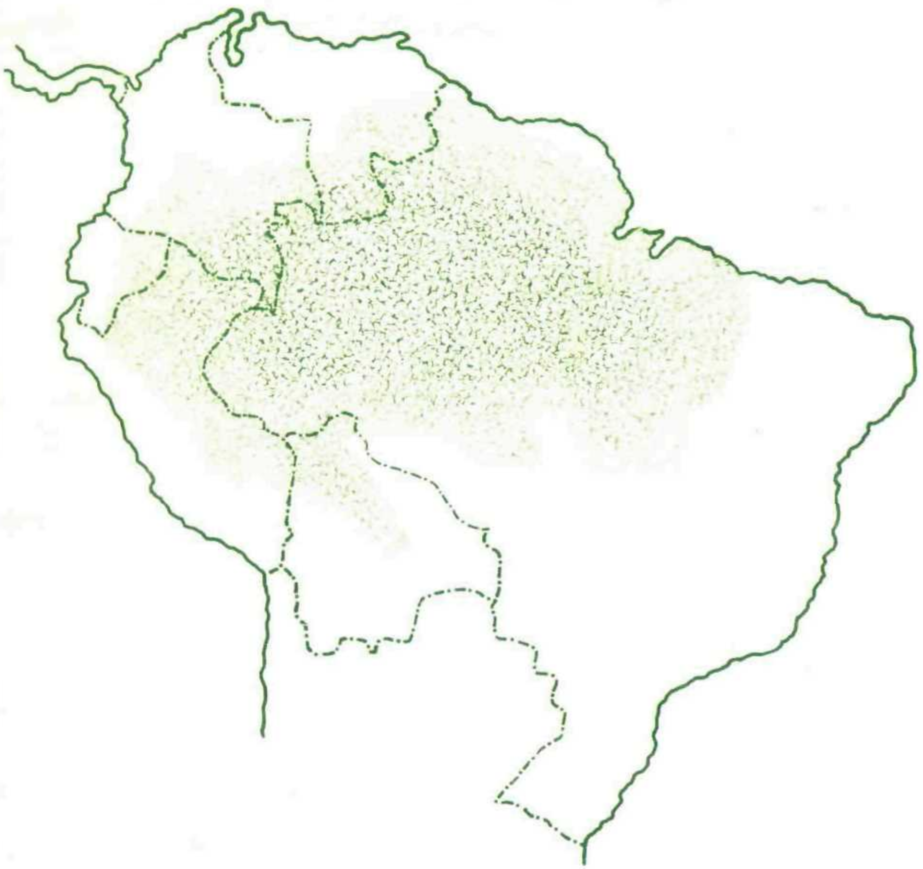
BEEK

AMAZONIA
Agriculture and Land Use Research



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Agriculture and Land Use Research

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Contents

The participants in this conference recommended the creation of a mechanism for strengthening agricultural and ecological research in the Amazon region. A small committee was appointed to implement the recommendation and this led to the establishment of an informal cooperative research network known as the Red de Investigación Agraria para la Amazonía (REDINAA). Scientists associated with REDINAA are presently in the process of preparing cooperative research proposals that will be submitted to appropriate national and international agencies.

The conference sponsors are pleased with this development and encourage others interested in contributing to the strengthening of agricultural and ecological research in the Amazon region to participate in the REDINAA programs.

Preface

Agricultural and forestry development in the Amazonian Basin have significant potential for contributing to economic growth and improved human welfare in this vast region of South America. Although national policies concerning colonization and the bringing of new lands into production vary greatly, the predominant trend in the Basin is toward accelerated development of frontier regions. Realization of the Amazonian agricultural potential will not, however, be an easy task, for experience has demonstrated numerous technical, social, and economic constraints. It is now well recognized that there is an urgent need to expand and strengthen research programs which will generate the much greater knowledge base necessary to ensure that agricultural development in the Amazonia is both technically and economically sustainable.

In response to this need, national governments hope to establish new, as well as strengthen, their existing research stations in Amazonia. Several international technical assistance and funding agencies have also demonstrated an increased interest in cooperating with research programs in the region. The latter group includes the five agencies that sponsored the International Conference on Amazonian Agricultural and Land Use Research which was held at CIAT in Cali, Colombia, April 16-18, 1980. The Conference brought together about twenty distinguished scientists and government officials from the six major Amazonian countries and an approximately equal number of international agency representatives. The objective was to identify and promote the most promising research opportunities that could lead to improved agricultural technologies appropriate for the ecological and economic conditions unique to Amazonia.

The presentations made and discussions held provided an overview of national policies concerning agricultural development in Amazonia, reviewed the current state of knowledge on alternative agricultural and land use options, identified priority research topics, suggested a strategy for improved cooperation amongst concerned agencies, and led to the establishment of a steering committee charged with formulating a mechanism for implementation of that strategy. A subsequent meeting of the steering committee held in Manaus, Brazil, resulted in the first steps being taken to form an Amazonian Agricultural Research Network (Red de Investigación Agraria para la Amazonía).

This publication is intended to make the results of the CIAT Conference available to all individuals and agencies interested in the Amazonian region and in agricultural development in the humid tropics in general. Hopefully it will also serve as a useful state-of-the-art document providing a base for and facilitating future research in the region.

We wish to thank CIAT for hosting the conference and the Rockefeller Foundation and the German Agency for Technical Cooperation for providing financial support. The contribution of each author is greatly appreciated. Special thanks go to Susanna Hecht for serving as rapporteur at the Conference and editor of this publication.

The Conference Organizing Committee

Gary H. Toenniessen
Gustavo Nores
Pedro Sánchez
Rudolf Binsack
Kenneth King

Welcome Address

John L. Nickel*

"On behalf of the Centro Internacional de Agricultura Tropical (CIAT), the International Council for Research on Agroforestry (ICRAF), the German Agency forTechnical Cooperation (GTZ), North Carolina State University, and the Rockefeller Foundation, I have the honor to welcome you to this Center and this International Conference on Amazonian Agriculture and Land Use Research. We are pleased that you accepted the invitation and managed to put aside the important issues you are dealing with daily, in order to be able to come to this conference. It is an honor to CIAT to host so many distinguished individuals. No doubt the success of the conference is guaranteed by your participation.

"CIAT is an international non-profit institution dedicated to the improvement of human welfare through increased food production. We attempt to contribute to the resolution of the important problems of poverty and hunger through the development and transfer, in collaboration with local institutions, of improved production technology. While we do not currently have any direct activities in the Amazon Basin, we are strongly interested in the developments there. Our interest stems from the fact that three of the four commodities with which CIAT works (i.e., tropical pastures, cassava and rice) are all important components of farming systems being utilized in that region. Secondly, as an institution dedicated to increasing production and productivity of food, we cannot ignore the great contribution that this large and valuable land resource can make towards food production on this continent. We recognize that the utilization of this valuable resource must be

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accomplished taking into account fully all the technological as well as the socioeconomic factors which will assure the productivity of these resources for the generations to come. This is a highly controversial issue. Thus, we believe that CIAT as a technical, non-governmental institution provides a reasonably neutral ground on which these important issues can be discussed. We have not invited the press to this Conference and have invited people with great technical competence with the hope that at this meeting people will speak freely and frankly and that more light than heat will be shed on these crucial issues.

"In addition to providing a forum for these discussions, we at CIAT hope to learn a good deal from the information and discussions in this conference. We want to learn about the state of knowledge on present land use and what the institutions conducting research have found regarding Amazonia. We also want to learn about your policies, programs and projects being conducted and planned, so we can eventually plan our own within our specific mandate.

"The job to be done is certainly extremely large and complex. It involves many disciplines, from ecology to forestry, from soils to economics, from physiology to agronomy, from plant pathology to animal nutrition and husbandry. The ecological questions and problems are large and conflicting. But very probably the answers and the solutions would come from a joint effort of very many disciplines.

"I am delighted that so many high level representatives of the various countries and research institutions in the Amazon region as well as interested donor agencies have accepted our invitation to this conference. On behalf of my colleagues at CIAT and of the cosponsoring agencies, I wish you every success in this conference and a very pleasant stay in this lovely Cauca Valley of Colombia.

"I hope that during your stay here you will also be able to find time to get to know something about the activities of our Center.

"Thank you very much."

Opening Address

John A. Pino*

"On behalf of the sponsoring agencies of this Conference and as a representative of The Rockefeller Foundation, I would like to indicate how pleased we are that so many distinguished individuals have accepted the invitation to participate. This high degree of interest on the part of national and international agencies reflects, I believe, the importance and timeliness of the issues we will be addressing, namely, the expansion and strengthening of agricultural and land use research and development in the humid lowland tropics of the world.

"The continent of South America contains over half of the earth's humid lowland tropics. The overwhelming majority of this consists of more than 600 million contiguous hectares located in the Amazon and Orinoco river basins. This vast region, which includes over half the land area of some countries represented here, still remains relatively undeveloped or in its natural virgin state. The number of people living in the Amazon region is increasing rapidly. Most national governments are now expanding their efforts to address the needs of this region and its people. Assessments are being made of the natural resource base. Incentives are being provided for industrial and agricultural development. And the movement of people into the region through both planned and spontaneous migration is generally encouraged. Many believed that agricultural development in the Amazon can make a substantial contribution to national and world-wide food production and would be the most

* Vice-Chairman. CIAT's Board of Trustees, and Director, Agricultural Sciences, the Rockefeller Foundation.

effective means of stimulating greater economic prosperity in the region itself. Experience to date has demonstrated, however, that additional research and new agricultural technologies designed specifically for the humid tropics are needed if such production is to be sustainable, economical and in balance with the ecologically fragile natural systems of the region.

"Everyone here is aware of the historical trends in human population growth and the resulting stresses which have been placed on natural resources to meet the demands of those populations. It would be foolish for us to ignore the implications of those trends. We have seen large land masses virtually destroyed and their recovery for some productive purpose may be lost forever. In the United States it is estimated that we lose over a million acres of productive land annually. In Asia and Central America, forest lands are being denuded and on hills the consequences of deforestation are disastrous.

"All of this we know!

"Yet we seem to be impotent in the face of these relentless forces. Few nations have addressed comprehensively the protection of their natural resource base including the land, water, flora and fauna. Nor have they articulated the basic principles and policies governing the use of these resources. One difficulty is the conflict between the "rights" of the individual to use his land as he pleases, versus the broader social or national interest. We recognize that these socio-economic forces are very powerful and the need to understand them is certainly as important as scientific and technological knowledge in making proper decisions. At some point the science and technology must converge with the policy making apparatus so that rational land use policies are made and followed.

"However, the objectives of this particular conference are to speed the development and propagation of appropriate new agricultural and land use technologies for the humid tropics of South America. We plan to review our current understanding of the potentials for and constraints to agricultural production in the Amazon Basin, to characterize the necessary new technologies and review current research on them, to identify future research needs, to formulate strategies for expansion and strengthening of appropriate research programs and to discuss opportunities where cooperation amongst various agencies might help to facilitate implementation of such strategies.

"Any future agricultural research programs must of course be designed within the context of established national programs and be consistent with national development goals and policies. In addition, much has already been learned from national programs concerning what agricultural technologies will or will not work in the Amazon, under what circumstances, and why. New agricultural technologies eventually have to be fine-tuned in order to become location and situation specific. We, therefore, propose to begin the conference with presentations and discussions which review national programs and policies relevant to development in the humid lowland tropics, including the lessons learned from experience, thereby placing subsequent discussions and recommendations within the appropriate framework.

"The second session of the conference will be a review of the state of knowledge concerning the agricultural resource base of the Amazon region and alternative agricultural and land use development options.

"Systematic mapping of and scientific research on the Amazon's agricultural resource base are relatively recent undertakings, and much still remains unknown. Therefore, we should also discuss the important resource topics on which further assessment is needed.

"For report preparation and discussion purposes the agricultural and land use options have been categorized into forestry, perennial crops, pastures and livestock, and annual crops. In the Amazon region, research on these options and other farming systems is also at an early stage. In fact, certain of the most appropriate agricultural crops may be essentially unknown with little or no understanding of their basic characteristics and production or market potentials. One of the problems which confronts administrators of agricultural research in the Amazon is the need to select from numerous potential new crops those few which warrant a concerted longterm research effort. In a difficult region such as the Amazon, it will also be necessary to evaluate trade-offs between the high production potential of monocultures of the greater yield stability and heterogeneous communities. Since it is likely that land use systems integrating various options will be most appropriate, the last reports address the topic of farming systems for the Amazon.

"The final session will deal with the question of "where do we go from here?". We hope to formulate a strategy for future research and to identify opportunities for cooperation amongst concerned agencies. It will be largely a discussion session and we encourage all of you to be thinking about ideas and recommendations which should be raised. Issues identified during the first two days that are relevant to a future research strategy should be surfaced again at the time. A draft strategy statement will be prepared for our review prior to Friday. Keep in mind, however, that it is just a starting point and that we hope to develop a more substantive and broadly acceptable set of recommendations.

"If more complex multiple use and multiple cropping arrangements are the most appropriate agricultural development for the Amazon, the research system necessary to design and test them will also be more complex, no doubt involving inter-disciplinary teams and linkages between institutions—making it all the more important to have a clearly defined research strategy. Hopefully we will be able to formulate a strategy that will help all of us in making decisions concerning manpower, institutional and financial requirements and commitments, as well as the design and location of specific research projects."

Country Reports

General Evaluation of the Agricultural Potential of the Bolivian Amazon

Francisco Pereira*
José G. Salinas**

Introduction

The purpose of this paper is to present general information about the agricultural potential of the Bolivian Amazon. It is necessary to emphasize that knowledge of the Amazonian ecosystems of Bolivia and of the alternatives for forestry, agricultural and animal production is superficial. The agricultural-ranching development of Bolivia's tropical region experiences difficulties that reflect the lack of detailed research and planning. Although some agricultural studies exist, their use is limited by technical and/or economic constraints and the lack of clearly defined objectives.

