> 3	15	1.5 — 2
III	< 2.5	15 — 16	1.5 — 2

Fig. 6. Agro-climatic zones in French Guiana.

All crops may be subject to a lack of sunlight during certain periods or to water excess at other times.

Figure 6 gives an agro-climatic zoning of the area under consideration. Criteria used are annual rainfall, length of dry season and the ratio between rainfall and potential evapotranspiration in March.

PRESENT USE OF THE FORMATIONS DISCUSSED

Figure 7 shows the various agricultural enterprises established or being established. It is striking how small the total cultivated area is, i.e. about 4 500 ha, concentrated in the coastal region.

On the Zanderij formation, mainly stock farms (about 900 ha) and annual crops (about 450 ha) have been set up in the Saint Jean and Acarouany regions, and some silviculture around St. Laurent. The rest of the formation is covered by forest.

The Lelydorp formation, which is always associated with Para formation, is being used for stock farming (about 1 100 ha), annual crops and orchards. The rest of the formation is covered by forest or savannas.

The agricultural potential of the soils of the various formations discussed, i.e. Zanderij, Lelydorp and crystalline basement rock, is far from known. In fact, without sufficient agronomic trials one cannot relate advanced knowledge of the soils' morphology and other proper-

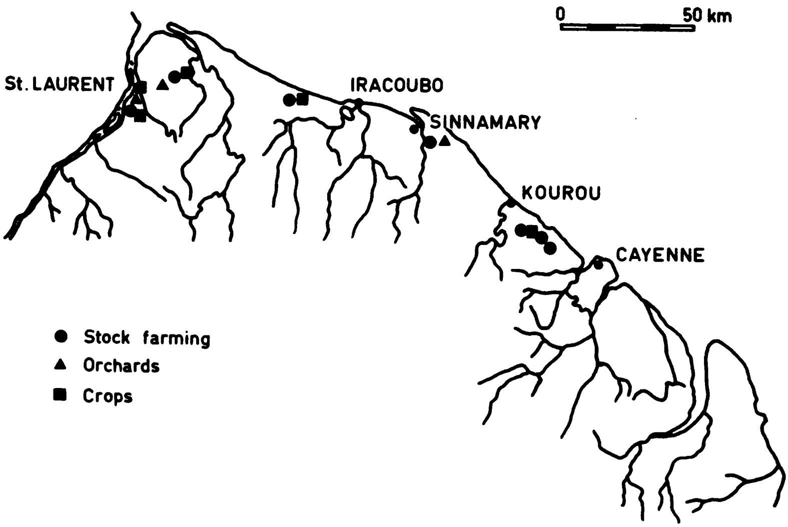


Fig. 7. Present agricultural enterprises on the Zanderij and Lelydorp formations in French Guiana.

ties to technology for intensive agriculture. However, quite a few problems can be noted.

- In areas on slightly weathered soils of the Zanderij formation, the infiltration rate varies extremely, locally leading to boggy patches. IRAT's observations at Acarouany show that these boggy patches have an important, negative effect on the growth of sugarcane. Moreover, areas where water stagnates at the surface, have a low mechanical resistance and low workability.
- The water infiltration rate and the finer textured subsurface horizons pose problems (perched water tables) on weathered soils of the Lelydorp formation.
- For pastures on the Lelydorp formation or on "blocked vertical drainage" soils on crystalline basement rock, weed invasion (especially *Carex*) becomes a serious problem.
- Citrus orchards on the Leydorp formation or on soils on the crystalline basement rock show a large variation in tree growth, which is

Sugarcane yields in tons / ha

	Cayenne	St. Laurent
Year and cut	Soils with vertical free drainage on crystalline basement rock	Soils on slightly weathered material of the Lelydorp formation
1976 2nd cut	65	56
1977 1st, 2nd 3rd cuts	80	73
	Acarouany	
	Soils with blocked vertical drainage on crystalline basement rock	Soils on slightly weathered material of the Zanderij formation
1977-78 2nd cut	74	114
1978 1st cut	80	102

directly related to the type of profile development.

Several agronomic trials are presently being carried out by IRAT, ORSTOM and INRA. These trials, however, are quite insufficient to be able to define the agricultural potential of the various soil types or to indicate a technology to be adapted for their development and use. However, the data on page 47 may give some idea. They have been obtained from trials by IRAT, the results of which are in press now.

The relatively high yields for the Acarouany Zanderij formation soils are due to recent clearing (1st year of cultivation); surface water infiltration problems have not yet shown up.

The response of the sugarcane (leaf analysis) to the chemical status of the soils of the Zanderij formation shows deficiencies, firstly in potassium and secondly in phosphate. No nitrogen deficiency has been observed. Trace elements seem to cause some problems.

CONCLUSIONS

The acid soils of French Guiana, situated on uplands or on the ancient coastal plain, show considerable pedological variation. These soils fit in a weathering sequence by which a soil mantle with favourable physical properties is changed into one marked by unfavourable physical characteristics, i.e. excessively drained, sandy profiles or a deficient internal drainage. These soil variations have important agronomic consequences. Although in French Guiana the morphology, physico-chemical features, and the dynamics of the soils of the Zanderij formation, Lelydorp formation and crystalline basement rock, are now well understood, information from agronomic trials still is insufficient for any sound forecast as to their cultivation.

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ACID SOILS OF THE INTERMEDIATE SAVANNAHS OF GUYANA

C.W. Bullen, M.A. Granger and H.B. Persaud
Ministry of Agriculture, Guyana

J.A. Piggott
Guyana National Service

R.E. Fletcher
CARDI, Guyana

INTRODUCTION

Guyana, situated on the northeastern coast of South America, has an area of approximately 214 000 km^2 and lies between north latitudes 1°10′ and 8°32′ and west longitudes 56°30′ and 61°20′. It has a coast line of some 284 km, and is bordered by the Atlantic Ocean to the north, by Suriname to the east, Brazil to the south and west and by Venezuela to the west (Fig. 1). The northern limits of the Amazon basin coincide with the southern limits of the country.

About 90 percent of the country's population of approximately 800 000 occupy the long, narrow, low-lying coastal plains, an ecozone that represents less than 10 percent of the total land mass. Most of the country's primary agricultural activities have traditionally been and still are confined to this region, with major emphasis on the production of rice, sugar and vegetables.

Physiographically Guyana can be divided into five broad units (Fig. 2) that reflect the influence of both geology and geomorphology. These units have been referred to as:

1) The coastal plains.
2) The "white sand" plateau and older peneplains.
3) The crystalline shield uplands.
4) The highlands, mountains and plateaus, and
5) The alluvial plains and low-lying lands of the interior.

A wide range of vegetation types has been described in Guyana. These types are due, in part, to the equatorial and tropical savanna climates of the country and to its diverse physiography, geology and consequently, kinds of soils. Fanshawe (1952) describes the vegetation by regions following basically Beard's classification of climax vegetation for tropical America. A general vegetation map of northern Guyana is shown in Figure 3. Fanshawe's description follows closely the physiographic units identified as follows:

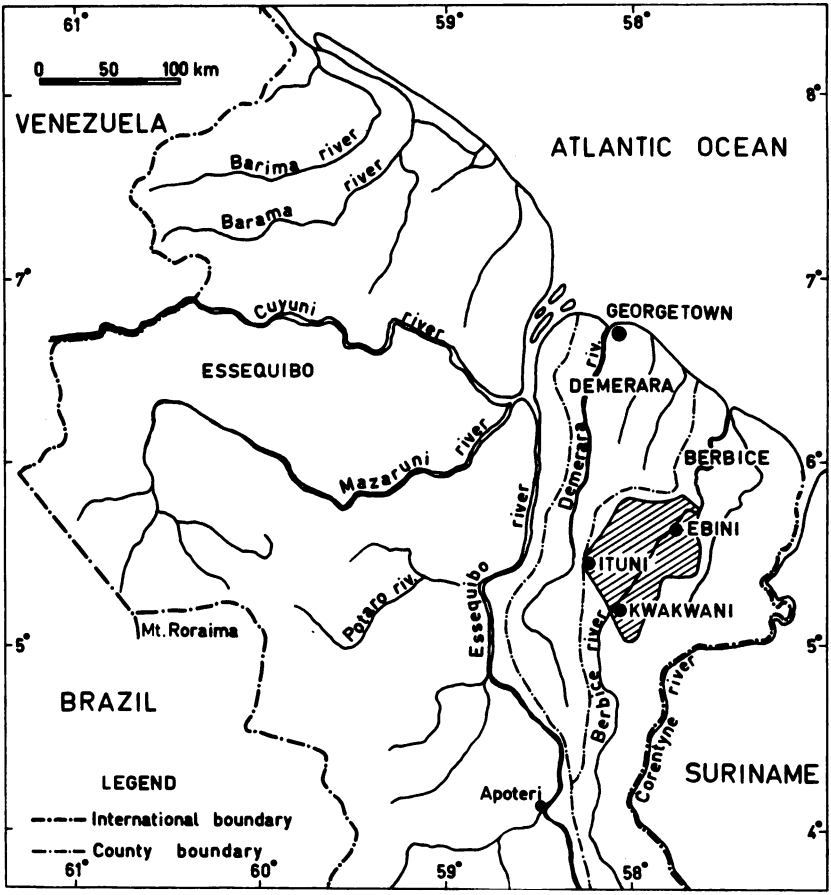


Fig. 1. Map of northern Guyana; the hatched area indicates the "Intermediate Savannahs".

1) Marsh and swamp forests.
2) Rainforests.
3) Evergreen seasonal forests.
4) Dry evergreen forest.
5) Montaine seasonal and dry evergreen forests.
6) Tropical savannas, and
7) Xeromorphic vegetation.

Guyana has an equatorial climate that has been classified using Köppen's system as a continuously wet tropical climate (Af, Tropical Rainforest Climate) for the main part of the country. However, major

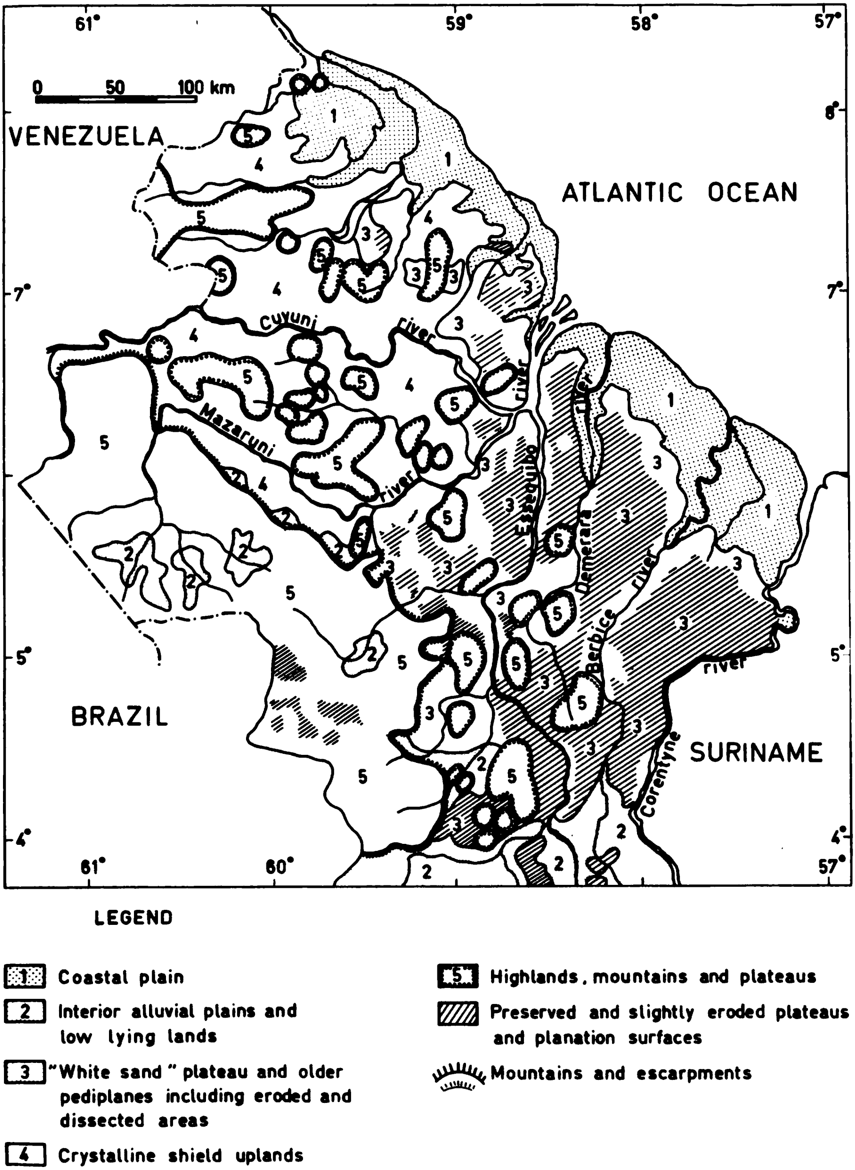


Fig. 2. General physiographic regions of northern Guyana.

differences have been found. In the coastal area east of the Berbice River a tropical monsoon climate with a moderate dry period (Am, Tropical Monsoon Climate) is recognized, and in the Rupununi savanna

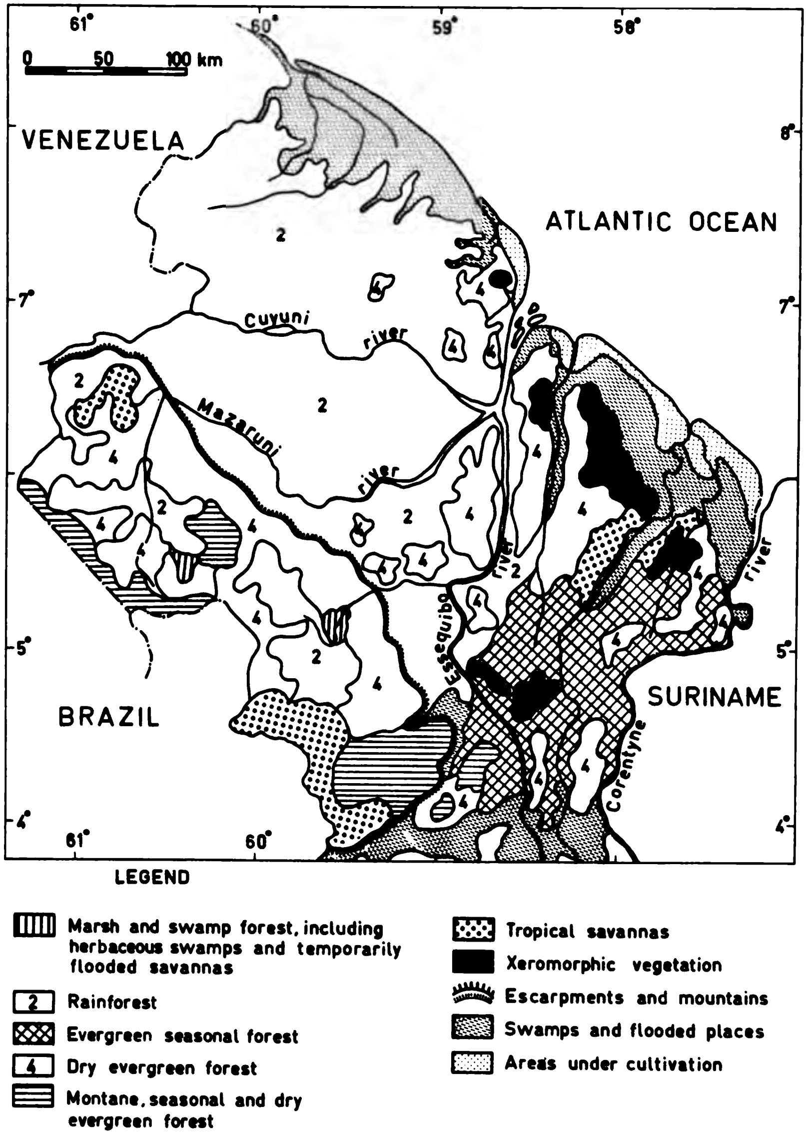
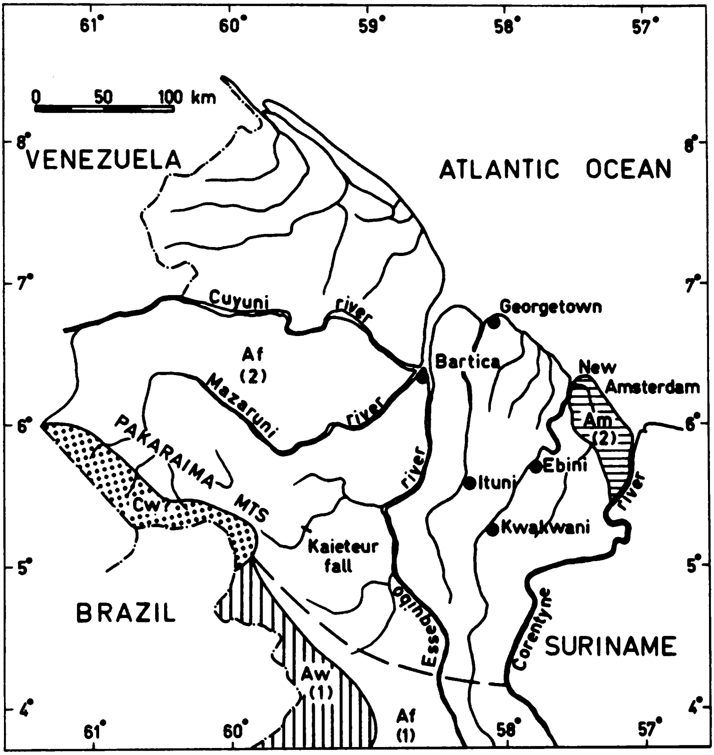


Fig. 3. General vegetation map of northern Guyana.

area a tropical monsoon climate with a severe dry period (Aw, Tropical Savanna Climate) is found. A third area of difference occurs in the Pakaraima mountains bordering Brazil and Venezuela, which is believed to have a warm, temperate rainy climate with a dry period (Cw,



LEGEND

Af Tropical rainforest climate (Continuously wet tropical climate)

Am Tropical monsoon climate (Tropical monsoon climate with a moderate dry period)

Aw Tropical savanna climate (Tropical monsoon climate with a severe dry period)

Cw? Tropical altitude climate (Warm temperate rainy climate with a dry winter)

(1) One wet and one dry season per year

(2) Two wet and two dry season per year

– – – Boundary between areas (1) and (2)

Fig. 4. Types of climate for northern Guyana. Boundaries are tentative due to limited number of rainfall stations, especially in the interior. No data available for the Pakaraima mountains.

Tropical Altitude Climate). Figure 4 presents a map of northern Guyana showing the types of climate.

Air temperatures (Table 1) are rather constant; the annual mean temperature for Georgetown is about 27°C. The relative humidity is generally high with a yearly mean for Georgetown of 80 percent. Winds are regular at about 5.35 knots. The prevailing direction is east-north-east. Very high speeds seldom occur but occasionally maximum readings of from 14 to 38 knots are recorded. There are some moderate differences between the wind speeds in the various seasons with maxima in March and April (6.8 and 6.3 knots) and minima in July and August (4.3 and 4.2 knots).

Table 1. Air temperatures at Georgetown (61-year averages)

	°C
Mean annual temperature	26.8
highest monthly mean temperature (October)	27.6
lowest monthly mean temperature (February)	25.9
Mean annual maximum temperature	29.4
highest monthly mean maximum (October)	30.7
lowest monthly mean maximum (January)	28.4
Mean annual minimum temperature	23.9
highest monthly mean minimum (September)	24.9
lowest monthly mean minimum (January)	23.4
Absolute maximum	33.9
Absolute minimum	20.0

The mean number of sunshine hours per day for Georgetown is given in Table 2. August and September have appreciably more sunshine hours per day than any other month while December, May and June have less sunshine hours.

The length of day at Georgetown varies from approximately 12 hours 30 minutes at June 21 to 11 hours 45 minutes at December 21.

Annual precipitation has a general bimodal distribution ranging from about 2 900 mm at Enachu in the west, 2 300 mm at Georgetown,

Table 2. Number of sunshine hours per day for Georgetown (66-year averages)

January	6.13	July	6.85
February	6.78	August	8.13
March	6.45	September	8.15
April	6.47	October	7.50
May	5.76	November	7.10
June	5.32	December	5.82
Year: 6.70			

to 2 260 mm at Ebini in the east. In the southwest at Lethem, there is a single annual wet season with an average precipitation of about 1 500 mm. Here, the wet season is defined from about mid-April to the end of August. On the coast and in the Intermediate Savannahs the climatic seasons can generally be described as follows:

1) Long wet season : from mid-April to mid-August
2) Long dry season : from mid-August to the end of November
3) Short wet season : from the end of November to the end of January
4) Short dry season : from the end of January to mid-April

The first comprehensive soil survey of Guyana was not completed until 1965 through a joint effort of the Government of Guyana and FAO (FAO, 1965). Ninety-nine different kinds of soils were recognized then and classified according to the USDA 1938 system with tentative placements in the 7th Approximation. Based on the five recognized physiographic units the available data have been adapted for approximations in Soil Taxonomy to the closest possible category as follows:

Physiographic unit	Land capability	Taxonomic category	Area
1) Coastal plains	I - II	Tropaquepts, Tropaquents	4 545 km^2
		Plinthaquults	1 554
		Other Aquults and Aquents	2 888
	III	Fragiaquults	1 140
	III - IV	Fibrists, Hemists	8 133
			18 260
2) White sand plateau	II - III	Typic Paleudults, Arenic Paleudults, Paleustults	30 044 km^2
	III	Grossarenic Paleudults, Typic Quartzipsamments	17 029
	IV	Typic Quartzipsamments	16 835
			63 908

Physiographic unit	Land capability	Taxonomic category	Area
3) Crystalline shield uplands	I - II	Paleudalfs, Paleudults, Tropudults	9 207 km^2
	III - IV	Oxisols / Ultisols (Ustox, Acrorthox, Ustults)	42 334
			51 541
4) Highlands, mountains	I - II	Tropudalfs, Tropustalfs, (and Inceptisols)	440
	III	Ustalfs, Udalfs, Ustropepts, Ustox	11 188
			11 628
5) Interior alluvial plains	I - II	Tropudults	1 761
	III	Paleaquults, Plint-aquults, Paleudults	10 619
	IV	aquents, Aquods	5 128
			17 508
Other areas		Rock outcrops etc.	35 806
		Unmapped areas	15 424

Since the attainment of Independence in 1966, emphasis has been on the development of the hinterlands. This is reflected in the 1972-76 Development Programme which outlined the need to open up the interior in an effort to diversify and expand the national agricultural base. The strategy was to relieve the country's economic dependence on rice and sugar and, at the same time, relieve the population pressure on the coastal area by providing farm lands in the hinterlands for resettlement. It is believed that the objective can be achieved, in part, through the exploitation of the interior land resources where a wider range of soil, climate and other ecological conditions would favour crops which are not particularly well adapted to large-scale cultivation on the coastlands.

The nature, properties, and behaviour of soils in the interior areas have remained largely undetermined or unresearched but a concerted effort in agricultural research has been made on soils of the Intermediate Savannahs. This research effort included pedological investigations of selected soils, crop suitability and adaptability studies, soil fertility and fertilizer trials, fertilizer requirements and soil-plant-fertilizer interactions involving such crops as legumes, pasture grasses and legumes, sorghum, cotton and maize. This effort is still going on. However, a large enough number of data was collected to allow the development of large production centres for the cultivation of maize, legumes, sorghum, cotton and the rearing of cattle at four locations in the Intermediate Savannahs.

This paper focusses on the soils of the Intermediate Savannahs of Guyana. A general description of the area is given in an attompt to define its location, extent, the nature and properties of selected soils, climatic and other factors all of which influence agricultural production. Efforts in the area of agricultural research and production are reviewed. Major problems which influence the use and development of the land resources are discussed. Finally, the potential for development of agriculture is examined in the light of previous research work and production efforts as well as the presently identified research needs of the ecozone.

THE INTERMEDIATE SAVANNAHS

Location, extent and accessibility

The Intermediate Savannahs are located in northeastern Guyana immediately south of the coastal plain. They extend both east and west of the Berbice River in a south-westerly direction and adjoin the upland rainforest regions. The intersection of meridian 58° west longitude and line of latitude 5°30′ north represents the approximate geographical centre of the Intermediate Savannahs. They cover an area of about 2 700 km^2 (see Fig. 1).

Access to the Intermediate Savannahs is gained by river, road and air. The Berbice River provides the main avenue for the movement of people and goods. The principal road linkages are from Georgetown to Linden via paved all-weather roads and from Linden to Ituni via a loose surface all-weather road. West-east access from the Linden/Ituni road to the Berbice River is accomplished by tracks. These tracks on sandy soil can be used by offroad type vehicles throughout the year. Road access to areas of the Berbice River is possible through the use of pontoons that ferry vehicles across the river. Air service is provided by charter aircraft using a number of small unpaved landing strips.

Geology and geomorphology

The Intermediate Savannahs have developed on the "white sand plateau" that occupies the greater part of the northeastern region of Guyana. This plateau covers an area of about 64 000 km^2 with a topography that shows a somewhat uniform and monotonous appearance.

Altitudes vary from about 16 m near the coast to more than 150 m in the interior. The relief is gently undulating.

Geologically, the "white sand plateau" corresponds to the Berbice formation (Pliocene to Pleistocene) comprising sub-continental and old deltaic deposits of sands and clays inter-bedded with kaolinitic clay, laterite, and bauxite. White quartz sand ("white sand") prodominates on the plateau surface with brown loamy and sandy clay ("brown sand") sediments irregularly dispersed with the white sand frequently overlying stratigraphically the brown sand. The white sand covers a major part of the northwest portion of the plateau forming extensive areas between the Berbice, Demerara, and Essequibo Rivers. Isolated remnants also appear scatterod over the brown sand areas.

The brown sand and clay sediments occur scattered over the plateau but are concentrated in the southeastern part, west of the Demerara River up to the Corentyne River.

Topography

Formed on an ancient peneplain (the Mazaruni surface) the area is of low elevation and relief. Low, gently undulating hills rise to about 30 m from their bases. Because of the homogeneity of the sands throughout the area, a simple dendritic pattern of drainage has developed, with the topography being an expression of this type of drainage system. Despite the sparse vegetation native to this ecosystem, natural erosion appears to be minimal. As a result no steep slopes occur. However, in places where the natural vegetation has been disturbed for development, erosion commences with surprising speed, which has led to severe gullying in some areas.

A striking feature of the landscape in the natural state is the presence of abandoned termite hills. These are found scattered throughout the landscape in most parts of the savannas, rising as high as two metres. These hills constitute the only major obstruction to land clearing operations because of the necessity to level them.

Climate

The climate of the Intermediate Savannahs has been variously described as tropical humid and tropical wet and dry, the latter suggesting a transitional climatic type. The mean annual rainfall of about 2 250 mm has a bimodal distribution with about 40-60 percent coming in the long rainy season of mid-April to mid-August and less than 20 percent in the short rainy season which is largely unpredictable in terms of commencement and duration. There are also variations in total amount of annual rainfall.

Mean annual temperature for the region is 26°C. Diurnal fluctuations of up to 10°C are more pronounced than seasonal changes (1.5°C). The highest temperatures are recorded from August to November, a period that coincides with the long dry season. Temperatures in excess of 34°C have been recorded during this period. January, February and March are the coolest months with a mean minimum of 20.8°C.

While mean relative humidity is 80 percent, the daily variation is quite large. Maximum humidity is experienced in the early morning with an annual average of about 92 percent. Minimum humidity occurs in the early afternoon period with an average of about 65 percent. The average difference of 27 percent points is usually exceeded in the dry months of September and October, when a 40 percent points difference can be recorded. In these months it is common to find low overhanging mist during the nights and lasting into the early morning period. Minimum daily differences in relative humidity of about 16 percent occur in May and June.

Despite the fact that the savannas are about 160 km from the Atlantic, there is a daily cycle of winds induced by the northeast trade winds. Wind speed increases gradually after about 0700 hrs to daily maxima at about noon to 1600 hrs. The first six months of the year are usually marked by higher sustained winds.

While accurate records of evaporation and evapotranspiration are lacking, these have been averaged at 14 and 11 cm per month, respectively. Water surface evaporation is highest in the dry months of

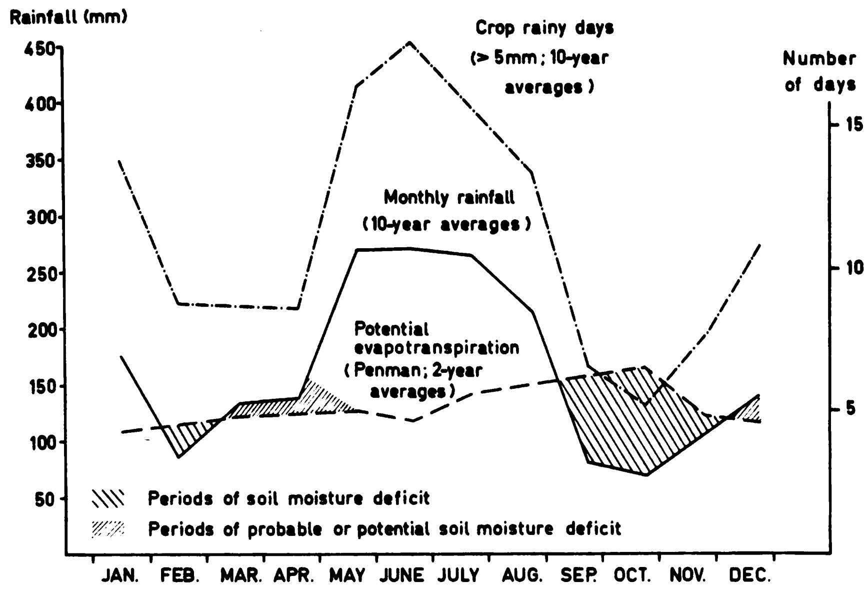


Fig. 5. Average monthly rainfall, potential evapotranspiration and monthly number of crop rainy days for Ebini, Guyana.

September and October and lowest in the wet months of May, June, December and January.

The average number of daily sunshine hours experienced per annum is about 6. While this figure may seem low for a tropical environment which is not classified as a rainforest climate, it is to be noted that cloud cover constitutes a barrier to the direct rays of the sun for much of a typical day. May and June are the months with shortest daily sunshine hours (average 5.0) while in September and October, on average, 8 sunshine hours per day are experienced.

The climatic pattern (Fig. 5) with its bimodal rainfall distribution facilitates two rainfed crop seasons per year, with annual crops. The first season, i.e. the long rainy season, commences in mid-April with harvesting being done in September - October. The second season or short rainy season sees planting in mid-November and harvesting in March - April. While the months designated for harvesting coincide with the drier months of the year it is not uncommon to find this operation being hamperod by unseasonal rains. The two seasons differ in the total amount of precipitation experienced over the growth period: about 900 -1 350 mm can be expected during the long rainy season. This has implications for the crops chosen for each season as well as for the diseaso and weed problems.

Vegetation

The native vegetation of this ecozone consists of about 70 percent woodlands, i.e. forest and shrub, approximately 25 percent savanna and associations of various kinds of marsh and swamp plants. Thus the term "savanna" can be considerod a misnomer when applied to the region as a whole. However, it is the savanna areas that are of national interest.

The rainforest on the finer textured, well drained soils includes various hard wood species such as greenheart *(Ocotea rodiaei)* and kakaralli *(Eschweilera sagotiana)*. Evergreen seasonal forest occurs on medium textured soils and contains hardwoods such as bulletwood *(Manilkara bidentata)*. The dry evergreen forest on the deep sandy soils contains wallaba *(Eperua falcata)* and dakama *(Dimorphandra conjugata)*. Savanna type vegetation is dominated by the grass *Trachypogon plumosus* with scattered sand paper trees *(Curatella americana)*. Along the river levees palm marsh forests occur consisting of kokerite *(Maximiliana regia)*, manicole *(Euterpe edulis)* and corkwood *(Pterocarpus officinalis)*. Swamp forests on the mineral-organic complexes and on the organic soils of back swamps also contain corkwood and sarebebe *(Macrolobium* spp.). There are small areas of herbaceous swamp occurring in depressions and containing mainly razor grass *(Scleria* and *Rhynchospora* spp.).

Less than 10 percent of the land area in the entire ecozone is cultivated. In the brown sand areas there are improved pastures for livestock and cultivated crops including cotton, maize, soybean, cowpea, groundnut and sorghum.

Soils

The soils of the "white sand plateau" include well drained Ultisols, Oxisols and Entisols. The soils are coarse to medium-textured, ranging from pure white quartz sand to yellowish red sandy clay. Thirty-eight different kinds of soils have been identified but the most extensive include the Ebini sandy loam (Typic Paleudult - 26 300 ha), the Kasarama loamy sand (Arenic Paleudult - 56 000 ha), the Tabela sand (Typic Quartzipsamment - 27 640 ha) and the Tiwiwid sand (Typic Quartzipsamment - 40 480 ha). The first three are referred to as "brown sands" while the latter - the most extensive - is referred to as "white sands".

These soils have been studied more intensively than others occurring within the Intermediate Savannahs. The brown sands appear to have the highest potential for agricultural development.

The Ebini sandy loam is classified as a member of the clayey, kaolinitic, isohyperthermic family of the Typic Paleudults. The surface soil is greyish brown or yellowish brown to dark greyish brown sandy loam with a moderate, coarse, granular structure. The subsoil is yellow or yellowish red to strong brown sandy clay or clay, with a moderate, medium, subangular blocky structure. Red clay with a massive structure, with medium white sand grains is found in the upper 0-8 cm with some penetration of organic matter to about 30 cm along root channels. Few fine roots occur in the subsoil with little or no penetration beyond 80-90 cm.

The Kasarama loamy sand is a member of the loamy, siliceous, isohyperthermic family of the Arenic Paleudults. The surface is brown to dark greyish brown sand or loamy sand with a weak, fine, granular structure to a depth of 25-40 cm. The subsoil is strong brown to light yellowish brown or yellowish rod sandy loam to sandy clay loam with a weak, medium, subangular blocky structure. The topsoil contains many fine and medium roots. In the upper parts of the subsoil old root channels containing dark materials are common.

The Tabela sand is a member of the coated isohyperthermic family of the Typic Quartzipsamments. The surface soil (0-20 cm) is brown sand with a weak, fine, crumb structure. The sand is loose when dry, and there is usually a thin layer of coarse sand grains on the surface between grass clumps. The subsoil is strong brown, loamy sand changing from single grain in the upper 20-50 cm to very weak granular to structureless with depth. Root penetration is limited to 50-90 cm.

The Tiwiwid sand is a member of the uncoated, isohyperthermic family of Typic Quartzipsamments. The surface soil (0-15 cm) is a dark greyish brown to grey sand with a loose, single grain structure. The subsoil ranges from a white sand in the upper part to coarse white sand further down the profile with a loose single grain structure. Fine and medium roots are common in the upper 10 cm, while old root channels can be found to depths of 30-80 cm.

The soils are all very acid with relatively large amounts of KCl-exchangeable acidity, almost devoid of natural fertility in both the topsoil and subsoil. They also have a very low CEC and base saturation. Organic matter content and water-holding capacity are also inherently low. The surface soils are predominantly sandy and this coupled with a high intensity of rainfall creates a potential erosion hazard which readily manifests itself when cultivation is attempted. Some of the soils have a tendency toward encrustment whenever the natural vegetation is removed. While this latter phenomenon has not been thoroughly investigated, it is potentially a hindrance to crop growth especially to seedling emergence.

UTILIZATION

Background

Approximately 70 percent of the area is under a forest type cover and slightly less than 25 percent under savanna type vegetation (TAMS, 1976). Agricultural and forestry activities affect about 10 percent of the area. Agriculture comprises primarily large-scale enterprises. Timber extraction is carried out essentially by one or several privately or co-operatively owned sawmilling enterprises within the Upper Berbice and Demerara regions.

The brown sand savanna areas have had attention for agricultural development for quite some time. Follet-Smith (1930) described a ranch in the Takama area as a "very unsuitable place to rest cattle, as cattle that remain there for a long period become emaciated and develop a pica for bones". His analyses showed the soils to be deficient in P_2O_5 and K_2O while the grasses were markedly deficient in P_2O_5 with low percentages CaO and K_2O. He advised burning of the savanna and feeding bene meal as means of improvement and recommended more research.

The two existing ranches - Waranama in the Takama savanna and Dubelai in the Wiruni savanna - both carry less than 300 head of cattle each and still rely on open range grazing of the native savanna grasses but are now attempting to establish improved pastures.

Of the six or seven true "savannas" within the Intermediate Savannah ecozone (Fig. 6), there have been large-scale agricultural production efforts on three of them since 1942.

The Ebini savanna, on the east bank of the Berbice River, consists essentially of a number of smaller savannas stretching eastward from the Berbice to the Haraculi River. The entire area covers well over 20 000 hectares and has a representative range of brown and white sand soils.

The Kibilibiri savanna occurs north of the Kibilibiri River and south of the Ituni River. This savanna is situated west of the Berbice River and has over 4 400 hectares of cultivable savanna land.

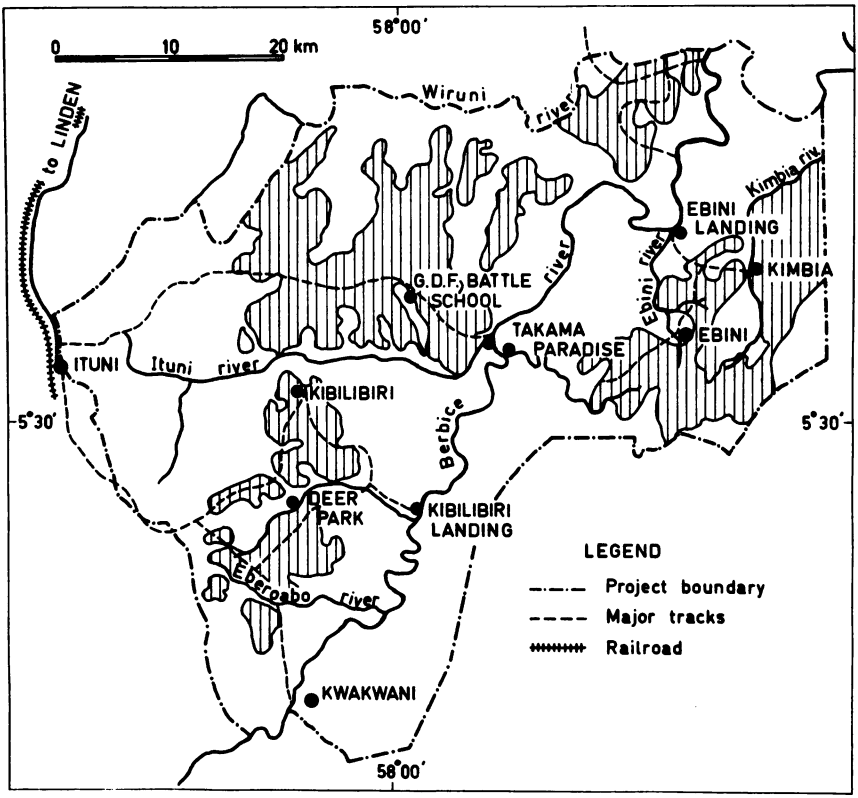


Fig. 6. The "Intermediate Savannahs".