Since the potential of a given ecosystem is determined by the characterization of its climatic, vegetative and soil resources, the purpose of this paper is to provide general information on those factors based on the main climatic regions identified by their total wet season potential evapotranspiration (TWSPE), by the dominant vegetation within each ecosystem and by the distribution of the principal soils at the levels of order, suborder and great group, including certain edaphic properties. The general features of Amazonia are discussed extensively in Cochrane and Sánchez, and Salati and Schubart elsewhere in this volume. The sum of these natural factors will generally indicate the agricultural potential of the Bolivian Amazon. Finally, an attempt is made to assess the potential of existing native pastures, parts of which are presently utilized, in order to visualize the ranching exploitation of the northeastern region of Bolivia.

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General Characteristics

Location and area

Ecologically, Bolivia is divided into three wide zones: (a) the altiplano,* (b) the meso and crothermic valleys,** and (c) the tropical plains. Each of these zones has different ecosystems so that the renewable natural resources are heterogeneous with regard to species, quantity and quality.

Of the total area of Bolivia, two-thirds (1,098,581 km²) are comprised by the area defined as lowlands (< 1500 masl); about one third of this area (360,000 km²) makes up the Bolivian Amazon règion (Weil *et al.,* 1974). Specifically, the Bolivian Amazon is the northeastern region influenced by the so-called Amazon hydrographic basin (Fig. 1). It is characterized by a large number of rivers tributary to the Amazon, which form basically five principal hydrographic systems: Madre de Dios, Beni, Mamoré, San Miguel and Itenez.

Figure 1. *Hydrographic systems of the Bolivian Amazon basin.* (Source: Weil et al., 1974.)

* The altiplano or Bolivian tableland is an 800 km long x 130 km wide area (3600 m average altitude) delimited by the Cordilleras Occidental and Oriental, which extends from the Vilcanota knot in Peru to the Argentine frontier. (Editor's note.)

** Intermediate zone between the altiplano and the plains (1500 - 3000 m altitude) forming the high valleys, (2600 - 3000 masl). central valleys (2000 - 2600 masl), low valleys (1500 - 2000 masl) and the semitropical valleys (1000 - 2000 masl) referred specifically as "yungas". (Editor's note.)

Considering that the Amazon basin covers areas of South America from approximately latitudes 5° N to 17° S and from longitudes 76° W (at the most western point) to 46° W (at the easternmost point), the Bolivian Amazon region would comprise the entire Department of Pando, the northern part of the Department of La Paz and a great majority of the Department of Beni, with other areas reaching into the regions of Chapare (Cochabamba) and Yapacaní (Santa Cruz).

This vast region of Bolivian territory has diverse physiographic regions, and Bolivia's Amazonia can be subdivided into three principal geographic units: (a) the Tertiary Plateaus of Pando, (b) the Plateaus of Guayaramerín and (c) the Plateaus of Beni. Figure 2 shows the principal physiographic units of northeastern Bolivia, including the three units making up Bolivian Amazon. This map was constructed from a more detailed "Land Systems" map drawn over images from the LANDSAT satelite at a scale of 1:1,000,000 (CIAT, 1979).

According to Cochrane (1973), the plains of Pando, located in the extreme northwest of the country, are characterized by a slightly elevated, level surface, dissected by erosion and forming a series of small hills generally having flat tops. Geologically, the parent material of the soils comes from a sedimentary deposit consisting of smooth, ferruginous sandstones possibly originating in the Tertiary Period.

The extensive area of the Plateaus of Guayaramerín makes up a great part of the north of the Department of Beni and a considerable portion of the Department of Pando. It is characterized by an extensive, low (200-230 masl), almost flat plateau. In general, the parent soil material is an old Quaternary alluvium. However, in the Guarayos region, located in the northeast of the country and south of the Itenez River, the Brazilian Shield appears as occasional rocky outcropping, and the major part of the area is covered by alluvium derived from shield rocks. In the extreme northeastern part of Bolivia, there is a similar physiography but it is interspersed with very low lying areas which are generally swampy (Cochrane, 1973).

Due to the adverse drainage conditions, annual flooding is characteristic of this region, and low areas remain saturated for approximately six months. On the other hand, higher areas are better-drained. Another interesting feature of the plains is the presence of the so-called "square lakes". While geologists still debate their origin, in practice they provide valuable watering holes for animals.

The third physiographic unit is the Plains of Beni (Pampas of Moxos), another extensive area occupying most of the central part of Beni with portions stretching into the regions of Chapare (Cochabamba) and Yapacaní (Santa Cruz).

The parent material or rock from which soils of this region are derived is an old Quaternary alluvium, probably of a mostly sandy nature. The surface of these plateaus varies from almost flat to slightly undulating. The higher parts support forest growth, in sharp contrast to the native pastures that are common in this region. Like the Plateaus of Guayaramerín, flooding is annual because of the poor drainage of the soil, especially on the lower areas (Cochrane, 1973).

It is important to note that along the rivers of the Bolivian Amazonia basin are found strips of land largely originating from alluvial deposits.

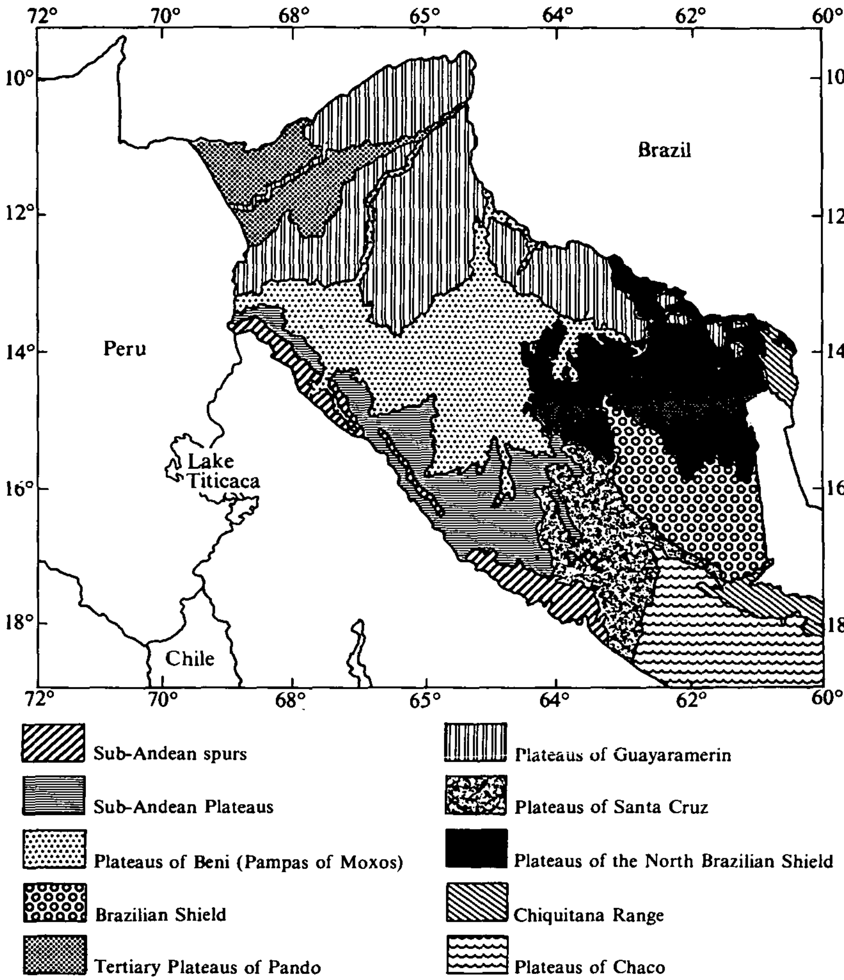

Figure 2. *Principal physiographic units of northeastern Bolivia.* (Source: CIAT, Evaluación del Recurso Tierra, 1979-80.)

The edaphic characteristics of the soils of the land strips depend on the age and origins of the sediments, which, in turn, are directly related to the origins and courses of the rivers.

Climate and vegetation

The northeastern region of Bolivia is characterized by environmental conditions that while variable are still typical of a tropical climate. The mean annual temperature is around 26°C without marked seasonal changes. Annual rainfall ranges from 1300 to 1800 mm, and is concentrated (85% of the total) between September and April.

Cochrane and collaborators (1979) determined that variations in total wet season potential evapotranspiration furnished a means to classify the vegetative cover existing in the tropics, based on the energy available for vegetative development during the growing season. On the other hand, the mean temperature during the wet season, defined as that part of the year when the moisture availability index (MAI) is greater than 0.33, is a satisfactory parameter to identify types of vegetation or ecosystems. In this manner, the five principal ecosystems of the South American tropics were identified (Table 1). Table 2 shows the principal ecosystems of Bolivian Amazonia. They are classified in relation to the meteorological stations considered representative of the region. It is evident that two principal ecosystems characterize this extensive zone: The semi-evergreen seasonal forests and the hyperthermic savannas.

Table 1. **Principal ecosystems identified in the South American tropics.**

Climatic characteristics*			Name of the principal ecosystem
TWSPE	>	1300 mm	
WS	>	9 months	
WSMT	>	23.5°C	Tropical rain forest
TWSPE		1060-1300 mm	
WS		8-9 months	
WSMT	>	23.5°C	Semi-evergreen seasonal forest
TWSPE		910-1060 mm	
WS		6-8 months	
WSMT	>	23.5°C	Well-drained, hyperthermic tropical savannas
TWSPE		910-1060 mm	
WS		6-8 months	
WSMT	<	23.5°C	Well-drained, thermic tropical savannas
TWSPE		variable	Poorly drained tropical savanna

* TWSPE = Total wet season potential evapotranspiration
WS = Wet season, determined from the moisture availability index (MAI)
WSMT = Wet season mean temperature.

Source: CIAT's Annual Report 1979.

Table 2. **Geographic location, climatic parameters and principal ecosystems of some representative meteorological stations in the northeastern region of Bolivia.**

Meteorological station	South latitude	West longitude	Altitude (m)	TWSPE* (mm)	WSMT** (°C)	Wet season*** (mo)	Principal ecosystem
Cobija	11°01'	66°44'	280	1022	25.3	9	Semi-evergreen seasonal forest
Guayaramerín	10°48'	65°22'	172	772	26.7	7	Hyperthermic savanna
Riberalta	11°00'	66°05'	172	902	26.9	8	Hyperthermic savanna
San Joaquín	13°04'	64°48'	202	995	27.0	8	Hyperthermic savanna
Magdalena	13°21'	64°08'	235	865	27.2	7	Hyperthermic savanna
San Ignacio de Moxos	14°53'	65°36'	220	791	25.1	9	Hyperthermic savanna
Santa Ana	13°45'	65°35'	220	1109	27.0	9	Semi-evergreen seasonal forest
San Borja	14°49'	66°35'	226	1155	25.4	9	Semi-evergreen seasonal forest

Source: Hancock and Jargreaves, 1979; Cochrane *et al.*, 1979; Cochrane, 1973.

* TWSPE = Total wet season potential evapotranspiration
** WSMT = Wet season mean temperature
*** Wet season = MAI > 0.33, where MAI is the moisture availability index.

Approximately 75 percent of the total Bolivian Amazonia region is within the semi-evergreen seasonal forest ecosystem and the other 25 percent is hyperthermic savannas (Table 3). Due to adverse drainage conditions, around 44 percent (16 million ha) are poorly drained lands. Fifty-six percent of poorly drained areas (9 million ha) are covered by native savannas and the rest (7 million ha), by seasonal forests. Of the total area of Bolivian Amazonia (36.4 million ha), 56 percent (20.5 million ha) are well drained with a seasonal forest vegetation; no well-drained savannas have been detected.

Soils

The distribution of soils at the level of order in the Bolivian Amazonia is shown in Table 3. Of the 10 orders considered in the United States soil taxonomy, four are identified in this region (Oxisol, Ultisol, Entisol and Alfisol). Table 3 also shows the locations of these soils within the ecosystems. Under conditions of the well-drained zones with seasonal forests, Oxisols predominate (67%) with Alfisols (18.5%), Entisols (11.0%) and Ultisols (3.5%) making up the remainder. This approximate information seems to indicate that the majority of the seasonal forests are on well-drained, low-fertility acid soils. Conversely, the seasonal forests on poorly drained lands have soils characterized as Ultisols, Entisols and Alfisols. These three orders make up 90 percent of the area of poorly drained soils with forest vegetation, where the Ultisols predominate (42%), followed by the Alfisols (32%).

In relation to the savannas of the Bolivian Amazonia, available information indicated that practically all have very poor soil drainage. Alfisols (68%) predominate with the remainder being Ultisols.

Table 4 provides more detailed information on soil distribution of the region. The majority are classified as Oxisols and Ultisols, which together make up 57 percent of the total. This high percentage indicates that, in principle, the soils have a low natural fertility. The rest of the region is covered by Alfisols (26%) and Entisols (17%), many of which are of alluvial origin and are found on the land strips along the rivers. Among the Oxisols and Ultisols, three important great groups are represented: The Haplorthox (27%), the Acrorthox (12%), and the Tropaquults (13%). The first two are well-drained soils with profiles uniform in depth and of low natural fertility. These soils are found primarily in the seasonal forest, as indicated in Table 3. As for the Tropaquults, they are found in the seasonal forest and the poorly drained savannas which remain flooded for a relatively long time during the wet season. Also important but within the Alfisols are the Tropaqualfs which comprise 25 percent of the poorly drained savannas.