Eberoabo is the southernmost of the large savannas and lies south of the Kibilibiri River and north of the Eberoabo River. There are over 3 000 hectares of potentially good agricultural land in this savanna. The other savannas which have remained essentially untouched by intensive agriculture, are the Ituni, Takama and Wiruni savannas.

Research, production and settlement

Ebini. Agricultural activities in the Ebini savannas began in 1941 with the establishment of the Ebini Research Station (then the Ebini Livestock Station). Originally, the station was established to investigate problems associated with economic beef-cattle production in the Intermediate Savannahs. Research focussed on animal survival which was shown to be affected by protein and mineral deficiencies, weather, infested pastures and predators.

In 1952 there was a marked intensifying of the research efforts with the assignment of scientists in range management and livestock husbandry. The performance of various breeds of imported beef cattle were assessed and recorded. Improved pasture grasses and forage legumes were also introduced. In 1969, a study of the reproductive behaviour of the cattle showed that conception was highly correlated with forage production and weather. This motivated management to move towards seasonal breeding (Holder, 1972). Subsequent research work included supplemental feeding of beef cattle (Holder, 1972), pasture management, establishment of grass-legume combinations, influence of species, plant age and soil type on dry matter production and management of various grasses and legnmes, and responses of grasses to fertilizer applications (Chesney, 1972 and 1973).

In 1975 the Livestock Development Company assumed responsibilities for the cattle operations and now runs a commercial beef cattle ranch at this location. The ranch has about 2 500 head of beef cattle on 2 000 hectares of improved pastures. The operations are essentially geared to produce steers. It has also a small dairy unit. Seasonal fluctuations in forage quality are still experienced at Ebini and soil and pasture management are being emphasized with a limited research effort in pasture agronomy.

The Ministry of Agriculture is conducting research at Ebini on the adaptation of sheep and goats for intensive pasture management. This aspect of research began in 1972 and aims at defining conditions for viable small-ruminant farms in the savannas. Some initial work included the isolation and control of poisonous weed species, screening of breeds of sheep and goats, evaluating the need for (and kinds of) supplemental feeding and the use of various types of pasture fencing. The unit has about 250 animals on 90 hectares of improved pastures, and a museum collection of a number of improved grasses and forage legumes.

A concerted organized research effort for annual crop production commenced in 1962. The first experiments involved maize, cotton, soybean and groundnut. Later, other crops like cassava, sweet potato, onions, tomato, tobacco, sorghum, sesame, castor bean, cowpea and mungbean were also included along with *Calopogonium*, velvet bean, *Centrosema pubescens* and *Centrosema plumeri*.

These initial experiments indicated a number of problems to be expected for agricultural development of the area. These included:

1) Climatic problems

The unreliability of the rainfall, the frequent, severe dry spells, the comparatively low humidity in the afternoons with wind blowing during most of the day-time. These problems affect soil-moisture relations which are already aggravated by the sandy nature and low organic matter content of the soils.

The brown sand soil, on average, will have about 1 inch of available water per foot of soil and water stress will manifest itself in many crops when about half of this amount has been used. It was concluded that outside the long wet season, economically justified production of annual crops without irrigation will be impossible.

2) Fertility and other soil problems

Field experiments confirmed the qualities and limitations of these soils for crop production. The soils are easily worked with machinery but the heavier textured Ebini sandy loam has a very narrow moisture range for tillage. These soils are also subject to severe encrustment upon wetting and drying.

Data on pH and KCl-acidity indicate that for many crops liming is necessary. The experiments also showed that cotton and soybean cannot be grown at all without lime; furthermore the need to supply magnesium was clearly shown.

The field experiments showed also, that without the application of phosphate, potassium, calcium and magnesium the crops being tested could not be grown and there were indications that trace elements will probably increase yields as the major elements become non-limiting.

Analyses of soil samples from fully fertilized plots where the fertilizers were applied at planting, showed no trace of the supplied fertilizers after harvest of a maize crop grown during the rainy season. Analyses of soil samples from pastures which had received fertilizer for several years also showed no residual effects of N, P and K. This indicated that leaching and fixation were major problems with these soils. The need for research was suggested to ascertain for several crops, the number, intervals and rates of fertilizer applications required, and the maintenance or improvement of the organic matter content through use of cover and green manure crops. The inclusion of grass leys in the crop rotation should also be studied.

3) Pests and diseases

One of the main problems inherent in the area is that of the Acoushi ants (*Atta* sp.). Other pests include fall army worm (*Spodoptera* sp.), corn ear worm *(Heliothis armigera)* and stem borer *(Diatraea gradoisella)*. Nematodes were also indicated as a major problem.

The conclusions and recommendations from these initial experiments indicated that agricultural development of this area must be approached with utmost care. However, there are indications that a large variety of crops can give good yields but factors such as the climate and soil-plant-fertilizer interactions must be studied in greater detail.

In 1969, the Ministry of Agriculture co-operating with the University of Florida, began evaluating a number of crops and varieties. The research effort led to the selection of the Jupiter variety of soybean (Hinson, 1972), and the Altika variety of groundnut as being suitable on the basis of its performance at Ebini (Norden et al., 1972). Fertilizer studies on rates of application and sources of nutrient elements have also been conducted and have provided basic information for recommendations used in commercial farming in other parts of the savannas.

During the second half of the 1970's emphasis was placed on seed production. Thus, the station fulfilled the needs for large-scale field testing of crop varieties while assisting to meet the national demand for seed, at the same time assessing the problems encounterod in large-scale crop production on the savanna soils.

Research on perennial crops has been confined mainly to assessing fertilizer requirements for citrus, mango, oil palm, coconut and cashew. Yields of citrus, which has been the most successful of the perennials, are still being monitored.

Kibilibiri. Farming in the Kibilibiri savanna was pioneered by Global Agri Industries of Guyana Ltd. This organization was formed by the Ministry of Agriculture in 1970 to test and research findings of large-scale farming techniques on a commercial basis for the Intermediate Savannahs. The farm is now being managed by the Guyana Police Force which is emphasizing groundnut as a crop along with sheep and goats.

During seven years of commercial farming at Kibilibiri a number of problems were encountered. Most of these were related to the application of the technology developed essentially from small-scale trials to large acreages. The range of crops cultivated commercially included maize, soybean, groundnut and cowpea. Unpredictability of rainfall, nonuniformity of land preparation and planting and lack of timeliness in the application of inputs contributed to a consistent trend of non-realization of target acreages and yields (Fletcher, 1977; TAMS, 1976). Yield data from the project reveal that for all crops, highest yields were obtained from small acreages. Table 3 shows the ranges in yields obtained as related to the anticipated, over a four-year period.

The above data are not only reflective of gaps in the available technology but in certain instances of the effects of unexpected weather patterns at some stages of crop development, unsuitability of chosen genetic material for mechanized cultivation and difficulties in timing harvesting operations (Fletcher & Gordon, 1977). The project, nevertheless, demonstrated that the technology developed with respect to soil management was not inadequate to meet some of the expected crop yields.

Table 3. Kibilibiri. Yields, yield ranges and expected yields

Crop	Range in yield (1970-74)	Average yield of dry grain	Expected yield of dry grain	Actual yield as a percentage of expected
	kg/ha			%
Maize	331 - 3 488	1 962	2 803	70
Soybean	135 - 1 756	852	1 682	51
Groundnut	138 - 571	353	897	39
Cowpea	221 - 1 103	701	897	78

Source: adapted from TAMS (1976)

Apart from commercial crop production, there was a major research effort on cotton at Kibilibiri. From 1972 tot 1977, technicians from the People's Republic of China in collaboration with scientists from the Ministry of Agriculture conducted experiments on fertilizer requirements, population densities, varietal differences, time of planting and ratooning for cotton. This research demonstrated the technical feasibility of growing cotton on the brown sands. Some varieties yielded in excess of a bale of lint per acre.

Kimbia. In 1974, the Government of Guyana established the Guyana National Service, a paramilitary organization which has as one of its mandates, hinterland settlement and development. The first chosen hinterland location was at Kimbia in the Ebini savanna. Agriculture was chosen as the major vehicle for development with emphasis being placed on cotton production. Training in a number of vocational skills accompanies agricultural production activities. There is also a settlement scheme on the left bank of the river which attracts graduates from the Service who wish to settle and farm in the area. Part of the centre's infrastructure includes a cotton gin capable of producing four bales of lint per hour.

Initially cotton production was targeted at over 1 000 hectares per season. This was actually achieved in 1976 but with very low yields. Downward revision of targets along with a demonstration of increased capability in applying recommended technology resulted in increased yields which now stand at 230 kg/ha. There has been a gradual increase in total acreage with improvements in the organization's farm management skills, manpower, and machine capability. Thus 1 000 hectares will be planted in 1982.

A rotation system with cowpea is practiced. While this has shown no serious technical setbacks beside erosion, research is currently being carried out to find a rotation system compatible with the maintenance of relevant soil characteristics. Research is now directed at increasing the rooting depth of cotton plants on the brown sand soils by overcoming the effects of a chemical subsoil barrier (Bullen et al., 1981). Observations of the crops at Kimbia and some crops in the other savanna areas have shown a consistent pattern where the tap or main roots grow downward for about 8-10 cm before running laterally and almost parallel to the soil surface. It is felt that yields can be increased by increased rooting depth that will allow greater exploitation of soil water and nutrients.

Cultivation of both cotton and cowpea is affected by the growth of a number of introduced weed species which depress yield. While chemical and mechanical weed control methods are practiced, a greater effort is requirod to study the succession pattern of weeds in order to refine the currently used technology.

Eberoabo. The most recent attempt at large-scale crop production in the Intermediate Savannahs is a joint effort by the governments of Guyana, St. Kitts-Nevis, and Trinidad and Tobago, through the incorporation of a Regional Grain Production Company in 1975. The project is located in the Eberoabo savanna and was originally designed to enable annual cropping, processing, and marketing of approximately 3 200 hectares of soybean, 4 000 hectares of maize and 800 hectares of cowpea.

During the six years of operation, production was hampered by severe logistics and agronomic problems and forced a re-appraisal of original objectives in terms of cultivated acreage and expected yields. Agronomic problems related mainly to:

1) Application of technology to cope successfully with adverse soil and climatic factors.
2) Identifying crops and varieties that are adequately adapted to the

environment and yet have a high yield potential, and
3) Identifying a field production system that is repeatable on an annual basis thereby making crop scheduling a less difficult task.

The specific agronomic problems faced by this project were similar to those encountered at Kibilibiri and Kimbia. In 1978, the Caribbean Agricultural Research and Development Institute (CARDI) began providing technical assistance to the project. Emphasis was on "the provision of technical services in crop varietal assessment, soil fertility, and farm management on insect pest control and farm management on the on-going project" (Fletcher, 1980). CARDI's work commenced early in 1978 with the main objectives being:
1) Soil fertility monitoring to establish the effect of fertilizer application on soil chemical characteristics and build-up of fertilizer residues, aimed at modifying the fertilizer regime to obtain optimum benefits, and
2) Institution of an integrated pest control programme to combine chemical and biological systems of pest control in commercial production. These objectives are still being pursued.

PROPERTIES AND BEHAVIOUR OF THE SOILS

Chemical and other properties

Some properties of the four dominant kinds of soils are presented in Table 4. A representative description of the morphology of each of these soils is given in the Appendix. The data show some general similarities and some unique characteristics among the soils.

All the soils are devoid of such cations as Ca^{2+}, $Mg^{2+}$and K^{+} with a relatively large amount of Mg^{2+} found in the Ebini sandy loam as an exception. The CEC-values (sum of cations + KCl acidity) are much less than 3 meq/100 ml and the phosphorus status (Truog) is less than 13 and generally even below 6 ppm. pH ranges from 4.3 to about 5.9 but this range is much narrower (4.3 - 5.3) in the brown sand soils. Percent base saturation is often below 50. Except for the Tiwiwid sand with 100 percent base saturation in the subsoil, there is a tendency for lower base saturation values in the immediate subsoil. Organic carbon content is high in the surface soil varying from 2.5 percent in the Tiwiwid and Ebini soils to 0.7 percent in the Tabela soil. The organic carbon expectedly decreases with depth to undetectable amounts from about 36 cm in de Tiwiwid sand.

The Tiwiwid sand and the Tabela sand have a textural composition in excess of 86 percent sand (dominated by a medium - 0.50 to 0.25 mm - sand fraction). However, the Tabela sand has a higher clay content which indirectly makes it a relatively better soil agricultur-

Table 4 Characteristics of the four dominant kinds of soils in the Intermediate Savannah area

Depth	Particle size sand	silt	clay	pH	Org C	Kjeld N	Exch acid	Ca	Mg	K	Na	total	ECEC	Base sat	Bray P
cm	%				%		mmol/100 ml							%	ppm
Twiwid sand (Typic Quartzipsamment, map unit 200)															
0 – 10	98	2	0	4.6	2.5	0.04	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0	8
10 – 17	98	2	0	4.5	1.7	0.02	0.3	0.0	0.0	0.0	0.1	0.1	0.4	44	8
17 – 56	98	2	0	5.4	0.1	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	7
56 – 86	97	3	0	5.8	0.0	0.00	0.0	0.0	0.0	0.0	0.1	0.1	0.1	100	8
86 +	97	3	0	5.9	0.0	0.00	0.0	0.0	0.0	0.1	0.0	0.1	0.1	100	7
Tabela sand (Typic Quartzipsamment; map unit 800)															
0 – 20	94	1	5	5.1	0.7	0.05	0.2	0.0	0.1	0.1	0.1	0.3	0.5	60	4
20 – 51	86	2	12	5.2	0.8	0.08	0.2	0.0	0.0	0.0	0.1	0.1	0.3	33	4
51 – 91	86	5	9	5.8	0.8	0.02	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0	7
91 – 122	87	3	10	5.2	0.2	0.01	0.3	0.0	0.0	0.1	0.2	0.3	0.6	50	4

Kasarama loamy sand (Arenic Paleudult; map unit 810)															
0 – 25	80	3	17	4.8	1.2	0.05	0.6	0.0	0.0	0.0	0.1	0.1	0.7	14	6
25 – 41	90	0	10	4.7	0.9	0.04	0.9	0.0	0.0	0.0	0.1	0.1	1.0	10	3
41 – 56	93	0	7	4.7	0.8	0.05	0.7	0.0	0.0	0.0	0.1	0.1	0.8	12	4
56 – 86	82	0	18	4.7	0.2	0.02	0.5	0.0	0.0	0.2	0.1	0.3	0.8	37	2
86 – 158	79	1	20	4.7	0.1	0.02	0.4	0.0	0.0	0.0	0.1	0.1	0.5	20	13
158 – 193	76	1	22	4.9	0.1	0.02	0.3	0.0	0.0	0.0	0.1	0.1	0.4	25	7
193 +	65	4	31	5.0	0.3	0.02	0.3	0.0	0.0	0.0	0.1	0.1	0.4	25	0
Ebini Sandy loam (Typic Paleudult; map unit 820)															
0 – 8	57	6	37	4.3	2.8	0.16	1.6	0.1	1.0	0.1	0.2	1.4	3.0	47	7
8 – 31	56	6	38	4.4	2.2	0.11	1.7	0.0	0.5	0.1	0.1	0.7	2.4	29	10
31 – 41	48	6	46	4.7	1.6	0.08	1.3	0.0	0.3	0.1	0.1	0.5	1.8	28	6
41 – 76	40	8	52	4.9	0.8	0.06	0.7	0.0	0.1	0.0	0.1	0.2	0.9	22	5
76 – 91	43	8	49	4.9	0.6	0.05	0.7	0.0	0.1	0.0	0.1	0.2	0.9	22	4
91 – 122	44	12	44	4.9	0.7	0.03	0.6	0.0	0.0	0.0	0.1	0.1	0.7	14	4

Table 4. Characteristics of the four dominant kinds of soils in the Intermediate Savannahs area

	Particle size				Org.	Kjeld	Exch	Exch. bases						Base	Extr.
Depth	sand	silt	clay	pH	C	N	acid.	Ca	Mg	K	Na	total	ECEC	sat.	P
cm	—— % ——				—— % ——		—————— meq/100 ml ——————							%	ppm
Tiwiwid sand (Typic Quartzipsamment; map unit 700)															
0 – 10	98	2	0	4.6	2.5	0.04	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0	6
10 – 17	98	2	0	4.5	1.7	0.02	0.2	0.0	0.0	0.0	0.1	0.1	0.3	33	6
17 – 36	98	2	0	5.4	0.1	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	7
36 – 86	97	3	0	5.8	0.0	0.00	0.0	0.0	0.0	0.0	0.1	0.1	0.1	100	9
86 +	97	3	0	5.9	0.0	0.00	0.0	0.0	0.0	0.1	0.0	0.1	0.1	100	7
Tabela sand (Typic Quartzipsamment; map unit 800)															
0 – 20	94	1	5	5.1	0.7	0.05	0.2	0.0	0.1	0.1	0.1	0.3	0.5	60	4
20 – 51	86	2	12	5.2	0.3	0.03	0.2	0.0	0.0	0.0	0.1	0.1	0.3	33	4
51 – 91	86	5	9	5.3	0.3	0.02	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0	7
91 – 122	87	3	10	5.2	0.2	0.01	0.3	0.0	0.0	0.1	0.2	0.3	0.6	50	4

Kasarama loamy sand (Arenic Paleudult; map unit 810)															
0 – 25	80	3	17	4.8	1.2	0.05	0.6	0.0	0.0	0.0	0.1	0.1	0.7	14	6
25 – 41	90	0	10	4.7	0.9	0.04	0.9	0.0	0.0	0.0	0.1	0.1	1.0	10	3
41 – 56	93	0	7	4.7	0.8	0.05	0.7	0.0	0.0	0.0	0.1	0.1	0.8	12	4
56 – 86	82	0	18	4.7	0.2	0.02	0.5	0.0	0.0	0.2	0.1	0.3	0.8	37	2
86 – 158	79	1	20	4.7	0.1	0.02	0.4	0.0	0.0	0.0	0.1	0.1	0.5	20	13
158 – 193	76	1	22	4.9	0.1	0.02	0.3	0.0	0.0	0.0	0.1	0.1	0.4	25	7
193 +	65	4	31	5.0	0.3	0.02	0.3	0.0	0.0	0.0	0.1	0.1	0.4	25	0
Ebini Sandy loam (Typic Paleudult; map unit 820)															
0 – 8	57	6	37	4.3	2.8	0.16	1.6	0.1	1.0	0.1	0.2	1.4	3.0	47	7
8 – 31	56	6	38	4.4	2.2	0.11	1.7	0.0	0.5	0.1	0.1	0.7	2.4	29	10
31 – 41	48	6	46	4.7	1.6	0.08	1.3	0.0	0.3	0.1	0.1	0.5	1.8	28	6
41 – 76	40	8	52	4.9	0.8	0.06	0.7	0.0	0.1	0.0	0.1	0.2	0.9	22	5
76 – 91	43	8	49	4.9	0.6	0.05	0.7	0.0	0.1	0.0	0.1	0.2	0.9	22	4
91 – 122	44	12	44	4.9	0.7	0.03	0.6	0.0	0.0	0.0	0.1	0.1	0.7	14	4

ally. The subsoils of the Kasarama loamy sand and the Ebini sandy loam profiles both show sufficient increase in clay content with depth to meet the requirements of argillic horizons. The Ebini sandy loam has a sufficiently high clay content to place it in a clayey family.

Physical characteristics

Few data are available on soil physical parameters of the brown sand soils. Some recently obtained data (Bullen et al., 1981) are presented in Table 5 for the three soils under virgin conditions and conditions during the first cropping season. The table provides a preliminary insight into conditions that may influence soil-water relations.

Implications

The data presented in Table 4 imply that there are severe constraints to crop production on these soils. Nevertheless, the constraints are not

Table 5. Some physical characteristics of the brown sand soils

Depth	Bulk density	Porosity total	Porosity NCP[a]	Porosity CP[b]	Sat. hydr. conduct.	Water retention at Sat'n	Water retention at 0.06 bar	Water retention at 0.3 bar	Water retention at 0.5 bar
cm	g/m^3				cm/hr	% dry weight			
Tabela sand (virgin)									
0-15	1.55	42	22	20	8.4	25	13	7	6
15-30	1.67	34	14	20	6.0	21	12	6	9
Tabela sand (cultivated)									
0-15	1.58	42	22	20	12.6	24	12	7	6
15-30	1.71	37	11	26	6.0	19	15	6	6
Kasarama loamy sand (virgin)									
0-15	1.65	35	4	31	1.20	22	-	-	14
15-30	1.66	34	7	27	0.60	19	-	-	12
Kasarama loamy sand (cultivated)									
0-15	1.36	47	21	26	1.20	31	-	-	14
15-30	1.55	39	6	33	1.20	25	-	-	15
Ebini sandy loam (virgin)									
0-15	1.58	37	8	29	6.6	22	18	10	10
15-30	1.64	36	7	29	5.4	21	17	10	9
Ebini sandy loam (cultivated)									
0-15	1.40	45	18	27	12.6	28	19	13	12
15-30	1.56	36	5	31	1.2	23	19	12	11

[a] non-capillary pores
[b] capillary pores

as severe in some as in others and this provides a basis for ranking their agricultural potential. From high to low the ranking is as follows:
Ebini sandy loam > Kasarama loamy sand > Tabela sand > Tiwiwid sand.
The Ebini sandy loam, because of its higher clay content and associated attributes, has been shown to be the most productive in terms of crop response to added nutrients (Chesney, 1979; Dookie, 1981). However, this clay content also poses limitations; the most severe is a very limited moisture range for tillage. The Kasarama loamy sand has been the one most used for agriculture because it offers a wider moisture range for tillage and because it can be mechanically manipulated more easily. It possesses some of the agriculturally favourable properties of the more clayey Ebini sandy loam although to a lesser degree, which is reflected in a lower yield response to fertilizer management. The Tabela sand is the poorest of the brown sand soils. It does not have moisture limitations for tillage but is very sensitive to drought and subject to rapid leaching making it a "high-risk" soil for farming. The Tiwiwid sand has no agricultural advantages and should be left under natural vegetation. Some attempts have been made to farm these soils but without satisfactory returns. Agricultural development is now being confined solely to the brown sand soils.

The colour of the brown sand soils is derived primarily from associated hydrated oxides of iron. There are no actual data available to indicate the nature or quantities of iron in these soils but it is assumed to be high enough to be a major contributor to phosphorus fixation (Chesney, 1979; Downer, 1972).

The high rainfall and temperature on these well to excessively drained upland soils create an intense oxidizing environment; organic matter is rapidly decomposed once the natural equilibrium is disturbed. One may suggest that these factors - which may also include a solution saturated with silica - contribute significantly to the crust formation that occurs especially on the Ebini sandy loam and the Kasarama loamy sand. They may also be responsible for the hard, brick-like cementation that develops in the Ebini sandy loam soils during dry periods.

The general tendency of lower base saturation values in the subsoils of these soils implies the existence of a chemical barrier that may inhibit root penetration, and thus retard effective use of both moisture and nutrients in the brown sands.

MANAGEMENT OF THE CROP GROWING ENVIRONMENT

The ecosystem appears to be quite fragile and demands exact management practices for the maintenance of viable agricultural systems. Key elements of any management system developed must take into consideration the relatively infertile and droughty nature of the soils, the erosion hazard, in addition to a number of climatic factors including the unpredictability of rainfall on a day to day basis. A failure to fully recognize and cope with these facets has contributed in the past, to low crop yields.

Tillage

Soil disturbing activities enhance the hazards of erosion and may lead to crust formation. Tillage appears to be necessary for the incorporation of stubble and other vegetative material which may improve the organic matter status of the soils. However, the rapid rate of oxidation of organic matter seems to nullify much of the supposed advantages of incorporation. Experience at the Kimbia production centre has indicated the advantages of well prepared, level land for efficient mechanized planting operations which result in the desired germination and plant population density. The necessary land preparations are quite intensive. The high incidence of soil erosion has caused a serious reexamination of the results and efficiency of minimum tillage as a reasonable alternative. However, with the existing land preparation technology careful consideration must be given to:

1) Size and type of machinery and implements used.
2) Timing of operations in order to achieve desired effects within the framework of weather and soil physical characteristics.

It is nevertheless believed that increases in organic matter content would significantly reduce the chances of crusting and also widen the moisture range of the soils for mechanical manipulations.

Fertilizer and lime applications

Fertilizers must be used for any crop production. Table 6 gives ranges

Table 6. Fertilizer requirements of some crops grown on the brown sand soils

Crop	N	P	K	Mg	Micro-nutrients
	kg/ha				
Legumes[a]	34 - 56	34 - 44	83 - 112	20 - 34	34 - 56
Groundnut[a]	34 - 56	44 - 59	112 - 139	27 - 41	34 - 56
Maize[b]	112 - 170	37 - 44	91 - 112	27 - 41	34 - 56
Cotton	84 - 120	47 - 56	66 - 89	9 - 20	34 - 56

[a] Groundnut and other legumes are inoculated
[b] Sorghum is fertilized similar to maize

for rates of application of the major nutrients as determined for the various crops grown. Despite continuous use of these rates of fertilizers the soils show an undesirable trend towards:

1) Inadequate amounts of bases in the 15-30 cm layer.
2) Imbalances in the Ca/Mg and Mg/K ratios, and
3) Poor levels of Mg and low levels of K.

Recent studies indicated a recovery rate for N by maize of less than 25 percent (Dookie, 1981). These observations indicate the need for closer examination of soil-fertilizer-plant interactions. Stricter requirements for micronutrients must be established. There are no conclusive data on micronutrient requirements; management practice has been to use standard commercially available formulations of fritted trace elements most of which contain unnecessarily high quantities of Fe at the expense of other micronutrients. At Eberoabo, for example, CARDI scientists have recommended that trace elements be supplied individually to permit application of correct ratios. Boron and zinc seem to be the most critical of the trace elements but the status of manganese is still in doubt.

Areas of deficiency in relation to application of fertilizers are:

1) Identification of the best (economical and agronomical) combination of fertilizer nutrient elements, and
2) Systems for efficient application of fertilizers in the field.

Management of the Eberoabo project has shown an economic preference (initial cost outlay) to use "straight fertilizers" which are bulk blended on the site. In practice this system is time-consuming and costly while not ensuring that the required amounts of each nutrient are applied. On the other hand, compound fertilizers are used at Kimbia, which has the following disadvantages:

1) Inadequate levels of Mg and trace elements are included in the blends.
2) Minimum quantity orders of desired blends are high (1 000 - 2 000 tons), and
3) The dust-free pelleted type of fertilizers are more expensive.

Lime applications are done on a three-year basis. Recent investigations have indicated that the soils may revert to the original pH before liming as early as one crop season. Soil analysis has also shown wide differences in KCl-exchangeable acidity and base status between the 0-20 cm and the 20-50 cm layers. The subsoils always have a significantly higher level of acidity, which is thought to be a chemical barrier affecting the ability of roots to exploit the lower soil horizons. This may also explain the poorly developed root systems of crops grown with apparently adequate fertilizer application rates. Other consequences of this chemical barrier are induced moisture stress and heat stress. Incorporation of limestone at the lower depths has been shown to have an ameliorative effect. The frequency, rate of limestone application, and residual effects still need to be ascertained.

Scheduling of operations

Many field operations are inevitably tied to prevailing weather conditions. The failure to execute pre-programmed field operations has undesirable effects on the crop production effort. For example, delay in land preparation or planting occasioned by unfavourable weather conditions can lead to:

1) Weed build-up in fields, and
2) Crops maturing at periods when harvesting may be hampered by the weather.

The need for an accurate weather predicting service is great. Available agro-meteorological data can be used in characterizing past weather patterns but so far are of little use in predicting the beginning and the end of the rainy seasons with the degree of accuracy required.

There are other factors which affect the timeliness of operations. The timely acquisition of all inputs, for example, is essential but in view of the limited logistic support for the savanna areas from resupply centre(s), the timeliness is always doubtful.

Numerical adequacy of machinery and implements should be carefully established. It is not uncommon to find in large-scale crop production operations that there is a clash of activities for available machines, e.g. planting and re-fertilizing being done at the same time.

Crop rotation

The need for economic crop rotation systems that will not have deleterious effects on the soil and, at the same time optimize the effects of fertilizers and limestone and their residual effects as well as preventing a build-up of weeds, pests and diseases is recognized. Several systems have been used involving the use of open row crops in each season. Such systems do not appear to account for all the added fertilizers either directly or through residual effects and thus result in the need for heavy inputs of fertilizer in each season. At the same time there is little evidence to suggest that crop rotation as presently practiced is effective in the control of a number of introduced weed species.

Present research assesses the value of a pasture grass (*Brachiaria* sp.) in the rotation system. The expected increase of the organic matter content is also seen as a means of raising the CEC of these soils.

SUMMARY: RESEARCH PRIORITIES

It is believed that economically viable crop and livestock production is possible on the Intermediate Savannahs. The experiences of agencies involved in large-scale agricultural activities have shown that notwithstanding the existence of a relatively large body of research data for the environment, there are major deficiencies both in the applicable technology and in the application of available technology. An approach to filling these gaps has been developed by scientists from the Ministry of Agriculture, CARDI and the Guyana National Service.

The problem

The major reported areas of technological deficiencies include:

1) Problems associated with lime and fertilizer use and management. These may be related, in part, to improper identification and correction of nutrient deficiencies, chemical toxicities, chemical imbalances and more generally, to an inadequate understanding of the soil in terms of soil-plant-fertilizer interactions.
2) Coping with subtle adverse environmental changes induced by continuous open-row cropping systems, and with the failure to identify and utilize appropriate crop rotation systems compatible with the maintenance of some relevant soil characteristics.
3) Utilizing an effective soil conservation programme for erosion control, moisture conservation and for the maintenance of soil physical and chemical characteristics.
4) A refinement of agro-meteorological data and their interpretation in terms of predictability of climatic conditions relative to critical crop growth stages.
5) A refinement of agricultural mechanization technology for crop production, and
6) Identification and use of appropriate systems for the control of pests and diseases.

Aspects of the proposed research

A reassessment of the crop-growing environment is proposed, taking into account the following aspects:

Climate. There have been serious efforts in gathering and analyzing some climatic data. This is to be continued on an expanded scale by including such parameters as sunshine hours, temperature (soil and above ground), percent cloud cover, potential rainy and rain-free days, rainfall intensity and evapotranspiration. These data must be wedded to soil moisture status and interpreted for the prediction of planting and harvesting dates, possible periods of drought stress and the scheduling of crop production activities.

Soils. Significant differences in crop response and required management systems for the different kinds of soils have been recognized. Experience has indicated that the Kasarama loamy sand may be best manageable for crop production. It is necessary to identify and define areas of this kind of soil to allow establishment of large enough management units. Re-examination of the other dominant kinds of soils with a view to identifying limiting parameters and/or developing alternative land use systems is also proposed.

Soil fertility and soil chemistry. The whole regime of soil-plant-fertilizer interactions must be re-examined in depth. A programme of regular soil testing is to be implemented. Some of the immediate objectives here would be

- determination of the existing nutrient status
- identifying levels of nutrient sufficiency and/or toxicities
- ascertaining the chemical behaviour of added nutrients
- ascertaining greenhouse crop response to various nutrients - utilizing the missing element and critical level techniques
- determining lime requirements and methods of application.

Additionally, work is proposed over the longer term to:

- develop field correlations between crop response and measurable chemical characteristics
- ascertain the fate of added nutrients, their residual effects, leaching characteristics and modifications of soil chemical behaviour
- determine fertilizer sources, placement, timing and rates of application for the range of crops.

Varietal selection. Re-screening and re-testing of a wider range of crop varieties is to be undertaken under improved soil management and other agronomic techniques with a view to identifying crop varieties that may be hardy, acid tolerant, low fertilizer requiring and high yielding.

Soil conservation and management. Along with soil fertility and chemistry, the aspect of conservation and soil management would seem to have the strongest effect on crop production. Several aspects of this programme would require investigation:

- Erosion control: It is felt that the nature of the soils will not allow the economic construction, maintenance, and functioning of terraces as a means of erosion control. It is believed that use of a vegetative cover and alternate land preparation methods would be more suitable. These approaches should be studied.
- Organic matter maintenance and management: Existing data and available experience indicate that soil organic matter plays a key role in the effective exploitation of soils for crop growth. However, its rapid rate of decomposition makes its management difficult. Grasses are known to be major contributors of organic matter to the soil. It is proposed therefore to examine the effectiveness of the use of a grass fallow in improving the organic matter status of the soils. On a

broader scale the exploitation of a grass-legume pasture fallow by livestock, and its compatibility with other crop production efforts should be studied.

- Rotation: A number of rotation systems involving the use of row crops e.g. cotton, cowpea, groundnut, soybean, as well as pasture grasses, will be tested. Identification of recommendable systems will be based primarily on benefits to be gained through an improvement of the soil physical and some chemical properties, the control of pests and diseases and ultimately, yields of crops.
- Tillage: The nature of the soils in the present environment has been quite deceptive in their workability. Aspects that need to be considered are: the timing of land disturbing operations, and the nature of these operations i.e. use of no-tillage, minimum tillage or conventional tillage.

Available data from project areas within the savannas indicate that a subsoil toxic condition exists both in the natural state and with cultivation. This subsoil acidity would need to be neutralized to allow a better and deeper root development thus making better use of soil water and reducing the leaching of nutrients. Liming the surface followed by mouldboard ploughing has been shown to be effective. This type of soil disturbance can however enhance erosion. The required frequency of this activity must be carefully established.

Integrated pest management. A programme for integrated pest and disease control utilizing both chemical and biological methods is considered necessary. Such a programme would also implicate the proposed rotation systems and necessitate an integrated approach to the research effort.

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APPENDIX[a]

PROFILE 1 TIWIWID SAND

Classification : Typic Quartzipsamment, uncoated, isohyperthermic (map unit 700)

Location : 3 km south of Ituni River crossing

Profile description

0 - 10 cm	Very dark greyish brown (10YR 3/2) sand; single grain structure; loose; many fine and medium roots; extremely acid; clear boundary.
10 - 17 cm	Greyish brown (10YR 5/2) fine sand; single grain structure; loose; many fine and medium roots; extremely acid; gradual smooth boundary.
17 - 36 cm	White (10YR 8/2) fine sand; single grain structure; loose;few charcoal specks in old root channels; extremely acid; gradual smooth boundary.
36 - 86 cm	White (10YR 8/2) coarse sand; single grain structure; loose; few medium roots; few charcoal specks in old root channels; extremely acid; diffuse boundary.
86 cm+	White (10YR 8/1) coarse sand; single grain structure; loose; extremely acid.

Range in characteristics

The colour of the surface may range from pinkish white to very dark greyish brown to dark grey. The subsoil colour is white to light yellowish brown. Subsoil texture ranges from sand to loamy sand and sand grain size from fine to coarse.

PROFILE 2 TABELA SAND

Classification : Typic Quartzipsamment, coated, isohyperthermic (map unit 800)

Location : 11.6 km northeast of Ituni River crossing

[a] All profile descriptions modified from FAO (1965)

Profile description

0 - 20 cm	Brown (10YR 4/3) sand; weak fine crumb structure; nearly loose when dry; many fine grass roots; very strongly acid; a thin layer of coarse sand grains is present on the surface between the clumps of grass; gradual smooth boundary.
20 - 51 cm	Strong brown (7.5YR 5/6) loamy sand; single grain structure; loose when dry, slightly coherent when moist; very few fine roots; extremely acid; diffuse boundary.
51 - 91 cm	Strong brown (7.5YR 5/6) loamy sand; very weak granular to massive structure; loose when dry, very friable when moist; no roots; extremely acid; diffuse boundary.
91 - 122 cm	Yellowish red (5YR 5/6) loamy sand; very weak granular to massive structure; loose when dry, very friable when moist; extremely acid.

Range in characteristics

In places there is a thin (1 to 2 cm) surface layer of bleached coarse sand. Surface colours may range from brown to dark greyish brown and subsoil colours from yellowish brown to yellowish red. Subsoil textures range from sand to loamy sand.

PROFILE 3 KASARAMA LOAMY SAND

Classification : Arenic Paleudult, loamy, siliceous, isohyperthermic (map unit 810)

Location : 1.6 km southeast of Ebini Livestock Station

Profile description

0 - 25 cm	Dark greyish brown (10YR 4/2) loamy sand; weak fine granular structure; very friable when moist; common vesicular pores; common fine roots; few medium to coarse sand grains; common insect casts; extremely acid; gradual smooth boundary.
25 - 41 cm	Brown (10YR 5/3) loamy sand; weak fine granular structure; very friable when moist; common fine vesicular pores; common fine roots; few insect casts; extremely acid; clear wavy boundary.

41 - 56 cm	Strong brown (7.5YR 5/6) light sandy loam; weak coarse granular structure; very friable when moist; common fine vesicular pores; few coarse sand grains; some penetration of surface soil material; common old root channels containing darker coloured material; extremely acid; clear smooth boundary.
56 - 86 cm	Strong brown (7.5YR 5/6) sandy clay loam; massive; friable when moist; extremely acid.

Range in characteristics

The deeper subsoil may contain few strong brown and red concretionary mottles and few to common laterite pebbles. The surface colour ranges from brown to dark greyish brown and subsoil colours from yellowish brown to yellowish red. Subsoil texture ranges from sandy loam to sandy clay loam.

PROFILE 4 EBINI SANDY LOAM

Classification : Typic Paleudult, clayey, kaolinitic, isohyperthermic (map unit 820)

Location : 4.4 km northeast of Takama, Berbice River

Profile description

0 - 8 cm	Very dark greyish brown (10YR 3/2) sandy clay loam; moderate coarse granular structure; very friable when moist, slightly plastic when wet; many fine and medium roots; common yellowish and white sand grains on the soil surface; common worm casts; extremely acid; clear smooth boundary.
8 - 31 cm	Dark greyish brown (10YR 4/2) sandy clay; weak medium granular structure; friable when moist, moderately plastic when wet; some penetration of organic matter in root channels; few iron-manganese concretions, about 5 mm in diameter; extremely acid; gradual smooth boundary.
31 - 41 cm	Yellowish brown (10YR 5/4) sandy clay; weak subangular blocky to massive structure; friable when moist, moderately plastic when wet; some penetration of organic matter in root channels; no clay skins evident; few iron-manganese concretions, about 5 mm in diameter; extremely acid; gradual

	smooth boundary.
41 - 76 cm	Yellowish red (5YR 5/6) clay; weak subangular blocky to massive structure; friable when moist but firm in places, moderately plastic when wet; few fine roots; common iron-manganese concretions; extremely acid; gradual smooth boundary.
76 - 91 cm	Yellowish red (5YR 5/8) clay with red and yellowish brown mottles; massive; friable when moist but firm in places; few roots; common iron-manganese concretions; extremely acid; gradual smooth boundary.
91 - 122 cm	Red (2.5YR 4/8) clay; massive; friable when moist; medium sized white sand grains throughout the soil matrix; many iron-manganese concretions; extremely acid.

Range in characteristics

The surface soil colour may range from brown to very dark greyish brown and its texture from loamy sand to sandy loam. The subsoil colour may range from strong brown to red and textures from sandy clay to clay. Few to common red and few white concretionary mottles as well as some laterite pebbles may be present in the lower subsoil.

SOILS OF THE PERUVIAN AMAZON; THEIR POTENTIAL FOR USE AND DEVELOPMENT

José R. Benítes
Estación Experimental "San Ramón", INIPA, Yurimaguas, Peru

INTRODUCTION

Peru is divided into three major physiographic regions: (1) the coast, a narrow strip of desert, irrigable from rivers running from the western slopes of the Andes to the Pacific; (2) the highlands, the Andean Massif of steep slopes, narrow valleys and high plains and (3) the jungle, including the high jungle (500-2 000 m) on the eastern slopes of the Andes and the low jungle (below 500 m) extending to the Ecuadorean, Colombian, Brazilian and Bolivian borders.

The coast and the highlands have severe limitations for crop and animal production, mainly because of drought or their cold environment. Virtually all land suitable for agricultural use in the highlands is being utilized. About half of the coastal strip that is suitable for agriculture is now in use. Incorporating the remainder will require irrigation works, the cost of which now is excessive relative to perceived benefits.

The jungle includes over 4.5 million hectares of land suitable for agriculture (60 percent of the national total), of which 10 percent is in use. In the jungle lives 10 percent of the population. The time to develop the acid infertile soils of the jungle has become ripe. Its development is impelled by Presidential Commitment and by the need to expand the area of agricultural land to meet production and employment requirements and to slow migration from rural to urban areas. Table 1 shows the population growth of some cities in the Amazon jungle. Within a tight development budget, jungle projects are the only alternative to extremely costly coastal irrigation projects for adding new agricultural

Table 1. Population growth of some cities in the Amazon jungle of Peru

City	Foundation year	1960	1970	1980
Iquitos	1864	60 000	80 000	220 000
Yurimaguas	1860	12 000	15 000	25 000
Tarapoto	1890	14 000	25 000	80 000
Pucallpa	1938	15 000	45 000	130 000

land. Figure 1 shows the development projects in progress or being planned in the Peruvian jungle. They cover more than 5 million hectares.

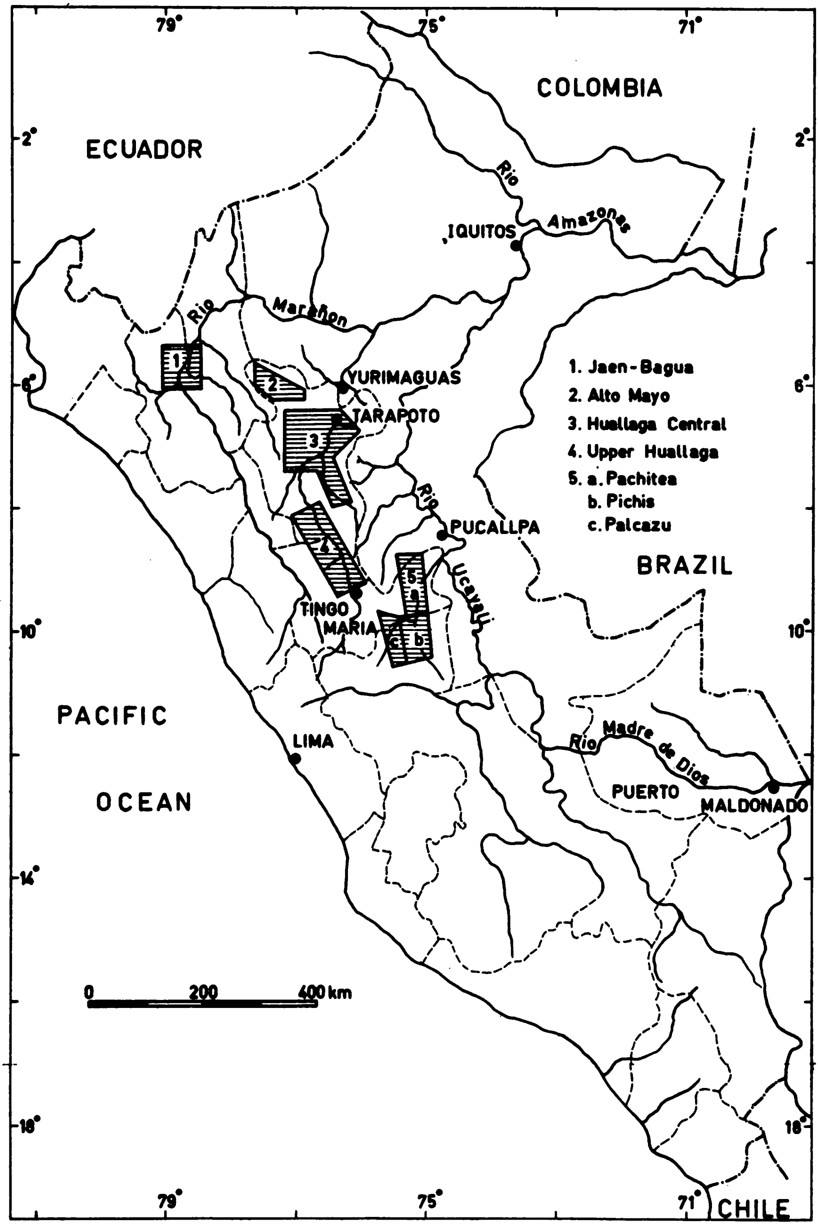

Fig. 1. Map of Peru showing settlement areas in the Amazon region.

CLIMATIC CONDITIONS AND VEGETATION

The Peruvian Amazon basin has a mean altitude of less than 350 metres. Average temperature exceeds 24°C. Annual rainfall varies between 2 000 and 4 000 mm for the humid zone and 1 500 mm or less for the sub-humid regions with marked dry seasons (Table 2). The predominant native vegetation consists in most parts of evergreen forests. Trees are generally large and form dense groups with the exception of areas with poor drainage where palms (*Mauritia flexuosa,* mainly) and many herbaceous species are abundant. A group of species of tall and thick trees, many of them of important commercial value, are found in the area (Zamora, 1975).

PREDOMINANT SOILS

In the Upper Amazon basin of Peru beyond the influence of the older shields, Ultisols are found to be associated with Alfisols, Inceptisols and Entisols. At the highest topographic positions, the predominant well-drained soils are Udults, i.e. very acid soils with an argillic horizon. In the oldest flat areas, the A horizons are sandy, forming Typic Paleudults. Down the slope one finds primarily a drainage catena with increasing wetness and a gleyed mottled horizon containing a mixture of kaolinite and montmorillonite as clay minerals. Tropaqualfs are found at intermediate and lower positions. The lowest terrace and floodplains along the river consist of Entisols and Inceptisols. One common characteristic of the extensive Amazonic plain soils is their low natural fertility. Table 3 shows the proportion of the soil orders occurring in the Amazon region of Peru.

Ultisols

This order comprises the most extensive soils in the Amazonic plains, including Paleudults, Plinthic Paleudults and Tropudults.

Paleudults. They are found in undulating terrain, consisting of old terraces, low hills in various degrees of dissection with slopes ranging from 3 to 50 percent. Morphologically, Paleudults have deep, intensively weathered profiles. Their main characteristic is the presence of a deep argillic horizon with a depth of over 1.50 m and a clay content not less than 20 percent throughout the profile. According to their chemical characteristics they are strongly acid soils (pH below 5.0) with high contents of aluminium. In the argillic horizon the base saturation is below 35 percent.

These soils have marked nutritional deficiencies, which make them the problem soils of the Peruvian Amazon region.

Plinthic Paleudults. As in the case of Paleudults, they have

Table 2. Elevation, ecosystem, soil and climate characteristics by locations

Location	Elevation	Ecosystem	Climate: Precipitation	Climate: Dry months	Climate: Mean temperature	Predominant soils
	masl		mm		°C	
Pucallpa	250	Seasonal forest	1 800	3	26	Ultisols, well and poorly drained
Yurimaguas	184	Rainforest	2 150	1.5	26	Ultisols, well drained
Tarapoto	330	Seasonal forest	1 060	3.5	26.5	Inceptisols, Ultisols and Vertisols
Tulumayo	670	Rainforest	3 200	1.5	24.3	Oxisols, Ultisols
Pichis Palcazu	350	Seasonal forest Rainforest	2 600	2.5	24	Ultisols, Alfisols
Iquitos	130	Rainforest	2 900	1	26.6	Ultisols
Iberia	250	Seasonal forest	1 800	3	25.8	Alfisols, Ultisols

Table 3. Proportion of soil orders occurring in the Amazon basin of Peru

Soil orders	Proportion
	%
Ultisols	59.9
Alfisols	22.4
Inceptisols	11.8
Oxisols	5.4
Mollisols	0.5

Source: Land Survey Unit, CIAT

developed from old alluvial sediments based on friable kaolinite clays located on undulating terraces, low hills (marked hillside formation) with slopes varying from 2 to 50 percent. Natural drainage of these soils is usually inadequate. Morphologically, they present a strongly weathered and developed profile with extensive mottling, based on iron oxide (pseudo plinthite) over a greyish clay substructure. This material does not indurate upon exposure and is obviously not plinthite. From a chemical point of view, they are extremely acid (pH below 4.0) with a medium to low organic matter content, and a base saturation of less than 35 percent in the argillic horizon.

Tropudults. They are found in the southern part of the Amazon jungle (Department of Madre de Dios). Physiographically, they extend throughout the hills and mountain sides with steep slopos (over 20 percent) where argillic sandy materials are predominant. Chemically, they are extremely acid (pH below 4.0) with base saturation levels below 35 percent in the argillic horizon.

Alfisols

This order comprises well-drained soils of mederate to high native fertility. They are found slightly above the lower terraces and flood plains along the rivers. Although they occupy 22 percent of the region only, these relatively fertile soils together with the alluvial soils not subject to flooding (Fluvents) deserve emphasis in terms of agricultural development.

Entisols

Tropofluvents. This group combines soils derived from recent alluvial sediments deposited by the large rivers such as the Amazon, Huallaga, Marañon, Ucayali, Napo, Tigre, Urubamba and Madre de Dios. They are distributed along the banks, islands and low terraces that are periodically flooded.

Topography of the area is flat with 0-4 percent slopos. Tropofluvents are without major diagnostic horizons, with fine sandy loam, sandy and silty clay loam textures and stratified morphology. Due to definite hydromorphic influences, many of these soils have been transformed into Tropaquepts which complete the group of soils within the flood plains. Chemically, Fluvisols are of slightly acid to neutral reaction (pH 6.5 to 7.0) and contain moderate amounts of organic matter in the A horizon.

Inceptisols

Tropaquepts. They comprise a group of soils formed from moderately fine material on relatively recent alluvial deposits and are closely associated with Tropofluvents. Physiographically, they are found on low terraces subject to flooding, of flat or concave topography and with gradients between 0 and 2 percent. They are locally known as "aguajales" due to the common name of one of the palm species, the aguaje. Chemically they are strongly acid soils (pH 4.0 to 5.0) with a base saturation of less than 50 percent.

Spodosols

Tropaquods. These soils have been identified within an extensive triangle formed by the banks of the Marañon and Ucayali Rivers and the upper Amazon. They are generally found in high old terraces with an undulating to flat surface and have developed from highly silicic and strongly leached materials. Their drainage is free, sometimes excessive and their vegetation is of a low commercial value. Morphologically, they present a thin horizon darkened by large amounts of organic matter, which rests on an extensive and deep highly eluviated A2 horizon mainly consisting of silicic or quartz materials, with a loose structure and a white yellowish or whitish colour. Chemically they are poor and very acid (pH bolow 4.0).

Oxisols

At the moment only a few soil profiles have been found in the Peruvian Amazon region that fit the definition of Oxisols, because this region was not influenced by the older shields.

PRESENT USE OF ACID INFERTILE SOILS

Settlement initially concentrated on the fertile high base status soils of the flood plains. Although food crop production should concentrate first on the more fertile soils of a region, the limited extent of such soils and the considerable flooding hazard associated with many of them, indicate that major increases in food production must come from the dominant Ultisols and Inceptisols located on the side slopes and uplands. At present, shifting cultivation is almost the only food crop production system on the acid, infertile soils of the Peruvian Amazon basin. It includes rice, cassava, maize, plantain, cowpea and groundnut amongst others. The main use of the acid, infertile soils still lies in the exploitation of their forest resources.

POTENTIAL FOR AGRICULTURAL DEVELOPMENT

Development of the area with acid infertile soils requires the following:
1) Roads providing access to land and egress of surplus products, and facilitating exploitation of natural resources and the operation of market mechanisms;
2) Development of a spatially organized economic structure which makes the market efficient in transmitting inputs, incentives and outputs;
3) Agricultural technology suited to sustained production on poor soils;
4) Land and resource utilization methods, orientation and controls which ensure sustained production.

All four are essential.

Roads
The Peruvian jungle is being or has been opened from San Ignacio-Jaen-Bagua to Pichis-Palcazu-Pachitea, from Tarapoto to Yurimaguas, from Tingo Maria to Pucallpa, and from Puerto Maldonado to Puerto Carlos. Settlement along these highways takes place as spontaneous colonization (Fig. 1).

Economic incentives
There are tax breaks of all types, including personal income tax exemptions for 20 years for those involved in the agrarian sector in the jungle. This includes not only farmers but also research and extension workers and those involved in agro-industry. The idea is to transfer capital from the cities into Amazonia.

Agricultural technology
The question arises whether enough is known to use the jungle productively. Early settlers using cut-and-try methods have developed low input - low output slash-and-burn agriculture. Native pastures have emerged. In most of the high jungle, permanent crops like coffee, cocoa, citrus, mango, rubber, oil palm, coconut, coca and sugarcane are growing well. Cassava, plantain, upland rice and maize are traditional crops in slash-and-burn agriculture throughout this region.

The main problem with continuous, productive commercial farming in large parts of the lower and some of the upper Peruvian jungle is the predominance of acid (pH 4.5) soils with toxic levels of aluminium saturation (70-90 percent). For the last nine years, North Carolina State University has been working on this problem in co-operation with the Ministry of Agriculture at the Yurimaguas Agricultural Experiment Station. They have identified and corrected the basic soil fertility problems with modest fertilizer applications resulting in continuous farming for nine consecutive years, compared with 1-2 years under traditonal slash-and-burn methods. They have also learned a great deal about the effects of alternative land clearing practices, crop rotations, and crop and forage adaptability to the acid and infertile soil conditions.

Land and resource utilization

The Natural Resources Evaluation Office of Peru uses the technique of remote sensing. Some soil surveys are already available at reconnaissance and semi-detailed level. More work is still needed for a planned land and resource utilization, for orientation and control, ensuring sustainable preduction in the region.

Existing problems for use and development

One may wonder whether the area with acid infertile soils can compete with areas with more fertile soils.

The jungle suffers competitive disadvantages:

1) A poorly organized input-output market structure;
2) High freight rates to and from the principal market (Lima);
3) World market price fluctuations.

Correcting the first is largely a matter of development. Settlers eat well but produce little surplus. As roads penetrate and the market becomes organized, they may produce more because they will be able to sell it. This development market structure is already apparent in Huallaga Central and Upper Huallaga.

Freight rates from the jungle to Lima are about US$ 0.06 per kilogramme. This is about twenty percent of the cif price of imported rice. The air freight rates of beef are even higher. The high freight rates can become limiting for some crops like coffee and cocoa when world prices are low. The long rough haul to Lima (24 to 36 hours) limits production of most perishables to quantities that can be consumed locally, unless processing plants are established. World price fluctuations determine the profitability of many crops: coffee, cocoa and rubber prices have dropped in recent years.

The question often arises whether the jungle can be utilized without serious environmental damage. Any development will cause change; some changes are acceptable in exchange for preduction. Most of the environmental damage is due to misuse: civil engineering works, continuous farming on steep land, cultivation up and down the hill, overgrazing, pasturing on steep slopes. These problems are common throughout the high and low jungle and reflect both the ignorance of the user and the lack of regulations. Misuse can be controlled by education and guidance provided there is a will and the resources are adequate. Some of these destructive practices will cease automatically when production declines and the user is forced to move. The land's capacity for absorbing and recovering from such damage is variable, and must be considered in selecting new sites for development.

CONCLUSIONS

Our conclusions are that adequate empirical data and research results are available to identify and utilize large areas of the jungle. There are also problem areas which should not be touched before further research has been carried out. Most problems are of social and economic instead of technical nature.

Each year may be expected to bring major advances in research. Besides the Yurimaguas station, Peru has six other research stations in the jungle. These stations are linked to both national and international research programmes. REDINAA (Red de Investigación Agraria para la Amazonia) is an international organization which links the tropical research programmes of Peru, Brazil, Bolivia, Ecuador, Colombia, Venezuela and CIAT to exchange information on tropical land, crop and livestock management.

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THE ZANDERIJ SOILS IN SURINAME

E. Soe Agnie
Ministry of Agriculture, Animal Husbandry, Fisheries and Forestry, Suriname

INTRODUCTION

Location
Suriname is situated on the northern coast of South America between 2 and 6° north latitudes and between 54 and 58° west longitudes. It covers an area of about 164 000 square kilometres.

Physiography
Suriname can be divided from north to south in three zones (Fig. 1), i.e.:
1) The coastal plain.
2) The Zanderij belt, and
3) The interior uplands.

The coastal plain, which is about 40 km wide in the east and 120 km in the west is almost flat and consists mainly of heavy textured,

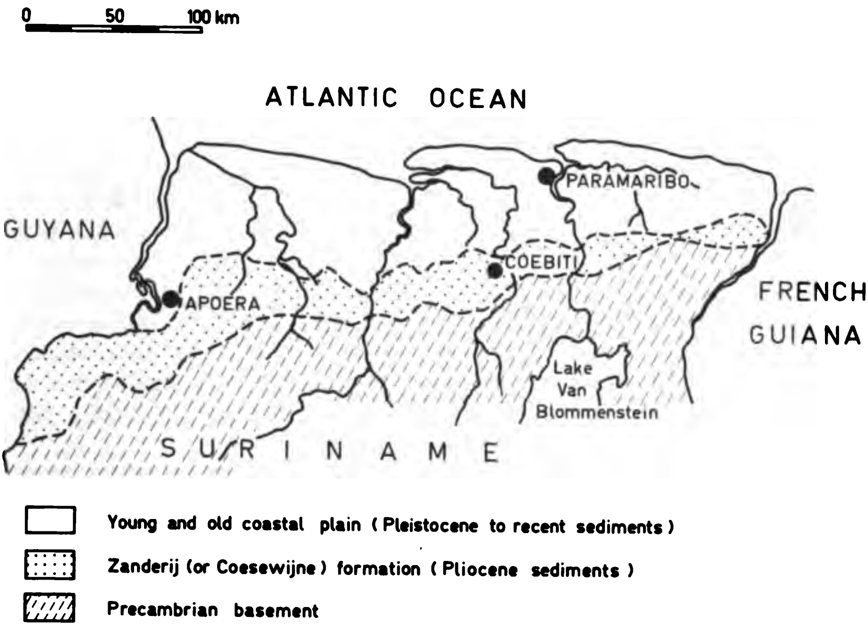


Fig. 1. Broad geological map of northern Suriname; location of Zanderij formation indicated.

marine clay deposits locally with swamps and sand or shell ridges. Its elevation varies from about 0 in the north to about 10 m in the south.

The Zanderij belt, which is 5-10 km wide in the east and 60-70 km in the west, with elevations varying from about 10 m in the north to 50 m in the south, consists mainly of sandy to sandy loam soils.

The interior uplands are part of the Guiana Shield, which consists mainly of metamorphosed igneous and sedimentary rocks of Precambrian age. It occupies more than 80 percent of the total area of Suriname, with elevations varying from 50 to about 1 280 m above sea level. It consists mainly of undulating to steep land.

Climate

According to Köppen's classification, Suriname has a wet tropical climate. The average annual rainfall ranges from 2 000 to 2 500 mm. The average maximum temperature is 31°C, while the average minimum temperature centers around 23°C. The relative humidity is very high: 70-90 percent.

Four seasons can be distinguished, i.e. a long rainy season from April to the middle of August, a long dry season from the middle of August to the end of November, a short rainy season during December and January and a short dry season during February and March. Extremely dry seasons do not occur.

THE ZANDERIJ FORMATION

General

The Zanderij formation, which is also called the Coesewijne formation, occupies a more or less continuous belt along the full width of Suriname. Its total area is estimated at about 875 000 hectares. Due to serious erosion of the Guiana Shield in the Tertiary Period alluvial fans have been deposited. Later on these fans were largely covered by marine sediments. The highest parts of the alluvial fans still occur at the surface and form the Zanderij belt. These relatively thin deposits cover the Guiana Shield as a blanket. Hence this zone is also called the Cover landscape. A charming, slightly undulating landscape was formed by the dendritic creek systems.

The soils of the Zanderij formation can be divided into two broad classes, i.e.: (a) bleached soils, and (b) unbleached soils. The bleached soils were formed as a result of strong podzolization giving rise to deeply bleached horizons of coarse sands. This eluviated horizon is sometimes underlain by a hardpan at a depth of 3 to 5 m, causing waterlogged conditions in the rainy seasons. The bleached soils, consisting of more than 99 percent silica (SiO_2) are extremely infertile. Moreover, they are very susceptible to drought. They are estimated to occupy 40 percent of the Zanderij belt.

The unbleached soils, except for a few brown sands, are loamy textured (sandy loams to sandy clay loams). Generally, the topoils are lighter textured than the subsoils. From a chemical point of view these soils are very poor.

In the field the transition between the bleached and the unbleached soils is mostly abrupt and the natural vegetation is closely related to soil conditions. In general, the areas with bleached sands form an open grass and shrub savanna or a tree savanna. The unbleached soils are covered with high tropical rainforest.

Soil properties

Texture. The position taken up by the Zanderij soils in the textural triangle is indicated in Figure 2. The silt fraction appears almost negligible, i.e. less than 5 percent, in all soils and soil horizons. The sand

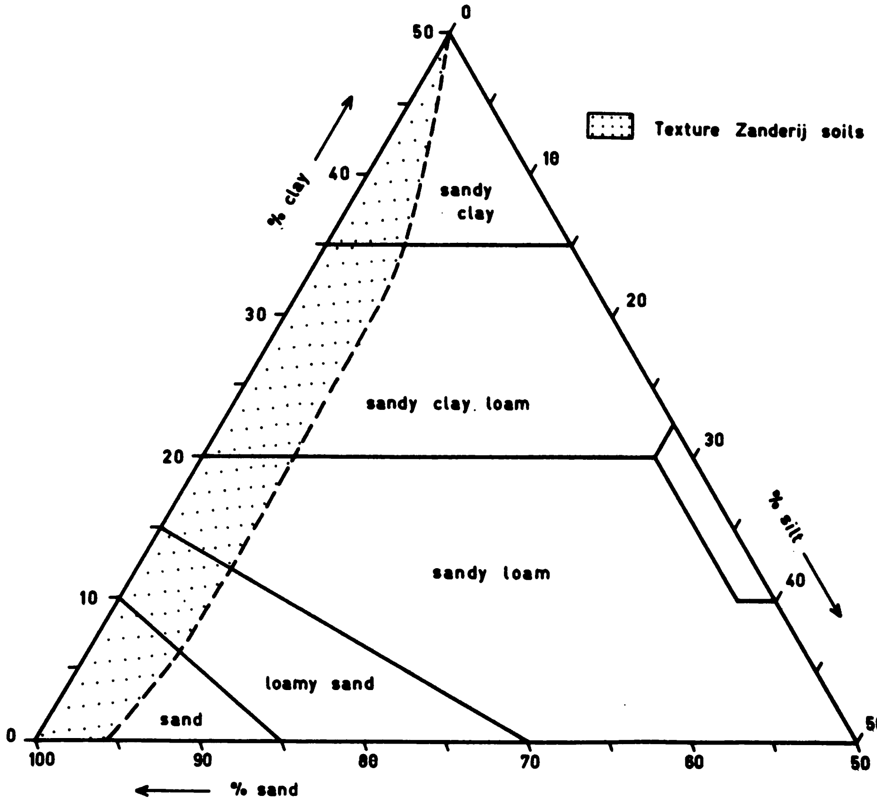


Fig. 2. Part of textural triangle showing the range of soil textures of the Zanderij soils.

fraction predominantly consists of medium sand (250-500 micron) and 85 to 90 percent of the clay fraction is kaolinite.

Organic matter. The average organic matter content (as determined by the modified method Walkley & Black and organic matter conversion factor 2.24) is rather low in the Zanderij soils. In most of the topsoil horizons on cultivated land within a depth of 30 cm an average of 1.6 percent was found. On a recently cleared forest area at Coebiti the average organic matter content was about 2.5 percent (medium low). It thus appears that the quantity of organic matter accumulating in the topsoil under forest is not high and that it rapidly declines once the area is opened and cultivated. Moreover, the chemical composition of this organic matter is rather poor.

Cation exchange capacity. The cation exchange capacity (CEC) of kaolinitic clay at pH 7.0 is approximately 4-6 meq per 100 g of clay according to our analyses of sandy loam horizons at a depth below 100 cm. Therefore, the CEC of these soils depends greatly on the organic adsorption complex, i.e. the organic matter of the soil. The average CEC of the topsoil is about 2.9 meq per 100 g of soil, with highest values up to 4.9 meq per 100 g of soil.

Soil reaction and base saturation. In general, the pH values and base saturation percentages of the Zanderij soils are low to very low, but show a tendency to increase with depth, i.e. with heavier texture. The pH values range from 4.6 to 5.2. The amounts of exchangeable cations are very low, mostly less than 0.1 meq per 100 g of soil. Base saturation is less than 20 percent. Occasionally, higher values, likely due to the influence of ashes left after burning, are encountered in the topsoil. In such cases pH values of 5.8 or more may be found and amounts of exchangeable cations - with the exception of exchangeable Na which is not affected - may be ten times higher.

Exchangeable Al. The average amount of exchangeable Al in topsoil samples of 12 Zanderij profiles was 0.73 meq per 100 g of soil and for subsoil samples 0.61 meq. Exchangeable Al was determined by means of 1.0 N KCl extraction. Al saturation is between 75 and 95 percent. It is obvious that in these very acid soils, Al is the predominant exchangeable cation. It was found that pH-KCl is the critical indicator for the amount of exchangeable Al on the adsorption complex. Below pH-KCl 4.5 there is no relation between pH and exchangeable Al; at pH-KCl 4.6 there is a sharp drop and above pH-KCl 4.7 exchangeable Al becomes zero.

Al toxicity depends on the concentration of free aluminium ions in the soil solution and the effect of the toxicity depends on the specific tolerance of plant species and crop varieties.

Plant nutrients. The Zanderij soils are deficient in all major plant nutrient elements: N, P, K, Ca, Mg and S. The deficiency is more pronounced in the light textured soils than in the heavy textured soils. P deficiency is predominant and in general represents the growth limiting factor.

Zinc deficiency may also prove to be a decisive growth limiting factor on the Zanderij soils. Liming will aggravate a potential zinc deficiency, which counteracts the beneficial effects of liming. The degree of zinc deficiency (and the availability of other trace elements) is believed to be related to the organic matter content.

Available moisture. The rainfall in Suriname is rather unreliable in relation to the needs of crops. Therefore, an assessment of the available moisture in the crop's rooting zone is of great importance, as dry spells during the cropping cycle may cause yield depression due to temporary moisture stress in the plant. The amount of available soil moisture, i.e. the moisture held between pF 2.0 and pF 4.2 (1/3 and 15 bar respectively) of the Zanderij soils depends on soil type and organic matter content. The ranges are 10 to 70 mm in the upper 30 cm and 25 to 125 mm in the upper 60 cm.

Permeability. The permeability of the soil is closely related to texture and organic matter content. The permeability of the sands can be called very rapid, that of the loamy sands rapid and that of the sandy loams moderately rapid to moderate. Therefore, internal drainage poses few problems, unless the subsoil has been compacted or a loamy surface soil has been puddled. A high permeability of the surface horizons can be accompanied by losses of fertilizers beyond rooting depth. This may have a negative impact on the growth of annual crops.

RESEARCH ACTIVITIES IN THE ZANDERIJ AREA

In 1970 agricultural research was started at the experimental farm of Coebiti in the central part of the Zanderij formation. This experimental farm was set up to examine the agricultural potential of the Zanderij soils. The exploratory work was carried out by research workers of the Agricultural Experiment Station and the Agricultural University Wageningen, The Netherlands, through the Centre for Agricultural Research (CELOS).

Based on the results obtained in the preceding years, it was decided to start a cassava-groundnut project in 1977. The objective of this project was to carry out more intensive research on these two crops, emphasizing cropping systems. The project was carried out by the Agricultural Experiment Station. At about the same time a joint project of the Agricultural University Wageningen, the Netherlands and the University of Suriname was started. That project: "The permanent cultivation of rainfed annual crops on the loamy soils of the Zanderij formation" investigates the possibilities and limitations for mechanized annual cropping on the sandy loam soils of the Zanderij formation, with the eventual object to develop farming systems on these soils. For this reason a new experimental farm, Kabo, at about 40 km southwest of Coebiti, was set up in 1978. Recently it was decided to pay more attention to grassland, so that more data will be available on grassland farming systems.

Another joint project of the two Universities is the forestry project: "Human interference in the tropical rainforest systems". This project's aim is to provide the facts upon which long-term land use decisions can be based. The project is not restricted to the Zanderij soils.

LAND CLASSIFICATION AND LAND USE

Present land use in the Zanderij belt is confined mainly to forestry and shifting cultivation in the neighbourhood of the Amerindian and Bushnegro villages.

Forestry activities, as recently practiced, were based on the extraction of wood and woodpreducts without considering the impact of these activities on the soil. A sound management scheme with good control is needed to diminish the deterioration of the soil and the ecosystem.

Shifting cultivation makes use of the regeneration of the soil during the fallow period. However, it is very time-consuming and often does not result in the desired economic results for the local population nor nationally.

The Suriname Forest Service started in 1958 with reforestation activities after clearing some 5 000 ha of land. The project was less successful than anticipated due to several constraints that were not taken into account because of lack of information, for instance on soil behaviour.

First of all there should be a proper land classification of the total area based on the available knowledge and on a definition of the main constraints affecting proper use. After formulation of the major kinds of land use research priorities should be established in relation to land qualities in general. Such a broad land use could be a subdivision of rural land use, for example rainfed agriculture, irrigated agriculture, grassland, forestry or recreation.

THE IMPORTANCE OF ACID SOILS FOR AGRICULTURAL PRODUCTION IN THE HUMID TROPICS OF BRAZIL

Raphael David dos Santos
EMBRAPA, National Soil Survey and Conservation Unit, Brazil

The humid tropics of Brazil comprise the western part of the State of Maranhao, the northern sections of the States of Mato Grosso and Goias, the States of Para, Amazonas and Acre and the Territories of Amapa, Roraima and Rondonia. Here a wide variety of soils developed from different parent materials is found, interrelated with various types of vegetation and climates.

At the beginning of my work in this vast area in 1971 I first believed that the soils of higher fertility and lower acidity should be used for the cultivation of annual and perennial crops, whereas I considered the acid moderately heavy to heavy loams suitable for timber exploitation followed by forest regeneration and management. Natural mixed stands of rubber trees, of Brazil nut trees or other valuable interesting native species found in this area could also be used economically. I was of the opinion that the poor sandy soils should remain untouched and be kept as plant and animal reserves. Our land use maps were based on three classes, i.e. land use for primitive, semi-intensive or intensive non-irrigated farming systems.

With the development of new colonization projects in the Amazon area following the settlement of peasants from northeast and south Brazil, while at the same time a more refined land classification system including new objectives like stock farming and silviculture was being developed, our opinion was reformulated. The best soils, i.e. those with a higher natural fertility and pH, should be used for annual food crops and for more demanding perennial crops like cocoa and coffee. The more acid medium to heavy textured loams of lower fertility should be reserved for the other perennial crops and for stock farming, in which case fertilizers and other financial inputs would be required. As to the use of the poor sandy soils of the Amazon area my opinion remained unchanged, i.e. they should remain untouched and kept as reserves and germplasm banks. Wherever this policy was applied, the land users showed increased interest in the development of the land resulting into a better management of their agricultural activities.

In view of this success and with the purpose of disseminating technical information among the Amazonian farmers, additional aspects with regard to specific crops and local conditions were included in the regional land use policy. For each land use unit occurring on our maps, even for the eutrophic soils, practical parameters were taken into account and information on crop choice based on soil characteristics, climate and the requirements of the crops was given. Much attention was being paid to the needs of the farmer. Production models and alternatives of low or relatively low input farming systems for small farmers were emphasized. Advice on pasture expansion, reforestation and enrichment plantings in exploited forest was similarly presented.

The final objective of this policy is to exert an increasing control and to restrict the nomadic agricultural activities particularly in the extensive areas of low fertility acid soils. Allowing the continuation of a type of shifting cultivation that is devoid of its primitive traditions, would otherwise lead to increasing areas of degraded, abandoned land following the wave of peasant settlers.

Many may think that this task is not without risks. But if the increasing numbers of large and small farmers will have to get access to better technology and social progross, there hardly are alternatives.

The achievements in the field of land use mapping and production systems are the result of co-operation between the National Soil Survey and Conservation Unit, the Planning Department of the Ministry of Agriculture, FAO and research officers of EMBRAPA. There is, of course, no doubt that such efforts should receive more substantial support and permanent co-operation from the member countries of the Amazonian Co-operation Treaty, especially since all of them have similar poor acid soils and a similar climate.

Finally, I would like to repeat that within the framework of our present land use policy for the Amazon area, we think that the poor sandy soils should remain untouched because of their strong limitations to agricultural practices.

TECHNICAL PAPERS

ACID SOILS OF THE HUMID TROPICS OF SOUTH AMERICA, WITH SPECIAL REFERENCE TO THE WELL DRAINED SOILS ON OLD ALLUVIAL SEDIMENTS

J. Bennema
Agricultural University, Wageningen, The Netherlands

INTRODUCTION

The acid soils of the humid tropics are numerous. Apart from Oxisols and Ultisols, other acid soil types occur like young acid sulphate soils, peat soils and acid younger soils - Entisols and Inceptisols in the terminology of Soil Taxonomy (Soil Survey Staff, 1975) - derived from consolidated rocks, such as the Oxic Dystropepts. In this paper emphasis will be on the characteristics of the Oxisols, particularly the Oxisols derived from sediments. Moreover, some attention will be paid to the Ultisols, i.e. acid soils with a clay illuviation horizon, particularly those that have many features in common with Oxisols. These Ultisols and the Oxisols mostly have a kaolinitic clay mineralogy. Some problems related to this clay mineral will be stressed.

Before starting the discussion on these soils and their properties, attention should be paid to the landscape and climate history of the humid tropical lowlands of South America.

LANDSCAPE AND CLIMATE HISTORY

The history of the landscape and climate of the equatorial part of central and western South America had a marked influence on the formation of the various soils in this region.

Landscape

The development of the landscape is interwoven with the geological history. Geologically, the region considered can be divided in the Brazil-Guiana Shield - south and north of the Amazon - the sediments of the Amazon and Orinoco and the belt of sediments along the east coast of South America.

The soils on the somewhat older sediments will have our special attention. These sediments, known in Brazil as Barreiras formation, are considered to date from the Tertiary Period. However, part of them are of Pleistocene age, occurring as terraces along the east coast and in the lower Amazon region. They were formed during the interglacials when the sea levels were higher. The older terraces are at a higher level than the younger terraces because the continent has risen since then.

Above these terraces the sediments rise landinwards (see e.g. Sombroek, 1966) - which might be seen as the influence of the steadily rising continent - unaffected by alternating high and low sea levels. These sediments can therefore be considered to be of Tertiary age.

Apart from the higher sea levels during the interglacial periods, also the low sea levels during the glacial periods exerted their influence. The sediments deposited when the sea levels were high, were drained and partly dissected, while the main drainage ways, like the lower Amazon and its tributaries, were - up to the rapids and waterfalls - broadened and deeply incised. The lower Amazon and its tributaries therefore look like drowned valleys, which to a greater or lesser extent havè been filled up, depending on the available amounts of sediment during and after the rise of the sea level.

In Suriname and Guyana the Pleistocene terraces are not found as such, because the coast in this area forms a synclinale with its axis along the boundary between Suriname and Guyana. It is possible that the well known bauxite layer, that is coverod by sediments of the coastal plain, is geologically equivalent to the old sediment terrace at the level of 80 m in the lower Amazon region. This 80 m terrace consists of very heavy yellow kaolinitic clay soils with relatively low iron contents.

Climate

Also in South America the glacial and interglacial periods were reflected by the rising and lowering of the sea level and by changes in the climate (Van der Hammen, 1972). Formerly it was thought that in the tropics the glacial periods corresponded with the "pluvials" and the interglacials with the "interpluvials". It has been proven that this, at least for the last glacial period and our present "interglacial period", is wrong. It is just the opposite. During part of the last interglacial period - at least between 20 000 and 14 000 BP - the climate was drier than it is today. The rainforest in South America was separated in island-like refuges (Prance, 1978). When comparing the situation in South America at that time with that in Africa, it appears that on the African continent the influence of the dry period was even more pronounced and only a small part of teday's tropical rainforest was still intact (see e.g. Flenley, 1979). This is understandable if one considers that the Sahara and Kalahari deserts were nearby and that a small shift of them towards the equator would already have large consequences. Even today the Sahara still has much influence on the tropical rainforest of West Africa as is proven by the relatively large amounts of dust (loess) which are blown in from the desert (Nye & Greenland, 1960).

The influence of the dry period on the soil formation in Africa was also enormous. Erosion and sedimentation played a great role even outside the areas which are now semi-arid or desert. Very old soils are therefore rare in Africa and it is understandable that the French school for a long time defended the thesis that the type of soil is directly related to the present climatic zones.

In tropical South America the influence of the dry periods has not been so dramatic because the desert was far away to the south and many old strongly weathered survived the dry period(s). As far as the vegetation is concerned, the influence of the dry period has probably resulted in a change of part of the forest into grassland savannas. An interesting question hereby is how the savannas could become forested again. The savannas in central Brazil are regarded as edaphic savannas. This savanna-ecosystem seems not to contain enough nutrients for forest growth, although as far as the climate is concerned a deciduous forest would well be possible. The soils of the Amazon forest are not richer, but the forest ecosystem contains more plant nutrients, which are present in the organic cycle. We may conclude that also the ecosystems of the grassland savannas, which constitute a smaller biomass, were poor in nutrients. The nutrients necessary to form a forest again were probably brought in by rain and dust.