Table 3. **Distribution of soil orders and vegetation types as a function of soil drainage conditions in the Amazon region of Bolivia.**

	Forests				Savannas			
	Well-drained		Poorly drained		Well-drained		Poorly drained	
	Area (millions of ha)	Proportion (%)	Area (millions of ha)	Proportion (%)	Area (millions of ha)	Proportion (%)	Area (millions of ha)	Proportion (%)
Oxisol	10.64	67.0	0.54	9.9	-	-	-	-
Ultisol	0.58	3.5	2.25	41.5	-	-	2.28	32.0
Alfisol	1.78	18.5	0.91	31.8	-	-	4.85	68.0
Entisol	2.97	11.0	1.72	16.8	-	-	-	-
Totals	15.97	100.0	5.42	100.0	-	-	7.13	100.0
Proportion of total area of 28.5 million ha (%)	56		19				25	

Source: CIAT, Evaluación del Recurso Tierra, 1979-80.

Table 4. **Distribution of soils of the northeastern region of Bolivia, at the great group level. Tentative classification.**

Order	Suborder	Great Group	Area (millions of ha)	Proportion (%)
Oxisol	Orthox	Haplorthox	7.68	26.9
		Acrorthox	3.50	12.3
Total Oxisols			11.18	39.2
Ultisol	Aquults	Tropaquults	3.59	12.6
	Ustults	Tropustults	0.20	0.7
	Udults	Tropudults	1.32	4.6
Total Ultisols			5.11	17.9
Alfisol	Aqualfs	Tropaqualfs	7.14	25.0
	Ustalfs	Rhodustalfs	0.23	0.8
	Udalfs	Tropudalfs	0.17	0.6
Total Alfisols			7.54	26.4
Entisol	Aquents	Tropaquents	1.10	3.9
		Psammaquents	0.16	0.6
	Fluvents	Tropofluvents	3.13	11.0
	Orthents	Troporthents	0.22	0.8
	Psamments	Tropopsamments	0.08	0.3
Total Entisols			4.69	16.5
Total			28.52	100.0

Source: CIAT, Evaluación del Recurso Tierra, 1979-80.

Table 5 presents a summary of some chemical characteristics of the soils of northeastern Bolivia. With respect to soil acidity, 35 percent of the Bolivian Amazonia is characterized by having pH values below 5.3, which, besides indicating acidity, also suggest the presence of toxic levels of Al. Approximately 29 percent of the soils are either classified as having high (40-70%) or very high (>70%) Al saturation, in the 0-20 cm depth. It is important to note that the majority of the soils are slightly acid (5.3-6.5) both in the plow layer (64%) and in the subsoil (51%). Due to this situation, the Al saturation condition is medium (10-40%) in 42 percent of the soils. Similarly, phosphorus availability is medium (3 - 7 ppm, Bray II) in approximately 50 percent of the soils and less than 3 ppm (Bray II), which is considered as low P availability, in 27 percent of the soils. From this general information, it can be inferred that for the soils of this region, most of which are classified as Oxisols and Ultisols, their degree of fertility ranges from medium to low. The majority of these soils are under the seasonal forest type of vegetation and, therefore, would be maintaining this soil fertility level by recycling the nutrients existing in that type of forest. However, the area is highly susceptible to a rapid degradation of soil fertility due to the fragility of the ecosystem.

Table 5. **Summary of some parameters for soil fertility in the northeastern region of Bolivia.**

Parameter and range	Soil depth			
	0 - 20 cm		21 - 50 cm	
	Millions of ha	%	Millions of ha	%
pH:				
Very acid (< 5.3)	14.5	34.9	20.2	48.4
Acid to neutral (5.3-7.3)	26.8	64.2	21.1	50.7
Alkaline and/or saline (> 7.3)	0.4	0.9	0.4	0.9
% Al saturation:				
Very high (> 70)	1.1	2.7	8.3	19.9
High (40-70)	6.9	16.5	10.4	24.8
Medium (10-40)	17.6	42.3	12.5	29.9
Low (< 10)	16.0	38.5	10.6	25.4
Cation exchange capacity (meq/100g):				
Low (< 4)	9.7	24.4	21.2	51.0
Medium (4-8)	17.5	41.9	9.9	23.7
High (> 8)	14.0	33.7	10.6	25.3
Available P (ppm, Bray II):				
Low (< 3)	11.3	27.2	35.4	85.0
Medium (3-7)	20.7	49.7	4.2	10.0
High (> 7)	9.6	23.1	2.1	5.0

Source: CIAT, Evaluación del Recurso Tierra, 1979-80.

Agricultural and Forestry Potential

The most important forest resources are found in the seasonal forest ecosystem, primarily in the Department of Pando and northern portions of the Departments of Beni and La Paz. This immense region produces woods of all types, furnishes forest products like cocoa, rubber, resins, nuts, cusi almonds and others, and boasts a diverse array of wild animals representative of Amazonia. According to Cochrane (1973), this forest region is one of the few remaining marvels of the world. The selective felling of non-productive forest trees and their replacement with modern, useful species would provide an increase in the forestry potential of this region. However, the programs of spontaneous colonization and directed human settlements, although solving the social and economic problems of the areas of the Altiplano and valleys, are also introducing systems of excessive land allottment which translate into destruction of the natural resources of the Amazonia.

The present model of agricultural development in Bolivia (research and extension) places a priority on the Bolivian Amazonia in such a way that the activities of the tropical experiment stations like Riberalta, Maral, Perotó, San Carlitos, Chipiriri, La Jota, Saavedra and Sapecho represent 70 percent of the agricultural experimental centers of the country. There are plans to establish agricultural extension units to offer technical assistance based on results of practical, effective research. There are also efforts to consolidate a transport infraestructure for Amazonia. The construction of three highways, the first between La Paz-Beni-Pando, the second between Santa Cruz and Beni, and the third, between Cochabamba and Beni, and the conclusion of the Yaculba-Santa Cruz-Mamoré railroad, would permit the Bolivian Amazonia to be incorporated geographically and economically with the rest of the country. With the development of the region, it is also necessary to introduce an appropriate technology for forestry, agricultural and ranching enterprises.

Potential of Native Pastures

According to Acre (1967), the appropriate lands for animal exploitation in the Bolivian Amazonia comprise two extensive physiographical units: (a) the Plateaus of Beni (Pampas of Moxos), and (b) the Guaraya formation (Plateaus of Guayaramerín).

The Pampas of Moxos comprise a large land surface almost entirely situated in the Department of Beni. These plateaus with typical savanna vegetation constitute the extensive native pastures of the region that are interrupted by the woody formations called islands. These pastures are of two types, those of the higher (upland) and those of the lower-lying ground (lowland).

The upland areas have vegetative associations of native savanna, among which the following species predominate: *Sporobolus poiretti* and *Sporobolus indicus* (paja cerda), *Paspalum conjugatum* (cintilla), *Paspalum virgatum* (paja cortadora), *Imperata brasiliensis* (sujo), *Trichachne insularis* (cola de ciervo), *Trachypogon secundus* (cola de ardilla), *Aristida complanata* (cepillo), *Boutoloua hirsuta* (grama), and other species primarily of the genera *Chloris, Andropogon, Digitaria, Manisurias, Pennisetum, Cenchrus, Tripsacum, Setaria* and *Agrostis.*

In general, these native grasses of the high zone have low nutritive values and limited productivity. The minimum values for nutritive quality and quantity produced by these grasses coincide with the period of least precipitacion (May, June, July and August). This situation consequently creates a period when forage is deficient and causes a common practice of burning the pastures in order to rely on tender regrowth during the dry season.

Forage legumes are scarce, possibly because of the annual burning of the pastures — a practice that considerably affects the persistence of the legumes. The most widely distributed species are of the genera *Indigofera, Tephrosia, Phaseolus, Desmodium, Centrosema* and *Galactia.* Species such as *Crotalaria* and *Aeschynomene* are utilized for browsing (Riera *et al,* 1978; Braum, 1963).

Riera *et al* (1978) indicate that the grasses *Paspalum plicatulum* (gramalote) and *Paspalum notatum* (grama negra) have good forage value and palatability, but they are present only to a minor degree in upland pastures.

The lower lands or temporarily flooded zones have a herbaceous cover of higher quality forage than the upland areas. Some of the species have good nutritive value and palatability and are available during dry periods. Among these favorable species are *Leersia hexandra* and *Leersia* sp. (arrocillo bajo), *Paspalum hidrophylum* and *Panicum repens* (cañuela blanca), *Cyperus* sp. (pelillo) and *Paspalum plicatulum* (gramalote). Among the other lowland forage species consumed by animals are *Eichornia* sp. (jacinto de agua), and *Poinsettia hectorophylla* (leche leche) (Riera, 1978).

The Guaraya region is also a savanna where the woody vegetation does not form islands but is scattered over the savanna. According to Arce (1976), another difference between the Pampas of Moxos and the Guaraya formation is that, in the latter case, pastures are found on sandy or sandy loam soils. The vegetative association of the Guaraya formation is characterized by the presence of several genera of grasses such as *Andropogon, Thrasya, Paspalum, Sporobolus, Setaria, Aristida* and *Elynuros*. Inluded in the tree-like species are the genera *Tecoma, Bombax, Copaifera, Dalbergia, Curatella* and *Machaerium*, and among the palms, the genera *Acronomia, Sheelea, Mauritia, Astrocarium* and *Copernicia* (Lara, 1979).

The major ranching activity of the country is found in this zone. Despite the importance of the native forage resources in the Bolivian Amazonia, it can be said that their management is deficient, with situations found of both under- and over-utilization of the native savanna. For this reason, ranching in this zone operates under a low stocking density in many cases and over-grazing in others.

Evaluations of the forage potential of native pastures of the Bolivian Amazonia are scarce. No basic research exists at present, which could effectively support the definition of management norms for these pastures. San Román (1979) affirms that the grazing capacity of native fields of the Beni region could be increased by utilizing the entire pasture area that is now unexploited without modifying its present carrying capacity, estimated at 1 animal/5 ha. This increase could be even greater if improvements (pastures, water facilities, grazing systems, etc.) are introduced into the overall system. These improvements would permit to reduce the number of hectares per animal to three, which means that the grazing areas of Beni could support about 5 million heads.(Table 6). A similar situation could be given for the Guaraya formation.

Table 6. **Estimates of the stocking rates and ranching capacity of the Beni savannas of Bolivia.**

Total available area	15,000,000	ha
Present cattle population	1,701;651	head
Present stocking rate	5	ha/head
Effective area presently utilized	3,750,000	ha
Potential capacity of total area without increasing stocking rate	3,000,000	head
Potential capacity of total area with improvements (increased stocking rate)	5,000,000	head
Future stocking rate	3	ha/head

Source: San Román, 1979.

Conclusion

Without rational use, the natural resources evolved over hundreds of years are easily destroyed by man's action as he does irreparable damage.

Penetration highways implanted without an adequate planning, good infraestructure and efficient conservation could also be easily damaged with the consequent isolation of populations. An accelerated program, with no thought to environmental and infraestructural maintenance would have little or no value. Therefore, an integrated program is necessary to assure continuity of action in the consolidation of the settlements as well as the development of new communities. Past experiences indicate that the advance toward the Amazonia region should be done with utmost caution and based on well-founded scientific studies.

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General Evaluation of Development Policies and Research in the Brazilian Amazon

Herminio Maia Rocha*

Introduction

There is, inarguably, an enormous potential for the production of food and other agricultural products for internal consumption and export in the Brazilian Amazon. It is estimated that on the upland areas of Legal Amazonia there are about 28 million hectares of soils of medium to high fertility. These soils are located mainly in the South of Pará, in the São Felix do Zingu and Altamira regions, in the Federal Territory of Rondônia, and in the State of Acre. The várzeas (flood prone rain forest plains), which are distributed throughout the entire Amazon region, contain approximately 20 million hectares of fertile soil that could be utilized for food production.

The climate varies within the region, and in spite of being still insufficiently known, when associated with some soil types, there exists a notable potential for exploitation of high value crops such as oil palm, cacao, rubber, black pepper, etc. in certain areas.

The natural vegetation, known for its extreme heterogeneity, includes not only forest formation (such as the tropical dense rain forests) and the forests of the flood plains and swamps, but also nonforest formations such as the cerrado**, upland grasslands and flooded grasslands. Figure 1 shows the Brazilian Amazon.

The Amazonian flora is very rich and contains the germplasm of species of great economic potential.

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** Open grasslands with small groups of trees, which occur mainly in the central Brazilian Plateau, in the Amazonia and in some northeastern regions of the country. (Editor's note.)