Areas with much rainfall can be considered as a sink, while areas with long dry periods will receive less or will lose materials and act as a source (comparable to loess deposits around an area affected by wind erosion). Usually one tends to overlook this type of inputs because they are small, but over many years these small inputs may accumulate to considerable quantities. In Manaus, for instance, the input of phosphorus by rain amounts to about 0.3 kg per hectare per year, or 3 000 kg over 10 000 years.

Some areas in the forest zone are still savanna. They could be considered as relics. However, there is little reason to believe this, since they occur in areas where soil conditions are unfavourable for forest growth, for instance because of the presence of an impermeable layer. Often these soils are chemically poor, too wet in the rainy season and/or too dry in the dry season.

So far mainly the older sediments were mentioned. The soils derived from these sediments constitute the main topic of the following chapters. A few remarks will nevertheless be made about the areas of the Brazil-Guiana Shield.

In central Brazil extensive areas are found with deep soils over a deep regolith (weathered rock). They form old planation surfaces, protected by permeable soils. These soils are among the oldest in the world and are also the most extremely weathered soils. Now they are found in a climate with a dry period of about six months. These old planation surfaces occur in tectonically stable areas, far away from the erosion bases of the various rivers. Some form even the divides between the northern and southern drainage system in South America.

Such extensive old planation surfaces which still have old deep soils and regolith, seem to be lacking north of the Amazon valley on the Guiana Shield. Some sesquioxides or manganese caps seems all what has remained of the old soil formation. The landscape, in general, is younger, more dissected or is in the stage of the forming of younger planation surfaces.

The differences in climate also have influenced the forming and the hardening of plinthite. Plinthite is a reddish mottled soil material occurring mainly in kaolinitic or sandy soils and is formed by the influence of an alternating or temporarily stagnant water table, becoming hard upon drying, forming continuous layers or gravel. The formation of plinthite is especially common in climates characterized by alternating periods of excess moisture and severe drought. Under such climatic conditons plinthite may be found throughout the landscape, even on steeper slopes like on the west coast of India (Western Ghats, Malabar coast). In areas with other climates the forming of plinthite is often more related to certain topographic positions.

During periods in which the climate is drier the soft plinthite may harden to petroplinthite. It often is difficult to decide in which climatic period the hardened material was formed. In some cases the hardening process may even date from pre-glacial times. Also erosion of the upper parts of the profile - exposing the still soft plinthite - may lead to hardening of this material. The hardened plinthite layers can remain in the landscape for a very long time.

THE YELLOW KAOLINITIC LATOSOLS (OXISOLS) AND RELATED SOILS ON SEDIMENTS

General

The name Yellow Kaolinitic Latosols was first used by Sombroek (1966). In Soil Taxonomy (Soil Survey Staff, 1975) these soils belong to the Oxisols and according to the legend of the FAO-UNESCO Soil Map of the World to the Xanthic Ferralsols (FAO-UNESCO, 1971). These soils are characterized by their chemical composition. The total iron oxide content is low, i.e. between 2 and 7 percent, and gibbsite is absent or occurs in very small quantities only. The sand fraction is mainly quartz and the clay fraction consists of kaolinites, while some interstratified clay minerals and small amounts of quartz may be present. The clay content may vary from very low to extremely high, i.e. up to 95 percent. Some related soils do not contain enough clay to qualify as an Oxisol or Latosol; in the FAO-UNESCO legend they are known as the Areno-Ferralsols.

The typical Yellow Kaolinitic Latosols (see also Bennema &

Camargo, 1979) have all the characteristics of an Oxisol, i.e. absence of weatherable minerals and low silt content in the solum, low CEC per 100 g of clay, absence of clear clay illuviation, absence of water dispersible clay in the B2 horizons, weak horizon differentiation (except for the A horizon) and a weakly developed macro-structure or the lacking of such structure.

The related soils are those that are very sandy throughout or that have relatively low amounts of clay in the toplayers (intergrades between Oxisols and Ultisols). In this case the increase of clay from the toplayer downwards is stronger than in a typical Oxisol. This stronger increase is often accompanied by some clay coatings in the B horizon, but normally not enough for a so-called argillic horizon. Finally, amorphous material may be present.

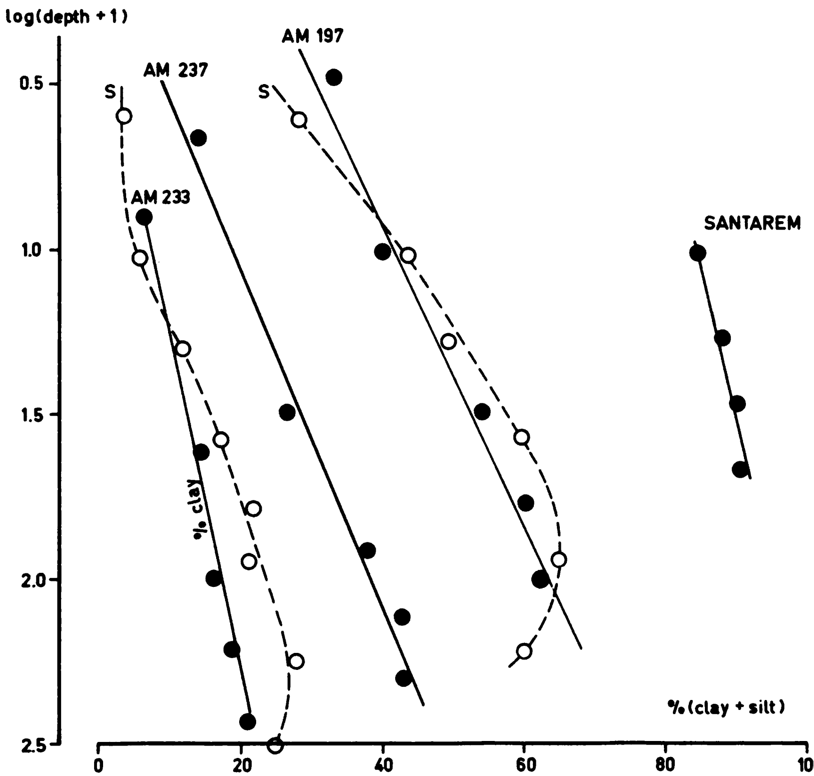


Fig. 1. Percentage (clay + silt) as a function of log (depth + 1) for sediments from the lower Amazon region (AM), Suriname (S) and Santarem Brazil.
Note: The horizontal and vertical axes have been reversed to recognize the profile.

The increase in clay (or clay plus silt) content with depth

The clay content in Oxisols mostly increases with depth. In a typical Oxisol this increase appears to be linear with the logarithm of the depth. Four examples of Yellow Kaolonitic Oxisols (Latosols according to the Brazilian classification) from the lower Amazon (Sombroek, 1966) are shown in Figure 1. The slope of the lines can be considered as a measure for the relative increase in clay content. This increase is highest in soils of medium texture.

The process responsible for this increase is a gradual loss either by erosion from the topsoil and/or by a slow destruction of the clay minerals under influence of the organic matter. One would expect such a process to lead to a sandy toplayer. However, if the process is slow enough, the biological activity will lead to a mixing of the topsoil with the subsurface soil (mostly down to 1 m or more).

Figure 1 also shows the increase of clay in two yellow kaolinitic Zanderij soils. These soils show a small deviation from the typical logarithmic increase of the clay distribution in the Oxisols. The clay content in the toplayer is too low whereas a little deeper in the profile it is somewhat too high. A slight degree of clay illuviation is probably present. In some medium textured soils in the Amazon valley near Manaus, in an area with relatively little rainfall, the same feature can be found.

The relation between clay content and log depth for Oxisols follows also from the following table, for which data from Sargel (1977) of Venezuela were used.

The linear relation between clay content (y) and log depth is expressed by the regression equation

$$y = a_0 + a_1 \log(\text{depth} + 1)$$

where a_0 and a_1 are constants. The regression data for five soils are presented in the following table.

	a_0	a_1	r^2	Sy.x	S_0	S_1	n
M(Ultisol)	-0.1	12.6	0.74	5.4	7.6	4.6	4
Y "	34.5	5.2	0.27	4.6	7.7	4.8	5
C (Oxisol)	16.7	10.1	0.95	1.6	2.3	1.7	4
T "	9.5	14.5	0.95	1.9	3.1	2.0	5
F "	-2.6	13.2	0.98	1.15	1.75	1.1	5

r = correlation coefficient
Sy.x = SE of the estimate of y
S_0 = SE of a_0
S_1 = SE of a_1
n = number of samples

The data clearly show that the fit of soils M and Y, both Ultisols, is poor whereas the fit of the three Oxisols is relatively good. Provided the parent material is homogeneous or if thoroughly mixed, the relation between clay content and depth to about 1 m is probably a better characteristic for Oxisols than the absolute or relative increase in terms of percentages within a certain depth.

The appearance of the kaolinites

Of the clay fraction of the Yellow Kaolinitic Latosols a few X-ray photographs are available. Sombroek (1966) published one obtained from a sample from the 95-150 cm layer of a very fine textured Oxisol. Most of the kaolinite crystals appeared smaller than 0.4 micron with their edges often somewhat rounded. A series of photographs - two of which (Plates 1 and 2) are published in this paper- was made by Van der Plas of material from a coastal terrace profile in Brazil (SNLCS, 1978; profile 30). In this case too the kaolinite crystals were smaller than about 0.4 micron and their edges rounded. Moreover the kaolinite in the upper layers of the soil profile had a pitted appearance. In addition some allophanes and some halloysite was found. It should be noted, however, that in this profile the increase of the clay content was not gradual. At 30 cm depth a rather abrupt change in clay content was found, while the grains in the topsoil were without clay coatings.

The pitted kaolinite crystals are, as one perhaps would expect, not restricted to the upper 30 cm; they are also found in the upper part of the B horizon. Lower in the B horizon, at a depth of 150 cm, the particles are still small and rounded but the pitting is absent.

From the clay mineralogy, especially from the appearance of the kaolinites in the soil profile studied, the following conclusions can be drawn:

1) The kaolinites are being decomposed by solution throughout the solum, resulting into ellipsoidally shaped particles.
2) In the upper layers of the profile the kaolinites have a pitted appearance.
3) Aluminium ions released from the crystals are not or only partly precipitated in the form of gibbsite. Amorphous materials including allophanes are also present, whereas the halloysite as detected in the Brazilian profile, is likely to be of secondary origin too.

The organic matter profiles

In the humid tropics the natural profiles of the Yellow Kaolinitic Latosols are found under natural forest. On top a layer of litter is often present covering a layer of partly decomposed material, though sometimes this layer is very thin or even absent. Below this layer the yellow subsoil is found and it looks as if organic matter is no longer present. However, the organic matter in these soils decreases not that fast. The

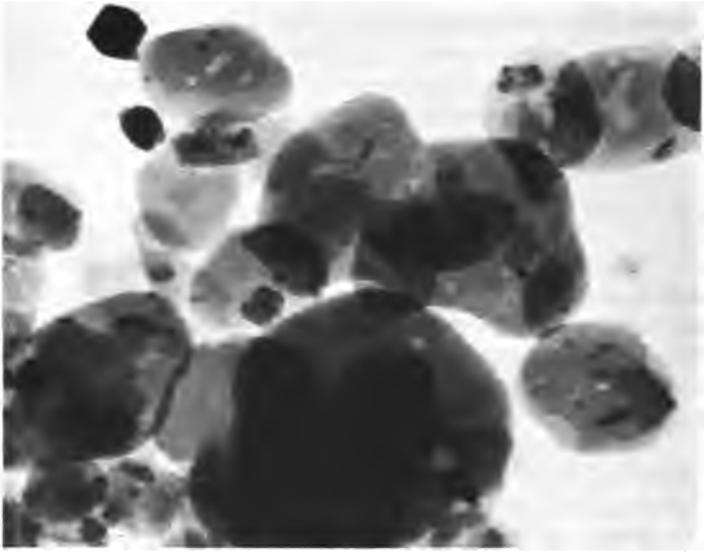


Plate 1. Electron micrograph of clay from the B23t horizcn (82-125 cm) of a soil developed on coastal sediments in Pernambuco, Brazil. For the scale see Plate 2. Note rounded and pitted kaolinite crystals. Their surface texture is not characteristic for kaolinite but is the result of the technique used (By courtesy of Dr. L. van der Plas).

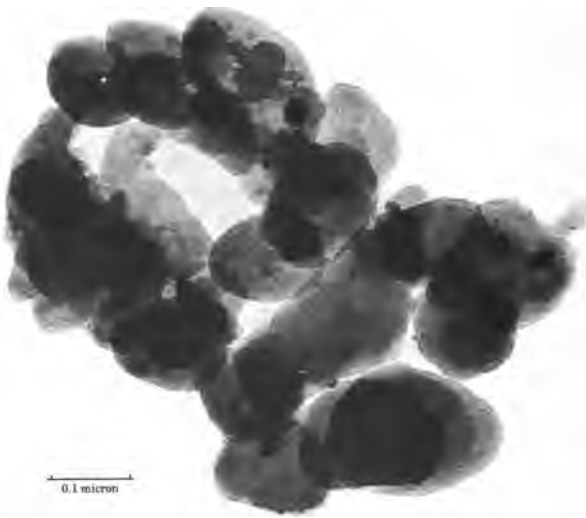


Plate 2. Electron micrograph of clay from the B26 horizon (190-220 cm) of the same soil profile as used for Plate 1. The kaolinite crystals are also rounded. No pitting is observed (By courtesy of Dr. L. van der Plas).

decrease is more gradual. In a typical Oxisol it can mostly be described as a power function of depth:

$$C = a_0 \text{ depth}^b \text{ (Bennema, 1974) or}$$
$$\log C = a_0 + b \log \text{depth}$$

where C is the organic carbon content and a_0 and b are constants. b for this type of soils is nearly constant: it often is around -0.5, in which case the organic carbon percentage can be expressed as a_0 divided by the square root of the depth. a_0 is the theoretical organic carbon content at 1 cm depth. Within the same climatic region a_0 differs for different textures; it increases with the clay content. Clay seems to preserve the organic matter. I believe that this better preservation is because part of the organic matter is included in small aggregates of clay particles.

Bennema (1974) gives various examples of organic carbon profiles in Brazilian Oxisols. In Figure 2 some other examples are given for a fine textured soil in Paragominas, Brazil. All carbon contents are from similar soils; they have been under grassland for 0, 3 and 8 years. It can be concluded that also in this case the carbon content can be expressed as $C = a_0 \text{ depth}^b$ or $\log C = a_0 + b \log \text{depth}$, and that using the soil for grassland does not lead to a loss of organic matter.

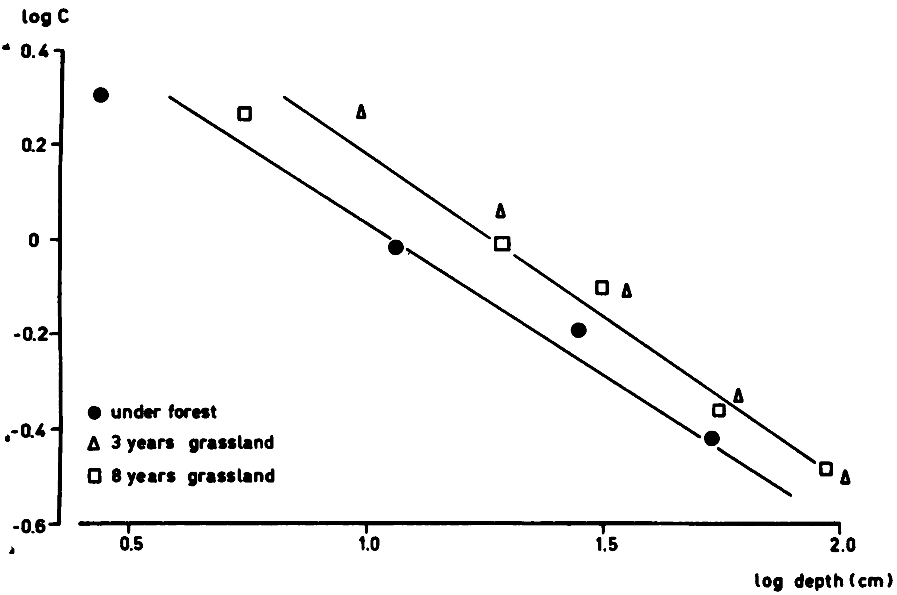


Fig. 2. Log organic carbon content as a function of log depth for a very fine textured Yellow Kaolinitic Latosol from Paragominas, Brazil. Source: adapted from Falesi (1976).

The above mentioned relation between carbon content and depth is only true for typical Oxisols in which the clay content increases with log depth. Sometimes, like in the case of the Suriname soils shown in Figure 1, the clay content is too low. This particularly applies to medium and coarser Oxisols. It is well possible that these are soils which during the last glacial period supported a savanna vegetation and thus were less protected against loss of clay from the topsoil, a loss which is still not counterbalanced by biological activity.

Where the relation between organic carbon content and depth can be described by the equation $C = a_0 \text{ depth}^b$, the organic matter profiles can help when studying the changes in organic matter content due to human interference. Some examples are given in Figure 3.

In the Amazon valley many old Indian dwelling places are found, where dark coloured soils occur which are known as "Terra Prêta dos Indios" (Sombroek, 1966). The same kind of soil is present in Suriname at Kabo. Figure 3 shows the distribution of organic carbon in two

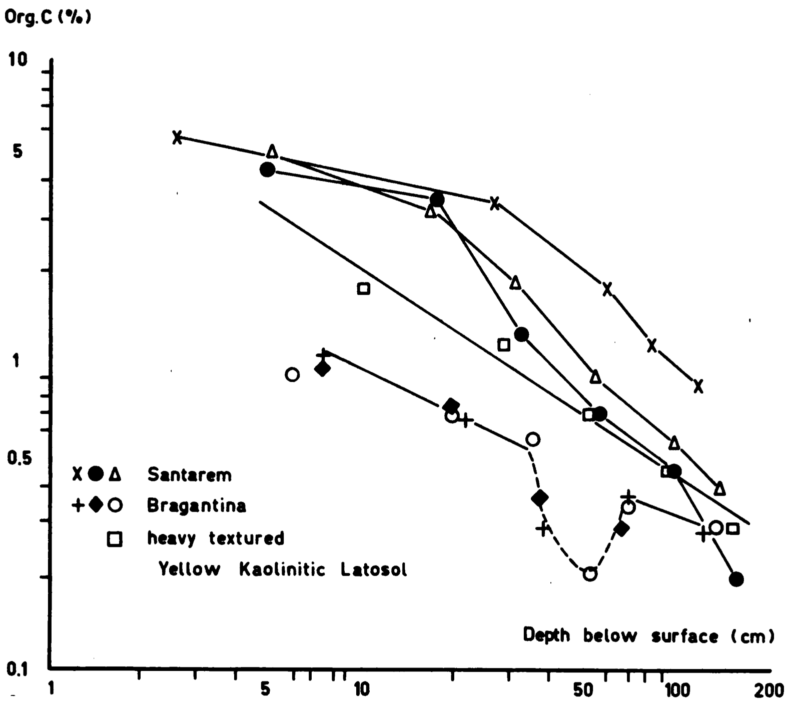


Fig. 3. Organic carbon profiles of three Terra Prêta Soils from Santarem, a comparable profile of a very heavy textured Yellow Kaolinitic Latosol and three Yellow Kaolinitic Latosols from Bragantina, Brazil used for shifting cultivation.

"Terra Prêta" soils together with a comparable soil not influenced by Indians. The profiles are from near Santarem, Brazil. In the "Terra Prêta" soils an extra amount of carbon is found in the 10-100 cm layer. The carbon contents in the upper 10 and below 100 cm, however, are not considerably higher than those of the soil not influenced by Indians.

In the same figure the carbon profiles of three medium textured yellow kaolinitic soils from Para near Belem, Brazil, are shown. The soils are used for shifting cultivation. The present vegetation is 5-years-old secondary forest. In these three profiles the organic matter content between 35 and 70 cm appears to be very low.

The dispersibility of the Yellow Kaolinitic Latosols

Under field conditions the Yellow Kaolinitic Latosols - particularly their subsoils - have a very low and largely variable negative charge or effective CEC. This is due to the type of clay mineral, the low pH and the low electrolyte concentration. The iron content of these soils is low too, but in the subsoil the amounts - perhaps together with the edges of the kaolonite crystals - are sufficient to generate enough positive charges to keep the soil flocculated in water. This has been concluded from the many data collected in Brazil where the SNCLS (National Soil Survey and Conservation Unit) since long determines the water dispersible clay content as part of their routine soil analyses.

Higher in the soil profile, where more organic matter is present, water dispersible clay occurs. The organic matter seems to act as a dispersion agent for the clay, providing negative charge in excess of the positive charge and thus leading to dispersion. The percentage water dispersible clay, however, is often somewhat lower in the A1 horizon than in the A3 horizon. Since the top layer receives more young, rapidly decomposing organic material, the bacteria with their exudates and the fungi involved in this decomposition process may be responsible for this lower dispersible clay content.

The occurrence of water dispersible clay strongly depends on the type of clay and on the organic carbon/clay ratio expressed as

$$(100 \times \% \text{ C}) : \% \text{ clay}$$

The ratio below which the soil material becomes almost totally flocculated will be called the dispersion-flocculation value or DFV. The DFV is rather high for Oxisols but lower for Ultisols and Alfisols, i.e. Oxisols disperse less readily than Ultisols and Alfisols. Bennema (1963) suggested a DFV for Oxisols higher than 1.25, but further work showed that a value of 0.8 might be more appropriate. Typical Oxisols have a DFV above 0.8 and typical Ultisols a DFV below 1.0. In other words, the clay in Ultisols normally disperses at a lower organic carbon content than the clay in Oxisols.

The dispersibility affects the displacement of the clay through the profile and thus the formation of an argillic horizon. Negatively charged water dispersible clay is absent in the B horizons of Oxisols but is present in the typical argillic horizons of Ultisols and Alfisols. The latter is anisotropic and the water dispersible clay is determined in the mixed fine earth fraction.

In these soils the walls of some pores may in fact have water dispersible clay in some places together with a higher carbon content than the total soil mass at that depth.

The stability of the Yellow Kaolinitic Oxisols

The absence of water dispersible clay in the Yellow Kaolinitic Oxisols - especially in the soils of medium texture - seems of little importance for the stability of the porosity and structure (mostly a very weak structure of fine aggregates). The swell and shrinkage of these soils being very limited (see Kool, 1977) the porosity and weak structures are mostly biogenetic. As will be brought forward later, a study of these soils shows that dense layers are readily formed below the top layers. This lack of stability may be caused by the near absence of stabilization forces. The flocculation is probably due to an equilibrium of weak forces of attraction and repulsion leading to a weak structure that is easily destroyed by mechanical forces. In Oxisols with larger amounts of iron oxides in the clay fraction (in other words, a larger total surface of the iron oxides) the structure is more stable because of the stronger cementation by the iron oxides (Koenigs, 1961), i.e. more positive and more negative charges at the zero point of charge. This results into a more stable porosity and into small, more stable aggregates, in the extreme case leading to the formation of pseudo sand structural elements.

A natural improvement of the structure and/or porosity of compact soils is difficult since shrinkage and swell are virtually absent. No aggregates or only large prisms will be formed. The dense layer is difficult to penetrate and it is an unfavourable habitat for the meso-fauna.

Before continuing it should be made clear that in some soils a slightly higher density in the upper part of the B horizon is regarded as normal (Ketelaars, 1976), since the density in these soils is a function of carbon and clay content. Where the organic matter content in the profile becomes rather low and the clay content has not yet reached its maximum, greater densites may be expected. Different cases have been described in which the densities seem to be higher than expected. Sombroek (1966) recognized a compact variant of the moderately heavy and heavy textured Kaolinitic Yellow Latosols in the lower Amazon valley. Compared with stands on other Yellow Kaolinitic Oxisols the trees on these soils had an abnormally superficial rootsystem. During their first soil survey the Brazilian Soils Commission (Barros et al., 1958) already noted that on coastal marine terraces in the State of Rio, soils occurred which often had very hard and dry B horizons. Janssen and Van der Weert (1976) stated that agricultural use could lead to a denser layer, while in Itabuna (Da Silva, 1979) an experiment with different methods of forest clearing showed that the use of heavy machinery not only compacted the topsoil but also the subsurface soil. The lack of a large specific surface of the iron oxides together with the textural composition may be responsible for these phenomena. As mentioned in the chapter on kaolinites yet another factor might be involved.

In various soil profiles a degradation of the soil mass has been observed (Sanchit, 1974; SNCLS, 1978: profiles 21, 30, 31). This phenomenon was seen in thin slides, diffraction diagrams and X-ray photographs. The presence of amorphous materials and signs of the dissolution of the kaolinites were unmistakable. These amorphous materials may at least in some cases be held responsible for the compaction of the soil.

The degradation of the Yellow Kaolinitic Oxisols and related sandy soils

Compaction of the subsurface layers leads to water stagnation in flat or depressed areas, resulting in a deferrization of the toplayers. The clay

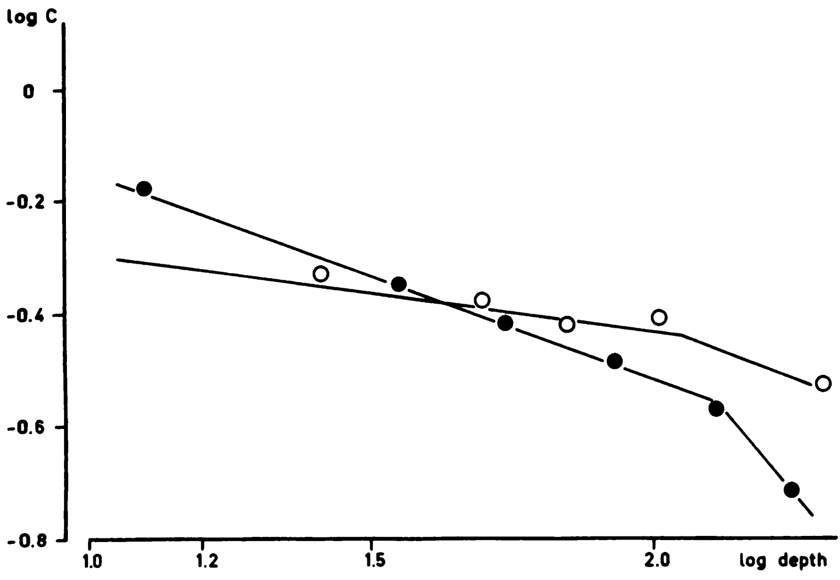


Fig. 4. Log organic carbon content as a function of log depth for two soils on a Tabuleiro which have an A2 horizon due to stagnant water.

then becomes more mobile and is partly lost to the subsoil where it may form clayskins. An abrupt textural boundary is often formed with some mottling below it. This sequence is similar to that of the process of ferrolysis as described by Brinkman (1979).

Simultaneously with the phenomena related to the mineral fraction also differences in the organic matter distribution occur. The decrease in organic matter content becomes less steep (see Fig. 4). In the equation $C = a_0 \text{ depth}^b$, the value of b is about -2 or -3. This higher organic matter content makes it also possible for the dispersed clay coming from above, to penetrate to greater depth, which may finally result in the forming of a podzol in the A2 horizon of this podzolic profile (Klinger, 1974). Thus the development of such a soil is: Oxisol → Ultisol (degraded Oxisol) → Spodosol.

Such Spodosols are different from the "giant podzols" with their deep to very deep A2 horizon ("white Zanderij soils" and soils northwest of Manaus), which are probably derived from coarser materials. The formation of such Spodosols is also related to periodic hydromorphic effects.

PHYSICAL AND CHEMICAL SOIL CONDITIONS FOR PLANT GROWTH

Physical soil conditions

Under natural conditions the water-holding capacity of these soils may be relatively high if medium amounts of clay and organic matter are present. The subsoil retains less water than the topsoil, the amount of clay present apparently having little influence, as long as it is above a certain minimum (compare also Wessel, 1971). In this respect the Yellow Kaolonitic Oxisols seem to belong to the less favourable soils (see e.g. Sombroek, 1966). Their water-holding capacity at lower depths normally is only about 10 percent by volume. Fortunately, in many places of the humid tropics the rather small amount of water that can be withdrawn from the soil is compensated for by a relatively even rainfall distribution.

In addition, for many crops the subsurface soil is unfavourable for root development. The causes may be of physical and/or chemical nature, viz. a high concentration of aluminium in the soil solution, low amounts of bases, a shortage of some micro-nutrients and of easily transportable phosphorus. Fertilization of the subsoil or the use of acid-tolerant cultivars may solve some of these problems.

Oxisols and related soils are known to have a high porosity and permeability. The porosity is of biological origin and the stability of the pores in many Oxisols normally is high. However, as mentioned before, in Oxisols with a low iron content, the pores easily collapse. The permeability of these soils under natural conditions is high but disturbance as a result of mechanized farming easily leads to deterioration.

Soil chemical conditions

The luxuriant growth of the rainforest on acid soils gives many a person the impression of a chemically rich soil. It has been known for some time, however, that the fertility of these soils is not high but often extremely low. This strong constraint to agriculture has been disregarded too often, resulting in the loss of vast amounts of money. Hopefully, such mistakes will not be made again.

No doubt the chemical fertility will be extensively dealt with by other speakers during this workshop, so only a few remarks will suffice.

Most of the plant nutrients of the ecosystem are present in the organic cycle. These relatively large amounts should be conserved as much as possible; they are indispensable in any low-input farming system. Losses after burning due to leaching, fixation and extraction will degrade the system if these nutrients are not replenished, even with the use of better adapted cultivars.

The low fertility has the following aspects (see also Sanchez, 1976).

1) A low effective cation exchange capacity.
2) Low amounts of bases and micro-nutrients.
3) A relatively high amount of exchangeable Al^{3+}.
4) Low amounts of "available phosphorus".
5) The difficulty of transportation of the phosphorus to the shoots of the plants.

The CEC of most Oxisols is extremely low, much lower than the CEC normally measured in the laboratory (mostly at pH 7.0). The CEC of the Oxisols is largely variable. It changes with pH, with the concentration and valency of the counterions near the exchange complex, the concentration of the equilibrium solution and with the dielectric constant of this solution. The permanent charge, which is important in the so-called 2:1 layer silicates, is very low in kaolinites. The organic matter also has a variable CEC.

To get an idea of the CEC in the field the so-called effective CEC (ECEC) is often measured. It is the sum of the exchangeable acidity (mostly Al^{3+}) extracted by KCl, and the exchangeable bases present. The term effective CEC suggests that it is the actual field CEC. Though it is nearer the field CEC than the CEC measured at pH 7.0, it also is an approximation of the value under field conditions.

If it is assumed that the CEC of the clay and the CEC related to the organic carbon content are constant (shallow toplayers; deeper layers should be excluded), the contribution of the clay and the organic carbon to the CEC can easily be calculated. The organic carbon content and the CEC of each layer in a profile is calculated for 100 g of clay. The results can be plotted (Bennema, 1966: CEC-plot), or they can be used in the linear regression equation

$$CEC = a_0 + a_1 C$$

where a_0 is the CEC of 100 g clay, a_1 is the contribution of 1 g C to the CEC and C is the percentage organic carbon. Figure 5 gives an example of such a CEC-plot for three different soils. For the purpose of this paper the very fine textured Yellow Kaolinitic Latosol and the "Terra Prêta" are of interest. The latter soil is formed in the same way as the very fine textured Yellow Latosol. The CEC (measured at pH 7.0; see Vettori, 1969) of its clay fraction, as indicated by the intercept of the X-axis, and the CEC of the organic matter (indicated by the slope), are considerably higher. In Figure 6 the amount of bases and Al^{3+} are indicated. It shows that the ECEC of the normal Yellow Kaolinitic Latosol is in fact very low (the data are for 100 g clay). The ECEC for 100 g of clay (intercept X-axis) is about 2 meq.

With respect to phosphorus a distinction has to be made between fixation and retention. Phosphorus in iron-rich Oxisols is largely

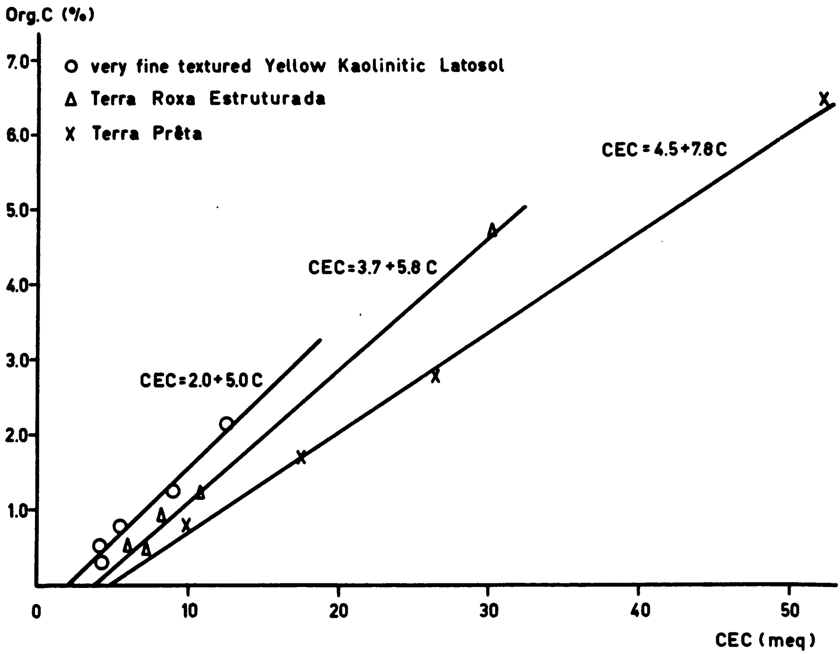


Fig. 5. Relation between CEC and organic carbon content (g per 100 g clay) for three Yellow Kaolinitic Latosols.

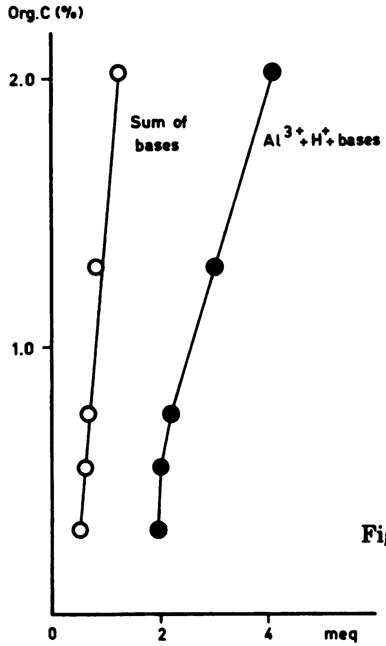
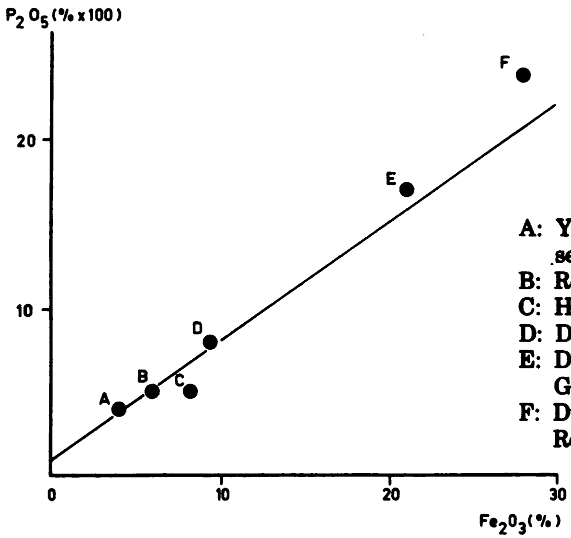


Fig. 6. Exchangeable bases and exchange acidity in a Yellow Kaolinitic Latosol from the lower Amazon basin, as a function of organic carbon content (g per 100 g clay).



A: Yellow Kaolinitic Latosols on sediments.
B: Red Yellow Latosols.
C: Humic Latosols.
D: Dark Red Latosols
E: Dark Red Latosols of Rio Grande do Sul.
F: Dusky Red Latosols (Terra Roxa Legitima)

Fig. 7. Rolation between the average P_2O_5 content and the average Fe_2O_3 content of six different groups of Latosols. The line represents the linear regression equation for a number of soil samples with an organic carbon content of 0.9 percent. Source: Bennema (1977).

bound to iron oxides in an occluded form (fixed); see Figure 7. Phosphorus added to the soil will not be immediately fixed. It will first be in a state which can be better described as "retained". Different surfaces e.g. of kaolinite and aluminium compounds play hereby a role. In Oxisols with a low iron content to total phosphorus content is low and the fixation of phosphorus can be expected to be relatively low too.

SUMMARY AND CONCLUSIONS

1. The older acid soils of tropical South America have been formed under climatic conditions that were not constant throughout their development. In the last glacial period, the climate was drier and somewhat cooler than today. The savanna area at that time was more extensive.
2. The soils in the humid region of tropical South America mostly have a kaolinitic clay mineralogy.
3. They belong mainly to the Oxisols (Ferralsols) and Ultisols (Acrisols).
4. The clay content in tropical Oxisols increases linearly with the logarithm of the depth. This does not apply to the clay content of Ultisols.
5. The carbon content in most Oxisols under natural forest decreases according to the equation $C = a_0 \text{ depth}^b$, in which a_0 and b are constants for a certain profile. For the Yellow Kaolinitic Oxisols b is mostly around -0.5. If the soil is used for arable farming this relation is disturbed, as organic matter is lost from the toplayer. This does not seem to happen if the soils are used for permanent grassland.
6. The Yellow Kaolinitic Oxisols are low in iron content. They form a very important group of soils on the sediments of the lower Amazon region and along the east coast of South America. These soils have a low stability.
7. The dispersibility of the topsoils of Oxisols and Kaolinitic Ultisols normally is positively influenced by organic matter which acts as a dispersing agent.
8. The Yellow Zanderij soils of Suriname can be regarded as Yellow Kaolinitic Oxisols intergrading towards Ultisols.
9. For typical Oxisols higher carbon/clay ratios are necessary to disperse the soil in water than for Ultisols.
10. The kaolinites in some profiles of yellow kaolinitic clay soils show signs of degradation. Dissolution of kaolinites and the presence of relatively high amounts of amorphous materials have been observed.
11. In Yellow Kaolinitic Oxisols often compact or hardened subsurface

layers occur, especially under mechanized farming systems. This is ascribed to the low iron content and may be enhanced by the presence of amorphous materials.

12. Under field conditions the CEC of the soils in question is very low. Al^{3+} is often the most important cation on the exchange complex.
13. The amount of water available for plant growth is rather low. This is due to the relatively low storage capacity leading to an unfavourable environment for root growth of many crops. This environment is also unfavourable from a chemical point of view and sometimes, like in the yellow kaolinitic soils, because of physical conditions.
14. For the classification of the Kaolinitic (Oxic) Ultisols it is important to distinguish two different types: the Ultisols that are somewhat less strongly weathered than Oxisols and the Ultisols that have developed by degradation of Oxisols. The latter may develop into podzols.
15. Other acid soils of some importance to the region are the giant podzols, probably derived from yellow kaolinitic sands. For some soils the formation and the hardening of plinthite have to be mentioned as important aspects.
16. The fertility of the forest ecosystem on the acid soils of the humid tropics is stored in the organic cycle. If the area is used for agriculture this fertility should be preserved as much as possible.
17. The porosity of the Oxisols is of biological origin. This porosity is rather stable in iron-rich subsurface soils, but collapses easily in soils poor in iron. Agricultural use in the form of agrosystems with a high biological activity in the soil, has the best chance to be successful. Much study is necessary to create such systems.

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CONSTRAINTS IN THE USE AND MANAGEMENT OF INFERTILE ACID SOILS IN THE HUMID TROPICS

José R. Benítes and Carlos L. Valverde
Instituto Nacional de Investigación y Promoción Agraria, Peru

INTRODUCTION

The humid tropics, defined as areas under acid savanna and rainforest with a udic and ustic moisture regime, encompass about 49 percent of tropical America (Table 1). Approximately 70 percent of this area is covered by acid infertile soils, mostly Oxisols and Ultisols (Sanchez & Cochrane, 1980). These fragile but potentially very productive ecosystems are presently under shifting cultivation and are experiencing many settlement attempts. The main agricultural system utilized by local farmers in the forested region is the slash-and-burn method, consisting of clearing the forest and cropping the land until native fertility provided by the ash is depleted. The large areas of land which must be cleared continuously under shifting cultivation, population pressures and the increasing worldwide concern about the potential depletion of tropical rainforests may soon restrict such practices. Therefore, the research for developing a sound soil management strategy for continuous cultivation of acid infertile soils of the humid tropics is one of high priority.

Table 1. Approximate areal distribution of major regions by soil moisture regimes in tropical America

Region	Main property	Soil moisture regime				Total	%
		udic	ustic	aquic	aridic		
		million ha					
A	High base status soils	46	299	60	0	405	27
B	Acid, infertile soils	620	299	124	0	1 043	70
C	Tropical desert	0	0	0	45	45	3
	Total	666	598	184	45	1 493	
	%	45	40	12	3		100

Source: Sanchez & Cochrane (1980)

Since the key issue is the soil as a limiting factor, the purpose of this paper is to define the main soil constraints and to discuss various soil management alternatives and conservation systems designed to alleviate them.

SOIL CONSTRAINTS

Systematic research toward developing realistic soil management practices for food preduction in the humid tropics can be done by the "constraint" approach, that is analyzing soil limitations (Sanchez, 1981). In using this approach, the Oxisols and Ultisols can be treated together even though there are some important differences between the two orders. The definitions of soil-related constraints used in this paper are shown in Table 2. The main physical and chemical constraints in the region were tabulated by Sanchez and Cochrane (1980), according to the Fertility Capability Soil Classification System described by Buol et al. (1975) and modified by Sanchez et al. (1982).

Chemical soil constraints

Soil acidity. Table 3 shows that 72 percent of the Oxisol-Ultisol region

Table 2. Definition of soil-related constraints used in this paper

Soil constraint	Definition
PHYSICAL	
Waterlogging for 2 months or more	Aquic soil moisture regime.Evidence of gley or mottled colours. Gleysols in FAO legend.
Low soil water-holding capacity	Less than 10% available soil moisture (0.1-15 bars) by weight in top 50 cm.
Severe erosion hazard	Erosion susceptibility due to slope, abrupt textural changes and/or poor structure.
Severe compaction hazard	Presence of compacted horizons or susceptibility to compaction due to texture and structure.
Laterite or plinthite	Presence of soft or hardened plinthite within 125 cm.
Mechanization difficulties	Slopes >30%, or other topographic irregularities seriously limiting large-scale mechanization.

Table 2 continued

Soil constraint	Definition
CHEMICAL	
Low CEC	<4 meq/100 g of effective cation exchange capacity in top 50 cm. Denotes high leaching potential.
Aluminium toxicity	$>60\%$ Al saturation in top 50 cm or pH <5.0.
Manganese toxicity	>100 ppm dilute double acid extractable Mn in top 50 cm.
N deficiency	Widespread agronomic evidence of nitrogen deficiency in principal crops. No quantitative soil definition.
P fixation	Topsoil clay fraction dominated by X-ray amorphous minerals or $>20\%$ of clay fraction as Fe and Al oxides and $>30\%$ topsoil clay content.
P deficiency	Widespread occurrence of available soil test values below critical levels for main crops.
Ca deficiency	As above
Mg deficiency	As above
S deficiency	As above
Fe deficiency	As above
Zn deficiency	As above
B deficiency	As above
Cu deficiency	As above
Mo deficiency	As above
Acid sulphate soils	pH <3.5 after drying or Sulfaquept or Sulfaquent classification.

Source: Sanchez & Cochrane (1980)

suffers from Al toxicity. Aluminium toxicity to plants is the main consequence of high soil acidity. Plants very sensitive to aluminium suffer at levels ranging from 10-50 percent Al saturation. In general, when there is 60 percent Al saturation or more within the top 50 cm, the soils are considered Al-toxic to most food crops. On the other hand, the extreme acidity of these soils permits the use of low solubility P sources, increases the availability of minor elements with the exception of molybdenum and controls some soil-borne diseases.

Low effective cation exchange capacity. A low effective cation

Table 3. Geographical extent of major soil-related constraints in the predominant acid infertile soils of tropical America (23°N-23°S)

Soil constraint	Percent of total area
CHEMICAL	
P deficiency	96
N deficiency	93
K deficiency	77
Al toxicity	72
S deficiency	71
Mg deficiency	70
Ca deficiency	70
P fixation	64
Zn deficiency	62
Low ECEC	55
Cu deficiency	30
Salinity	0
Alkalinity	0
Fe deficiency	0
Acid sulphate soils	-
Mn toxicity	?
B deficiency	?
Mo deficiency	?
PHYSICAL	
Low water-holding capacity	56
Water stress >3 months	29
Erosion hazard	29
Compaction	16
Waterlogging	12
Laterite	11
Shallow depth	8

Source: adapted from Sanchez & Cochrane (1980) exchange capacity (ECEC) is an important soil constraint. Table 3 shows that 55 percent of the Oxisol-Ultisol region suffers from low ECEC, which is both an advantage and a disadvantage (Spain, 1978). The advantage is that less lime is required to neutralize exchangeable acidity; therefore, when it is necessary to lime for annual crops, relatively low rates are required for adequate crop performance. In contrast, low ECEC results in less retention of nutrient cations such as K, Ca, Mg under leaching conditions. Rapid losses by leaching and serious K-Mg imbalances have been recorded in sandy Ultisols of Peru (Villachica, 1978). Thus, it is usually more difficult to maintain adequate fertility in these soils than in soils with greater cation exchange capacity (Spain, 1978).

Phosphorus deficiency. Approximately 82 percent of the land area of the American tropics is deficient in phosphorus in its natural state (Sanchez & Cochrane, 1980). In the Oxisol-Ultisol savannas and rainforests the estimate increases to 96 percent of the area. Table 3 shows that 64 percent of the region has soils with a high P fixation capacity defined as those topsoils requiring more than 100 kg P/ha to correct phosphorus deficiency. They usually have more than 35 percent clay and a high proportion of iron oxides (Sanchez & Uehara, 1980; Sanchez et al., 1982).

Deficiency of other nutrients. Nutrient deficiency symptoms are frequently observed in annual or perennial crops, pastures and even forest plantations throughout the humid tropics of tropical America. Table 3 shows that 93 percent of the Oxisol-Ultisol region suffers from nitrogen deficiency, 71 percent from sulphur deficiency, 62 percent from zinc deficiency, and 30 percent from copper deficiency. About 77 percent has low potassium reserves indicative of potassium deficiency. Unlike soil acidity and low P contents, there are no plant genetic strategies to get around potassium deficiency. Consequently, this is an important economic constraint in about half the humid tropics of tropical America (Cochrane & Sanchez, 1981). Because of high initial cost of fertilizer required by non-adapted species, much work needs to be done in identifying such constraints, develop appropriate soil test or plant analysis methods before correction can take place.

Physical soil constraints

Low water-holding capacity. Another very important constraint is the low water-holding capacity of the soil. Approximately 56 percent of the region has sandy or loamy textures in the top 50 cm with a retention of less than 10 percent by weight of available soil moisture (0.1-15 bars). This disadvantage is offset to some extent by very deep profiles and the usual absence of physical barriers to root penetration. However, only acid tolerant species are capable of developing roots into Al-saturated

Table 4. Major characteristics of Oxisols-Ultisols (low activity clay soils) of the humid tropics and resultant advantages and limitations[a]

Characteristic	Advantages	Limitations
1. Low native fertility	Low initial weed potential	Limited range of adapted species. High initial cost of fertilizer required by non-adapted species
2. Extreme acidity	Permits use of low solubility P sources. Increases the availability of minor elements with exception of Mo. Controls some soil-borne diseases. Fewer adapted weed species.	Limited range of adapted annual crop species. Al and Mn toxicity.
3. Low cation exchange capacity	Lower lime requirement Lower initial fertilizer requirement. Promotes downward movement of Ca and Mg into subsoil.	Limited reserve and retention of bases. Potential nutrient imbalance.[b]
4. High P fixing capacity	Increases dissolution rate of rock phosphates[b,c]	Low efficiency of P fertilizers
5. Low water-holding capacity	None	Crops are susceptible to even short drought periods. Susceptible to high leaching losses.
6. Lack of primary minerals	None	Limited reserve of nutrients

7. Predominance of 1:1 type clay minerals	Soils are generally friable and are easily tilled	
8. High sesquioxide content	Stable micro-structure. Good internal drainage and aeration, easily tilled.	Strong macro-structure
9. Relatively smooth topography	Easily mechanized	
10. Deep profiles generally free of physical obstacles to root penetration	Permits deep rooting of adapted species. Good subsoil moisture reserve	
11. Presence of laterite	Very useful for road building and general construction	Impedes tillage and cultivation when on surface

[a] Source: adapted from Spain (1978)
[b] Sanchez & Salinas (1981)
[c] Smyth & Sanchez (1982)

horizons to take advantage of subsoil stored moisture. Most annual crops are relatively limited in their capacity to penetrate into the deep subsoil and therefore are very susceptible to relatively short periods of drought even during the rainy season when the subsoil is always moist. Consequently, it is important to point out that plants growing on most well-drained soils of the humid tropics can suffer from drought stress during some part of the year.

Waterlogging for three months or more. Approximately 12 percent of the area has an aquic soil moisture regime, indicating the presence of waterlogging conditions in some part of the solum during the year. However, most of the humid tropics of Latin America have well-drained soils. In this sense, the Oxisols have a good to excessive internal drainage and rarely suffer from excess moisture even under very high rainfall regimes. In Ultisols water moves less rapidly downwards because of their argillic horizon.

Mechanization difficulties. The Oxisols and oxidic families of Ultisols are easily tilled because of their good to excellent physical properties. The predominance of 1:1 type clay minerals plus the high sesquioxide content forms a stable micro-structure, providing soils with good internal drainage and aeration, friable and easy to till. In addition, those areas with smooth topography usually favour simplified management and rather efficient mechanization. Table 3 shows that 16 percent of the region exhibits serious compaction hazards. Coupled with the 29 percent high erosion hazard, more than half of the soils of these areas are not likely to present serious difficulties for mechanized farming.

Erosion hazard. The presence of an abrupt textural change within 50 cm of the soil surface, such as a loamy on clayey, sandy on loamy, and sandy on clayey textures makes the soils susceptible to erosion, particularly on steep slopes. Such soils cover about 29 percent of the region. The steep soils, mostly classified as Entisols, Inceptisols, Ultisols or Alfisols are generally quite susceptible to erosion unless protected by a plant canopy during periods of heavy rains.

Laterite hazard. The literature on tropical soils continues to propagate the myth of the widespread danger of laterization - the fear that most tropical soils when cleared of rainforests or savannas will dry up and partly change into laterite or hard plinthite, brick-like materials through the process of laterization. Moormann and Van Wambeke (1978) estimate the extent of such active plinthite formation to be less than 2 percent of all tropical lands, but even on these soils the plinthite will be rarely exposed in such a way that it would harden irreversibly when cleared for agricultural use. Plinthite generally occurs only in soils which are subjected to a fluctuating water table in the upper part of the profile. Buol and Sanchez (1978) estimate that plinthite exists in the upper 1.25 m in 7 percent of the soils in the

Oxisol-Ultisol region in South America, about the same percentage found in southeastern United States. Kellogg (1970) points out the usefulness of laterite in the tropics as building material for roads and general construction. Table 4 shows a summary of the major characteristics of Oxisols-Ultisols of the humid tropics and the resultant advantages and limitations.

In conclusion, the major soil constraints in the Oxisol-Ultisol regions are chemical rather than physical, including deficiencies of phosphorus, nitrogen, potassium, sulphur, calcium, magnesium, and zinc plus aluminium toxicity and high phosphorus fixation. The main soil physical constraints are the low available water-holding capacity in many Oxisols and the susceptibility to erosion and compaction in many Ultisols with a sandy topsoil texture. Laterite hazard covers a minor areal extent and most of the plinthite occurs in subsoil layers in flat topography not prone to erosion (Sanchez & Cochrane, 1980).

MANAGEMENT OF ACID INFERTILE SOILS

The development of improved soil management practices, designed to alleviate the main constraints of acid infertile soils is top priority for continuous agricultural production on an economically and ecologically sound basis for the humid tropics (IRRI, 1980). This section summarizes most of the information available to the authors.

Land clearing methods

Soil dynamics before clearing tropical rainforest. Most subsistence cropping in Oxisol and Ultisol areas is found in forest regions. The major reason for this is that a much greater biomass is accumulated in tropical forests than in savannas (Spain, 1978). Before clearing, the soil and forest have a remarkably closed nutrient cycle in which most nutrients are stored in the biomass and topsoil, and transformed from one to the other through rainwash, litter fall, timber fall, root decomposition and plant uptake. For example, Cornforth (1970) measured, throughout one year, a leaf fall from a *Mora excelsa* rainforest in Trinidad of about 7 000 kg leaves/ha containing 60 kg N, 3 kg P, 11 kg K, 65 kg Ca and 15 kg Mg.

Sanchez (1979) reported that in many nutrient cycling studies it has been found that the bulk of the N and P in the ecosystem is located in the topsoil. This is not the case with K, Ca and Mg, which are concentrated in the biomass. Stark and Jordan (1978), working with surface root mats on Oxisols and Spodosols using ^{45}Ca and ^{32}P, found that the root mats on the surface efficiently utilize these nutrients.

The exchangeable K content in the soil of the humid tropical forest is low and diminishes rapidly with depth. Potassium release from litter is very fast, 70-80 percent being released during the first two weeks (Benhard-Reversat, 1973). In studies where the nutrient composition of the rainwash was also recorded, K additions through this mechanism were more than twice the amount added through litter decomposition (Fassbender, 1977). Regarding the amount of nutrients transferred from the forest to the soil, losses from this system are usually negligible; therefore, lush tropical vegetation grews without nutrient deficiency symptoms on soils with very low native fertility.

Slash-and-burn versus mechanical clearing. The choice of land clearing methods is the first and probably most crucial step affecting the future productivity of agricultural systems. Several comparative studies conducted in the humid tropics of Latin America confirm that manual slash-and-burn methods are superior to different types of mechanical clearing because of the fertilizer value of the ash and because of less soil compaction and topsoil displacement compared to mechanized land clearing (Seubert et al., 1977; Sanchez, 1979).

The nutrient content of the ash (Table 5) produced after burning a 17-year-old secondary forest in Yurimaguas contributed the equivalent of 145 kg/ha of urea, 67 kg/ha of simple superphosphate, 50 kg/ha of muriate of petash, 0.25 tons/ha of dolomitic limestone plus significant quantities of sulphur, zinc, copper, manganese and iron (Seubert et al., 1977). These additions preduced major positive changes in soil properties during the first year after clearing (Fig. 1). The availability of calcium, magnesium, potassium and phosphorus increased after burning as a consequence of the liming effect of the ash, and organic

Table 5. Nutrient contribution of ash and partially burned material to an Ultisol of Yurimaguas, Peru after burning a 17-year-old forest

Element	Composition	Total additions
		kg/ha
N	1.72%	67
P	0.14%	6
K	0.97%	38
Ca	1.92%	75
Mg	0.41%	16
Fe	0.19%	7.6
Mn	0.19%	7.3
Zn	132 ppm	0.3
Cu	79 ppm	0.3

Source: Seubert et al. (1977)

matter contents of the topsoil remained higher in the plots cleared by slash-and-burn than those cleared by bulldozing (Seubert et al., 1977). This significant beneficial effect of ash on soil chemical properties produced consistently higher yields of a wide variety of crops during the first two years after clearing (Table 6). Variability in the quantity of ash and its nutrient content occurs because of the age and proportion of the forest biomass actually burned, related to the type of soil and the clearing technique.

Soil compaction by machinery produces a further detrimental effect in Yurimaguas. Water infiltration rates one month after clearing

Table 6. Effects of two land clearing methods on crop yields at Yurimaguas[a,b]

Crop	Fertility level[c]	Slash and burn	Bulldozed	Bulldozed / Slash and burn
		tons/ha[d]		%
Upland rice (3)	0	1.3	0.7	54
	NPK	3.0	1.5	50
	NPKL	2.9	2.3	79
Maize (1)	0	0.1	0.0	0
	NPK	0.4	0.04	10
	NPKL	3.1	2.4	77
Soybean (2)	0	0.7	0.2	29
	NPK	1.0	0.3	30
	NPKL	2.7	1.8	67
Cassava (2)	0	15.4	6.4	42
	NPK	18.9	14.9	79
	NPKL	25.6	24.9	97
Panicum maximum (6 cuts/yr)	0	12.3	8.3	67
	NPK	25.2	17.2	68
	NPKL	32.2	24.2	75
Mean relative yields	0			37
	NPK			47
	NPKL			48

[a] Source: Seubert et al. (1977)
[b] Yield is the average of the number of harvests indicated in parentheses
[c] 50 kg N/ha, 172 kg P/ha, 40 kg K/ha, 4 tons lime (L)/ha
[d] Grain yields of upland rice, maize and soybean; fresh root yields of cassava; annual dry matter production of *Panicum maximum*

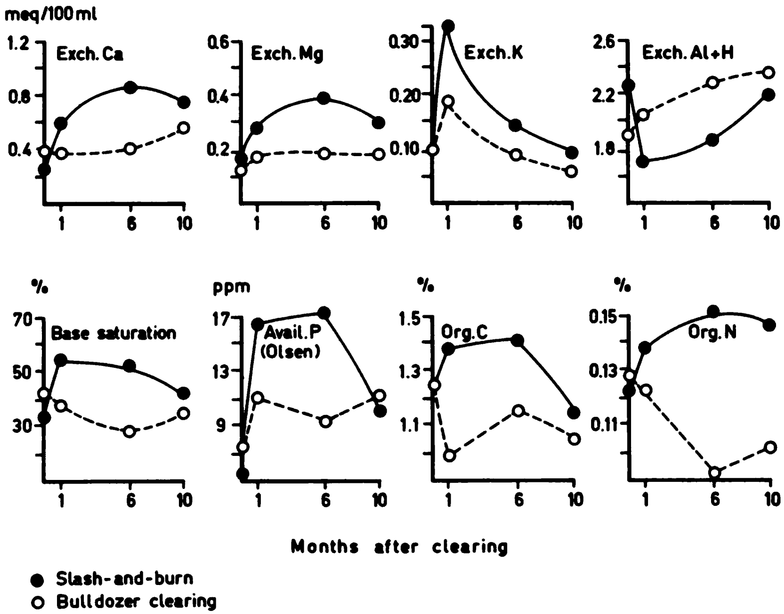

Fig. 1. Effects of two land clearing methods on changes in topsoil (0-10 cm) properties in a Typic Paleudult of Yurimaguas, Peru. Source: Seubert et al. (1977).

showed an average of 10.5 cm/hour for manual clearing and about 0.5 cm/hour for mechanized clearing (Fig. 2). Similar differences were also evident 11 months after clearing. These results indicate that this Ultisol with a sandy topsoil is very susceptible to compaction if machinery is used to clear the vegetation. Table 7 shows the decrease in infiltration rate for Ultisols in Peru (Seubert et al., 1977) and Brazil (Schubart, 1977; Da Silva, 1979).

The third major consideration is the degree of topsoil removal by the bulldozer blade, and by dragging uprooted trees and logs. Although no quantitative data are available, topsoil removal in high spots and accumulation in low spots is commonly observed. The better jungle regrowth near windrows of felled vegetation suggests that topsoil displacement can result in major yield reductions (Sanchez, 1976). For example, Lal et al. (1975) in Nigeria observed that maize yields decreased by 50 percent after the top 2.5 cm of an Alfisol had been removed.

Soil dynamics after clearing. When a tropical humid forest is cleared and burned, the following changes in soil properties generally occur within the first six months: (1) Large volatilization losses of

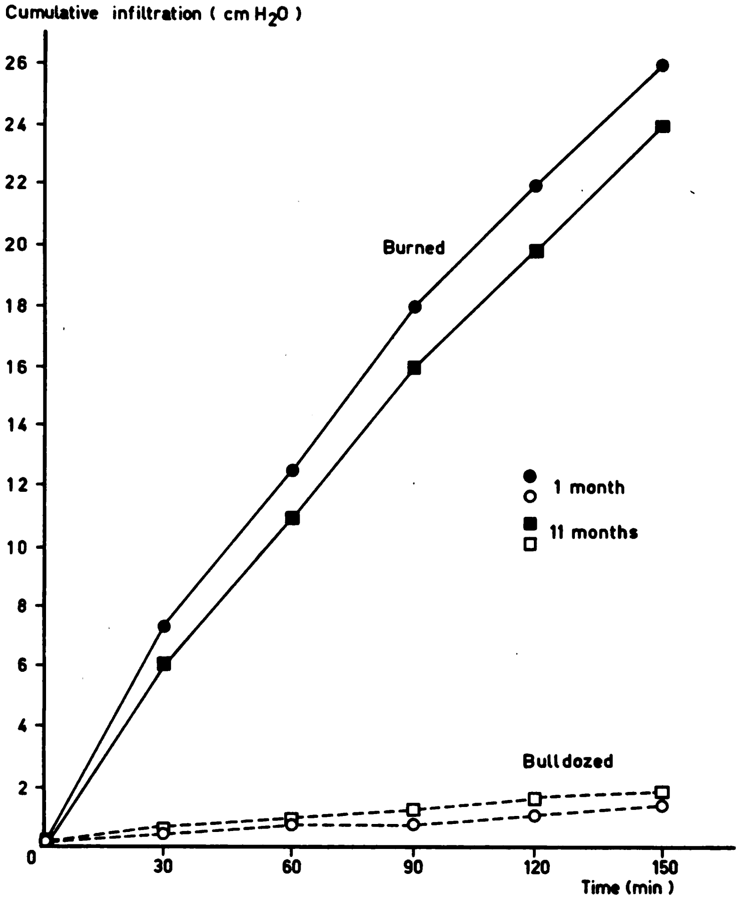

Fig. 2. Effects of two land clearing methods on water infiltration rates at one and 11 months after clearing an Ultisol of Yurimaguas, Peru. Source: Seubert et al. (1977).

biomass nitrogen and sulphur occur upon burning, and soil organic matter decreases with time until a new equilibrium is reached; (2) the pH of acid soils increases, aluminium saturation values decrease, exchangeable bases and available phosphorus increase; (3) soil temperatures increase and greater fluctuations in the soil moisture regime occur because of solar radiation reaching the soil surface. These changes are gradually reversed with time (Sanchez, 1979). Many studies have demonstrated how dynamic the system is and explain why low yields were obtained in the unfertilized soils. The absence of data for sulphur and the majority of the micronutrients is a major research gap

Table 7. Effects of clearing methods on water infiltration rates in Ultisols from Yurimaguas, Peru; Manaus and Barrolândia (Bahia), Brazil

Clearing methods	Yurimaguas Peru	Manaus, AM Brazil	Barrolândia, BA Brazil
	cm/hr		
Undisturbed forest	26	15	24
Slash and burn (1 year)	10	-	20
Bulldozed (1 year)	0.5	-	3
Slash and burn and 5 years in pasture	-	0.4	-

Sources: Schubart (1977), Seubert et al. (1977) and Da Silva (1979)

but it is known that many of these nutrients rapidly become limiting after the forest is cleared (Sanchez, 1979).

Bandy and Sanchez (1982) will summarize later in this workshop the main changes in both fertilized and unfertilized plots in the continuous cropping experiment at Yurimaguas and they will present the suggested fertility maintenance schemes for continuous cultivation in the upper Amazon river basin of Peru.

Alternative land clearing methods. Clearing methods also have economic implications. In Peru, the cost of mechanically clearing one hectare of forest is three times higher than with the traditional method, and there are difficulties in transporting and maintaining the equipment. Given the current difficulties associated with mechanized clearing, traditional methods remain more practical.

Management of soil acidity

Major constraints to crop production in acid soils are toxicities of aluminium and manganese and deficiencies of calcium and magnesium (Jackson, 1967). In order to have successful agriculture in these regions, acid soil stresses need to be alleviated. Three main strategies are used to alleviate acidity problems: (1) Liming to roduce aluminium saturation below toxic levels for specific farming systems; (2) liming to supply calcium and magnesium and to promote their movement into the subsoil; (3) use of plant species and varieties tolerant to aluminium and manganese toxicities (Sanchez & Salinas, 1981).

Lime rates based on amounts of exchangeable aluminium. The use of exchangeable aluminium as the criterion on which to base lime rates has been proposed for soils with a low permanent charge and a relatively high pH-dependent charge (Kamprath, 1967, 1970; Reeve & Sumner, 1970). The rationale was that aluminium is the toxic factor in many acid mineral soils, and one purpose of liming is to remove aluminium toxicity as a constraint to crop growth. Soils with aluminium toxicity problems can be identified by extracting aluminium with potassium chloride and determining the proportion of the active cation exchange sites - i.e. the sum of aluminium + calcium + magnesium + potassium - occupied by aluminium. When the Al saturation is greater than 60 percent, the concentration of Al in the soil solution generally exceeds 1 ppm, a level that is detrimental to many crop species (Kamprath, 1970). Lime rates sufficient to neutralize exchangeable aluminium are considerably less than those required to raise the pH to 6.5. Various studies have shown that lime rates chemically equivalent to 1.5 to 3 times the amounts of exchangeable aluminium must be added to neutralize the aluminium (Table 8). Therefore, the amount of lime required to neutralize aluminium can be estimated by the equation:

$$\text{meq } CaCO_3/100 \text{ g} = \text{meq exchangeable Al}/100 \text{ g} \times 2$$

Cochrane et al. (1980) developed a formula for determining the amount of lime needed to decrease the aluminium saturation level of the topsoil to the desired range, instead of neutralizing all the exchangeable Al:

$$\text{Lime required (tons } CaCO_3\text{-eq/ha)} = 1.8 \text{ Al-RAS (Al+Ca+Mg)}/100$$

Table 8. Liming factor (meq Al/100g x factor) required to give equivalents of calcium carbonate to reduce aluminium saturation to less than 10 percent

Area	Soil (surface 15 cm)	pH	Aluminium	Aluminium saturation	Factor	Final pH
			meq/100 g	%		
Brazil	Red Yellow Latosol	4.0	0.7	70	3	4.9
	Red Yellow Latosol	4.4	0.9	75	2	5.5
	Dark Red Latosol	4.0	1.9	86	2	5.0
Colombia	Oxisol	4.3	3.5	78	2	5.3
Panama	Latosol	5.1	1.2	53	1.5	5.9
	Latosol	5.0	3.0	64	1.5	6.0
United States	Ultisol	4.5	0.9	82	2.0	5.9

Source: adapted from Kamprath (1980)

where RAS is the critical percent aluminium saturation tolerated by a particular crop, variety or farming system, and Al, Ca, and Mg are the exchangeable levels of these cations expressed in meq/100 g. When compared with actual field data, the predictability of this equation is excellent (Cochrane et al., 1980). An additional advantage is that it requires no soil analysis other than the N KCl extraction of aluminium, calcium and magnesium as well as the information about crop tolerance to aluminium in terms of percent aluminium saturation.

Lime as calcium and magnesium fertilizer. In many of the soils concerned, plants require fertilization with calcium and magnesium.

This can be accomplished by small lime applications or by fertilizers containing sufficient amounts of these two essential nutrients. Small applications of lime (dolomitic lime) are probably less expensive per unit of nutrient than calcium and magnesium fertilizer (Sanchez & Salinas, 1981). A very positive attribute of many Oxisols and Ultisols of tropical America is the relative ease of movement of calcium and magnesium into the subsoil. It is possible to take advantage of what is normally considered a soil constraint: low ECEC. Together with a favourable soil structure and plenty of rainfall, a low ECEC favours the gradual amelioration of the chemical properties of the subsoil. This, in turn, favours deeper root development and less chance of drought stress (Sanchez & Salinas, 1981).

Selection of aluminium-tolerant varieties. Another approach to overcoming soil acidity problems is to select varieties that are tolerant to high concentrations of aluminium or manganese, or both. Interest in this approach has increased during the last decade, especially as a part of the research at the international centres. Some species have shown a wide variation in varietal tolerance for aluminium (Kamprath, 1980). Using 10 wheat varieties on a typic Haplustox from Brasilia, Brazil (Fig. 3), it was determined that the critical level of aluminium saturation varied from 22 to 60 percent, which for that soil corresponds with a lime requirement of 0.5-1.6 tons $CaCO_3$-eq/ha (Foy et al., 1965). Similar ranges exist with other species. At a workshop on plant adaptation to mineral stress in problem soils, work on tolerance of plants for aluminium and manganese was reviewed in detail (Wright, 1976).

Because liming can correct aluminium and manganese toxicities in the plough layer, the greatest benefit from the use of tolerant varieties is an increased rooting depth in acid subsoils. Beneficial effects of increased rooting depth are primarily the use of subsoil moisture. In many regions of the humid tropics it is common to have periods of one to two weeks without rain. If toxicities below the limed plough layer restrict rooting depth, drought stress can develop and limit crop yields.

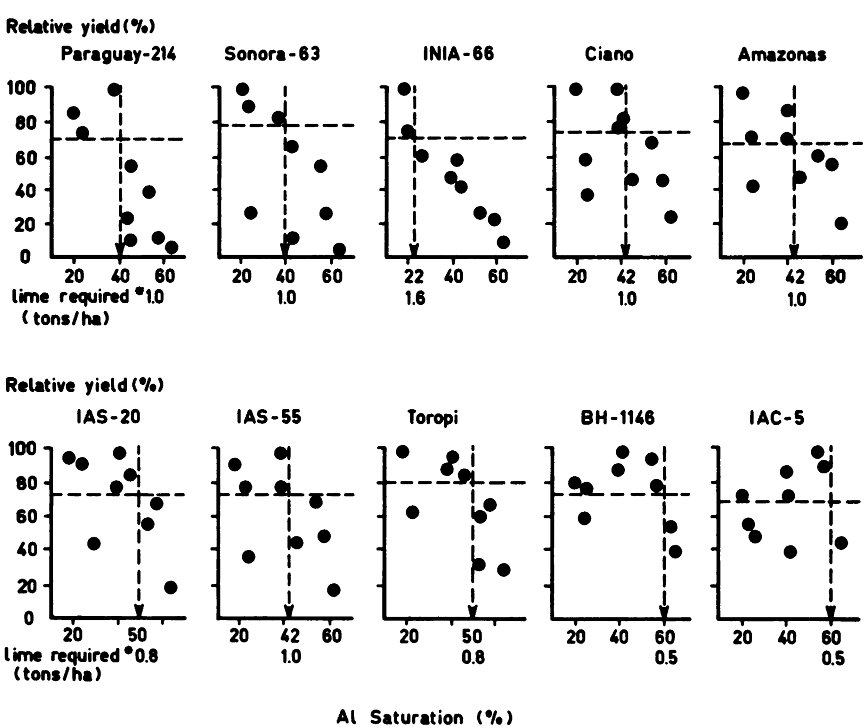

Fig. 3. Critical aluminium saturation levels for 10 wheat varieties grown on a Brazilian Oxisol. "Lime required" refers to the formula of Cochrane et al. (1980). Source: Sanchez & Salinas (1981).

Phosphorus management

Phosphorus concentrations of the soil solutions in temperate regions range from 0.3 to 3 ppm (Hossner et al., 1973; Mengel & Kirby, 1978) but levels of 0.05 to 0.08 ppm frequently occur in tropical soils and are regarded as adequate for optimum growth of rice plants (Katyal, 1978).

In most acid tropical soils with high levels of iron and aluminium oxides, phosphorus absorption is high and the concentration in the soil solution low (Dabin, 1980). Soils with a high phosphorus fixation capacity can be defined as those that require additions of at least 200 kg P/ha in order to provide an equilibrium concentration of 0.2 ppm P in the soil solution (Sanchez & Uehara, 1980). Acid soils that fix such amounts of phosphorus can be identified as those with loamy or clayey topsoil textures with a sesquioxide/clay ratio of 0.2 or greater, or by the dominance of allophane in the clay fraction of the topsoil (Buol et al,. 1975).

The strategy proposed by Sanchez and Salinas (1981) in order to develop a sound phosphorus management for crops and pastures on the acid, infertile soils of tropical America consists of: (1) Determination of the most appropriate combination of rates and placement methods for fertilizers to enhance initial and residual effects; (2) improvement of soil fertility evaluation procedures for making phosphorus recommendations; (3) use of less costly sources of phosphorus such as phosphate rocks, either alone or in combination with superphosphate; (4) use of moderate amounts of lime to increase the availability of soluble phosphorus; (5) selection of species and varieties that can grow well at lower levels of available soil phosphorus; and (6) exploration of the practical possibilities of mycorrhizal associations to increase phosphorus uptake by plants.

In order to maximize the efficiency of phosphorus fertilization, it is possible to select plants that have a lower requirement of phosphorus for maximum growth than those commonly used. Fortunately, aluminium tolerance and "low phosphorus tolerance" often occur jointly because the latter seems associated with the plant's ability to absorb and translocate phosphorus from the root to the shoot even in the presence of high levels of aluminium in the soil solution and in the root tissue (Salinas, 1978). Other strategies are discussed in detail in a recent paper of Sanchez and Salinas (1981).

Management of low native soil fertility

The elimination of soil constraints by applications of the necessary amounts of fertilizers and amendments can be considered as high input soil management technology. Its basic concept is to change the soil to fit the plant's nutritional demands. The applicability of high input soil management technologies, however, diminishes in marginal lands where soil and water constraints are not easily overcome at low cost. Many research efforts in the tropics are now directed towards developing low input soil management technologies, which do not attempt to eliminate the use of fertilizers or amendments but rather attempt to maximize the efficiency of purchased inputs. The main low input technologies required to manage low native soil fertility centre on: (1) Maximum use of nitrogen fixation by legumes in acid soils; (2) increasing the efficiency of nitrogen and potassium fertilization; (3) identification and correction of sulphur and micronutrient deficiencies; and (4) promotion of nutrient recycling (Sanchez & Salinas, 1981).

Maximum use of biological nitrogen fixation. The need for nitrogen fertilization could bo essentially eliminated with the use of acid tolerant *Rhizobium* strains in association with acid-tolerant grain legumes, but definitely not for cereal and root crop species. Many of the plant species of economic importance that are adapted to acid soil conditions are legumes. Among the annual food crops, there are three important acid-tolerant legumes, namely cowpea, groundnut, and pigeon pea, and several less widespread ones, such as lima bean or mungbean. There is also a wealth of very acid-tolerant forage legumes of the genera *Stylosanthes, Desmodium, Zornia, Pueraria, Centrosema,* and many others.

In order for those legumes to fix sufficient nitrogen, it is essential that the nutritional requirements and the degree of acid soil tolerance of the associated *Rhizobium* match those of the plant (Munns, 1978). If not, plant growth will be severely hamperod because of nitrogen deficiency. Consequently, soil management practices require the matching of nutritional requirements and tolerance of both legumes and *Rhizobia.*

In terms of nutritional needs, *Rhizobia* generally require greater amounts of cobalt and molybdenum for symbiotic nitrogen fixation than does the host legume for growth (Robson, 1978). The relative requirement and the interactions between legume nutrition and *Rhizobium* nutrition merit additional research.

Increase of the efficiency of N and K fertilization. Applications of fertilizer nitrogen are essential for cereal or root crop production systems in these regions. Rotating or intercropping grain legumes with cereals may decrease the overall amount of nitrogen needed, not because of a significant transfer of fixed nitrogen to the cereals, but because the legumes occupy space in the fields (Benítes, 1981). Apparent N recovery by maize fertilized with 80 kg N/ha ranged from 35 per-

Table 9. Effect of fertilization and cropping systems on the supply and accumulation of potassium

Source of K change	System 1			System 2		
	Maize	Maize	Maize	Rice	Groundut	Maize
	a	b	c	a	b	c
	Potassium, kg/ha					
Soil Exch. K, kg/ha	131	218	284	122	87	79
Applied K (Fert.), kg/ha	101	41	124	101	41	124
Applied K (Mulch), kg/ha [a]	60	60	60	--	--	60
Total, kg K/ha	292	319	468	223	128	263
Uptake, kg K/ha	55	95	137	135	64	92
Est. Residual K, kg/ha	237	224	331	88	64	171

[a] Maize plots received approximately 4 tons dry matter/ha of rice straw (x content 1.5% K) = 60 kg K/ha.

Source: Benítes (1981)

cent for the rotation greundnut-rice-rice to 64 percent at intercropping maize/rice-cassava/groundnut on an Ultisol at Yurimaguas, and was more affected by the grewing period and the N responsiveness of the crop components than by the system in which a given maize crop happened to occur. In addition, an N fixing legume included in the system had no significant effect on apparent N recovery of the non-legume crops (Benítes, 1981). Since soil testing for nitrogen fertilization is of little value in well-drained Oxisols and Ultisols because of the mobility of nitrate, fertilizer recommendations are based on field experience, plant analysis, and crop uptake data. Nitrogen fertilization for cereal and root crops is therefore one of the weakest aspects of low input strategy for these soils.