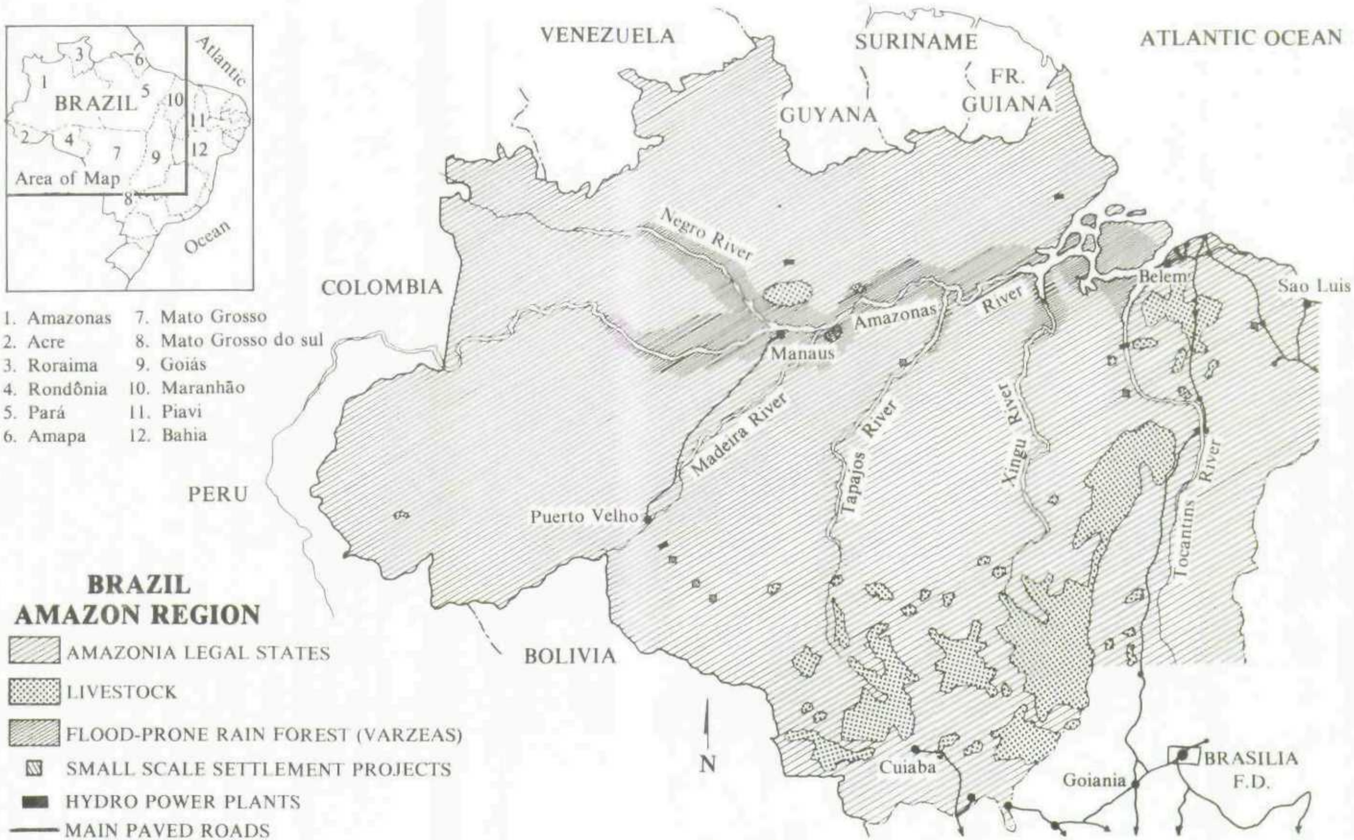

Figure 1. *The Brazilian Amazonia*

General Planning and Policy in Brazil

Government planning for the Amazon dates back to the early period of this century (Plano de Defesa da Borracha in 1912) but the postwar period witnessed the active creation of development programs and agencies in the Amazonian area of Brazil. SPVEA (The Superintendência do Plano de Valorização Econômica da Amazônia) was formed in 1946 and was active until 1964. This agency was responsible for the development of the initial infrastructure linking Amazonia to the rest of Brazil (the Belém-Brasilia highway) and was intrumental in expanding "Classic" Amazonia to "Legal" Amazonia with the incorporation of parts of Goiás and Mato Grosso. This increased the area under its jurisdiction by about one-third, and thus SPVEA became the planning agency for about 60 percent of the Brazilian national territory. SPVEA began the programs for integrating Amazonia through infraestructure expansion, agricultural credits, health, education and agricultural and scientific research.

"Operation Amazonia", which focused on increasing migration to the region, opening a new agricultural frontier, as well as providing fiscal incentives to private capital, infrastructure and land use research, began after the revolution of 1964. The programs of Operation Amazonia were oriented to development poles that would integrate the multiple objectives of settlement, infrastructure development and agricultural expansion. Development banks and credit funds were formed, and legislations to promote development in the region were enacted that were ultimately to come under the jurisdiction and coordination of SUDAM (Superintendência de Desenvolvimento da Amazônia).

The goals of SUDAM were articulated in the First Five Year Plan (Primeiro Plano Quinquenial) and the First Guiding Plan (Primeiro Plano Director). These policies provided funding mechanisms, orientation, goals and strategies for Amazonian development. By the early 70's, the Federal involvement in Amazonia was dramatically increased with the major emphasis on land occupation and agricultural settlement. The National Integration Program (Programa de Integração Nacional, PIN) was formulated to develop infrastructure (the Transamazônica Cuiaba-Santrem, and Perimetral Norte highways) in order to promote the agricultural settlement of the region. This was carried out with a companion program, PROTERRA (Programa de Redistribução da Terra), which provided rural credit, financed agroindustry, subsidized the use of agricultural inputs, stimulated agricultural exports, and supervised land titling and use.

The first National Development Program and SUDAM's Amazon Development Program focused on the physical, cultural and economic integration of Amazonia with the rest of the country (particularly the center-south and the northeast) through settlement and agricultural expansion achieved by means of colonization programs, rural credit and fiscal incentives. Further, these plans stressed natural resource surveys and agricultural research in the Amazon. Agricultural and Livestock expansion were given priority, as well as the food processing industries.

The Second National Development Program explicitly emphasized the POLAMAZONIA program (Programa de Pólos Agropecuários e Agrominerais da Amazônia), that created 15 growth centers for integrated infraestructure, mining, and economic development as a continuation and modification of the PIN and PROTERRA programs.

Land use policy

This subject has been widely discussed by diverse segments of Brazilian society, and the opinions, in general, are divergent. There are extremist opinions that on one side defend the "untouchability" of the forests (the position usually taken by naturalists) and on the other, the occupation of the area at whatever price and by whatever means, with very immediatist objectives, without any concern or planning for the future of the region. Fortunately, there is a strong moderate current that places itself in an intermediate position between the two extremes, that defends rational occupation and production in the Amazon, using a sound base of available scientific and technical knowledge.

Undoubtedly there is relatively little knowledge about Amazonia, and although there is still much to learn, the available information already allows us to orient, within a safety margin, rational exploitation strategies of certain, determined areas.

Research Activities

Research in the Amazon must be oriented toward two distinct areas. On the one hand, basic research should be developed to augment the scientific understanding of the region. This is research dedicated to the exhaustive study of the flora, fauna, river biology, and their potential for exploitation, disease potential, water recycling, etc. On the other hand, applied research directed at the agricultural producer must be expanded to give support for agricultural activities.

Agricultural research for Amazonia must be oriented to complement other government actions, in order to create an economically viable agriculture. The different research institutions should also integrate their efforts to be able to determine priorities for scientific, technological, ecological, economic and social aspects.

Many national and state agencies are involved in Amazonian development and research. Most important among them are the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) with CPATU (Centro de Pesquisa Agropecuária do Trópico Umido), UEPAE (Unidades de Execução de Pesquisa de Âmbito Estadual) and research programs (such as PROPASTO, the pasture research programs), throughout the Amazon. EMBRAPA is actively engaged in research for the producer, and has emphasized a triple focus on ecological, economic and social research questions. The results of these programs are discussed later in this paper, and in greater detail in the works by Toledo and Serrão, and Valverde and Bandy elsewhere in this volume.

Other research institutions active in the region are dedicated to scientific research that can expand the understanding of natural resources and their potential. EMATER (Empresas Estaduais de Assistência Técnica e Extensão Rural) is the extension organ charged with transferring the information developed at research stations to farmers in the region. Forestry research is carried out by IBDF (Instituto Brasileiro de Desenvolvimento Florestal) and PRODEPEF (Programa de Desenvolvimento e Pesquisa Florestal) in collaboration with EMBRAPA, INPA (Instituto Nacional de Pesquisas da Amazônia) and SUDAM. IBDF is also involved with natural resources surveys. The Comissão Executiva do Plano da Lavoura Cacaueria (CEPLAC), in collaboration with EMBRAPA, CPATU, and SUDAM, is expanding cacao cultivation in the Amazon. The Centro Nacional de Pesquisa de Seringueira (CNPSe) also works with EMBRAPA and state agencies. INATA (Agricultural Institute for Tomé-Açu) works with a number of cash crops in an area of predominantly Japanese settlement. INCRA (Instituto Nacional de Colonização e Reforma Agraria) is in charge of land survey, colonization and titling of lands in the Amazon. This is by no means a complete list, but gives an idea of the commitment of the Brazilian government to development of its Amazonian states and territories.

Experiments

The agricultural development of the region will be achieved only by great effort, taking into account limitations such as the absence of infrastructure, the nutrient deficiencies of much of the soil, the high rainfall and the wide occurrence of diseases and pests, among others.

The great challenge for the scientists who work in the region is to discover alternative, appropriate agricultural systems for the humid tropics that, beyond being economically attractive, are ecologically viable.

Some experiments that EMBRAPA is carrying out on the upland areas have generated a great deal of interest because they are attemps at seeking and developing agricultural systems that are appropriate to tropical conditions. These experiments are oriented towards understanding the alterations that occur under different management systems, and are considered to be quite innovative and with good prospects for success. They occupy experimental plots of 10 hectares each on various soil types and involve diverse perennial or annual crops such as oil palm, cacao, rubber, Brazil nut, guarana, pepper, important timber species, pastures, corn, rice, beans and cassava.

In each plot, different crop combinations under different management are studied noting the physical, chemical and biological changes that occur using the natural forest and secondary growth as reference points. Utilization of natural forest, alone or in association with exploitation of other crops in the understory, as well as the utilization of diverse agricultural systems under differing management schemes are all being examined. The main concern is to develop systems of agriculture that are economically attractive and that avoid undesirable and irreversible damage to the ecosystem. The advantage of the agricultural systems under study is that they reduce or avoid soil damage by erosion or leaching because they are based on perennial crops that promote nutrient cycling. Also, due to their production characteristics, they maintain a rural labor force on the land.

In the várzeas, some experiments are being carried out based on food crops such as rice, corn and beans. The inundated areas are also being studied by EMBRAPA with emphasis on buffalo production, including the feeding, improvement and management of these animals.

Forestry research in the region has as its main objective to develop systems of exploitation that are also conservationist using sustained yield management of natural forest, implantation of agroforestry systems, and repopulation with pure stands of degraded areas.

Some research results

Some research results of great significance for the agricultural development in the region have been achieved in the last few years. The recuperation of degraded pastures which encompass some 500,000 ha of the total artificial pasture in Amazonia depends basically on a phosphorous supplement to the soil. The technology consists of cleaning the area and then applying 50 kg of P_2O_5/ha, half the rate in the form of rock hyperphosphate and the other half in the form of superphosphate. With the application of fertilizers, the grass which had been suffocated by weeds, develops rapidly and soon dominates the area. The increase in green matter three months after application is estimated at 300 percent.

Experiments on rice production systems on the várzeas of the Caeté River (in Pará) under natural irrigation, showed that the cultivar IR-841 (at 20 x 20 cm spacing with traditional cultivation) produced 8.9 t/ha/harvest, an increase of 200 percent over the traditional system used by local farmers. On the várzeas of the State of Amazon, mean productions obtained for beans, corn and rice were 1,500, 4,500 and 5,000 kg/ha, respectively, without using fertilizers.

In the Federal Territory of Rondônia, trials with coffee showed high levels of productivity indicating the feasibility of exploiting this crop. The control of coffee rust along with other cultural practices allowed an increase in production of between 98-200 sacks per 1,000 plants.

With reference to leaf blight of rubber *(Microcyclus ulei),* the main limiting factor for this crop in all of Latin America, studies of ecological zonation have demonstrated that the disease can be controlled using a variety of cultural techniques. The research aims at selecting areas with a pronounced dry season that coincides with the period when rubber trees set leaves. The studies also include the selection of clones most adapted to these conditions. This approach is a genetic and ecological solution.

The feasibility of planting pure stands of important timber species of the region has been demonstrated, and is mainly oriented toward recuperation of degraded areas.

The buffalo research has shown the capacity of these animals to produce up to 450 kg of meat at 18 months of age and 2,000 kg of milk per year. The fertility of these animals is about 70 percent. In addition, the buffalo has possibilities as a work animal, either in harness with agricultural implements for rice in the várzeas, or for wood transport or even as a saddle animal.

Recently, a technology has been developed for producing "instant" guaraná, opening up new perspectives for this product which is widely used as a soft drink in Brazil.

Various other results have been achieved in the last few years and are in the process of diffusion for adoption by producers.

Considerations on the Colombian Amazon Region

Jaime Navas Alvarado*

Introduction

The Amazon area is one of the seven natural regions in Colombia that because of its size and rich resources (forests, fauna, flora and its agricultural potential developed through the use of sound, appropriate agricultural systems) is vitally important to the country's social and economic development.

This paper presents a brief description of this region and its principal features. Management options based on research findings for the area are also presented. Finally, this paper proposes some basic criteria that can be used in defining development policies for this region.

General Characteristics

Location and size. The Colombian Amazon is a typical tropical region located in the southeastern part of the country between the Eastern chain of the Andes and the borders with Peru and Brazil, and the Colombian Orinoco area from 4° N to 4° S. The region's 405,685 km^2 account for 35 percent of the Colombian territory and include the "Intendencias" of Caquetá and Putumayo and the Administrative Territories of Amazonas, Guaviare, Vaupés and Guainia. Much of the information presented here was taken from Guerrero (1974, 1977) Cortes *et al* (1972, 1974), Benavides (1973), Castellanos (1970) and Alarcón *et al* (1980).

Population. The region is very sparsely populated by a few Amerindian tribes that are slowly becoming extinct. People earn their livelihood by hunting, fishing and farming. The region's myriad rivers provide the main form of transportation and communication.

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Climate. The climate is hot and humid with humidity increasing from north to south and from east to west. Ecologically the zone falls into the category of tropical rain forest (Fig. 1). Rainfall is plentiful year round; the annual average for the Amazon Basin is 2300 mm. Local records show the following averages: San José del Guaviare, 2500 mm; Miraflores, 2900 mm; Mitu, 3200 mm; Arauca, 3800 mm; Leticia, 3000 mm; Florencia and Puerto Asis, 4500 mm.