For potassium the situation is similar to that for nitrogen. Unlike nitrogen, the identification of potassium deficiency through soil tests is straightforward. The established critical levels are in the range 0.15-0.20 meq/100 g for most crops. At present there are no low input potassium management systems and there are no plants that thrive at low levels of available soil potassium. The main avenues for increasing the efficiency of potassium fertilization are split applications and avoidance of removal of crop residues, particularly stover, in order to attain some degree of recycling. Benítes (1981) showed that nutrient accumulation patterns by specific crops as well as management of previous crop residues were important in the utilization and recycling of potassium in intensive cropping systems on light textured soils with a low base status (Table 9).

Identification and correction of deficiences of sulphur and micronutrients. Insufficient knowledge of the requirements of sulphur and several micronutrients particularly zinc, copper, boron, and molybdenum is probably the weakest aspect of low input technology. This gap can be corrected by systematic determination of critical levels of these nutrients in the soil and in the plants. Fortunately, the application costs are low and zinc and copper fertilization produce long residual effects.

Promotion of nutrient recycling. Soil management practices in low native fertility soils should encourage nutrient recycling. Organic inputs as mulch, green manure and compost have been studied in an attempt to promote nutrient recycling for low input soil management. Tabel 10 shows the variability in the effects of mulches within yields of maize, rice, soybean and groundnut in Yurimaguas. For four years and 22 crops, the yield increase in most cases was minimal; for rice the effect was even negative. There was no major effect in soybean. In general, mulches had a favourable effect on soil moisture during dry periods of the year, but under excessive moisture conditions, the effects were negative, especially with rice (Valverde & Bandy, 1981).

Making compost out of crop residues appears more promising

Table 10. Effects of mulching on yields of several crops in Yurimaguas, Peru

Crop	Date planted	With mulching	Without mulching
		—— grain yield (kg/ha) ——	
Soybean	July 1979	2 450	1 840
Maize	July 1979	3 950	2 710
Rice	Feb. 1978	1 870	2 800
Rice	Feb. 1978	1 850	2 800
Soybean	Oct. 1978	2 800	3 110
Groundnut	Oct. 1978	2 350	2 320
Maize	June 1978	4 530	4 040
Soybean	June 1978	3 120	2 920
Rice	Jan. 1978	2 640	3 000
Rice	Jan. 1978	2 650	2 630
Groundnut	Sept. 1977	2 800	2 200
Maize	Sept. 1977	4 300	3 900
Rice	Feb. 1977	2 063	2 589
Rice	Feb. 1977	1 298	2 445
Maize	Apr. 1976	2 965	3 610
Soybean	Apr. 1976	2 213	2 546
Soybean	Sept. 1976	1 933	2 300
Groundnut	Sept. 1976	4 167	4 133
Soybean	April 1974	1 000	1 040
Cowpea	Nov. 1975	640	740
Groundnut	April 1975	2 530	2 880
Rice	Sept. 1975	2 310	2 740
Average		2 556	2 448

Source: Valverde & Bandy (1981)

than green manure. For the first four consecutive crops, replacing complete fertilization with compost produced from crop residues resulted in only a 20 percent yield reduction. The potential use of this pratice is restricted by the extra K fertilizer applied with the compost and the high labour requirements of compost-making.

SOIL CONSERVATION

Sanchez (1979) pointed out that in udic soil moisture regimes, where there is no prolonged dry season, soil erosion is less of a problem than in ustic regimes, since there is usually a plant cover protecting the soil throughout the year. Visual sheet or gully erosion in udic areas of tropical America and in other similar regions is mostly caused by civil engineering, roads, farm pathways, and improperly designed drainage and sewage outlets rather than agronomic mismanagement. These observations do not imply that erosion is not important in udic regions, but that it is more extensive and critical in regions marked by ustic or aridic soil moisture regimes.

The best method of erosion control is soil and crop management practices that minimize water runoff and improve water infiltration (Lal, 1980). The low input legume-based pasture systems keep the soil protected by a plant canopy year-round, providing good erosion control even in sloping areas. There are other viable strategies such as changing from annual to permanent crops like rubber and oil palm (Alvim, 1977). Continuous cultivation of annual crops under moderate to high fertilizer inputs to correct acid soil infertility, where economics and infrastructure considerations make it feasible, is also a good soil conservation practice since the soil is protected almost year-round.

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CONTINUOUS CROP CULTIVATION IN ACID SOILS OF THE AMAZON BASIN OF PERU

Dale E. Bandy and Pedro A. Sanchez
North Carolina State University, Raleigh, USA

INTRODUCTION

The humid tropics, covering about 10 percent of the world's land surface, will play an important role in supplying the 200 million hectares of additional land that must be cleared and put into food production by the turn of the century in order to maintain the present per capita food consumption according to FAO (1978). Many of these marginal land areas have climatic conditions suitable to support year-round crop production but encounter severe soil constraints. In the past the management of these tropical soils for sustained and efficient food production has mainly produced well documented failures because of the tendency to directly transplant temperate region soil management technology to the humid tropics. The purpose of this paper is to present crop and soil management practices that show promise for the development of the Amazon basin of south America and that are based primarily on research conducted by the Instituto Nacional de Investigación y Promoción Agraria and North Carolina State University in Yurimaguas, Peru.

SOILS OF THE AMAZON BASIN

The prevailing climatic conditions of the humid tropics favour the development of deep, highly leached soils with low reserves of weatherable material characterized by kaolinitic and oxidic clay minerals. Most of these soils are classified as Oxisols and Ultisols which together cover 75 percent of the Amazon basin (Table 1). Next in abundance are the poorly drained alluvial soils which cover 15 percent of the region located either in flood plains (várzeas or restingas) or in palm swamps (igarapés, aguajales). Alluvial soils developed from the sediment-rich rivers originating in the Andes are usually high in native fertility whereas alluvial soils developed from materials of the ancient Guiana and Brazilian shields are often low in native fertility. Approximately 40 million hectares of the Amazon basin are well drained with moderate to high native soil fertility such as Alfisols, Mollisols and Vertisols (Cochrane & Sanchez, 1981).

The main soil limitations in the Amazon basin using the

Table 1. General distribution of major kinds of soils in the Amazon basin

General soil grouping	Million ha	% of Amazon basin
1. Acid, infertile soils (Oxisols and Ultisols)[a]	362	75
2. Poorly drained alluvial soils (Aquepts, Aquents, Gleysols)	66	14
3. Moderately fertile, well drained soils (Alfisols, Mollisols, Vertisols, Tropepts, Fluvents)	40	8
4. Very infertile, sandy soils (Spodosols, Psamments, Podzols)	16	3
Total	484	100

[a] Soil Taxonomy or FAO terminology in parentheses
Source: calculated from data by Cochrane and Sanchez (1981)

Fertility Capability Soil Classification System (Buol et al., 1975) and the CIAT study (Cochrane & Sanchez, 1981) are described in Table 2, showing that the most extensive soil constraints are chemical, rather than physical. The most serious disadvantages for the Oxisols and Ultisols are their low phosphorus availability (90 percent) and strong acidity or high aluminium toxicity (73 percent), low reserves of

Table 2. Summary of main soil-related constraints in the Amazon basin under native vegetation

Soil constraint[a]	Million ha	% of Amazon basin
Phosphorus deficiency	436	90
Aluminium toxicity	352	73
Low potassium reserves	271	56
Poor drainage and flooding hazard	116	24
High phosphorus fixation	77	16
Low cation exchange capacity	71	15
High erodibility	39	8
No major limitations	32	7
Steep slopes (>30%)	30	6
Laterite hazard if subsoil exposed	21	4
Shallow (<50 cm deep)	3	1

[a] Also nitrogen, sulphur, magnesium and zinc deficiencies plus temporary drought stress are widespread, but cannot be quantified with data
Source: adapted from Cochrane and Sanchez (1981)

primary minerals such as potassium (56 percent), and low effective cation exchange capacity (15 percent of the soils). In practical terms this suggests that lime and most plant nutrients will have to be regularly applied for sustained food crop production systems. The low cation exchange capacity indicates few negative charges in the soil capable of retaining nutrient cations such as calcium, potassium and magnesium. Consequently, when these nutrients are applied they can be rapidly lost by leaching. Also, low CEC soils are poorly buffered which means that even moderate doses of lime and fertilizer may affect the behaviour of other soil properties. For example, overliming induces manganese deficiency and potassium applications can trigger magnesium deficiency by creating nutrient imbalances (NCSU, 1978; Villachica, 1978). Thus it is more difficult to maintain an adequate fertility level in these soils than in soils with a higher cation exchange capacity.

Another important disadvantage of these soils is their relatively low water-holding capacity. Although the soils are very deep and lack physical barriers to root penetration, aluminium saturated subsoil conditions present a chemical barrier to root development. Most annual crops are severely limited in their capacity to penetrate these acid subsoils in order to exploit available water during drought periods which occur even during the rainy season.

Oxisols and Ultisols, however, also have favourable characteristics. For example, they withstand mechanized agricultural production systems because of their good to excellent physical properties and topography. They are easily tilled, rarely suffer from excess soil moisture, and are not highly erodible unless left unprotected by vegetative cover for extended periods of time.

The main limitations of poorly drained alluvial soils are related to the height of the perched water table and to their flooding hazard. These soils are economically important due to their usual location near the natural transport and communication system in the Selva - the rivers - and their moderate to high native fertility, which results in lower fertilizer requirements to sustain permanent crop production. The main requirement is the selection of crops that are adapted to poorly drained conditions or the construction of water management systems that will either facilitate drainage and/or decrease flooding hazard.

CONSTRAINTS TO ANNUAL CROP PRODUCTION

Agronomic management of annual crops under humid tropical conditions may be more easily understood than tropical soils management but poor crop agronomy can also result in failures to develop sustained and efficient food production systems. The economically most important annual food crops for the Amazon basin are rice, maize, soybean, groundnut, cowpea, cassava and plantain.

Rice *(Oryza sativa)*. The principal limiting factor to both lowland and upland rice preduction at Yurimaguas is the blast disease caused by *Pyricularia oryzae*. Another important disease problem is brown leaf spot caused by *Helminthosporium oryzae*, particularly when potassium availability and/or soil moisture are limiting. With an upland rice variety, good soil fertility and moisture conditions experimental grain yields of 4.5 tons/ha have been obtained on an Ultisol and over 6 tons/ha on alluvial soils at Yurimaguas (NCSU, 1972-82; Sanchez & Nureña, 1972).

Maize *(Zea mays)*. The main limiting factors to efficient maize production are related to climatic, disease and insect stresses. The prevalent disease and insect problems in the area are leaf blight caused by *Helminthosporium* sp., kernel dry rot caused by *Diplodia* sp., and European corn borer *(Ostrinia nubilalis)*. Low solar radiation (average 335 langleys/day), relatively short days (11.5-12.5 hours/day) and high night temperatures (›20°C) affect photosynthesis - lowering the rate and efficiency - and the distribution of photosynthates, thus decreasing the availability of carbohydrates for grain filling. In addition, poor root distribution due to subsoil acidity can cause plants to lodge if short statured varieties are not used.

Soybean *(Glycine max)*. The diseases frog eye spot caused by *Cercospora sojina*, ped and stem blight caused by *Diaporthe phaseolorum* var. *sojae* and purple stain caused by *Cercospora kikuchii* can reduce yields and/or seed quality drastically when cloudy humid conditions exist during the ped filling stage. An important aspect is the selection of genotypes with good seed viability and storage capacity.

Groundnut *(Arachis hypogaea)*. One problem with groundnut is the incidence of thrips, probably *Scirtothrips dorsalis* and *Frankliniella schultzei* that can transmit serious virus diseases. There is little concern for rust caused by *Puccinia arachidis* and black spot caused by *Cercospora* sp. since resistance is present in many native Peruvian cultivars. Black spot, however, is an important constraint in imported cultivars. In addition, high K levels in the soil can reduce the incidence of *Cercospora* during the ped filling stage. Low calcium levels contribute to empty pods which can reduce yields.

Cowpea *(Vigna unguiculata)*. The main limitation to cowpea yields is excessive rainfall during the pod filling stage which can cause fungal infestations by *Choanephora curcurbitarium* and others on the plant and ped and reduce grain yield essentially to zero. Otherwise they are well adapted to an acid infertile soil environment.

Cassava *(Manihot esculenta)*. Experience in the Amazon basin indicatos that cassava is adapted to extensive areas of Oxisols and Ultisols because of its tolerance to low levels of nutrients, high acidity and high amounts of Al and Mn. The major disease problem found in this area is superelongation caused by *Sphaceloma manihoticola*.

Plantain *(Musa paradisiaca)*. This crop is well adapted to Amazon conditions, but its continuous production is often affected by root-knot nematodes.

DEVELOPMENT OF A CONTINUOUS CULTIVATION TECHNOLOGY

Continuous cropping systems are needed for the more fertile soils of the region, because of their proximity to natural transportation systems plus the lower requirement of soil amendments, as well as for the predominant upland soils consisting of Oxisols and Ultisols. At present shifting cultivation is almost the only food crop production system of the Amazon basin. Small farmers slash and burn 1 or 2 hectares of forest and grow a monocultural crop of rice. The second crop is usually an intercroppod combination of maize, cassava, plantain and pineapple after which the fields are abandoned to forest regrowth. For alluvial soils the principal reason for shifting to new sites is weed control whereas for upland soils it is the decline of soil fertility derived almost entirely from the ash of the burned vegetation. Although shifting cultivation in its traditional form is ecologically sound (Nye & Greenland, 1960), it is also a guarantee of perpetual poverty for those farmers who practice it (Alvim, 1978).

In spite of the fact that average yields are low, shifting cultivation can be considered efficient because of the return per unit of labour and the low requirement of agricultural inputs. The system conserves the ecological balance when there is a high land to population ratio but, when population densities increase due to spontaneous or directed colonizations the fallow period is shortened thus breaking the process of soil fertility regeneration. This converts an ecologically sound farming system into an unstable, unpreductive one which is also ecologically damaging.

Research location

Yurimaguas (5°45′S, 76°05′W, 184 m above sea level) has a mean annual temperature of 26°C and a mean annual rainfall of 2 100 mm well distributed throughout the year, with 3 months averaging 100 mm and the others about 200 mm.

The properties of the two major kinds of soils are shown in Tables 3 and 4; their distribution corresponds with the two geomorphologic surfaces encounterod in the surrounding area. The Ultisol is found on the mainly flat uplands about 10 m above river level and has a sandy

Table 3. Poperties of the Yurimaguas Ultisol (Typic Paleudult) used in the continuous cropping experiment prior to clearing

Depth	Clay	Sand	pH 1:1H_2O	Org. C	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Al	ECEC	Al Sat.
cm	%	%		meq/100 ml						%
0 - 5	6.4	80.2	3.8	1.25	0.84	0.37	0.20	2.05	3.49	59
5 - 13	10.1	69.6	3.7	0.84	0.05	0.03	0.04	2.63	2.76	95
13 - 43	14.9	61.0	3.9	0.42	0.05	0.03	0.03	3.11	3.24	96
43 - 77	16.6	57.2	4.0	0.29	0.03	0.01	0.02	3.12	3.20	98
77 - 140	24.8	50.6	4.1	0.18	0.03	0.01	0.03	4.48	4.58	98
140 - 200	24.1	53.7	4.4	0.17	0.06	0.03	0.04	3.80	3.94	96

Source: NCSU (1974)

Table 4. Properties of an alluvial soil profile (Typic Tropaqualf) found on the first main geomorphologic surface described at the Yurimaguas Experiment Station

			pH	Exchangeable						Al
Depth	Clay	Sand	1:1H_2O	Al	Ca	Mg	K	Na	ECEC	Sat.
cm	%	%		meq/100 ml						
0 - 8	18	30	4.3	0.3	10.0	1.9	0.2	0.1	12.5	2
8 - 15	24	24	3.1	1.9	9.4	2.4	0.1	0.1	13.9	14
15 - 30	30	17	4.3	4.5	11.1	4.2	0.3	0.2	20.3	22
30 - 50	24	34	4.9	6.3	10.6	4.4	0.2	0.2	21.7	29
50 - 75	18	52	5.2	3.2	8.9	3.5	0.2	0.2	16.0	20
75 - 100	19	62	5.4	0.8	8.3	2.9	0.2	0.2	12.4	6
100 - 130	12	75	4.8	0.3	6.0	1.3	0.1	0.1	7.8	4

Source: NCSU (1974)

Table 5. Yield decline due to continuous monocropping with adequate fertilization at Yurimaguas, Peru

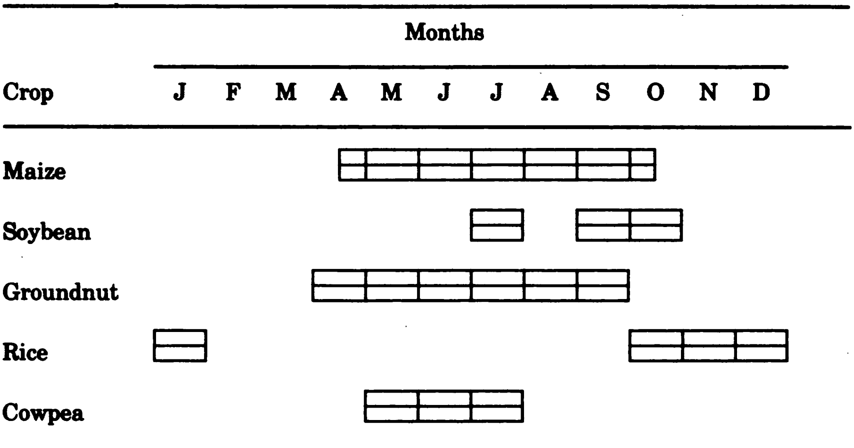
Crop	Sequence of monocrops					
	1	2	3	4	5	6
	Grain yields (tons/ha)					
Maize	4.0	4.4	2.7	1.5	1.7	1.6
Rice	3.9	3.3	3.1	2.5	1.4	1.3
Soybean	3.4	2.5	3.5	3.4	2.2	1.0
Groundnut	3.3	3.0	2.5	2.0	2.5	2.1

Source: Valverde and Bandy (1981)

loam surface over a clay loam subsoil. The Alfisol is found on the flood plains, is poorly to moderately drained, and has a silty clay loam surface layer with clay contents increasing with depth.

The climate permits the cultivation of three annual food crops per year. Several cropping systems and time-of-planting studies were conducted at Yurimaguas with maize, soybean, groundnut, rice and cowpea to determine the most promising three crops per year systems. Table 5 shows that continuous monoculture of the same crop did not preduce sustained yields because of the adverse effects of climate and a population increase of the various pathogens (Valverde & Bandy, 1981). Many of the constraints encountered in continuous monoculture

Table 6. Recommended planting dates for maize, soybean, groundnut, rice and cowpea in the Yurimaguas area



Source: Valverde and Bandy (1981)

have been eliminated by using crop rotation. In addition, planting date experiments show a strong correlation with the rainfall pattern. Table 6 shows the recommended planting dates for the main food crops in Yurimaguas. The most promising results so far have been obtained by growing three crops per year rotations (upland rice-maize-soybean or upland rice-groundnut-soybean). Most recently a two-year rotation of six crops has been initiated in Yurimaguas. It consists of rice-rice-cowpea-rice-groundnut-cowpea. The reason for the two-year rotation is to ensure that no build-up of mole crickets (*Gryllotalpa* sp.) occurs in the rice-rice sequence. The two-year rotation should also control any increase in the population of nematedes that can attack groundnut or cowpea, especially the *Pratylenchus* species.

Figure 1A shows the grain yields of 21 consecutive crops harvested from the same field since it was cleared by slash-and-burn in October 1972 and grown to the rice-maize-soybean rotation. Without fertilization yields dropped to zero after the third consecutive crop. With "complete" fertilization, the long-term average of this rotation, which was replicated in three fields, is 7.8 tons/ha/year of grain. The upland rice-groundnut-soybean rotation was also successful (Figure 1B), and perhaps more appropriate because of the higher yield potential of groundnut relative to maize in this environment. Maize suffers more from the effects of low solar radiation and high night temperatures, and from insect attacks than the other three crops. Figure 2 shows the long-term average yields of 88 harvests of these four crops with or without adequate fertilization during the last eight years. Upland rice, soybean and groundnut yields are excellent, but maize yields are moderate. Figure 2 also indicates a reasonable yield stability for the four crops. These results show that continuous production of these annual food crops can be achieved in the Amazon basin with adequate fertilization.

Soil fertility dynamics under continuous cultivation

The term "adequate fertilization" deserves scrutiny because it took about four years to understand the changes in soil properties that took place after clearing and burning a 17-year-old secondary forest and growing annual crops continuously.

The nutrient dynamics were monitored by sampling soils after each harvest and analyzing for pH, organic carbon, total nitrogen, exchangeable aluminium, effective CEC, available phosphorus, exchangeable potassium, calcium and magnesium, and available zinc, coppor, iron and manganese (see Fig. 3). Sulphur, boron and molybdenum were determined periodically by plant analysis. Such records have been kept for three fields cleared in 1972, 1973 and 1974. They include several fertility treatments with four replications. Of special interest is the "check" which has never received fertilizer and the "complete" which received what we then considered the best fertili-

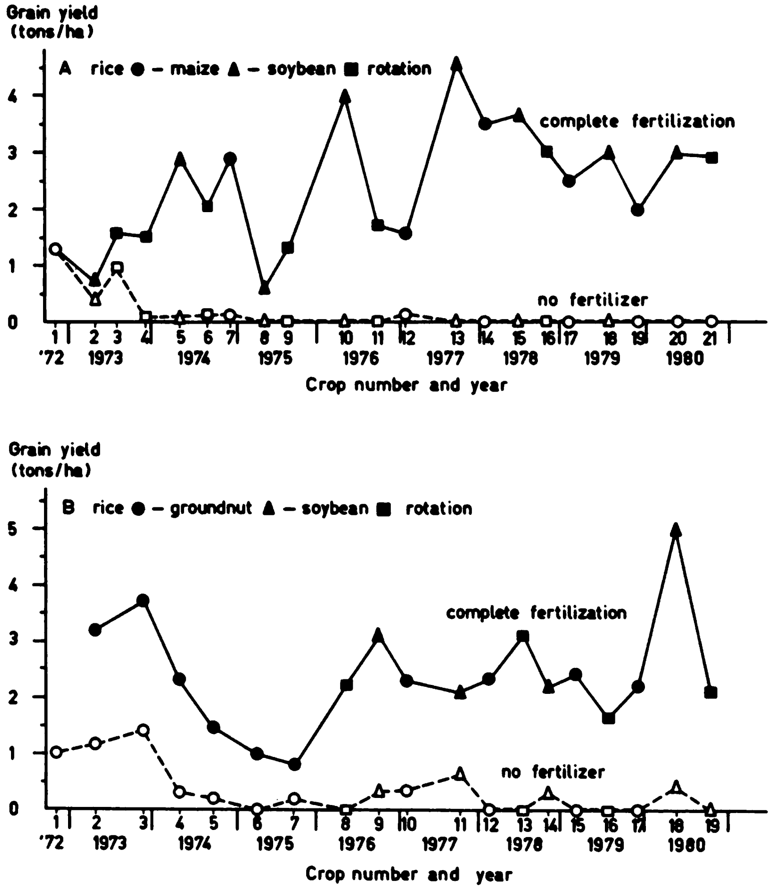


Fig. 1. Yield record of two continuously cultivated plots on an Ultisol of Yurimaguas, Peru with and without fertilization. Source: NCSU (1982).

zation practice based on soil tests and accumulating experience. The appearance of the first signs of nutrient deficiencies and the intensity of the symptoms varied between the three fields even though they were near each other, within one soil mapping unit, and in a similar landscape position, and had the same pre-clearing vegetation. The intensity of the burn is considered a factor contributing to this variability. A generalized summary of nutrient dynamics is as follows. Ash from the burn produced a temporary increase in soil fertility as reflected by increases in pH, available nitrogen, phosphorus, potassium, calcium, magnesium and some micronutrients plus a decrease in exchangeable aluminium to below-toxic levels. As a result upland rice, the first crop planted, did not suffer from fertility limitations. At about

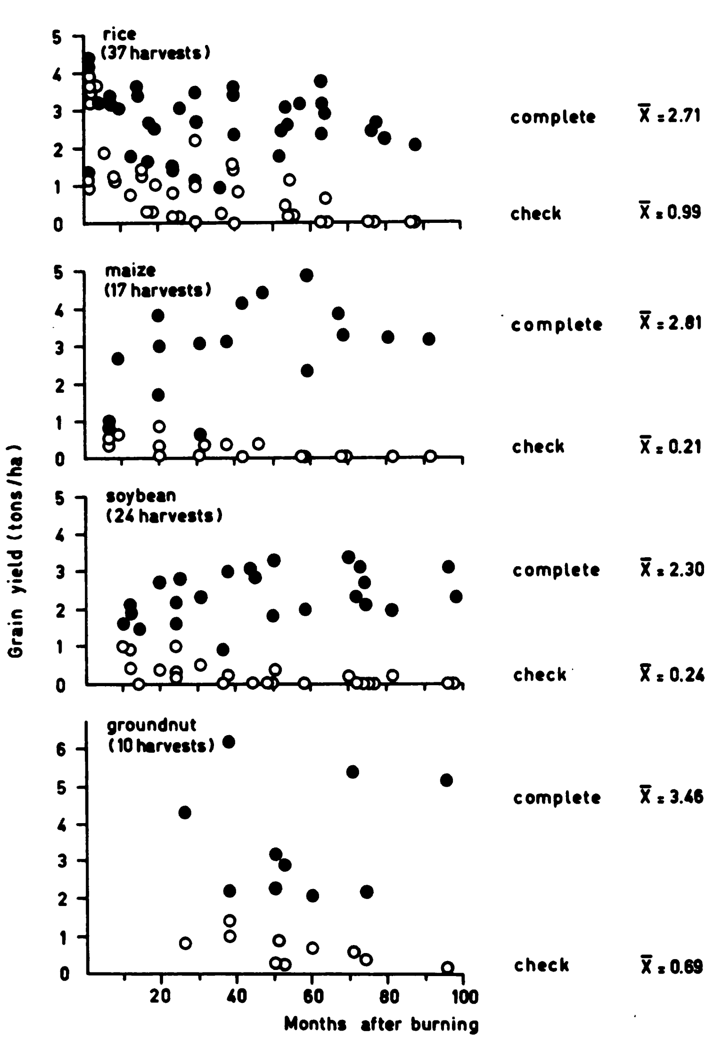


Fig. 2. Crop yields as a function of time after clearing with (•) and without (o) fertilization. Yurimaguas (1972-1980). Source: NCSU (1982).

eight months after clearing, however, the levels of available nitrogen and potassium were reduced such that deficiency symptoms of these two elements appeared along with sporadic sulphur, copper and boron deficiencies. Organic matter contents in the topsoil decreased sharply during the first year with a decomposition rate of 25 percent per year. From the second year organic matter contents reached a new equilibrium level. The rapid organic matter decomposition probably released many H^+ ions that acidified the soil and increased

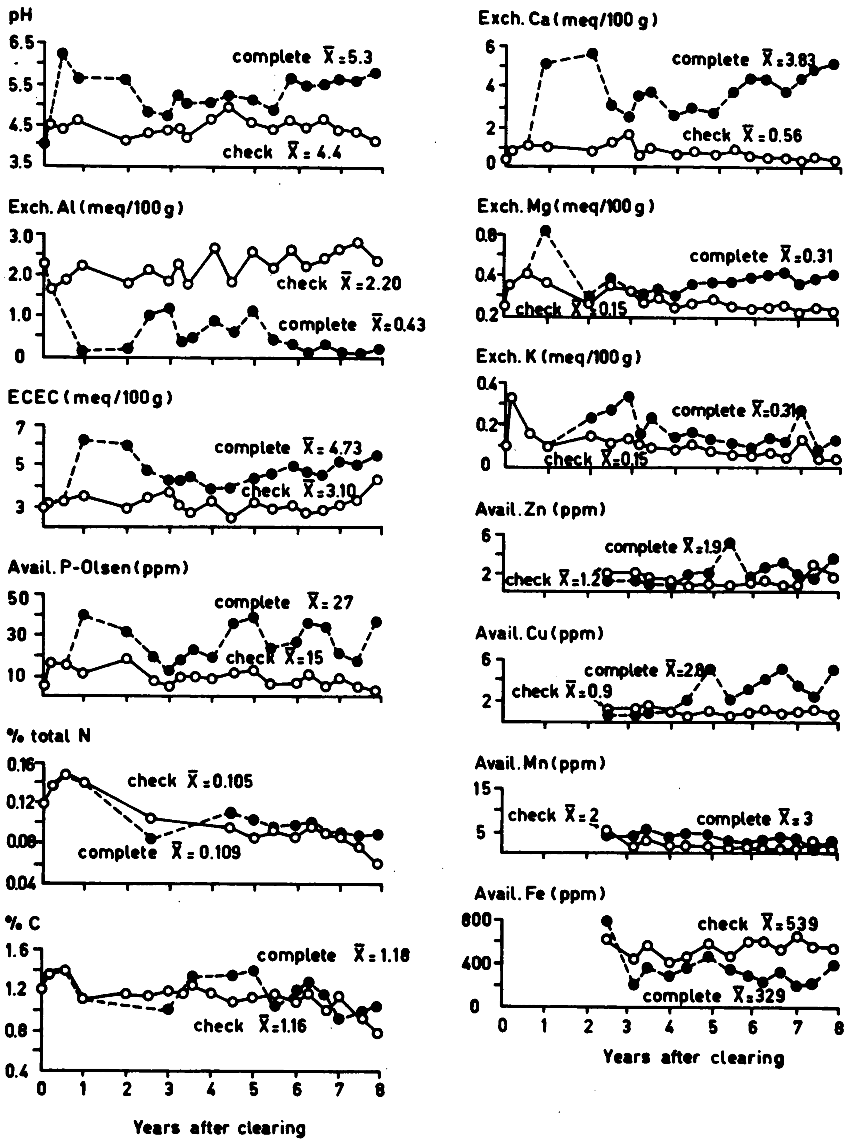


Fig. 3. Soil fertility dynamics after converting a forest fallow Ultisol into continuous crop production with (●) and without (o) fertilization. Yurimaguas (1972-1980). Source: NCSU (1982).

exchangeable aluminium to toxic levels, reversing the liming effect of the ash.

Phosphorus and magnesium became deficient during the second year, calcium within the first 30 months, zinc during the fourth year, and manganese deficiency is suspected during the eighth year. Molybdenum deficiencies were detected sporadically in grain legumes, particularly when seed produced in acid soils of the Amazon basin was used, but not when seeds came from more fertile soils of the Peruvian coast. After eight years of continuous cultivation, therefore, this Ultisol has shown deficiency of all essential soil nutrients except for iron and chlorine.

In the "complete" treatment, fertilizers and lime were added according to soil test recommendations. During the second or third year, however, all yields began to decline rapidly in the "complete" treatments. Soil analysis identified two factors responsible for this decline: a shorter than expected residual effect of the lime applied, and the triggering of magnesium deficiency induced by potassium applications resulting in K/Mg imbalance (Villachica, 1978). After these factors were corrected, crop yields have stabilized as shown in Figures 1 and 2. Thus, a monitoring of the nutrient dynamics during the period when the soil was undergoing a transition from forest to cropland provided the key for continuous cultivation. It is relevant to point out the value of long-term field research: the key problems did not develop until the second to third year, and estimates of sustained yields required at least seven years.

The fertilizer needs for intensive continuous cultivation of this soil are substantial, but similar to those requirod for crop preduction in

Table 7. Fertilizer requirements for the continuous cultivation of 3 crops per year (rice-maize-soybean or rice-groundnut-soybean) in an acid Ultisol of Yurimaguas

Input[a]	Rate	Frequency
Lime	3 tons/ha	Once every three years
N	60-100 kg N/ha	Rice and maize respectively, split applied
P	25 kg P/ha	Every crop
K	100 kg K/ha	Every crop, split applied
Mg	25 kg Mg/ha	Every crop, unless dolomitic lime is used
Cu	1 kg Cu/ha	Once a year or once every two years
Zn	1 kg Zn/ha	Once a year or once every two years
B	1 kg B/ha	Once a year
Mo	20 g Mo/ha	Mixed with legume seeds only

[a] Ca and S requirements are covered by the application of lime, simple superphosphate and Mg, Cu and Zn carriers

other Ultisols. After the first crop, which normally does not require chemical inputs, the scheme responsible for producing the high yields obtained is shown in Table 7. Like all sound fertilizer recommendations they are site-specific and thus only applicable to the soil and cropping system concerned. In other soils, recommendations should be based on local soil analysis. Nevertheless, Table 7 - developed after some 8 years of cultivation - gives an indication of the level of input required for continuous crop production in Ultisols. It also should be emphasized that these fertilizer levels do not differ substantially from those of maize, soybean, and groundnut grown in Ultisols of southeastern United States. On a yearly basis, the total amounts are somewhat higher in the Amazon basin because three crops a year are grown instead of one.

Effects of chemical and physical soil properties

The issue of soil degradation with cultivation in the humid tropics is one of common concern in the literature (Goodland & Irwin, 1975; McNeil, 1964). Our results, however, indicate just the contrary: soil properties improve with intensively managed, appropriately fertilized continuous crop production systems. Table 8 shows that after 20 consecutive crop harvests, the topsoil pH increased from a very acid 4.0 before clearing to a favourable level of 5.7. Organic matter contents decreased by 27 percent most of which occurred during the first year. Exchangeable aluminium decreased from very high levels to negligible amounts, decreasing aluminium saturation on the exchange sites from a toxic level of 82 percent to a negligible 1 percent. Exchangeable calcium levels increased twentyfold as a result of lime applications. Exchangeable magnesium levels doubled but this figure fluctuates with time. Exchangeable potassium levels did not increase in spite of large quantities of K fertilizer applied, suggesting rapid utilization by crops and perhaps leaching losses. Effective CEC, a measure of the soil's capacity to retain cations against leaching, doubled as a consequence of the pH-dependent charge characteristics of the kaolinite clay and iron oxides. Fertilization also increased available P levels from below the critical level of 12 ppm P to values substantially above it. A similar trend was found for zinc and copper. Available manganese levels, however, decreased suggesting the possibility of manganese deficiency. Available iron levels remained considerable above the critical range of 20-40 ppm. On the whole, these changes are indicative of an improvement in the topsoil's nutrient status.

No unfavourable changes in soil physical properties have been detected thus far because of the protection three well fertilized crops per year provide against the rainfall impact. Although crop residues are left in the field until the experimental plots are tilled again in preparation for the next planting, the soil is exposed for a period of up to 30

Table 8. Changes in topsoil (0-15 cm) properties after eight years of continuous cultivation of 20 crops of upland rice, maize and soybean with complete fertilization in Yurimaguas, Peru

Time	pH	Org. Matter	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	ECEC	Al Sat.	Available P	Available Zn	Available Cu	Available Mn	Available Fe
		%	meq/100ml					%	ppm				
Before clearing	4.0	2.13	2.27	0.26	0.15	0.10	2.78	82	5	1.5[a]	0.9[a]	5.3[a]	650[a]
94 months after clearing	5.7	1.55	0.06	4.98	0.35	0.11	5.51	1	39	3.5	5.2	1.5	389

[a] 30 months after clearing
Source: NCSU (1982)

days until a crop canopy is established. Occasional run-off losses have been observed with no apparent effect on yield.

Severe surface compaction, however, is rampant in the continuously cultivated plots without fertilization, because the very weak crops do not develop a complete canopy. Continuous cultivation without fertilization, therefore, can cause severe soil erosion.

Acid infertile subsoils of Oxisols and Ultisols frequently act as a chemical barrier to root development. Crop roots are unable to enter a subsoil highly saturated with aluminium ions and very low in exchangeable calcium (Bandy, 1976; Gonzalez et al., 1979; Ritchey et al.,

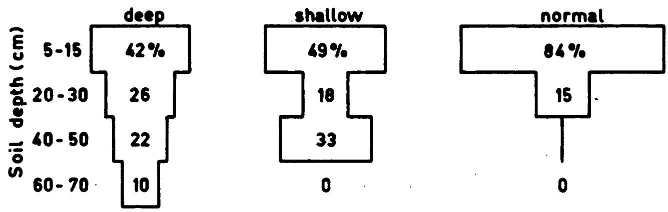


Fig. 4. Percent root distribution of maize (dry weight basis) as affected by depth of lime placement. Source: NCSU (1980).

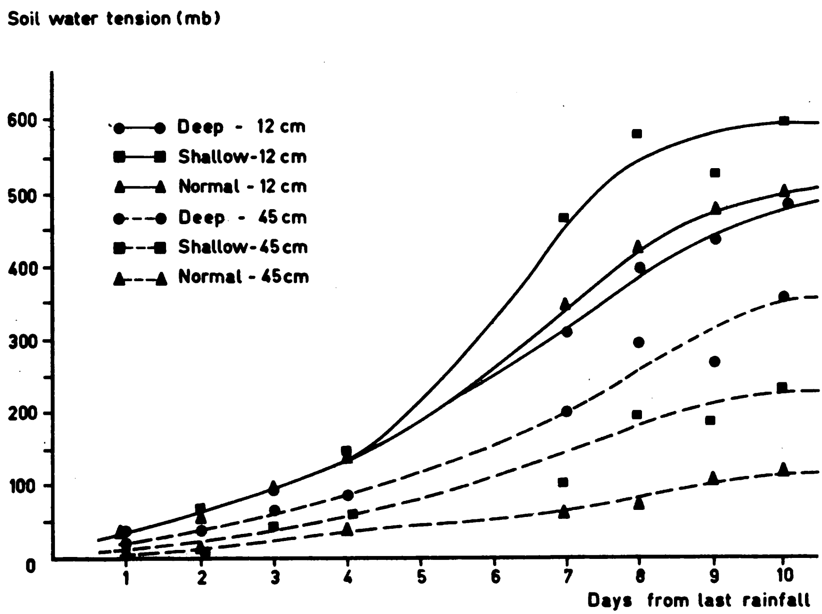


Fig. 5. Soil water tension at 12 and 45 cm depths for three lime treatments. The ten days of stress occurred during the dry season planting (August 5-25, 1978). Source: NCSU (1980).

1980). This situation produces shallow root systems (Fig. 4) which often result in plants suffering from drought stress during rainless periods while the subsoil has plenty of available water. An example of soil water use at 12 and 45 cm depths by the maize plant during a 10-day dry period in August, 1979 is shown in Figure 5. At 12 cm depth, the shallow lime and normal treatments had soil water tensions approaching 600 mbars, while their subsoil water tension stayed below 250 mbars. This low value suggests that little subseil water was being used by plants to roduce plant water stress. The deep-liming treatment showed a more even distribution of soil water use by maize through the 45 cm layer. There was a minimum of 8.0 mm more soil water used by the plants on the deep-lime plots; that amount equals 2 to 3 days of evapotranspiration from maize plants.

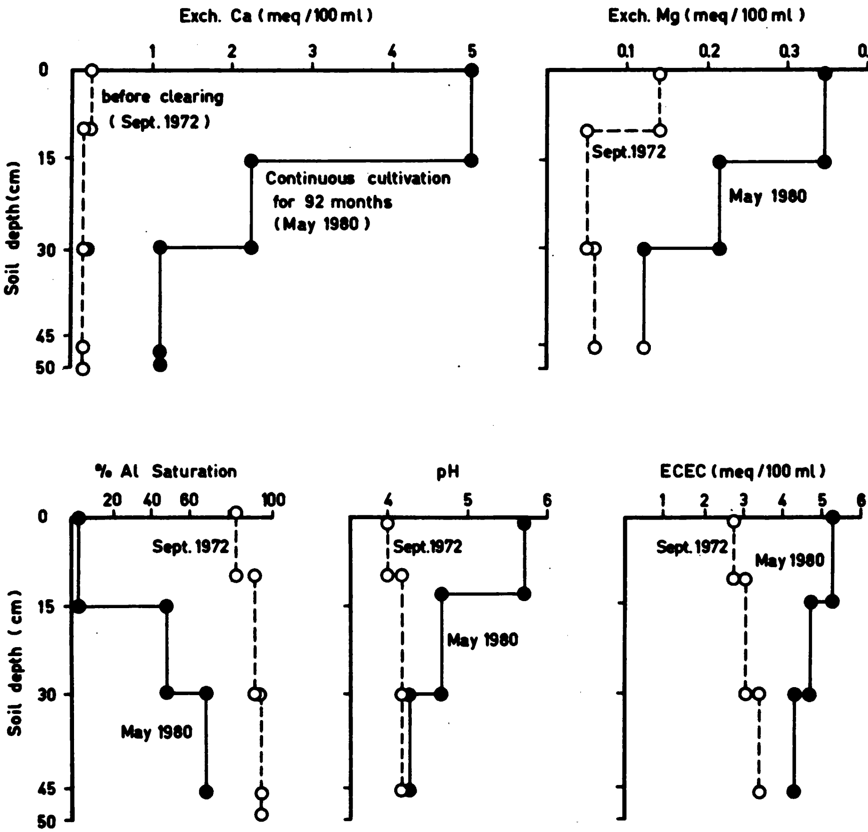


Fig. 6. Effects of eight years of continuous cultivation with fertilization on the improvement of subsoil chemical properties in an Ultisol of the Amazon basin of Peru. Source: NCSU (1982).

We have observed that these chemical subsoil constraints are alleviated with time. Figure 6 shows significant increases in calcium, magnesium and effective CEC in subsoil layers of 15-45 cm depth as well as a decrease in aluminium saturation. The lime and fertilization scheme promoted the downward movement of calcium and magnesium, which resulted in a more favourable environment for root development than before clearing. Appropriate fertilization and continuous cultivation, therefore, improved rather than degraded this Ultisol of the humid tropics.

Technology validation in farmer fields

By 1979, results from formal experiments appeared to have sufficient practical applicability to test them at the farm level. A series of demonstration plots were established in shifting cultivator's fields within an 80 km radius of Yurimaguas. Three crop rotations were tested with an equivalent of the "complete" treatment adjusted by on-site soil tests (Mesia et al., 1979). Results to date, summarized in Table 9, show high crop yields with total annual grain production ranging from 6 to 10 tons/ha/year. Individual crop yields were similar to those obtained at the station. The tests have expanded and farmers are increasingly attracted by the prospect of increasing yields from their traditional average of 1 ton/ha per year by six to ten times while avoiding the need to clear new land every year.

Given the favourable Peruvian government response to what is now being called "the Yurimaguas technology" the local availability of fertilizer and credit has increased and marketing facilities have improved. A few farmers are using the continuous cropping technology,

Table 9. Results of extrapolation trials around Yurimaguas. Means of 8 farmer fields

	Crop rotation		
Crop no.	Maize Groundnut Maize	Groundnut Rice Soybean	Soybean Rice Groundnut
	Grain yields (tons/ha)		
First	4.8	1.6	2.3
Second	1.6	3.9	2.0
Third	4.1	2.8	2.2
Total	10.5	8.3	6.5

Source: NCSU (1982)

and are planting areas larger than one hectare. To do so outside labour or hand tractors were hired by the farmers. It is too early, however, to ascertain the performance of these pioneers who are changing from shifting to continuous cultivation.

Continuous cultivation in alluvial soils

As was stated earlier in this paper another important area for intensive annual crop production in the Amazon basin are those alluvial soils not subject to flooding due to their inherent native fertility status and proximity to natural transportation systems. Rotations of three crops per year are presently producing excellent yields in farmer field trials with much lower inputs of fertilizers and lime (NCSU, 1980). In addition research is now in progress in studying the most adaptable paddy rice production system. Again the emphasis is on maximum production using both paddy rice systems and crop rotations of maize, soyboan, and cowpea with paddy rice where the soils are moderately well drained and/or where suitable drainage systems have been constructed.

Alternative crop production systems

Once the soil dynamics were reasonably understood the project began looking into developing technology for other alternative land uses with emphasis on systems requiring lower levels of chemical inputs, on legume-based pastures and agroforestry. Figure 7 illustrates some of these alternatives.

Economic studies pointed out that on Ultisols decreasing the levels of fertilization is likely to increase economic returns. Present research includes the use of organic inputs, rock phosphate, improved nitrogen and potassium efficiency, selection of crop varieties for tolerance to soil acidity and low levels of available phosphorus thus decreasing the need for lime and phosphorus (NCSU, 1982).

Organic inputs such as mulch, green manures and compost have been studied in an attempt to see how far they can substitute or supple-

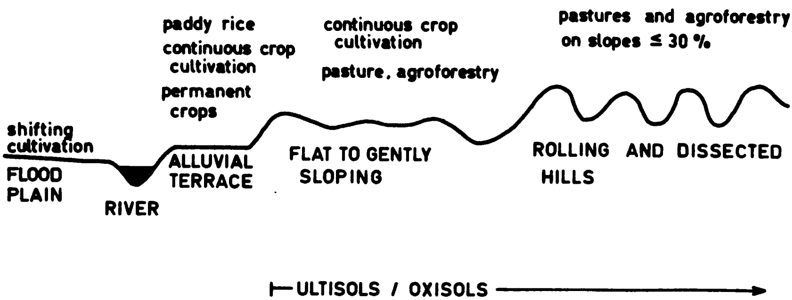


Fig. 7. Some alternative land use schemes of Amazonian landscapes according to soil and topographical conditions. Source: NCSU (1982).

ment chemical fertilizers. Mulching crops with residues from the previous crop or with *Panicum maximum* grass has produced unreliable results after over 20 experiments with generally detrimental results for upland rice, some positive yield increases in maize and little effect on soybean and groundnut (Valverde & Bandy, 1981). The use of kudzu *(Pueraria phaseoloides)* as a green manure has provided positive results, often attaining crop yields similar to complete fertilization (Wade, 1978). The labour involved in harvesting kudzu, transporting it and incorporating it by hand into the soil has made this an unattractive alternative. Making compost out of crop residues, however, appears more promising. For the first four consecutive crops, replacing complete fertilization with compost produced from crop residues resulted in a 20 percent yield roduction only. In order to maintain this rate, it was found to be necessary to apply potassium fertilizer with the compost. The potential use of this practice is restricted by the high labour requirements of compost making (Table 10).

Research is also in progress on the use of managed kudzu fallows as an intermediate stage between shifting and continuous cultivation. Kudzu has the capability of establishing itself on fairly impoverished soils, quickly developing a lush green canopy underlain by numerous nitrogen fixing nodules on its roots. After one or two years of fallow, kudzu can be killed by slashing with a machete and burning it. Reasonable crop yields have been obtained by rotating 2 crops with 1 to 2 years

Table 10. Relative crop yields from kudzu and maize stover compost as compared with complete fertilization

	Compost	
Crop no.	Maize stover	Kudzu
	%	%
1	99	90
2	90	108
3	68	70
4	94	84
5	35	52
6	46	20
Potassium applied:		
7	65	93
8	46	82
9	72	79
10	59	74

Source: NCSU (1982)

of kudzu fallow (NCSU, 1978). During the second rotation, it was again found that potassium was needed in order to obtain moderate crop yields.

Technology is also being developed for legume-based, low-input pasture production, primarily for the sloping areas of Ultisols, using acid-tolerant grass and legume species selected by CIAT's Tropical Pastures Program (Toledo & Serrão, 1981). Promising germplasm has been tested for adaptation in an Ultisol with pH 4.0 and 80 percent Al saturation adding only 25 kg P_2O_5/ha as simple superphosphate. Results so far show that the grasses *Andropogon gayanus, Brachiaria humidicola* and *B. decumbens* plus the legumes *Desmodium ovalifolium, Pueraria phaseoloides,* and a *Centrosema* hybrid (CIAT 438) are well adapted to the soil, climate, pest and disease constraints of the region. Grass-legume pastures are now being tested under grazing pressure but it is too early for conclusive results.

It is the belief of many scientists that the natural vocation of the Amazon basin is tree crop production and that ultimately a tree canopy should replace crop or pasture canopies. Research is being initiated to combine crop production systems at various input levels with promising tree species that can produce food, such as peach palm (chontaduro, pijuayo, pupunha, pejibaye), *Guilielma gasipaes,* oil palm *(Elaeis guineensis)* or pulpwood species such as *Gmelina arborea.*

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SUSTAINED TIMBER PRODUCTION IN THE TROPICAL RAINFOREST OF SURINAME

N.R. de Graaf
Centre for Agricultural Research, Suriname

INTRODUCTION

Agricultural use of the land includes forests, in particular managed forests more useful to man. Timber and other wood products are necessary commodities in our society and the threat of a substantial shortage of timber and wood in coming decades forces us to make timely decisions.

A local timber industry utilizing the primary forest was developed in Suriname after World War II. The gross area of accessible forest in the so-called Exploitable Forest Belt of Suriname is presented in Figure 1, and estimated to cover 1.5 million ha (Vink, 1970). First-class timber is rapidly becoming exhausted in this belt, with second-rate timber remaining for second harvests. This situation was already predicted in the fifties by the Suriname Forest Service. Beside regeneration treatment of the exploited forest, plantations of *Pinus caribaea* in

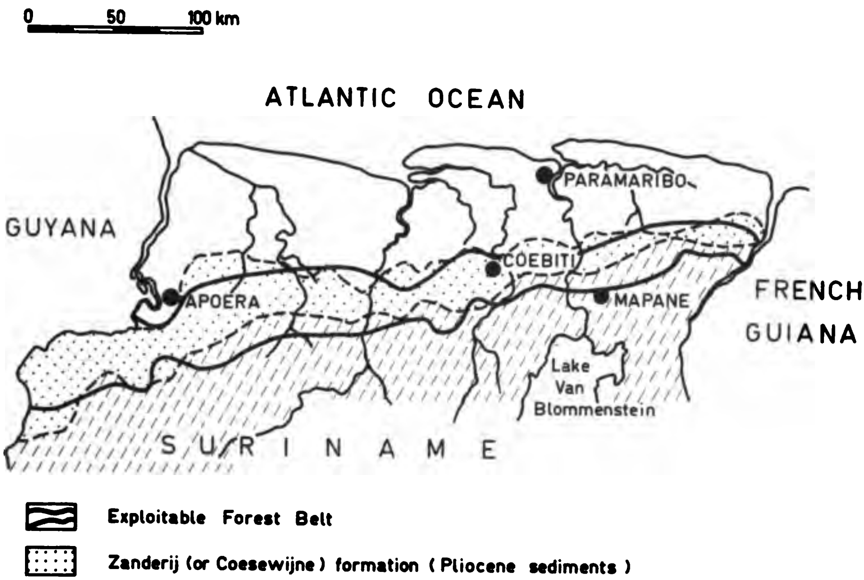

Fig. 1. Map of northern Suriname, indicating location of "exploitable forest belt" and Zanderij formation.

monoculture on 8 000 ha of cleared forest and line plantations in natural forest were attempted. High weeding costs, low annual volume increment (10 m^3/ha) and lack of a pulp wood industry forced termination of the pine planting efforts in 1978. Line plantations of valuable natural forest species like *Cedrela*, might be rewarding, provided the system is practiced intensively and on a small scale. The silvicultural system developed at the Centre for Agricultural Research (CELOS), which is based on natural regeneration, will yield a quality timber for second harvests at reasonable costs and in relatively short time. This silvicultural system is the subject of this paper.

THE NUTRIENT CAPITAL OF THE RAINFOREST ECOSYSTEM

In traditional forestry the nutrient "capital" present in the ecosystem received very little attention. Litter harvesting, for instance, was forbidden in European forests only when the negative effects were realized. Generally the soil was thought to have enough mineral reserves for sustained timber production. The traditional Malayan Uniform System as practiced in South East Asia, stresses the need for a permanent vegetation cover of the forest soils, but this was chiefly meant to minimize the dangers of soil degradation by erosion and insolation.

The possibilities of depleting the nutrient capital present in the tropical forest on acid low fertility soils have already received attention from both biologists and ecologists (Brünig et al., 1975; Stark, 1977). The tropical rainforest has developed a very efficient and closed system for the conservation of its nutrients. An important role is played by the tree roots that have mycorrhizas, i.e. an association between roots and fungi. These mycorrhizas probably enable the trees to extract nutrients directly from the undecomposed forest litter thus minimizing leaching losses. As a result the rainforest ecosystem on the acid infertile soils of the American humid tropics has built up and conserved a considerable amount of nutrients.

The dryland forest in Suriname

Table 1 gives an idea of the nutrients present in good Suriname dryland forest. From the data it appears that N is relatively abundant. There are many leguminous trees - among them various important commercial species - and it is assumed that the forest fixes aerial nitrogen. On the other hand, phosphorus is very scarce, and might be the most limiting growth factor. P, Ca, Mg and K together are for more than 70 percent present in the living phytomass. For K this percentage is even above 90!

Depleting the nutrients from such an ecosystem has considerable ecological and economical consequences. If some 200 tons/ha (71 per-

Table 1. Phytomass and mineral contents of the rainforest ecosystem at Kabo, Suriname*

	Phytomass	N	P	K	Ca	Mg
	tons d.w./ha			kg/ha		
Leaves	16.5	217	13	164	86	27
Branches	117.9	450	38	394	848	75
Stems	280.4[g]	811	51	712	1 716	139
Roots	65.3	561	37	246	272	50
Total living phytomass	480.1	2 039	139	1 516	2 922	291
Coarse litter[a]	22.6	82	4	13	99	12
Fine litter	12.2	149	5	30	112	18
Soil						
0 - 50 cm	79.8[e]	3 861 [b]	13[c]	66[d]	126[d]	40[d]
50 - 170 cm	49.5[e]	4 008 [b]	7[c]	47[d]	47[d]	43[d]
Total ecosystem	644.2	10 139	169[f]	1 672	3 306	404

[a] Including standing dead wood

[b] Total nitrogen

[c] Available P (P-Bray I)

[d] Exchangeable

[e] Soil organic matter

[f] Underestimation

[g] Stem volume ca. 375 m^3/ha (specific gravity 0.75)

* Most data are based on twelve 0.01 ha plots; soil data are from pits in the immediate vicinity

Source: adapted from Ohler (1980)

cent) of the stemwood would be removed in pulpwood harvesting, leaving crowns and roots, a large part of the nutrients would be lost from the ecosystem. Per hectare this would amount to 576 kg N (6 percent of the total), 36 kg P (22 percent), 506 kg K (30 percent), 1218 kg Ca (37 percent) and 99 kg Mg (24 percent). Assuming that these quantities could be replaced simply by applying commercial fertilizers, the corresponding costs at local prices would be more than US$ 1 600. Since pulpwood harvesting almost completely destroys the ecosystem, the remaining nutrients run a considerable risk of being lost before the vegetation has restored itself. Replenishment of the nutrients from the parent rock can be ruled out on the old deeply weathered soils under consideration. Replacing the entire nutrient capital of the forest ecosystem by fertilizers would cost US$ 14 000 per hectare. This nutrient capital, the production capacity of the forest, should not be sold or bartered away.

Quality or quantity?
Commercial fertilizing of forests, especially conifer forest, is practiced since long in, for instance, Sweden and the USA. Beside the increased volume preduction, an important argument for fertilizing older stands often is the increased value per unit volume when pulpwood-sized trees are stimulated to grow into timber-sized ones. The crucial question is what to grow, big volumes of a low-quality product or small volumes of a high-quality product. Personally I am of the opinion that here lies a clue for the partial solution of the problem of how to use the acid infertile soils of the humid tropics. As the conservation of nutrients present in the forest ecosystem is an important matter, one should not think in terms of producing bulk like pulpwood or charcoal, but in that of growing high-value timber of good size and in small quantities per hectare. The timber harvested today from the tropical rainforest commands high prices per cubic metre. These prices will continue to rise because of an increasing pressure on the producer, i.e. the forest. Last year, sawlogs of commercial species in Suriname were priced above US$ 100 fob per cubic metre roundwood. Such prices are high enough for sustained-yield management, also if harvesting, handling and transport costs are included. Even the cost of fertilizers to replenish the nutrients removed with the harvested timber could be borne as it would amount only to about US$ 10 per cubic metre.

The 20 m^3 of wood harvested every twenty years, wich our management system permits, do not constitute a large nutrient drain. In conserving nutrients, we believe our management system to be second to natural forest only. However, during the first cycles of the management an application of P and K might be necessary and effective.

If a total harvest for pulpwood or charcoal is chosen instead of a low-volume harvesting, a low-value commodity is obtained and exported from the area, removing most of the costly nutrients. Making such an area productive again, will require a series of expensive treatments, including clearing, ploughing, planting and perhaps fertilizing. If this follow-up is lacking - a likely future for large parts of deforested areas - the result will be a severely degraded vegetation with very little value other than soil cover. Further soil deterioration can be expected if such secondary vegetation becomes subject to periodic fires.

THE SILVICULTURAL SYSTEM DEVELOPED AT CELOS

In its approach to forest productivity the silvicultural systems as developed at CELOS differs from the classic evenaged plantation forestry that is practiced over most of Europe. It resembles more the selection forestry of some regions of that continent than the planted forest. In selection forestry a mixed stand comprising all sizes of trees is managed for the production of mainly big timber which is harvested in small quantities at a time; the smaller unwanted trees are regularly removed for silvicultural reasons mainly. The harvesting is very selective and the timber stand has a high value per hectare. Mayer (1968), comparing the management and financial results of evenaged with selection forestry, concludes in favour of selection forestry.

Contrary to the forest in Europe, the Suriname forest has a low value per hectare. In most unexploited forest areas only one fifth or less of the total stand consists of valuable species. Moreover, when harvesting the logs, a lot of damage is done to this hardwood forest with its wide-crowned trees. European selection forest always contains a high percentage of conifers, which - because of their narrow crowns - makes harvesting less destructive. Finally, the potentially harvestable annual increment in Suriname is less than one third of that of good selection forest in Central Europe.

Selection forest systems have the ecological advantage of a permanently large phytomass, though in Europe this is not as important as in the humid tropics. From a management point of view the main output of selection forest is timber-sized wood, resulting in lower harvesting costs per log. Planting is not practiced since the forest is fully capable of seeding itself where trees have been removed. Tending the forest stand remains necessary. Problems in selection forestry are, for instance, the scattered harvesting operations and the resulting damage, whereas overhead costs tend to be higher than with clearfelling or plantation forestry.

Cyclic cutting being essential, the low exploitable volume increments per hectare of the Suriname dryland forest forces us to increase the length of the harvesting cycle - which is five years in true selection forest - to twenty years. The close attention per tree of true selection systems cannot be afforded because of the low value per hectare. This stresses the need for silvicultural measures that will increase this value. Such measures should not aim at the production of large quantities of low-value wood. It must be emphasized that preduction and added value should be expressed not only per unit area - as is usually done in cultures - but also in terms of revenues per unit invested capital and labour.

Economic aspects

The costs per hectare of the CELOS silvicultural system are low. Roughly one third of the input is arboricide, the rest is labour. Total investment at 1978 prices, is US$ 140 per hectare for the first 20 years. At 8 percent interest rate this will amount to US$ 420 at the end of this period. With an estimated timber output of 20 m^3/ha the cost of this timber then is US$ 21 per m^3, which is far below the world market price, even when harvesting costs are added. This implies that at 8 percent interest rate the price in year 0 would be US$ 4.50 per m^3. In other words, this is the money to be spent or reserved in year 0 to produce 1 m^3 of timber in year 20. This price has to be compared with the present price for timber from the virgin forest. And this future timber crop is produced in an only partly modified forest leaving large parts of the original ecosystem intact and having much of the beneficial properties of primary forest.

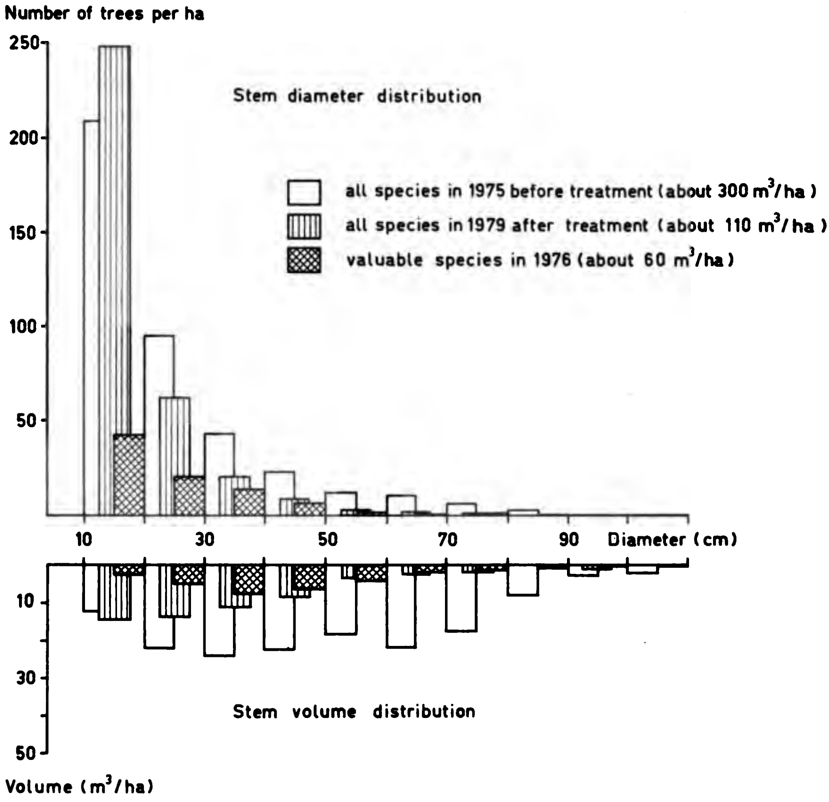

Fig. 2. Stem diameter and stem volume distribution of three categories of trees in an experimental forest plot in the Mapane Area, Suriname.

The structure of dryland forest

The data presented in Figure 2 for 16 ha of experimental forest in the Mapane Area of Suriname show that the original, lightly exploited forest comprises many small and only few large trees per hectare. This frequency distribution fits the "normal distribution" or the De Liocourt distribution. The decrease in numbers with increasing diameter can be calculated from the corresponding mathematical equation. Figure 2 also shows the number of trees per diameter class that were destroyed as a result of the first silvicultural treatment to achieve refinement. The corresponding stem volumes demonstrate the relatively small contribution of the large number of small trees and the importance of the large trees in this respect. The stem volume of the trees killed by the refinement appears more impressive than the number of trees. The valuable trees above 45 cm dbh (diameter at breast height) in this stand are of commercial size and could be economically harvested provided their total volume was not too small. This forest has already been exploited lightly in the sixties. Allowing for losses due to crooked stems, felling damage (breakage), hidden rot and others, about 10 m^3 are now available only. This is about half the standing volume.

The need for silvicultural measures

The silvicultural treatment of managed forest primarily aims at:
1) Increasing the growth rate of the valuable species by reducing the competition from the non-valuable ones.
2) Stimulating the recruitment of valuable species to replenish the stand with new individuals and to compensate for the individuals lost due to the harvesting of large trees.

In virgin forest there is a continuous process of trees growing and dying. Young trees fill the gaps left by the dead ones whether big or small. The virgin forest is dynamic though its total phytomass fluctuates very little.

Preliminary data from research carried out at CELOS indicate annual mortality rates in lightly exploited forest of 1-2 percent. These figures correspond well with data found elsewhere. The mean annual girth increment of all trees in the earlier mentioned forest stand in the Mapane Area ranges from 10 to 15 mm. Many trees grow faster, others do not grow at all: in virgin forest the tree stand is crammed.

The selective cutting as is practiced nowadays in the Suriname dryland forest removes 8-15 m^3 of timber-sized logs per hectare. That part of the forest that is disturbed - but not necessarily destroyed - is not so large that the forest is damaged "beyond repairs". A more intensive harvesting, however, removing some 30-50 m^3 and using the crude methods available, would certainly hamper the economic regeneration of the forest.

Though the selective cutting alters the competition in the forest, the possibilities for the remaining small and medium-sized valuable trees to grow at a reasonable rate, are far from optimal. A very low productivity of the remaining stand is the forest manager's main problem after logging. Without further treatment such stands have an annual increment of valuable timber of about 0.2 m^3 per hectare. In other words, it would take more than 50 years to regenerate the standing valuable timber to a mere 10 m^3, or 3-5 stems per hectare. This period is too long, and the small harvest forms no incentive for an enthousiastic and attentive forest guarding. The expensive infrastructure rapidly disintegrates if not properly maintained, and the timber industry cannot wait that long until the next harvest. The possibility of harvesting a constantly changing assortment of second-class timber tree species which still are available in good quantities, will eventually lead to gathering fuelwood quality timber.

The silvicultural treatments and their effects

Results from the CELOS experiments indicate a beneficial effect of silvicultural treatment on the development - especially girth increment - of the valuable trees. The valuable species as used at CELOS are listed in the Appendix. In the future this list may be extended with species that will then command a good price. In view of the objective of our management system, i.e. the production of first-class timber, the list is not open to fuelwood, pulpwood or other low-priced woods.

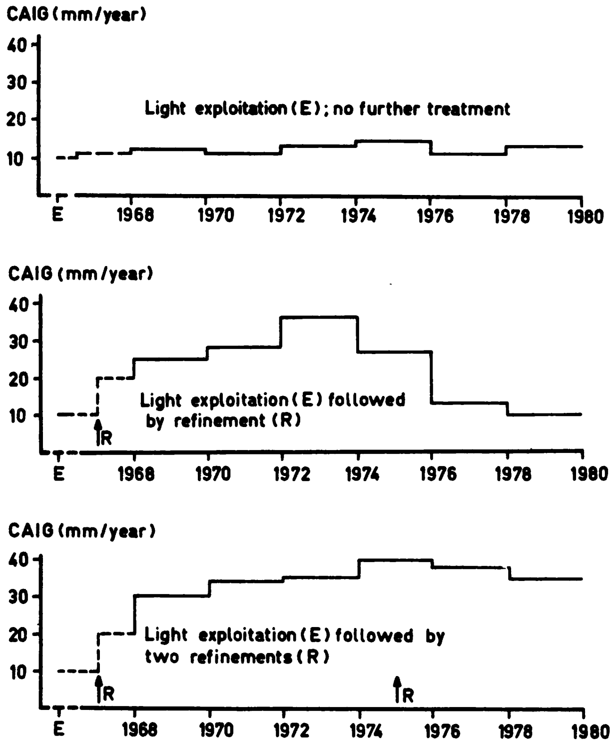

Fig. 3. Current annual girth increment (CAIG) of a group of valuable timber trees (15-29.9 cm diameter at breast height) treated in three different ways.

The silvicultural treatments can simply be described as a repeated refinement. Although not equivalent, refinement resembles thinning. All unwanted trees above a certain diameter limit are killed with arboricide. Tree spotters mark the trees to be killed. Further treatment is done by unskilled labour.

As a result of the first refinement the current annual girth increment (CAIG) has increased significantly. Figure 3 compares the CAIG-values for three different treatments. One treatment has resulted in a five times higher yield of valuable timber compared with the forest that was not treated after exploitation. Although the experimental data available cover only a period of 12 years - and not a full 20-year cycle - it is already possible to outline a silvicultural system based on natural regeneration for the Mapane Region. Basic thought is a polycyclic harvest of timber-sized (>45 cm dbh) trees. Calculation of the harvestable volume is done according to the Brandis method. Better - e.g. computer based - models should be used whenever available. Management and administration, however, should remain simple enough to be fully mastered by undergraduate staff.

The treatments given during the cycle of 20 years are specified below. Basal area reductions are from 28 to 12 m^2/ha at first refinement, from 20 to 10 m^2/ha at second refinement and from 18 to 15 m^2/ha at third refinement. Each refinement includes the killing of thick lianas. The cost per ha can be indicated as follows:

Year	Treatment	Operations	Labour (mandays)	Materials
0	refinement	line cutting, sampling, marking frilling, spraying	4.9	20-40 litres arboricide; 1 litre paint
8	refinement (incl. filler-tree system)	do	3.3	10-15 litres arboricide; 1 litre paint
16	refinement (incl. thorough liana cutting)	do	3.3	10-15 litres arboricide; 1 litre paint

Total amount of labour is about 12 mandays, producing a gross volume of 40 m^3 timber per ha, rotten and hollow trees included. To keep harvesting damage at an acceptable level, only 20 m^3 of this volume should be selectively removed; a more efficient and less damaging way of harvesting would allow a larger volume to be removed. The arboricide used in the experiments was a 5% solution of a commercial formulation of a sodium ester of trichlorophenoxyacetic acid in diesel oil. After frilling the trees, a 10-cm wide band of arboricide is sprayed on the bark above the frill, and the frill itself is filled with arboricide. Trees are dying slowly, providing ample time for the remaining vegetation to take up the minerals released from the dead trees, and thus minimizing the danger of nutrient losses by leaching.

To give some idea of what the forest looks like after the refinement treatments described, three forest profiles are given (Fig. 4). The treatments roughly correspond with those of Figure 3. Treatment (C) appears optimal for valuable volume production; it still has a large phytomass and shows much diverstiy, though less than treatment (A).

In treatment (B) growth has stagnated since year 10, as can be seen from the thick canopy mass concentrated at a height of about 20 m. Here the phytomass is still far below the original mass of the primary forest but competition is severe already; probably many trees are in the same stage of development.

Fig. 4. Forest profiles; 50-m wide and 20-m deep cross sections.

A. 15 years after light exploitation; no further treatment.

B. 15 years after light exploitation followed by heavy refinement 3 years later.

C. 16 years after light exploitation followed by light refinement 3 and 11 years later.

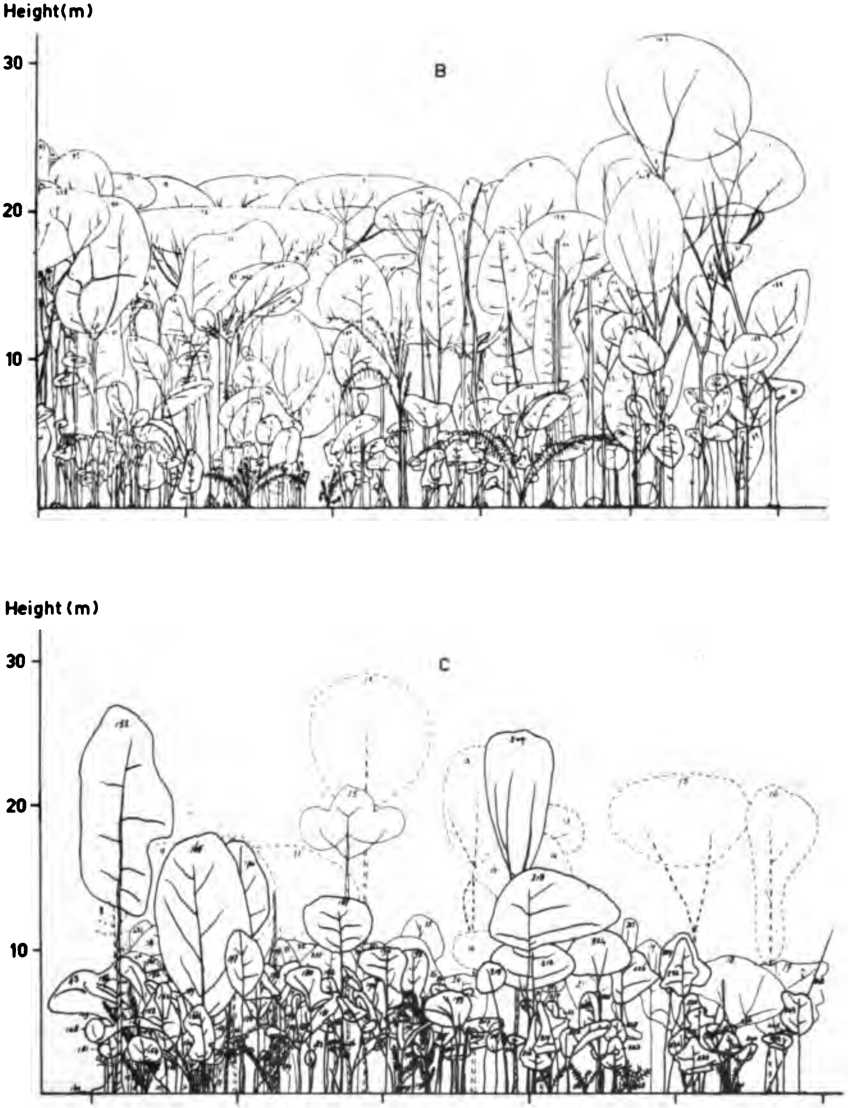

Fig.4 continued

Ultimately, it will be preferable to create a stand more or less intermediate between the one depicted in Figure 4 by treatment (C) and the one by treatment (A) but composed of as many valuable trees and tree species as possible. Competition in such a stand has to be periodically reduced by exploitation or silvicultural measures.

Practical aspects

The refinement procedure as a whole is rather simple. The intervals between refinement treatments can be determined by periodic inventory of a series of permanent sample plots to establish the level of competition in the treated stands and the corresponding increment rates.

It is remarkable that a complicated ecosystem such as the tropical rainforest should be treated with simple though cautious methods. But most tropical rainforest countries cannot afford to do more, although they still should make some money out of it.

The intensity of the treatments to be applied can be determined only after a proper forest inventory, revealing the specific qualities of the forest concerned. The stand composition as regards the diameter-classes of valuable species larger than 25 cm dbh, is very important when starting with management. These classes will yield the first harvest (20 years) and part of the second harvest (40 years) while the species composition cannot be changed very much without great losses. At least during the first cycle one has to work with the stand as it is encountered. Forests rich in valuable regeneration do not need to be treated as intensively as forests poor in this respect. In Suriname, the Mapane forests have to be treated more intensively than the Kabo forests, making the latter much more attractive for management and exploitation.

A rule of thumb for proper management would be "do as little as possible", i.e. keep the forest in a natural state as far as economy allows. The maximum harvest to be allowed by the manager will limit the intensity of the treatments. The best way to maintain the advantages of extensive systems is to focus on a low volume of high-value timber per hectare. Such advantages should not be underrated. Semi-natural management systems such as the one discussed above, remove many of the worries inherent to intensive systems. The threat of pests and diseases and forest fires in intensively managed plantations - which are very costly to fight - should be mentioned in this context. Such troubles often arise when natural control has disappeared due to the radical treatments applied.

Perspectives

The best perspectives for sustained-yield forest management as based on the CELOS system, are found in regions that are still under virgin forest. The cost of permanently managing such forest would be minimal. Moreover, a wood industry on the spot would result in a substantial roduction of transportation costs, as only sawn timber would be taken to the market or to the harbour. Log transport should be restricted to the forest roads. A sawmill should be built not only to operate during the first exploitation cycle, but also for processing the sustained yield from the area during many decades. Such a mill should have an annual capacity of say 50 000 m^3 logs, which would require a net productive area of 50 000 ha well managed forest. Roughly 150 men would be needed for the silvicultural treatments, 50 men for the harvesting operations and 50-100 men for the sawmill, depending on the level of mechanization and automation. This would result into the development of a settlement or village for at least 1 000 people. From such a centre further development could follow in the form of commercial plantations or the cultivation of annual crops. This, in turn could lead to real development of a region, creating permanent work for a settled population.

The investment costs per hectare are decisive for the size of the area that could be brought under management. The cost per hectare pine plantation is US$ 1 400 for clearing and US$ 800 for planting and maintenance, totaling US$ 2 200. Establishing 1 600 ha of pine plantation would cost US$ 3.5 million. With the same amount of money some 25 000 ha of natural forest can be brought under natural regeneration management.

Taking into account the large extenses of dryland forest and considering that only few people are willing to live in the forest areas, the situation in Suriname calls for extensive management systems.

It would be naive to think that the future will be a continuation of the past. All signs point at a world shortage of timber and other wood products in the next decade. The timber industry might do better than just caring for this and next year's commercial results. The forest managers should proceed to long-term production planning of their raw material.