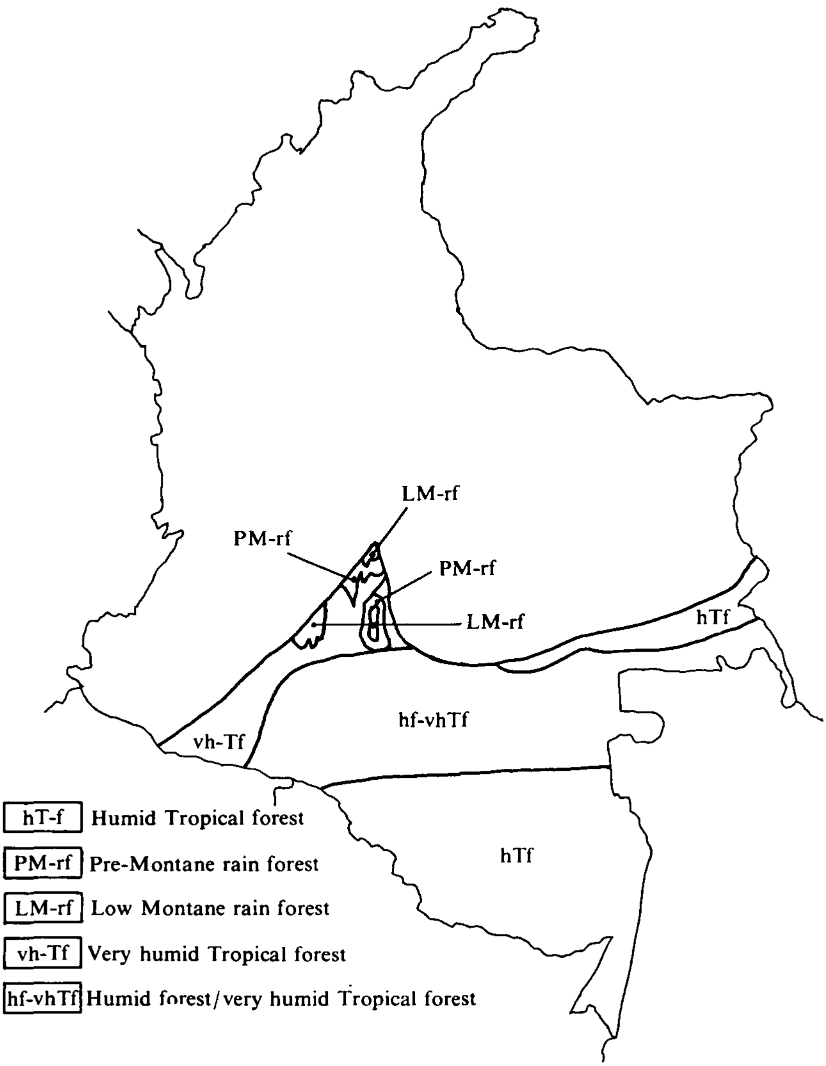

Figure 1. *Ecological map of the Colombian Amazon natural regions.*

The mean annual temperature ranges between 25°C in Florencia and 27°C in Leticia, but the mean monthly variation in temperature is never higher than 50°C. A dry period occurs in December and February in the west and from June to October in the east.

Figure 2 shows the year round rainfall distribution and temperatures in Puerto Asis. Relative humidity is high—an estimated annual average of 82 percent (Alarcón *et al,* 1980).

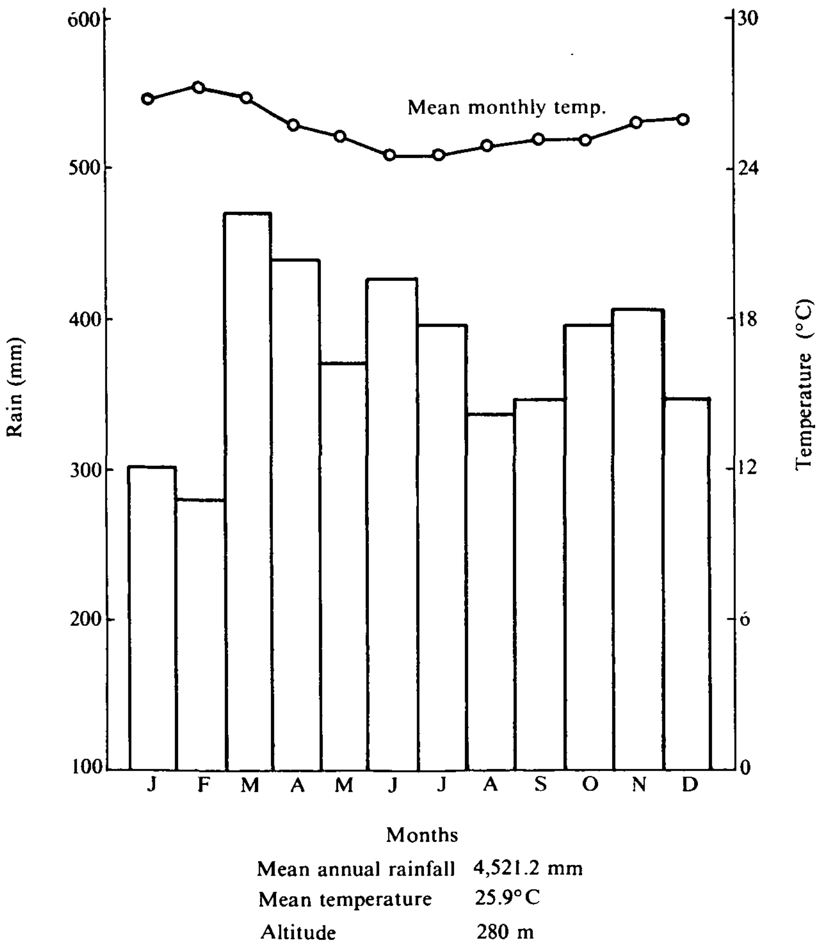

Figure 2. *Annual distribution of rainfall and temperature in Puerto Asis, Putumayo (Source: Alarcón* **et al,** *1980).*

Topography. The relief of the region is rolling hills that turn into steep slopes near the piedmont (called "mesones" in the vicinity of Florencia); along the rivers, there are intermediate terraces and low plains; moving away from the Andes towards the south, the land grows flatter. The hills range from 20 to 50 m from the top to the concave areas between hills which, when filled with water, are called "chuquios".

The rivers are bordered by alluvial plains that are basically flat. The altitude in Guaviare is less than 200 masl, and in Vaupés, Caqueta and Putumayo it reaches 200-400 masl.

Geology. The region is composed of different tertiary deposits that date anywhere from 445 to 1200 million years ago. These deposits are arranged with very thin layers of clay at the bottom, followed by layers of sandy clay, coarse sand and gravel, and finally a rolling surface layer of clay. These clays are the parent material for most of the soils in the area. In general terms, the Colombian Amazon region is composed mostly of alluvial materials.

Soils. Several types of Amazon soils were classified by Cortés (1973) as Typic Eutropept, Aquic Dystropept, Typic Haplorthox and Typic Gibbsiorthox. Benavides classified most of them as Dystropepts (Table 1).

Table 1. **Classification of representative soils of the Colombian Amazon region.**

Relief	Source	Taxonomy*
Terraces	Cortes (1973)	Tropeptic and Typic haplorthox (3)
Hills		Typic Gibbsiorthox (1)
Terraces		Oxic and Aquic Dystropept (2)
Undulations		Typic Eutropept (1)
Undulations	Benavides (1973)	Aquic Paleudults (2)

* Thenomenclature was taken from Soil Taxonomy. The numbers in parentheses represent the number of profiles studied.

Source: Guerrero. 1974.

Amazon soils are characterized by very low fertility, high acidity, very low base saturation, extremely low levels of exchangeable Ca, Mg, and K, low levels of available P, and a high exchangeable Al content that reaches toxic levels for most crops (Table 2).

The soils are poor in organic matter, which is limited to a 10 cm top layer of soil. The climatic regime of high temperature and humidity results in rapid breakdown of the organic matter.

Table 2. **Chemical and textural characteristics of piedmont and flood plain soils in Caqueta.***

Characteristics	Flood plains	Piedmont
pH	5.20	4.00
Organic matter (%)	2.10	3.60
P (Bray II, ppm)	5.00	3.00
Al (meq/100 g)	1.80 (38%) **	5.30 (82%)
Ca (meq/100 g)	2.00	0.60
Mg (meq/100 g)	0.40	0.13
K (meq/100 g)	0.10	0.12
Na (meq/100 g)	0.47	0.30
ECEC (meq/100 g)	4.80	6.45
Texture	Sandy loam	Clay loam

* Physiographically there are two zones: the piedmont characterized by hills which vary in steepness and by low fertility soils and flood plains characterized by their flatness, fairly fertile soils and in some cases by flooding problems.

** The number in parentheses indicate the percentage of Al saturation.

The active cycling of organic matter between the soil and the biomass creates an ideal environment for the luxurious vegetation of the region. However, when forests are cut the nutrients in the biomass can be rapidly lost through erosion and leaching.

According to Benavides (1973), the principal mineral found in the clay sections of several profiles studied was kaolinite (40%). Between 8-45 percent of mica was found in all soils studied. Vermiculite and lesser quantities of 2:1-2:2 clay were also found in these soils. Quartz was the main mineral reported in fine sand particles (105-250 microns) and in very fine sand particles (50-105 microns) (Table 3). The predominance of quartz in the sand layers (95%) and of kaolinite in the clay ones (40%) explains the very low nutrient-supplying capacity of these soils.

In summary, the available information suggests that these soils developed on materials poor in nutrients (therefore limiting crop development) and that through the processes of pedogenesis of tropical climates are at an advanced stage.

Vegetation. For the most part it is tropical forest. Over 90 percent of the area is covered with virgin forest; the rest has been cleared and planted with subsistence crops or is used for extensive ranching and, to a lesser extent, to grow cash crops such as maize, rice, plantains and cassava. On the uplands, there is a great variety of forest species and a few palms. The number of palm trees increases and the number of forest trees diminishes on the flood plains.

The vegetation types are presented in Table 4, showing their location, temperature and rainfall ranges and main characteristics.

Table 3. **Mineralogy of clay in three profiles representative of the Colombian Amazon region.**

Horizon	Depth	Minerals in the clay fraction*
Profile 5, Tacana - Udoxic Dystropept		
Al	0 - 10	K4 V2 V/C2 Mi1 Ql Gl**
B21	30 - 50	K4 V2 V/C2 Mi1 Ql Gl P
B21	70 - 83	K3 V2 V/C2 Mi1 Q2 Gl Pl
Profile 6, Leguizamo - Typic Dystropept		
Al	0 - 20	K4 Mi2 Ml Vl V/Cl Ql Pl
B21	20 - 80	K4 M2 Vl V/Cl Ql Pl
B22	80 - 133	K4 M2 M2 Mi2 Vl V/Cl Ql
IIC2	215 - 243	K3 M3 Vl V/Cl Mil
Profile 8, Florencia - Udoxic Dystropept		
Al	0 - 16	K4 Mi2 Vl V/Cl Gl
B21	16 - 85	K4 Mi2 Vl V/Cp Gl
B22	85 - 173	K4 Mi2 Vl V/Cl Gl

* K=kaolinite; Mi=mica; V=vermiculite; C=chlorite; integrated V/C 2:1 - 2:2; M=montomorillonite; Q=quartz; G=gibsite; P=Pyrophylite.

** The numbers ranging from 1-4 indicate relative abundance: 1<10%; 2, 10-25%; 3, 25-50%; 4>50%.

Source: Adapted from Benavides, 1973

Land Uses

Agriculture. Spontaneous colonization in Amazon areas with easy access, such as the piedmont and along the rivers, has already occurred. For the most part, farming focuses on subsistence crops and, to a minor degree, on cash crops with local markets (e.g., Neiva, Cali, Bogotá). Most important are cacao, sugar cane, plantain, cassava, maize, rice, African palm and rubber.

Table 5 gives some statistics on agricultural production for the Intendencia of Caquetá. Cultivation of rubber, African oil palm and cacao has been successful. These crops are not only economically important but also provide a sound conservation alternative for Amazon vegetation since they allow replacement of the native forest with another type of vegetation of greater economic value and fewer ecological disruptions.

Forestry. The forestry potential of the Amazon is high because the region is particularly well suited due to its climatic and edaphic conditions.

Table 4. **Vegetation types, location, climatic ranges and main characteristics of the Colombian Amazon in 1979.**

Vegetation types	Location	Average climatic ranges		Observations
		Temperature (°C)	Rainfall (mm/yr)	
Very humid tropical forest (vhT-f)	Piedmont of the eastern slope of the Eastern Chain of the Andes and part of neighboring plains	24 +	4000-8000	Belongs to the piedmont. High rainfall is due to orographic factors
Humid tropical forest (hT-f)	The Caqueta, Putumayo and Amazon Rivers basins	24 +	2000-4000	Area of intense humidity
Transition from humid forest to very humid tropical forest (hf/vhTf)	Located between the Intendencia of Amazon and the Eastern Plains from the piedmont to the Brazilian border			Occupies a large area. Has intermediate characteristics between vhT-f and hT-f
Pre-montane rain forest (PM-rf)	Part of the cool piedmont on the eastern slope of the Eastern Andean Chain	18 - 24	4000 +	Area of extreme humidity
Low montane rain forest (LM-rf)	From the eastern slope of the Eastern Chain of the Andes to the Eastern Plains and even into the Amazon region.	12 - 18	4000 +	Area of extreme humidity.

Source: Alarcón *et al.*, 1980.

Table 5. **Annual agricultural production in Caquetá.**

Product	Production
Paddy rice	1,105 t
Hulled rice	2,913 t
Maize	21,212 t
Plantains	23,952 t
Cassava	154 t
Coffee	2,840 t
Cassava flour	127 t
Peach palm	50 t
Cacao	11 t
Rice flour	195 t
Bran	12 t
Uncut lumber	75,126 m^3
Sawed lumber	293,112 pieces
Palm oil	15,300 gallons

Source: 1979 Annual Bulletin, Chamber of Commerce, Florencia, Caqueta.