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APPENDIX: 1978 Commercial species list as used by CELOS

Family and species	Code	Local name	Trade name	No.
Anacardiaceae				
Loxopterygium sagotii	SLA	Slangenhout		31
Annonaceae				
Xylopia aromatica	PEP	Pegrekoepisi		24
Araliaceae				
Didymopanax morototoni	KAS	Kassavehout		36
Schefflera paraënsis	MOR	Morototo		39
Bignoniaceae				
Jacaranda copaia	GOE	Goebaja		48
Tabebuia serratifolia	GRO	Groenhart	Tabebuia	17
Burseraceae				
Protium insigne	GTI	Tingimoni-grootbl.		45
Protium neglectum	HTI	Tingimoni-harde bas		44
Tetragastris altissima	SAL	Rode salie		40
Tetragastris hostmannii	TIS	Tingimonisalie		47
Trattinickia burserifolia / *Trattinickia rhoifolia*	ATI	Ajawatingimoni		46
Colastraceae				
Goupia glabra	KOP	Kopi	Goupie	21
Guttiferae				
Platonia insignis, *Rheedia* sp.	GEE	Goelhart, Pakoelie		55
Symphonia globulifera	MAT	Matakki	Manni	50
Humiriaceae				
Humiria balsamifera	MER	Meri (Blakaberi)		56
Lauraceae				
Licaria cayennensis	KAN	Kaneelhart		20
Nectandra grandis	ZPG	Pisi, zwarte, gr.bl.		27
Ocotea glomerata	ZPK	Pisi, zwarte, kl.bl.		28
Ocotea petalanthera	WIP	Pisi, witte		26
Ocotea sp.	WAP	Pisi, wana	Canela	25
Ocotea rubra	WAN	Wana	Rod Louro	33
Lecythidaceae				
Lecythis davisii	KWA	Kwatapatoe		49
Meliaceae				
Carapa procera	KRA	Krapa	Andiroba	37
Cedrela odorata	CED	Ceder	Cedar	16
Moraceae				
Brosimum paraënse	SAT	Satijnhout	Satiné	30
Piratinera spp.	LET	Letterhout	Snakewood	22
Mimosaceae				
Parkia nitida	AGR	Agrobigi		54
Myristicaceae				
Virola melinonii	HBA	Hoogland baboen	Baboen	11
Virola surinamensis	LBA	Laagland baboen	Baboen	12

APPENDIX continued

Family and species	Code	Local name	Trade name	No.
Papilionaceae				
Andira spp.	RKA	Rode kabbes	Angelin	18
Dicorynia guianensis	BAS	Basralokus	Angélique	13
Diplotropis purpurea	ZKA	Zwarte kabbes	Tabatu	19
Dipteryx odorata	TON	Tonka		57
Hymenaea courbaril	RLO	Rode lokus	Courbaril	23
Mora excelsa	MRA	Mora		53
Peltogyne spp.	PUR	Purperhart	Purpleheart	59
Platymiscium spp.	KOE	Koenatepi		58
Vouacapoua americana	BRU	Bruinhart	Wacapou	15
Rutaceae				
Fagara pentandra	PRI	Pritijari		29
Sapotaceae				
Manilkara bidentata	BOL	Bolletrie	Balata	14
Micropholis guyanensis	RIW	Riemhout, wit		51
Micropholis guyanensis	RIZ	Riemhout, zwart		52
Simaroubaceae				
Simarouba amara	SOE	Soemaroeba		32
Sterculiaceae				
Sterculia spp.	OKR	Okerhout		42
Vochysiaceae				
Qualea albiflora	HGR	Hoogland gronfolo		35
Qualea coerulea	LGR	Laagland gronfolo		41
Qualea rosea	BGR	Birgi gronfolo		34
Vochysia guianensis	WIS	Wiswiskwari		38
Vochysia tomentosa	WAK	Wanakwari		43

THE ROLE OF PASTURES IN ACID INFERTILE SOILS OF THE HUMID TROPICS IN LATIN AMERICA

James M. Spain
Centro Internacional de Agricultura Trepical, Colombia

INTRODUCTION

Tropical Latin America is faced with an urgent need to increase food production. Demand for most commodities is growing faster than supply. As an example, the increase in demand for beef during the period 1971-79 has been estimated at 5.9 percent, more than double the estimated 2.5 percent increase in supply (Nores, 1981). All of the countries in the region are either net importers of beef or are barely self-sufficient. Most have abundant, underutilized land resources which could provide both medium and long-term solutions to the problem of inadequate food production to meet growing demands. These land reserves are almost all comprised of acid, infertile soils in frontier areas of the humid tropics.

Pastures can play a special role in the development of these "new lands" for a number of reasons:

1) Many high quality, potentially productive tropical forage species are well adapted to the edaphic environment with minimum fertilizer requirement, having evolved in acid infertile soils (Spain, 1979). A few species combine these qualities with sufficient disease and insect resistance to persist under grazing in stable associations.
2) Well managed perennial pastures comprised of acid soil tolerant, deep rooting legumes and grasses conserve the soil resource, protecting it from erosion and efficiently recycling nutrients from the subsoil to the surface.
3) Pasture-based livestock systems result in low nutrient export from the soil.
4) Well adapted legumes are capable of supplying the N requirements of associated grasses for productive, high quality pastures.
5) Perennial C-4 tropical grass species are among the most efficient converters of solar energy.
6) The above characteristics make it possible to achieve relatively high output from low-input (purchased) systems.
7) Pasture-based livestock systems catalyze the development process in frontier areas by generating capital and stimulating the development of infrastructure; this, in turn, leads to more intensive land use and increased production.

STRATEGY FOR INCREASING AGRICULTURAL PRODUCTION

In the humid tropics where vast land areas remain unexploited or underutilized, there are two major strategies for increasing agricultural productivity. One is to increase the productivity of lands presently being farmed through adoption of modern agricultural technology and providing the necessary credit and technical assistance. The other strategy is to expand production through expanding the area, either by draining alluvial lands, developing irrigation projects, or by expanding into frontier areas with new access routes opening these regions for development.

At CIAT, both strategies are pursued, varying by commodity. Research in the Bean and Rice Programs is directed almost exclusively to increasing production in traditional agricultural areas. The Cassava Program, emphasizes increased production on marginal soils in existing agricultural areas, as well as expansion into new areas of low-fertillity soils.

The Tropical Pastures Program focusses almost exclusively on the expansion of production in the "new lands" which are generally marginal with respect to soil fertility and acidity for most annual crops. These are areas which contribute very little to total food production at present but offer great potential for the future when economic conditions favour their use.

THE ECOSYSTEMS

The initial focus of the Program was on the well-drained savannas. This has been gradually expanded geographically to include poorly drained savannas and seasonal and evergreen forest areas, where the dominant soils are almost all extremely acid and infertile. Figure 1 shows the areal distribution of these major ecosystems in tropical South America. The Program continues to concentrate primarily on the well-drained savannas where its two major field sites are located. The Colombian Institute of Agriculture (ICA) provides facilities for co-operative work at Carimagua in the Llanos Orientales. This national research centre is located at 3°30′ north latitude, 150 metres above sea level. The mean annual temperature is 27°C and annual precipitation is 2 100 mm, well distributed during an eight-month rainy season from April to December, with a sharp dry season from December through March. In Brazil, co-operative work is carried out with EMBRAPA at the Cerrado Centre (CPAC) in Planaltina at 15°30′ south latitude, 1 000 metres above sea level, with a mean annual temperature of 21.3°C and an average annual precipitation of 1 578 mm distributed during a seven-month rainy season from October through April.

Soils

Climate, parent material, topography and time combine to dictate that predominant soils in the target area are Oxisols and Ultisols. The Oxisols dominate in the tropical savannas. They are characterized by good to excellent physical properties, usually deep profiles free of physical barriers to root penetration. They have a relatively low water-holding capacity. The other major limitations are chemical as can be seen in Table 1. The soils are extremely acid, with very low levels of base saturation and correspondingly high levels of aluminium saturation. They

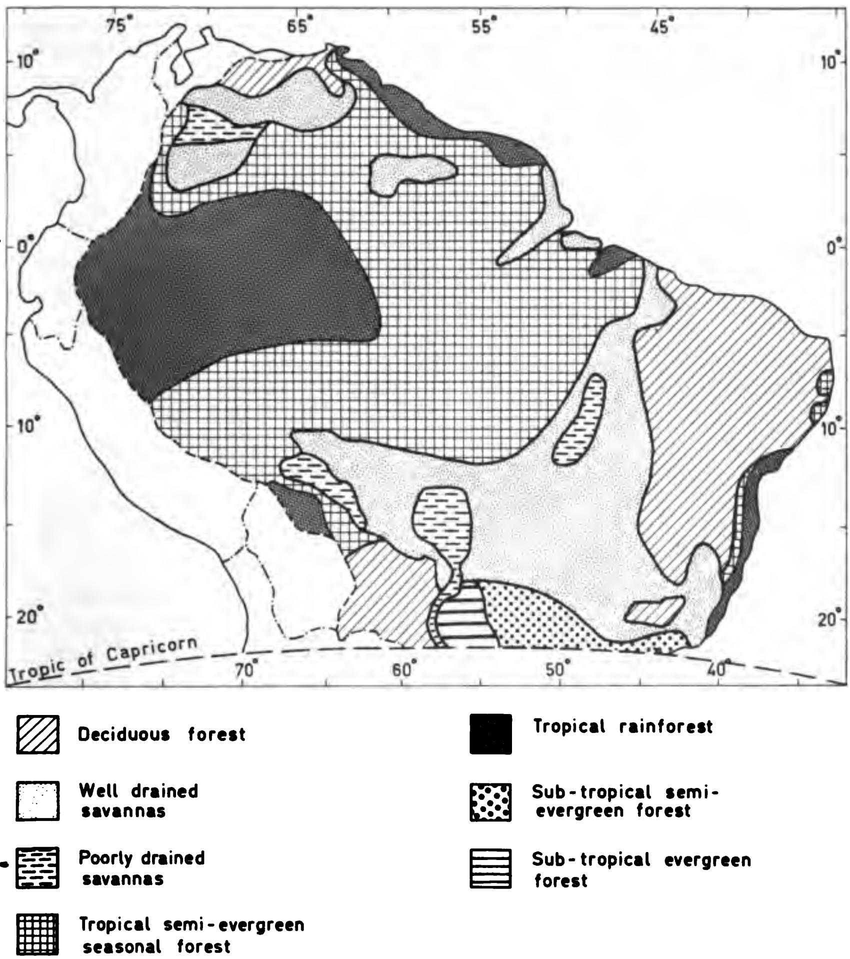

Fig. 1. Savannas and forests in tropical South America east of the Andes.

Table 1. Chemical characteristics of three soils (0-20 cm) at savanna field locations in Colombia and Brazil

Location	Profile	pH	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Al Sat.	P-Bray II
			meq/100 g				%	ppm
Carimagua, Colombia	C_1	4.5	3.6	0.40	0.09	0.10	86	1.5
Planaltina, Brazil	DRL[a]	4.5	1.9	0.40 (Ca + Mg)		0.10	79	1.0
	RYL[b]	4.4	0.9	0.20 (Ca + Mg)		0.10	75	trace

[a]Dark Red Latosol
[b]Red Yellow Latosol

have low levels of available P and exchangeable K, Ca and Mg. Micronutrient deficiencies are common in the older areas, especially on sandy soils, but are much less frequently observed on the finer-textured, younger soils such as those found in Carimagua. Phosphorus fixation is a problem, especially on older, more highly weathered, fine textured soils.

Biotic factors

When agronomic research was initiated in the Colombian Llanos, it was thought that edaphic and climatic factors were the principal limitations to agricultural production. The variety and virulence of pathogens and pests endemic in the region were grossly underestimated. It has been much more difficult to find species which are tolerant or resistant to the wide range of diseases and insects common to the savanna ecosystem than to identify species well adapted to adverse soil conditions with minimum fertilizer requirements.

GERMPLASM BASED LOW-INPUT SYSTEMS

The effects of adverse environmental factors related to climate, soil, diseases and pests can theoretically be controlled by management (irrigation, fertilizer, lime, fungicides, pesticides), but in practice the costs of all but minimum fertilizer inputs are often prohibitive for pasture production in the tropics. Therefore, a strategy of selection of species which evolved in similar areas for genetic tolerance to these factors has been followed in the Tropical Pastures Program.

Over 7 000 accessions have been collected or acquired from other institutions. These are subjected to a long and complex selection process. To date, there are very few species which combine desirable agronomic characteristics with an acceptable range of adaptability to edaphic and climatic conditions and adequate tolerance or resistance to diseases and pests. Thus, the choice of legumes and grasses available to the farmers in any given area is still quite limited. In Table 2 a tentative rating of adaptability of germplasm to three major ecosystems is presented (CIAT, 1981). This classification is based on the results of extensive trials conducted in Carimagua and Planaltina and from a network of regional trials which are conducted co-operatively with national institutions throughout the Program's target area.

TECHNOLOGY FOR LOW-INPUT SYSTEMS

In addition to the use of adapted species to avoid the need for lime and reduce fertilizer requirements to a minimum, the Program is also

Table 2. Summary of most promising germplasm in various ecosystems of the CIAT Tropical Pastures Program target area

Species	Tropical savannas, well-drained		Tropical forests[c]
	Hyperthermic[a]	Thermic[b]	
GRASSES			
Andropogon gayanus	yes	yes	yes
Brachiaria decumbens	yes	yes	yes
B. dictyoneura	yes	?	?
B. humidicola	yes	no[e]	yes
LEGUMES			
Centrosema brasilianum	yes	yes	?
C. macrocarpum	yes	yes	no
Desmodium gyroides	yes	no	?
D. ovalifolium	yes	no[e]	yes
Stylosanthes capitata	yes	yes	no
S. guianensis[d]	yes	yes	?
S. macrocephala	yes	.yes	?
Pueraria phaseoloides	yes	no[e]	yes
Zornia brasiliensis	yes	yes	?

[a] Represented by Carimagua
[b] Represented by the Cerrado Centre
[c] Based on preliminary information from regional trials
[d] Late-flowering, fine-stemmed ecotypes with viscous pubescences
[e] Length of growing season appears to be limiting factor, not temperature.

developing and testing low cost establishment methods and efficient management and maintenance systems.

Establishment methods

The establishment of pastures in tropical savannas using traditional seedbed preparation is easy during periods of reliable rainfall. In Carimagua it is possible to plant during six to eight months of the year and obtain adequate stands of adapted pasture species. However, the high cost of establishment and the erosion hazard on sloping sites during the establishment phase are major limitations. Efforts have been focussed on non-traditional systems making use of minimum tillage, and lower cost planting systems. Tables 3 and 4 summarize the principal advantages and limitations of tillage and vegetation control systems and of planting methods used in pasture development research in Carimagua.

Low density seeding

A description of a new planting system will serve as an example of the

Table 3. The principal advantages and limitations of tillage and vegetation control systems used in pasture establishment. Carimagua

System	Advantages	Limitations or disadvantages
Conventional tillage (ploughing and/or discing)	Good vegetation control Suitable for all species, if not overdone It is a traditional method	High cost Heavy machinery requirement May result in unfavourable seedling environment if overdone.
Minimum tillage (stubble mulch sweeps, chisel tines)	Lower cost Less erosion hazard Favourable seedling environment	Requires heavy machinery Does not control all native vegetation.
Zero inter-row tillage	Low cost Little erosion hazard Suitable for rolling landscapes	Still requires machinery for row tillage Not suitable for all species Limited control of native vegetation Not tested at commercial scale
Chemical control + manual tillage	Low cost No erosion hazard Suitable for steep sloping sites Simple, inexpensive equipment Takes technology to small farms	Suitable for few species only Limited vegetation control Not thoroughly tested

Table 4. The principal advantages and limitations of planting methods and spatial distribution systems used in pasture development. Carimagua

System	Advantages	Limitations or disadvantages
Conventional (broadcast) seeding	Can be done manually or with spinner type seeders. Is a traditional method	Higher seed requirement More weed problems Low fertilizer efficiency
Row seeding	Less seed required. Higher fertilizer efficiency. Allows better initial establishment of each component. Reduces early competition. Reduces shading	Requires more complex machinery Slower than broadcast seeding
Spatial distribution (species planted in separate strips)	Results in more stable and persistent association of some species than if intimately mixed. Permits association between species otherwise not compatible. Does not lose advantage of association; avoids some problems of "protein banks".	More complex than traditional planting. Wide strips may not favour efficient nitrogen use by associated grass.
Low density methods	Low labour, seed and initial fertilizer requirements. Well suited to small farms. Results into very strong, persistent mother plants. Reduces the risk of failure inherent in pasture establishment.	May require more time for establishment. Not suitable for all species May not work where weed potential is high.

type of research conducted in Carimagua, based on the low-input philosophy. Oxisols of the tropical savannas are often so infertile that they remain weed-free during several months after land preparation. This characteristic can be taken advantage of by planting a very low density stand of "mother" plants (500-1 000 hills/ha) which in time cover the entire area either with stolons *(Brachiaria decumbens, B. humidicola)*, trailing stems *(Desmodium ovalifolium, Pueraria phaseoloides)* or seed *(Andropogon gayanus, Panicum maximum)*. Initial fertilizer is concentrated in the hill with the area between hills fertilized at the usual rate but only after establishment is assured. Weed competition is thus minimized, while extremely vigorous mother plants develop with minimum initial fertilizer investment (3 kg P_2O_5,1 kg K_2O, 0.5 kg Mg and S/ha). Labour and seed costs are also kept to a minimum. Nine species were successfully established, ready for grazing in periods ranging from 6 to 12 months from planting. This system has now been used for establishment of several commerical-scale pastures, mostly associations of *A. gayanus* and *P. phaseoloides* (Spain et al., 1979).

Savanna replacement

Another approach to reducing the cost of pasture establishment is currently being tested in Carimagua. Native savanna is being gradually replaced with selected introduced pasture species under grazing. Four different grass-legume associations were established in strips which were prepared, fertilized and seeded in a conventional manner as shown in Figure 2. Strip widths vary from 0.50 m to 5 m and are alternated with savanna strips of 2 m to 20 m. In all cases, 20 percent of the area is planted. The strategy for management and gradual pasture establishment involves grazing, beginning in the first year with stocking rates adjusted to forage availability. This was initially 0.5 animal units/ha. Each year an additional 20 percent of the total area will be fertilized in strips adjacent to the planted area. Previous research (CIAT, 1979) has shown that once established, both *D. ovalifolium* and *P. phaseoloides* aggressively invade and displace adjacent native savanna when fertilizer is applied. Once the area has been colonized by the legume, conditions are favourable for invasion by stoloniferous associated grasses. During the first grazing season, stocking rate has been increased to 1 animal unit/ha and will be gradually increased as the proportion of improved pasture increases, with complete establishment expected at the end of four years. The strips are initially functioning as protein banks and have resulted in improved productivity from the outset, which should more than pay for annual fertility applications. Associations of *B. humidicola* x *P. phaseoloides* and *D. ovalifolium* are the most promising to date. Initial cost of establishment is in direct proportion to the percentage of the area seeded, i.e. approximately 20 percent of conventional establishment cost. In subse-

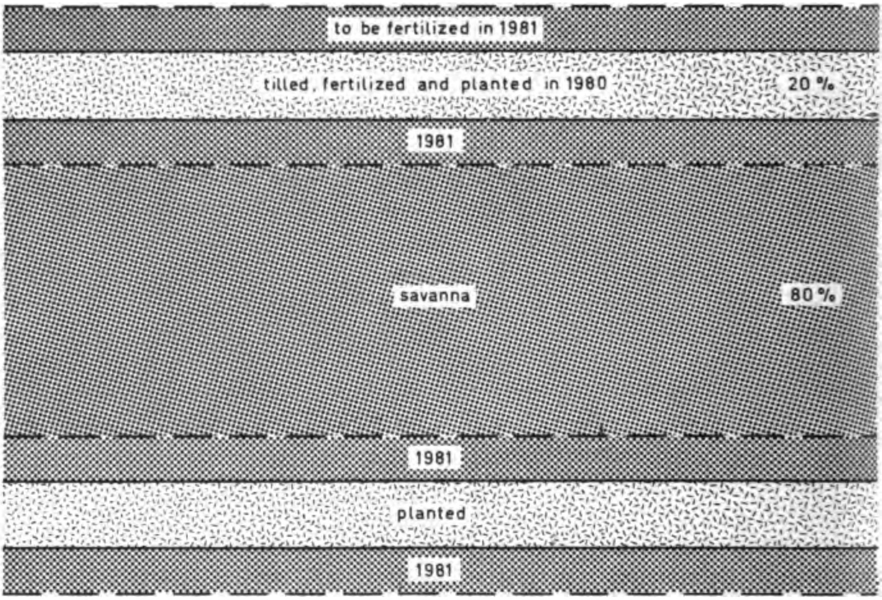

Fig. 2. A design for gradual replacement of native savanna under grazing based on strip planting 20 percent of the area to improved species. Planted strip widths are 0.5, 2.5 and 5 m, associated with savanna strips of 2, 10 and 20 m respectively. *Brachiaria humidicola* and *Andropogon gayanus* are each associated with *Desmodium ovalifolium* and *Pueraria phaseoloides* for a total of four combinations. Source: CIAT (1980).

quent years, the only additional cost will be that of the fertilizer.

The strip system could also be useful in establishing protein banks to be used for supplementing the native savanna rather than replacing it. Perhaps 5-10 percent of the total area would be sufficient to supplement the savanna and reduce or eliminate the need for burning. Under present management, cattle only graze the savanna for 20-25 percent of the time; the rest of the time is required for accumulating sufficient fuel for the next burn.

ANIMAL PRODUCTION POTENTIAL OF LEGUME-GRASS ASSOCIATIONS

In Table 5 a summary of research results from the past 10 years in Carimagua illustrates the dramatic increase in production potential as one moves from native savanna to improved grasses and finally, grass-legume associations (CIAT, 1981). Productivity of pure grass stands in

Table 5. Pasture productivity in terms of live weight gains. A summary of evaluations at Carimagua, 1970-81

Type of pasture	Average live weight gains			
	Dry season	Wet season	Total for year	
	—g/animal/day—		kg/animal	kg/ha
Managed savanna[a]	-167	449	90	22
Grass pastures				
Melinus minutiflora[a]	-445	508	97	43
Brachiaria decumbens[a]	180	443	131	282
Andropogon gayanus[b]	- 44	480	110	350
Associations[b]				
A. gayanus x *Stylosanthes capitata*	187	707	183	345
A. gayanus x *Pueraria phaseoloides*	390	693	203	364
Protein banks[c]				
B. decumbens x *P. phaseoloides* in blocks	350	535	159	293
B. decumbens x *P. phaseoloides* in strips	484	577	185	299
Savanna + 5% *P. phaseoloides*	145	457	123	31
Savanna + 10% *P. phaseoloides*	63	388	102	51

[a] More than three years
[b] Average of last two years
[c] Average of three years

terms of live weight gain/ha/year is surprisingly high for pastures which receive no nitrogen fertilizer. However, the gain/animal/year is still rather low compared to the gains achieved with animals grazing on grass-legume associations. This is of special importance where pastures are to be used primarily in cow-calf operations, where one of the major objectives is to provide pasture of sufficiently high quality so that the lactating cow maintains or improves body condition and conceives within 3-4 months of calving.

STRATEGIC USE OF PASTURES

In most tropical savanna areas, planted pastures will be used strategically in combination with native range for many years to come. The planted pastures can be used to enhance the value of native range and to increase herd preduction in a number of different ways. Legumes may be used as protein banks to supplement native pastures, either in blocks or strips planted in the native savanna, or associated with grasses as separate pastures for use at critical times in the life cycle of breeding animals or for fattening animals for sale. Perhaps the most important use of improved pastures for most regions will be to improve the reproductive performance of breeding herds.

THE CATALYTIC ROLE OF PASTURES IN THE DEVELOPMENT PROCESS

Historically, livestock production has played a very important role in the development process. The Oxisols of tropical savannas are potentially very preductive, not only in terms of pastures and livestock but also for crop production when economic condítions provide the incentive for tropical farmers to make the necessary investments. The use of improved pastures in livestock production systems is one more step toward the incorporation of frontier regions into the agro-industry of the region. The transportation of necessary inputs to the farm, and livestock products to the market will hasten the development of access routes and other infrastructure fundamental to the development of the "new lands".

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RESEARCH PRIORITIES ON THE SANDY SOILS OF SURINAME

Rufo Bazán
Inter-American Institute for Cooperation on Agriculture
San José, Costa Rica

INTRODUCTION

The Zanderij formation, comprising light textured soils, occupies quite an extensive area in Suriname in a belt approximately 400 km long which continues into both Guyana and French Guiana. The total area is about 875 000 hectares.

Originally the soils consist of fluviatile sediments composed of predominantly quartzitic material. The landscape has a flat to slightly undulating topography. The formation comprises two main soil types which occur as soils associations. These two soil types are:

1) Bleached, strongly podzolized, coarse white sands, which are locally underlain by a hardpan. They are extremely infertile, being composed of more than 99 percent silica (SiO_2). They are very susceptible to drought and occupy about 40 percent of the total area.
2) Unbleached, yellowish brown sands, loamy sands, sandy loams and sandy clay loams or sandy clays, all of which are chemically poor.

In the terrain the transition between these two main soil types is mostly abrupt and topographically determined, the bleached sands occupying the more elevated positions (plateaus).

The natural vegetation varies according to soil type. On the bleached sand (eastern and central part of the formation), the predominant vegetation type comprises open grass and shrub savanna or a tree savanna, whereas in the western part a high walaba vegetation is found. The unbleached soils support a high tropical rainforest. In the transition areas between both main soil types, mainly a low savanna forest is found.

Though not systematically, most of the Zanderij soils have been surveyed at different degrees of intensity. Sufficient information on these soils has been collected, and it has allowed to select a representative area in the central part of the Zanderij formation, where the Coebiti experimental farm has been set up some 12 years ago. Most of the studies on soils and on crops have taken place at this farm.

At Coebiti nine soil types have been distinguished, mainly based on texture and colour, which still serve as the pedological base for all research since 1970. These nine soil types are the following:

Za = sands

Za - A: unbleached sand
Za - B: unbleached sand on loamy sand
Za - C: bleached sand

Leza = Loamy sands

Leza - A: sand on loamy sand on sandy loam
Leza - B: sand on loamy sand on sandy loam on heavy sandy (clay) loam

Zale = Sandy loams

Zale - A: loamy sand on sandy loam on heavy sandy loam
Zale - B, C, D: sandy loam on heavy sandy loam or clay with reddish, brownish and yellowish colours, respectively

Agriculturally, both the bleached and unbleached sands are of little interest because of their extreme infertility and droughtiness, and only the Za - B soils offer possibilities for permanent pastures and for the preduction of green manure in the wet season, if fertilizers are applied. Therefore, only the loamy sands and the sandy loams offer better possibilities for agricultural use under mechanized farming systems, the prevailing shortage of hand labour making mechanization a must.

MAIN PROBLEMS OF THE ZANDERIJ SOILS

Based on soil characterization data from the Coebiti farm as well as from soil studies carried out elsewhere in the Zanderij formation, problem aspects of the more suitable soils are chiefly of two kinds:

1) Chemical aspects; as indicated by lack of mineral reserves, strong acidity, low base and high aluminium saturation and low organic matter content.
2) Physical aspects; as indicated by drought hazard for the lighter textured (top)soils, puddling for the loamy textured topsoils and compaction for the loamy textured subsoils.

There are some intrinsic features that characterize sandy textured soils, which, in turn, may account for the above problem aspects. To begin with, the occurrence of sandy textured soils is not restricted to any particular ecological or climatic zone. They can be found in arid areas, in the humid tropics or in any intermediate climatic zone.

In their morphology sandy soils reflect the weak processes of soil formation. In fact, all sandy soils are weakly developed, with a low to very low organic matter content due to their sparse vegetation cover and a weak and very unstable structure.

From an agricultural point of view, the fine soil fraction is the natural source of nutrients on which plants feed. The main constituent of sandy soils is the sand fraction, and this supplies hardly any nutrient. Therefore, the nutrient level of sandy soils is controlled by their clay and organic matter content. The lacking of clay and humus would lead to rapid loss of nutrients - if applied to raise the low fertility status - by leaching since these nutrients cannot be sufficiently retained.

Moreover, sands are noncoherent. They have a high bulk density and low total porosity. However, their pores are relatively large thus contributing to a good aeration, a rapid drainage but to a low water-holding capacity.

These chemical and physical soil conditions adversely affect their agricultural potential. Consequently, for better utilization and cropping these soils, one has to overcome their disadvantages; in other words, the prevailing limiting factors should be controlled.

POSSIBLE LINES OF RESEARCH ON SANDY SOILS

In order to improve the agricultural potential of sandy soils, the following aspects should be emphasized in designing a research programme:

1) Raising their fertility through organic and inorganic fertilization.
2) Improvement of their physical conditions, particularly their water-holding capacity.
3) Selection of appropriate cropping systems to achieve the maximum economically profitable return.

Improvement of soil fertility conditions

Organic fertilizers. The organic matter content of the Zanderij soils is rather low, with an average value of 1.6 percent in the topsoil. Taking into consideration the positive effect of organic matter on both the chemical and physical soil conditions, the need to incorporate - in a systematic approach - organic matter in the topsoil, and to maintain it through adequate soil management practices, should have first priority.

Normally, in sandy soils, the residues of harvested crops do not contribute substantially to the increase or maintenance of the organic matter content, especially in the humid tropics, where high rainfall and high temperatures prevail. A better system to achieve this goal is the addition of various organic products such as farm manure, compost, green manure and human wastes.

Furthermore, organics should be tested not only as surface applications to topsoils, but also at different depths in the form of layers, say at 20, 35 and 50 cm depth. If organic materials are applied in layers below the surface soil, they are less easily decomposed and remain as a less permeable layer reducing the downward movement of water, thus improving soil conditions physically rather than chemically.

Inorganic fertilizers. The majority of the inorganic fertilizers available on the market are highly soluble and prone to loss from the soil by leaching, especially in the case of sandy soils and where high rainfall is prevalent, like in Suriname.

Under such conditions, research focussing on routine aspects such as levels of NPK fertilizer or of other elements, becomes non-relevant if such tests are not carried out visualizing additional management practices such as (a) split applications in order to overcome or minimize losses by leaching or (b) the use of slow-release forms such as fertilizers coated with resins or wax or other less soluble materials which prevent or control the rate of release of nutrients from the fertilizer material. Fertilizers of this sort are, for instance, the sulphur-coated urea or the sulphur-coated KCl, which has been produced initially by the Tennessee Valley Authority, at Muscle Shoals, Alabama, U.S.A., and later by the International Fertilizer Developement Center, IFDC, in the same location. Even recently, IFDC researchers are studying the production of urea-briquettes for deep placement of urea fertilizer as another means to control nutrient leaching. Along the same line IFDC will test other briquetted materials, besides urea, such as triple superphosphate/urea, single superphosphate/urea, rock phosphate/sulphur and rock phosphate/urea. This line of research should be worth to be developed under Suriname conditions.

Foliar sprays. Foliar sprays is another way to apply inorganic fertilizers in order to avoid leaching and consequent loss of nutrients added to sandy soils. Research performed elsewhere in this field has shown that nutrient elements sprayed on the leaves have the same efficiency as those added to the soil in non-sandy soils.

Improvement of soil physical conditions

The main problem associated with the physical features of sandy soils is their low ability to retain moisture and consequently their low capacity to supply moisture to plants, which is due to their free drainage and high surface infiltration and permeability throughout the profile. To overcome these unfavourable conditions, two main management practices should be considerod in a research programme:

1) Mulching and the increase of organic matter content, at various depths in the profile;
2) The placement of relatively impermeable barriers in the subsoil. Asphalt barriers is one of the most common types being used elsewhere in sandy soils where rice, sugarcane or other crops are

grown.

As to asphalt barriers, the economics of their application should be looked at carefully. Existing data state that they pay for themselves in one year and that in many cases they are economically feasible, since they are a long-term investment. However, such statements should not be generalized, since favourable economic data will also depend on other factors, such as type of crop, and depth and extent of placement of the barrier.

Selection of appropriate cropping systems

From an agricultural point of view, in Suriname two main regions are distinguished, each characterized by a certain type of agriculture. First, the coastal clay soils, where the main limiting factor is poor drainage of the soils, but which are suitable for growing rice under highly mechanized conditions to overcome the low availability of hand labour. In the other region, comprising the Zanderij formation, shifting cultivation is prevalent, using dry annual crops, especially on the loamy sands and sandy loam soils, which are mostly affected by a low fertility status.

In designing a research programme focussing on the agricultural use of these soils, the basic statement to be kept in mind is that: "while normally cropping systems are delineated to maximize yields per unit area, under Suriname conditions where hand labour is scarce, cropping systems will have to be delineated to maximize yields per unit man (hand labour) or unit H.P. (motor-power)".

A research programme on cropping systems can have two main orientations:

1) The testing of alternative cropping patterns.
2) The testing of alternative agricultural components, such as plant species and varieties, plant density, fertilization, weed control and tillage practices.

As to the first one, the social conditions prevalent in Suriname, i.e. the lack or shortage of hand labour, may limit the cropping pattern alternatives to those suitable to be developed under mechanized conditions, such as crop rotations or some simple patterns of relay-cropping. In any case, a sound research programme should aim at the solution of problems or of limiting factors affecting crop production, which are to be identified in the region.

PROPOSED RESEARCH STRATEGY

A successful research programme should follow a comprehensive approach such as the following:

1) Identification, through soil survey, of the most important soil types

in the problem region. This field study must be combined with a detailed characterization of the identified soil units.
2) Selection of representative areas comprising those soils with the highest potential for agricultural development. In turn, these areas should be utilized as selected experimental sites for laboratory, greenhouse or field research.
3) Identification, through a base line survey, of the existing know-how of the farmers in the region, in order to get acquainted with what the farmer does, how, when and what his main problems are.
4) To identify what the existing cropping systems are in the region, whether simple agricultural systems (annual and/or perennial crops), forestry systems, or more complex agroforestry systems.
5) Designing experiments based on identified problems and in accordance with the selected orientation, i.e. cropping patterns or agronomic components.
6) Research evaluation and extrapolation of results throughout selected areas in the problem region.

In designing research on cropping systems, it should be kept in mind that in the case of the Suriname sandy soils one of the objectives should be to keep the soil surface covered with a crop preferably during most of the year, but especially during critical periods, as in the rainy season to prevent soil erosion, or in the dry season to prevent excessive soil moisture losses by evaporation. Finally, one should consider the possibility for conducting some double-purpose type of research whereby food crop production and crop-energy production potential is studied either through an individual type of system or else in combined systems. The last suggestion is thrown into the picture with the idea of investigating the agricultural potential of the sandy soils of Suriname as a renewable source of energy, which in the short or long run may produce substitutes for fossil oil and its derivatives. Among the crops to be considered in this respect, and that may thrive on sandy soils, are some root crops such as cassava and yam.

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WORKING GROUP REPORTS

WORKING GROUP REPORTS

On the last day of the Workshop simultaneous working group sessions were organized. Three groups were formed, each of which discussed a separate topic. The following summarized group reports were presented in the Workshop's final session.

GROUP 1. LAND UTILIZATION FOR CROPPING SYSTEMS

Introduction

In French Guiana, Guyana and Suriname we are concerned with two types of ecosystems: savannas and rainforests. Soil types in the three countries are of great similarity. Cropping is restricted to the loamy soils; the bleached and unbleached sands are least suitable for arable farming.

Site selection

Research stations at Kabo and Coebiti, both situated in Suriname, may be different in soil properties that soil surveys do not indicate. It is therefore suggested that research, e.g. on texture and clay mineralogy, is initiated to study these differences.

Clearing methods

Clearing methods in both savanna and forest areas should aim at minimal soil disturbance.

1. Trees should be felled and left in place while stumps of deep rooted species should not be removed.
2. The felled vegetation should be burned in situ with a minimal amount of windrowing.
3. A mozaic pattern with stepwise clearing should preferably be maintained.
4. Monitoring of the soil environment after clearing is recommended.
5. Land clearing should be followed by pastures or perennial crops. Species or associations of species should be selected such that soil chemical and physical properties will be improved rather than aiming for the highest short-term economic returns.

Management for annual crop production

Continued emphasis should be placed on varietal adaptability to soil and climate conditions in these ecosystems.

1. Erosion and compaction of surface and subsurface horizons were identified as the two main constraints. It was suggested that research be initiated on methods of no-tillage with living mulch, on post-harvest tillage, chisel ploughing, disc harrowing, controlled

traffic management and on contouring.

2. Continuous routine chemical analyses of soils and plants during a cropping cycle and once a year a micronutrient analysis is recommended.
3. The application of fertilizers should be matched to weather conditions and tillage practices, i.e. top dressing during months of low precipitation with lime and phosphate applied when deep tillage is practiced. Supplementary irrigation may be practiced to avoid drought stress in months with low precipitation.
4. More research is required on crop rotation and cropping systems. Crops like sugarcane - which is reported to grow well on similar soils in Brazil - and pineapple should be considered.

Exchange of experience

It was suggested that more frequent exchanges of experience between the Guianas and other countries in Latin America are instituted.

GROUP 2. LAND UTILIZATION OF FORESTED AREAS

Introduction

The objective of the group's discussions was to recommend on appropriate utilization of the forests of the Berbice or Zanderij formation. General concern was expressed as to the uncontrolled forest exploitation that is going on in the area and which might continue unless some measures of planning its utilization are effected. The forest is only a renewable resource provided it is properly utilized. How this forest can best be utilized and remain a renewable resource, at the same time fulfilling its impertant environmental task, was seen as the major question put to the group.

Controlled exploitation

Controlled forest exploitation can - at least in part - be achieved through legislation, education and economic incentives.

Effective utilization

Effective utilization of the forest resource can include:

1. Developing permanent settlements which are based mainly on the labour force (and families) of the forest industry, i.e. including logging, processing, silvicultural operations and nature conservation.
2. Developing a permanent farming system to provide the food required for the settlements.
3. Developing commercial farming or plantation systems as a viable self-supporting alternative to forestry, required to sustain the community.

Possible approaches

The development of permanent settlements may be achieved by:

1. Applying silvicultural methods to increase the preductivity of the forest stands.
2. Utilizing less known species to relieve the pressure on the better known species.
3. Improving the methods of harvesting and processing.

The proposed settlements should have adequate social and other infrastructure so that permanent, self-supporting communities can be formed.

The farming systems to be developed must be compatible with the general forest environment.

Research priorities

1. The research on natural regeneration of the forest and on silvicultural systems derived from it, should be extended.

2. The economic viability of natural regeneration silviculture should be studied.
3. The possible utilization of less known species should be investigated.
4. Basic principles should be developed for making recommendations on appropriate legislation for forest utilization.
5. Viable farming systems that are compatible with the forest ecosystem should be developed to avert the encroachment of shifting cultivation on the high-forest lands.

GROUP 3. LAND UTILIZATION WITH PASTURES

It was agreed that discussion of the group be focussed on the unbleached soils of the Zanderij formation; that pastures are not recommended for the bleached sands.

1. Pastures have a number of characteristics which make them especially well suited to the acid infertile soils of the area.
   a. There are many acid soil tolerant legumes and grasses with good production potential and minimum fertilizer requirements.
   b. Well managed pastures can protect the resource base, capture some of the fertility released from the forest biomass and efficiently recycle nutrients.
   c. Pastures managed under grazing result in low nutrient export. Nitrogen can be supplied through the legume-Rhizobia symbioses.
   d. The transition from forest to pasture can be made with minimum damage to soil physical and chemical properties.

2. Pastures can serve as pioneers in both savanna and forest areas. It is recommended that research be undertaken on methods of clearing which utilize pasture species immediately after clearing to take advantage of the fertility released and to help "dominate" the cleared area while the unburned logs and stumps decompose. The pastures are being used during this period for grazing.

3. Pastures can also play an important role in rotation, being used for grazing and at the same time restoring soil fertility and improving soil physical conditions. It is recommended that research be initiated to focus on the transition from pastures to crops and back again to pastures. It would be advisable to look at "living mulch" possibilities as well as strip cropping and minimum tillage systems for planting in the pasture, to take maximum advantage of the improved physical conditions and the fertility stored in the pasture biomass.

4. Expanded screening of legumes and grasses should eventually include grazing trials. Maximum advantage should be taken of results from trials conducted in similar ecosystems in neighbouring countries, including Brazil.

5. It is recommended that steps be taken to strengthen links between neighbouring countries and to improve communications between all countries in the region working on acid infertile soils. The translation of relevant Spanish and Portuguese language reports into English would be a valuable contribution. Periodic meetings

and exchanges are highly desirable.

6. Steps should be taken to secure appropriate training for pasture research staff, taking advantage of regional and international institutes.

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