The large number of timber species in this region is well known; however, poor timber management has led to the irrational felling of the best species, and no plans have been made for reforestation. Consequently, despite its enormous biomass, the Amazon jungle has a low population of good timber-yielding species. Data from Caquetá indicate that 25 percent of the available timber is hardwood and 75 percent is softwood. Among the hardwoods, some 600 species are of very good quality for construction and carpentry. The Amazon region is also home to numerous species of fiber-producing palm trees and lianas for textiles, cables and other products of industrial value.

Cattle raising. Most of the Amazon region is covered with forests, and cattle raising is centered in the piedmont of Caquetá and Putumayo. Table 6 shows the area in pastures in this region. Caquetá is the most important area in terms of grazing lands and cattle raising. Eight percent of Colombian Amazon is in pastures, and of this only 37 percent is used for meat and milk production. The ratio of beef to dairy farming is 47:1 (Alarcón *et al,* 1980).

Table 7 shows the most important grasses in the region. The predominant varieties are those that have been introduced by colonists. The main native species are: *Homolepsis aturensis* (paja amarga), *Paspalum paniculatum* (paja brava). *Paspalum virgatum* (maciega) and *Echinochloa erusgalli* (liendre puerco), which have a low forage value (Alarcón *et al,* 1980). *Paspalum conjugatum* and *Axonopus compressus* are often observed in the area of Leticia. The important native legumes include *Desmodium tortuosum* (pega pega) and species of the genus *Stylosanthes*. Introductions of good forage value are *Pueraria phaseoloides* (kudzu). *Calopogonium mucunoides* (calopo) and *Centrosema* spp.. Kudzu is the most promising legume species at the present time (Alarcón *et al*, 1980).

Table 6. **Total area in pastures, area currently in use, land area used for beef and dairy farming.**

Intendencies and administrative territories	Area in pastures (ha)	Area currently in use (%)	Area used for beef cattle (ha)	Area used for dairy farming (ha)
Caqueta	1,123,418	40	430,000	18,500
Amazonas, Putumayo, Guainía	2,064,952	35	718,370	6,163
Total	3,188,370	37	1,148,370	24,663

Source: Alarcón *et al*, 1980.

Table 7. **Main grass forage species used for feeding animals in the Amazon region.**

Scientific name	Common name	Use
Axonopus micay	Micay	Grazing
Axonopus scoparius	Imperial	Grazing and pasture for cutting
Brachiaria decumbens	Braquiaria	Grazing
Brachiaria mutica	Pará	Grazing
Digitaria decumbens	Pangola	Grazing
Echynochloa polistachya	Alemán	Grazing
Erynochloa polistachya	Janeiro	Grazing
Hyparrhenia rufa	Puntero	Grazing
Melinis minutiflora	Gordura	Grazing
Panicum maximum	Guinea	Grazing
Paspalum conjugatum	Pasto horqueta	Grazing
Paspalum notatum	Grama trenza	Grazing
Paspalum plicatulum	Pasto negro	Grazing
Pennisetum purpureum	Elefante	Pasture for cutting

Source:. Alarcón *et al.*, 1980.

The procedure for introducing grasses in virgin forest involves the following steps: (a) extraction of high quality timber; (b) felling and clearing forest; (c) burning; (d) planting maize, rice or cassava for two to three years and planting grasses (*A. micay, B. decumbens, H. rufa, P. phaseoloides,* etc.); (e) using pastures for breeding and fattening for about four years; and (f) using pastures for cow-calf operations. In some cases, depending on the management, artificial pastures are invaded by native species and can be abandoned to secondary forest for five to 10 years. Then again, the forest is cut, beginning the new cycle of exploitation.

The predominant cattle breed for beef production in Caquetá and Amazonia in general are zebu crosses, criollo x zebu crosses, brown swiss and romosinuano. The birth rate fluctuates between 45 and 62 percent, which is considered low. The mortality rate is high, at about 6 percent. No statistics for meat production exist in the Amazon, but it has been estimated at approximately 35 t/ha/year. The milk production for the Colombian Amazon is 40,378 kg/year, which accounts for 0.6 percent of the national production (Alarcon *et al,* 1980).

Development of the Colombian Amazon

Table 8 shows the agencies charged with the integrated development of the Colombian Amazon, indicating their responsibilities. The following pages summarize the main research, production and development activities carried out by ICA (Instituto Colombiano Agropecuario) in Caquetá.

Table 8. **Agencies involved in Amazon development.**

Acronym	Name of agency	Field of work
ICA	Instituto Colombiano Agropecuario	Research, technology transfer
INCORA	Instituto Colombiano de la Reforma Agraria	Colonization, credit
INDERENA	Instituto de Desarrollo de los Recursos Naturales Renovables	Conservation
IGAC	Instituto Geográfico Agustín Codazzi	Soil survey and classification
CICOLAC	Compañía Colombiana de Alimentos Lácteos S.A.	Promotion of beef and dairy farming
SENA	Servicio Nacional de Aprendizaje	Training of colonists and indians
C.U.S.	Comando Unificado del Sur	Colonization, agricultural and ranching promotion.

Plantains and bananas

Plantain and banana collections. The purpose is to observe the performance of the different varieties of plantains and bananas that have been introduced into the region from other parts of the country, in order to promote the cultivation of those best suited to the region's environmental conditions.

Studies on the "moko" disease of plantains. Caused by the bacteria *Pseudomonas solanacearum,* this disease limits the production of plantains in the Amazon region. It is rapidly spread by the heavy annual rainfall and river tides since plantains are mainly grown in flood plains. The purpose of these studies is to determine the etiology of the disease and to design control measures.

Chemical control of nematodes in the Colombian humid tropics. Nematodes are a significant limiting factor in plantain and banana production. High populations of nematodes have been detected in the soil and on the roots. The project aims to study the most effective nematocides in order to significantly reduce nematode populations.

Tubers

Cassava adaptation trials. Different improved cassava materials were tested to determine the best adapted to regional conditions. The best results were obtained with the hybrids ICA H 18, ICA H 108, ICA H 61 and the variety ICA CMC 40; production fluctuated between 13.5 and 20.3 t/ha. Variety M Mex 59 not only showed good resistance to the gall midge *Silva pendula,* but also produced 59 t/ha.

Sugarcane for sugar loaf

Adaptation of sugarcane varieties in Caqueta. The purpose of this work is to technically evaluate the performance of the most promising varieties of sugarcane since this crop is already widely grown in the region.

Maize and sorghum

Adaptation of improved maize varieties in Caqueta. Traditionally, regional varieties have provided the seed for this crop. This study seeks to find the most promising improved varieties and hybrids for the region in an attempt to increase production.

Cacao

Performance of six cacao hybrids under different planting distances. There is great potential for cacao in the most fertile zones of the Colombian Amazon region, especially considering its economic importance, its tolerance of the ecological characteristics of the region and its appropriateness for replacing or restoring the natural forest. The objective of this project is to determine the best distance between cacao plants and to observe performance of the most promising hybrids under these ecological conditions.

Agricultural potential of Caqueta soils

A series of fertilization trials were conducted to evaluate crop response and the agricultural potential of these soils. Some of these trials include:

Maize response to NPK and lime. Experiments were set up in piedmont (mesones) and flood plains (vegas) soils. In the former, maize responded well to rates of 75-150 kg P_2O_5 / ha and gave some response to applications of 40-80 kg K_2O/ ha. In the flood plains, the best results were obtained with 50 kg/ha of N, 150 kg/ha of P_2O_5 and 40-80 kg/ha of K_2O. There was a gradual yield decrease from one harvest to another and also a definite growing season effect: yields were better during the first six months of the calendar year. Maize could become an economically important product in flood plain areas where 4 t/ha yields have been obtained with native maize and where even higher yields could be obtained with improved varieties.

Response of sugarcane to NPK and lime. An experiment was established in flood plains to determine the response of the variety POJ 2878 to the application of N - P_2O_5 - K_2O and dolomitic lime. The first harvest showed a response to P with a 15 t/ha increase when compared with the control, and a yield of 85 t/ha of cane and 18 percent saccharose, with the 62-117-63 treatment. The study will allow for four harvests in order to determine residual effects. At present, an experiment is being set up to determine sugarcane response to sources of P which include national phosphate rock. Table 9 shows sugarcane response to P_2O_5 in flood plains of Caqueta (one harvest). It is interesting to note that although cane yields are not high, the percentage of sucrose is relatively high.

***Axonopus micay* response to P fertilization.** *A. micay* is widespread in Caqueta where cattle raising is an important part of the economy. Given the poor fertility of piedmont soils and the limited availability of P, it is important to determine grass response to this nutrient using low-cost sources such as phosphate rock. An experiment is being conducted at present to determine the response of this grass to different sources and rates of P in piedmont soils. Table 10 shows some of the results obtained thus far. Phosphate rock from Pesca has shown itself to be very promising as has phosphate rock from Huila when used with 50 kg S/ha.

Table 9. **Response of the sugarcane variety POJ 2878 to P_2O_5 in flood plain soils in Caqueta (one harvest).**

N	P_2O_5	K_2O	Yield (t/ha)	Saccharose	Yield increase (%)
63	9	63	60	19	18
63	63	63	71	17	39
63	117	63	85	18	67
0	0	0	51	17	0

Table 10. *Axonopus micay* **response to P fertilizers in piedmont soils in Caqueta.**

P_2O_5	kg/ha	Yield (t/ha)		
		II harvest	III harvest	IV harvest
TSP	0	16,6	16,1	15,5
	200	20,5	21,3	19,9
	400	21,9	20,0	17,3
PRP*	200	18,0	18,1	18,0
	400	21,6	21,1	19,0
PRH**	200	16,3	16,3	17,3
	400	16,6	17,2	17,8
PRP + S	200 + 50	19,1	20,2	16,3
PRH + S	200 + 50	19,6	20,2	17,5

* Phosphate rock from Pesca
** Phosphate rock from Huila

Response of the Dominico Hartón plantain to NPK and lime. Despite the poor technology used. Caqueta is one of the largest producers of plantains in Colombia. An experiment has been started to determine plantain response to NPK and lime in flood plain soils. The crop is currently five months old and thus no results are yet available.

Soil conservation and management

Both the high volume and intensity of rainfall as well as the topography of the Colombian Amazon create very favorable conditions for erosion, especially when natural forests are replaced by crops that do not have a canopy that covers the soil adequately. In response to this problem, a FAO sponsored research project, begun in 1976, is under way at the Macagual Experimental Station. Its aims are to: (a) study the erodability and erosion of Amazon soil using different soil and crop management systems; (b) evaluate the erosive potential of rains; and (c) define management systems that minimize soil erosion when natural forests are replaced with crops.

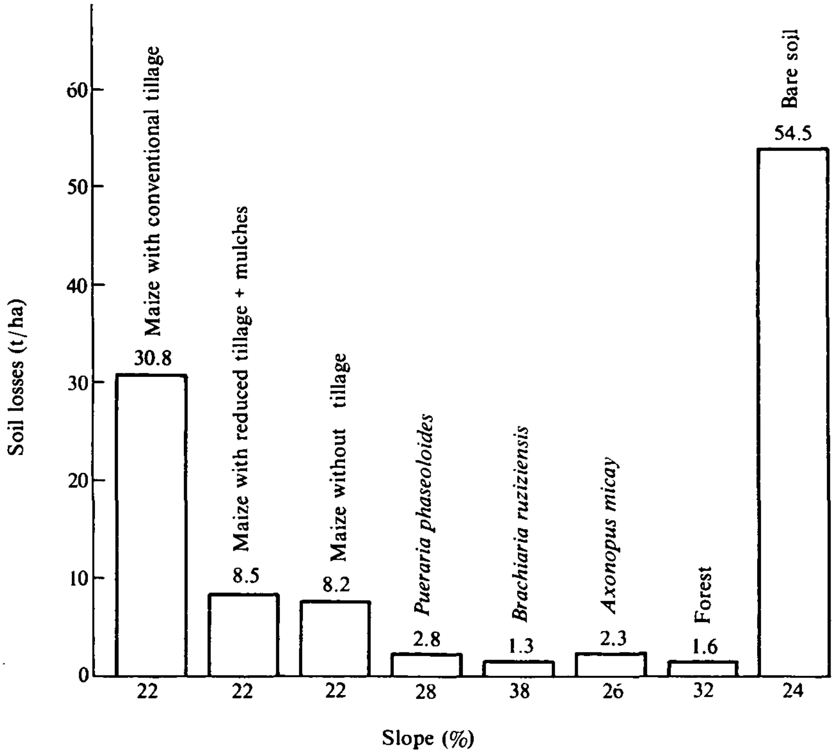

Figure 3. *Total losses of soil over a 32-month period using different crops and soil management systems.*

Figure 3 presents preliminary research results which summarize the accumulated soil losses caused by erosion over a 32 month period. The greatest losses occurred on bare soil and the smallest on soil covered with *Brachiaria ruziziensis*. This finding is very significant, especially when considering that the brachiaria was on the steepest slope. This means that brachiaria provides excellent protection against the erosive effect of the rain, presenting an alternative for soil management; furthermore, this grass is well adapted to the region and palatable to cattle. Other cover crops such as *Axonopus micay* and *Pueraria phaseoloides* can also help reduce erosion significantly.

Significant differences can be observed with maize as a result of soil and crop management. The greatest soil losses occurred with conventional tillage, but these losses were greatly reduced when minimum tillage and mulches were introduced. Finally, the protective structure of the forest itself greatly helps reduce soil erosion.

Rainfall measurements indicate that relatively low intensity showers seem to play an important role in the level of erosion when soil is completely exposed to rain.

Cattle research

Pastures and forage (ICA-INCORA agreement)

Grass collection. The purpose of this project is to measure the establishment, production and adaptation of different promising grass species in other zones. Observation has shown that *Brachiaria decumbens* and *Axonopus micay* give the highest yields in both piedmont and flood plain areas when fertilizers are used. Slightly lower yields were obtained with *Hyparrhenia rufa*.

Beef production in *Brachiaria decumbens* with rotational grazing in the piedmont of Caqueta. All plans for cattle raising must be directed towards the use of brachiaria since this grass is highly adaptable and could help realize the full cattle-raising potential of Caqueta.

Determination of stocking rates under continuous grazing in pastures of *A. micay, H. Rufa* and *B. decumbens*. This project aims to evaluate their carrying capacity in order to establish the optimum stocking rate for these promising pastures.

Regional adaptation trial for forage species. Its purpose is to evaluate and select legume species with high nutritive value that can adapt to prevailing regional conditions.

Dairy and beef cattle. There are several projects under way to promote the development of the cattle sector by means of genetic and nutritional methods that improve beef and milk production while preserving positive traits. These projects include: (a) Maintenance of hybrid vigor by crossing the zebu cattle with native breeds; (b) mineral deficiencies in cattle feed; (c) herds of pure native breeds; (d) evaluation of cattle lines for the production of meat and milk; (e) herd reproductive management systems.

Agricultural production and development activities

ICA is developing extension agencies for technology transfer, especially in the piedmont areas. ICA, in collaboration with the Caja Agraria (the Agricultural Credit Bank), provides credit for the small farmer. Samples taken on different cattle ranches in Caqueta are analyzed and evaluated at the ICA Diagnostic Center in Florencia to determine the main diseases affecting cattle in the region. Vaccination campaigns against foot and mouth disease and brucellosis have been undertaken.

A coffee rust campaign is also under way in an effort to avoid introduction of this disease into Colombia; the campaign for Amazonia focuses on trying to induce the coffee grower to change over to other crops such as cacao. Other research in the areas of plant pathology and entomology seeks ways to insure phytosanitation for crops in the region. Lastly, as part of the work done with agricultural inputs, the quality of herbicides, pesticides, fertilizers, feed concentrates and other agrochemical products sold in the region are subject to supervision and controls.

Some Limiting Factors for the Development of the Colombian Amazon

This section summarizes the main limiting factors that, acting together or separately, affect the rational and ecologically sound development of this region. These factors must be evaluated and solutions to them found through government action and through the coordinated efforts of the different institutions working towards the development of this important and vast region.

Soils. The low natural fertility and potential of these soils restrict the agricultural development of the region. Some of the principal problems are: poor nutrient-supplying capacity, high acidity, low base saturation, low levels of P, high exchangeable Al content and low organic matter content.

Climate. High rainfall in this region poses obstacles for growing many crops and makes it difficult to apply such agronomical practices as fertilization, land preparation, etc. Heavy flooding causes sheet erosion and gullies in the valleys, with increasing sedimentation in the rivers. The high temperature regimes (>25°C) accelerate the process of organic decomposition, and high relative humidity favors the development and proliferation of both plant and animal diseases.

Topography. The rolling topography in the Amazon region makes the use of agricultural machinery in crops and pastures difficult. The steep slopes, which can reach gradients of 30-40 percent, are an important factor in erosion.

Forest and soil management. Unguided spontaneous colonizations have led to the irrational use of the forest and to soil deterioration.

Infrastructure. There is lack of roads and other basic infrastructure necessary for handling agricultural inputs and products and for agricultural development in general.

Human health. Rigorous climatic conditions and numerous diseases slow down population development in the area.

Conclusions

Over the past few years, much discussion has taken place about expanding agricultural frontiers and making the Amazon region an active participant in the country's production process. In part, the debate has fomented colonization which, as a rule, has been undirected. Much has also been said about preserving the Amazon as the world's "lungs" and about creating forest, plant and animal reserves for "future generations".

We must define and establish clear criteria based on conservationist principles that enable us to draw up development plans for the Amazon region in Colombia. We must review and expand our inventory of the Amazon to increase our knowledge of this region, and we must train specialists and technical experts in soils, crops, meteorology, forests, ecology, physiology, animal husbandry, etc., to create the know-how and technology needed to overcome the restraints and shortcomings of development models.

Today, most researchers agree that with the current knowledge and technology, forestry exploitation is the best alternative for this region;

efforts must be made to improve species by incorporating other more productive ones that are either wood-yielding species or cash crops like cacao, African oil palm, rubber, fruit trees and plantains, or a combination of them in what is called multistrata cropping. In this way, the natural architecture of the forest is preserved and the negative ecological changes that cause soil deterioration can be avoided.

Extensive cattle raising activities are a good alternative for certain areas in this region, depending on their topographical features, fertility, etc. and on the use of conservationist methods. Current information on soil erosion under established pastures and experiences in this region confirm the feasibility of this type of land use.

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Development Policies and Plans for Ecuador's Amazon Region

Raúl de la Torre F.*

Introduction

The Amazon area, comprising all of Ecuador's area east of the Andes, is the country's major zone for agricultural expansion. While there is increased interest in augmenting funds for development, the Amazon continues to be the national region receiving the least attention by the Government, in terms of investment and financing. The principal reasons for this situation include the relatively low population density, the ecological conditions that hamper human settlement and infrastructure development, as well as ignorance of the region's potential.

In spite of these drawbacks, Amazonia is seen as the means for enlarging the agricultural frontier to increase food production. Those who question the region's real agricultural potential argue that it is a fragile ecosystem where environmental disruption would produce irreparable alterations that could destroy the soil, plants and wildlife.

Such concerns suggest that major efforts should be focused on the research and land use planning in Amazonia. A greater understanding of the region's ecosystems oriented to programs based on sustainable production techniques that also conserve soil and other natural resources will be fundamental for regional development.

Ecological Factors affecting Development

In addition to the following data, general information on the Amazon can be found in Sánchez and Cochrane's paper on land use potential, and

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specific features of Amazonian ecology in Salati and Schubart's paper elsewhere in this volume.

Geographical location

The most extreme points of the region are 0°25' north latitude and 6°00' south latitude, and 71°50' and 79°00' west longitudes. The Ecuadorian Amazon region occupies the extreme west of the great Amazon River basin. The region has a 354.3 km northern border with Colombia. On the east and southeast, it borders Peru for 902.6 km. The eastern range of the Andes makes up its western limits (Fig. 1). The region's closest point to the Pacific Ocean is 140 km from the Gulf of Guayaquil.

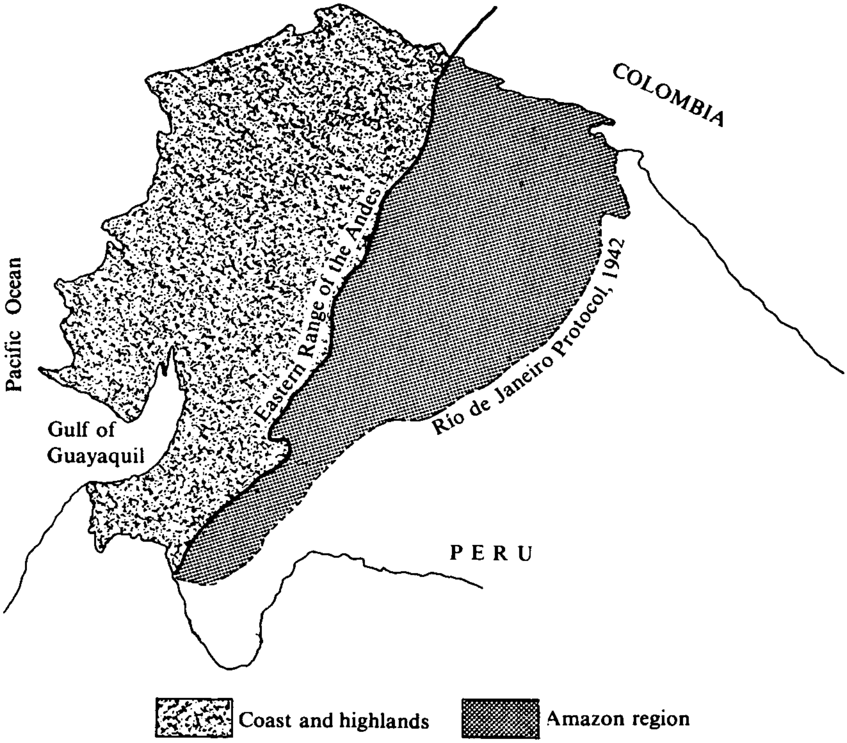

Figure 1. *Geographic location and limits of the Amazon region of Ecuador.*

Area and population

The region covers 134,760 km², or 48 percent of the national territory. According to the third Population Census and Second Housing Census of

1974, the population was 173,469 inhabitants-only 2.6 percent of the country's total population. The population density of 1.28 inhabitants/ km^2 is low.

In addition to reflecting the low population density, Table 1 shows the unequal distribution of human settlements in the different provinces. The most obvious case is Pastaza, with the lowest population density but the highest urban population.

Table 1. **Total population, population density and rural and urban populations of provinces of eastern Ecuador.**

Province	Population		Rural population (%)	Urban population (%)
	Total (Inhabitants)	Density (Inhabit./km^2)		
Morona Santiago	53,325	2.09	82.1	17.9
Pastaza	23,465	0.73	77.2	22.8
Napo	62,186	1.20	93.1	6.9
Zamora Chinchipe	34,493	1.65	88.9	11.1

Source: Third population census and second housing census, 1974.

Climatology

In 1977, the Instituto Nacional de Investigaciones Agropecuarias (INIAP) conducted an in-depth study of the eastern region in order to determine the location of an experiment center. INIAP compiled weather data from 11 metereological stations (of first, second and third classes) and two pluviometrical stations in the region (Table 2).

Table 2. **Altitudes, rainfall and mean temperatures for 12 meteorological stations located in the eastern region of Ecuador.**

Location	Altitude (masl)	Annual rainfall (mm)	Mean temperature (°C)	No. of years recorded
Sucúa	910	1664	21.7	9
Zamora	970	1907	21.2	8
Cumbaratza	930	2063	24.0	7
San Francisco	1800	2292	19.0	7
Tiputini	220	2387	25.3	9
Curaray	300	2749	24.9	7
Putumayo	230	2917	25.3	7
Taisha	511	2920	24.0	6
Limoncocha	220	3074	24.6	5
Sangay	970	3853	21.5	4
Shell Mera	1043	4223	20.2	9
Tena	527	6315	23.1	7

Source: Instituto Nacional de Investigaciones Agropecuarias, 1977.

The average annual minimum temperature fluctuates between 12.3°C in Zamora and 19°C at Putumayo. The average annual maximum temperature is highest (33.8°C) in Putumayo, Tiputini and Curaray and lowest (28°C) in Shell Mera (Pastaza).

Geography

The most notable orographic feature of the region is the third branch of the Andes mountains, called Cordillera del Cóndor, situated between the Cenepa and Nangaritza Rivers. The mountain range is interrupted by the bed of the Santiago River but then continues northward with the heights of the Cutucú to the head of the Yuquipa River. The range reappears at Tena, with the elevations of Galeras which extend toward the north to Sumaco Volcano and the hills of Guagraurco and Yanaurco. The range ends in the great bend of the Coca River, at the Reventador Volcano. The majority of the region's urban and rural population has settled between these orographic spurs and the eastern Andean range, due to the proximity of the Andean area and its intermediate climate. The towns of Chaco, Borja, Baeza, Archidona, Tena, Puyo, Macas, Méndez, Gualaquiza and Zamora are found in this sub-Andean belt.

Hydrography

The rivers of this region have three sources of origin:

-Rivers originating in inter-Andean valleys and that receive their waters from the two mountain ranges. These long, torrential rivers are not navigable. They deposit great quantities of rocky material along most of their courses. In this category are the Pastaza, Santiago (Paute) and Zamora Rivers.

-Rivers beginning in the spurs of the eastern Andes. Because of the great amount of precipitation throughout the range, the upper jungle has many rivers with great volume but low velocity. These rivers, which are navigable below the elevation of 300 m have shores with uniform topography, and little rocky material in their middle and lower reaches. These rivers include the Aguarico, Coca, San Miguel, Napo, Palora, Upano and Nangaritza. The most important population centers have been developed in their zones and include Quijos Valle, Archidona, Tena, Coca, Macas, Sucúa and Méndez.

-Rivers originating in the Andes below 300 m elevation. They have unstable riverbeds, are fed by rivers from the other sources already mentioned, and are characterized by a slow rate of flow in their upper reaches. Among these rivers are the Payamino, Suno, Curacay, Macuma and Cenepa. Because of their length, the Curacay and the Macuma (Cangaime-Morona) are the most important. Rivers originating below 300 m, as a consequence of drainage, have minimal velocity and soft banks. They are formed by the rains of the lower jungle and originate from subsurface waters and swamps. Such is the case of the Güepí, Cuyabeno, Yasuní, Tiputini, Bombonaza and Conambo Rivers.

Soils and geomorphology

The following information on the physiography and soils of the region is taken from the diagnostic study carried out by INIAP experts in 1977.

In agreement with preliminary work done by Colmet and others (1975) and by Anda and Espinosa (1975), INIAP found that the soils of the east possess a physiographic distribution that sometimes has a common pattern, following this general scheme: (a) alluvial plains, (b) dissected low plateaus, and (c) heavily dissected high plateaus.

Alluvial plains. These are formed by valleys that have recent low terraces and ancient terraces. The recent low terraces which are frequently flooded are made up of thick alluvial deposits and recent sands. The ancient terraces are made up of ancient fine-textured alluvial deposits. Volcanic ashes and sand of the Quaternary period are the main parent material of this physiographic formation. The soils with the best physical and chemical characteristics are found in this region.

Low plateaus. These have hilly topography, because they have been dissecting and eroding during their evolution. The parent material of this formation is made up of marine sediments of the Tertiary and Pleistocene periods. The formation has received periodic superficial additions of volcanic ash that has accumulated on the most level parts.

High plateaus. These are severely dissected and have a markedly hilly topography, due to intense weathering and erosion. The parent material of the soils of this region is made up of deep sediments of the Tertiary and Pleistocene periods. The high plateaus constitute the major expanse of the Amazon basin and form the most severely weathered and leached soils.

Soils

In accordance with the three physiographic regions described above, the predominant soils of the northeastern, east-central and southeastern regions are characterized as follows:

Northeastern soils. Most of the surface of this region is alluvial plains where the soils have developed from volcanic material (ashes and sands) of alluvial and probably eolian origin. In accordance with their degree of evolution, the predominant soils in this region are Vitradepts, Tropaquepts, Distropepts, Tropoudults and Tropofibrists.

East-central soils. The physiography of this region is like that of the northeast, except that the great alluvial plains do not appear, because the deep and torrential rivers cause the formation of small, narrow valleys. In these valleys, an association of Vitradept, Tropaquept, Dystrandept and Fluvent soils is found.

.Vitradepts and Fluvents are found on the small terraces adjoining the rivers that are subject to periodic flooding. The area covered by these soils is small, consequently, they are not important for agriculture and ranching.

In the ancient terraces, Dystrandepts and Tropaquepts are found, with Dystrandepts predominating. The Tropaquepts are found on small, flat, poorly drained areas, wich support a great part of the agriculture and cattle-raising of the east-central region. Hidrandept soils predominate in the dissected low plateaus, which are used almost exclusively for cattle raising; they have the same problems as the northeastern soils. An association of Distropepts, Tropaquepts and Hidropepts is found in the heavily-dissected high plateaus. The Hidradepts and Tropaquepts are found in the flattest areas.

Southeasterm soils. In this region, two well-differentiated physiographical areas can be distinguished: the area of General Plaza-Macas that is similar to the east-central region, and the Upano Valley that is similar to the northeast.

In the narrow valleys of the first area, almost all of the agriculture and cattle production is developed on Vitradepts and Dystrandepts; the Dystrandepts are dominant and present the same use and management problems as the soils of the east-central region.

The Upano Valley area is physiographically similar to the northeast, but it must be emphasized that there is a fundamental difference in the distribution of the alluvial plain soils. While Vitrandepts and Dystrandepts cover the major surface area of the northeast, the dominant soil in the Upano Valley is the Hydrandept. This is a deep soil approximately 2 m thick, having the same use and management problems of similar soils.

Table 3 presents the results of the analyses of soils of different profiles and their range of variation and Table 4 gives the same information for the surface samples.

Table 3. **Soil analyses results and their variations, from soil profiles of three regions of Ecuador.**

Depth in profile (cm)	pH	Element content (μg/ml)						
		N	P	K	Ca	Mg	Zn	Mn
Northeastern region (8 profiles observed)								
0- 20	4.4-6.2	17-47	2- 7	15- 47	75- 800	30-420	1.2- 5.9	0.7-13.2
28- 60	4.7-6.4	3-12	2- 6	25-110	75- 950	20-325	0.3- 4.4	0.7- 9.7
70-100	4.9-7.0	3- 7	2- 6	35-105	75-1000	20-345	0.3- 3.5	0.7- 1.7
+ -100	5.1-6.1	3- 7	2- 5	20-105	75- 625	15-120	1.5- 3.2	0.7- 4.2
East-central region (3 profiles observed)								
0- 22	5.1-5.7	53-17	2	30- 75	200- 400	30- 50	3.4- 6.7	1.8- 6.3
26- 56	5.1-5.8	14-24	2	15- 25	125- 275	15- 75	4.6- 6.7	1.8- 3.8
60- 75	5.1-5.9	4-14	2	15- 25	150- 200	25-110	5.5- 5.7	1.8- 7.8
+ - 75	5.9	14	2	15	200	40	6.4	1.8
Southeastern region (7 profiles observed)								
0- 25	4.9-6.2	22-54	2- 6	15- 75	75-1600	50-470	1.8-12.9	5.4-49.4
35- 50	4.8-5.7	8-35	2-15	15- 75	75- 750	40-350	1.5- 8.7	3.4- 7.9
+ - 50	5.2-5.7	2-13	2	15- 40	75	25-365	1.2- 3.3	1.4-10.4

Table 4. **Soil analyses results and their variations, from surface samples of three regions of Ecuador.***

Frequency	pH	Element content (µg/ml)						
		N	P	K	Ca	Mg	Zn	Mn
Northeastern region (23 samples observed)								
More frequently	4.8-6.3	10- 17	2	35-265	800-1500	80-155	0.5-2.0	0.7-2
Less frequently	6.4-6.7	18- 20	4- 8	400-415	200- 600	160-350	2.1-4.0	2 -4
Rarely	4.6-6.8	7- 25	24	20-495	150-2000	35- 40	8	6.7
East-central region (15 samples observed)								
More frequently	5.4-5.5	30- 55	2	25- 50	250- 450	30- 60	5 -8	2.1-12
Less frequently	5.9-6.1	90-127	3	70- 90	495- 700	110-225	8.1-10	50
Rarely	6.2	10- 15	8	100	1175	25	37.6	12.1-20
Southeastern region (18 samples observed)								
More frequently	5.5-6.0	20- 40	2- 4	80-315	950-3100	115-460	4.1-7	4 -12
Less frequently	6.3-6.5	5- 10	5-13	25- 60	75- 425	30-110	2.1-4	27.9-33.4
Rarely	5.1-5.4	58	35	160	4000	515	7.5	+50

* Compiled by INIAP-MAG work group.

Soil fertility characteristics of the northeastern zone

In general, there are wide variations in pH in these soils, but acid and slightly acid pH's predominate.

The N content in the first 20 cm of soil varies from 17-47 µg/ml. Contents of 10-17 µg/ml, representing a medium level, are most common.

The amount of available P is very low (2-8 µg/ml) both deeply and at the surface, with the exception of some samples from Shushufindi and the Marcella Cooperative, which had a high content of available P (about 24 µg/ml).

The K content in the soil profiles is low to medium, while there is great variation in content in the surface samples; there are samples with a very low content (35 µg/ml) and others with a high content (>400 µg/ml). The Shushufindi area has soils with both very low and high K contents. In the Marcella Cooperative, K content is very high (20-30 µg/ml).

Contents of Ca and Mg are very variable both in the profiles and near the surface; generally, soils with high contents of both predominate.

Contents of Zn and Mn are low both near the surface and deeper.

Soil fertility characteristics of the east-central zone

The pH's of the soils in this area are lower than in the northeast; acid soils predominate near the surface and deeper.

Levels of N are medium to high in the top layer, but decrease sharply at lower depths. Available P is very low (2-8 µg/ml) both in upper and deeper levels. Available K is also low in the top 20 cm and deeper; these soils do not have a top layer with a higher content of this element.

Ca is present in high levels throughout the soil layers. Near the surface there are low to medium levels of Mg, but occasionally high levels are found more deeply.

The Zn content is satisfactory in the upper 20 cm as well as deeper; its levels are medium to high (5-27 µg/ml). Mn content is low at deeper levels and low to medium in surface samples.

Soil fertility characteristics of the southeastern zone

The pH of the soils in this region is variable; acid and slightly acid soils predominate. The N level of the surface layer is low to medium. Available P is very low in both the surface and deeper, but there are exceptional cases such as the Granja El Tesoro, Sur de Humbai, and Cantón Sucúa where the P content is high (35 µg/ml).

The K content is low at deeper levels, and fluctuates between medium and high near the surface. There are cases of surface samples with very low K (25 µg/ml). The Ca and Mg contents are quite variable at deeper levels; in the surface soil samples, levels range from medium (75 µg Ca/ml and 50 µg Mg/ml) to very high (4000 g Ca/ml and 515 µg Mg/ml).

There is a low to medium content of Zn in the surface layers as well as the profiles. The Mn varies greatly in the surface samples, while its content is low in the profiles.

From this discussion, it can be inferred that the soils studied have the following fertility problems:

1. The soils are predominantly acid and require amendments to improve their chemical and physical-chemical conditions.

2. The N content is low to medium in the surface layer (20 cm) and sharply decreases in deeper levels. This indicates that the reserves of this nutrient are very limited and that the soils require special management to maintain or improve the availability of surface organic matter.

3. The content of available P is very low; the situation is aggravated by the soil acidity and high content of amorphous materials which cause P fixation to be strong.

4. The content of K varies greatly; some areas have very low amounts and others high levels. A zonification and basic study of the K supply must be made.

5. Apparently there are no problems of availability of Ca and Mg, but this cannot be definitively concluded because the Ca/Mg and Mg/K relations have not been studied.

6. Content of Zn and Mn are variable. It will be necessary to develop a well-correlated analytic methodology to predict with better probability the content of these nutrients.

For all the above, it will be necessary to develop a special management technology in order to maintain and improve the fertility of these soils.

Non-Ecological Factors affecting Development

Accessibility

Transportation is possible from the inter-Andean region through penetration roads that cross the eastern range of the Andes and descend to Amazonia. The unavoidable and difficult crossing over the eastern range has been a serious limitation for constructing other roads that would promote settlement and development of the region. Until 1976, the Amazon region was accessible only by three roads: (1) A 99-km road from Quito to the spur of the eastern range of the Andes in Baeza; (2) a 175-km road from Ambato to Misahuallí, a river port where the lower reaches of the Napo River can be navigated in small boats; and (3) from Loja, by a 60-km road to Zamora.

When petroleum was discovered, construction began of a highway from Baeza to Lake Agrio and Puerto Francisco de Orellana (Coca). This highway has made the lower jungle more accessible and has facilitated settlement along the roadsides.

Figure 2 shows the highway situation in 1978, and Figure 3 shows the basic road network that the Ministry of Public Works is planning to construct in the next decade under the Feasibility Plan for Development of the Ecuadorian Amazon Region.

Aspects of human geography

There is no doubt that the upper jungle subregion has an environment that could receive a great demographic influx, when and if communication routes are prepared that will penetrate from west to east and from north to south. The upper jungle that does not have river access requires terrestial routes, as well as urgent public health measures, for its economic development.

Some 85 percent of the Ecuadorian Amazonian populations is found in the upper jungle. The majority of these settlers are from the mountain regions and have mountain culture. They have adapted reasonably well to tropical forest conditions. The culture of the migrants to the upper jungle is markedly different from that of the residents of the lower jungle, mainly due to initial cultural differences, as well as more social contact, more governmental attention, and a favorable environment. Very few settlers from the sierra have moved to the lower jungle areas where a river-oriented way of life predominates. In the lowlands live indigenous groups practicing agriculture and hunting and gathering as they have for centuries. These native populations are generally hostile to encroaching groups from the more western settlements.

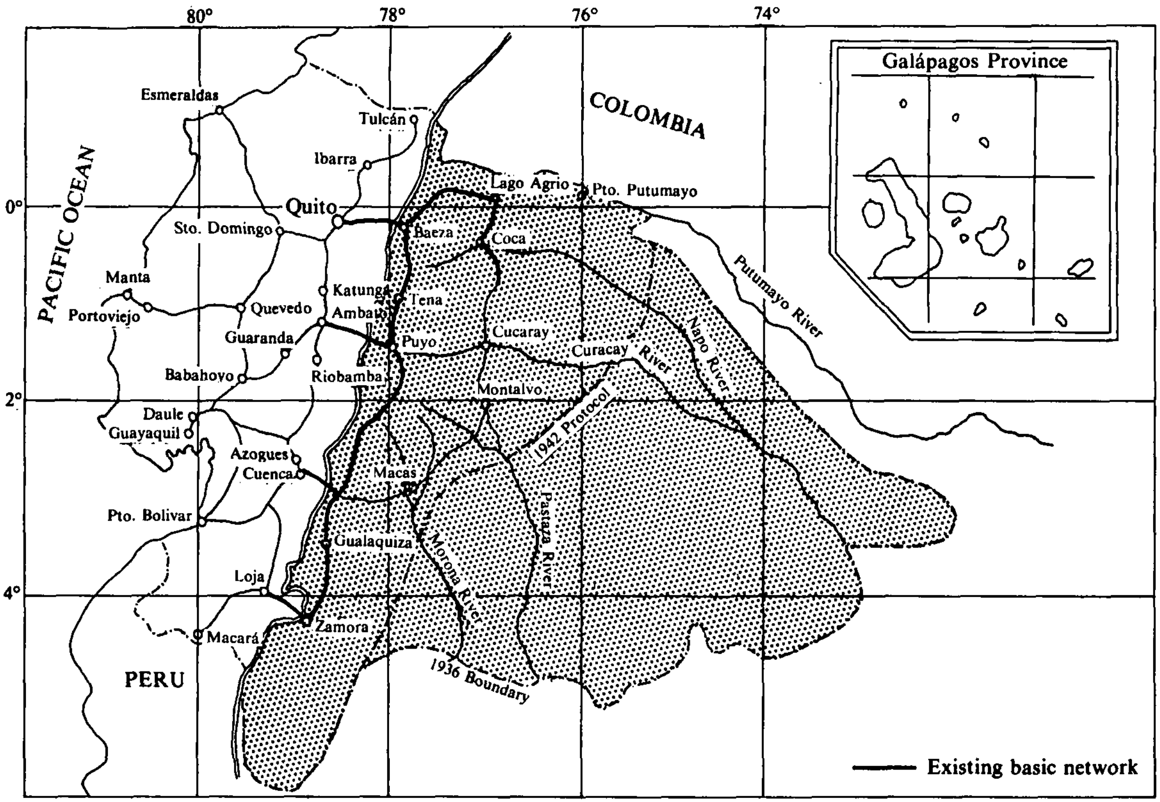

Figure 2. *Location of highways in the Amazon region of Ecuador as of 1978.*
Source: Instituto de Colonización de la Región Amazónica Ecuatoriana, 1978

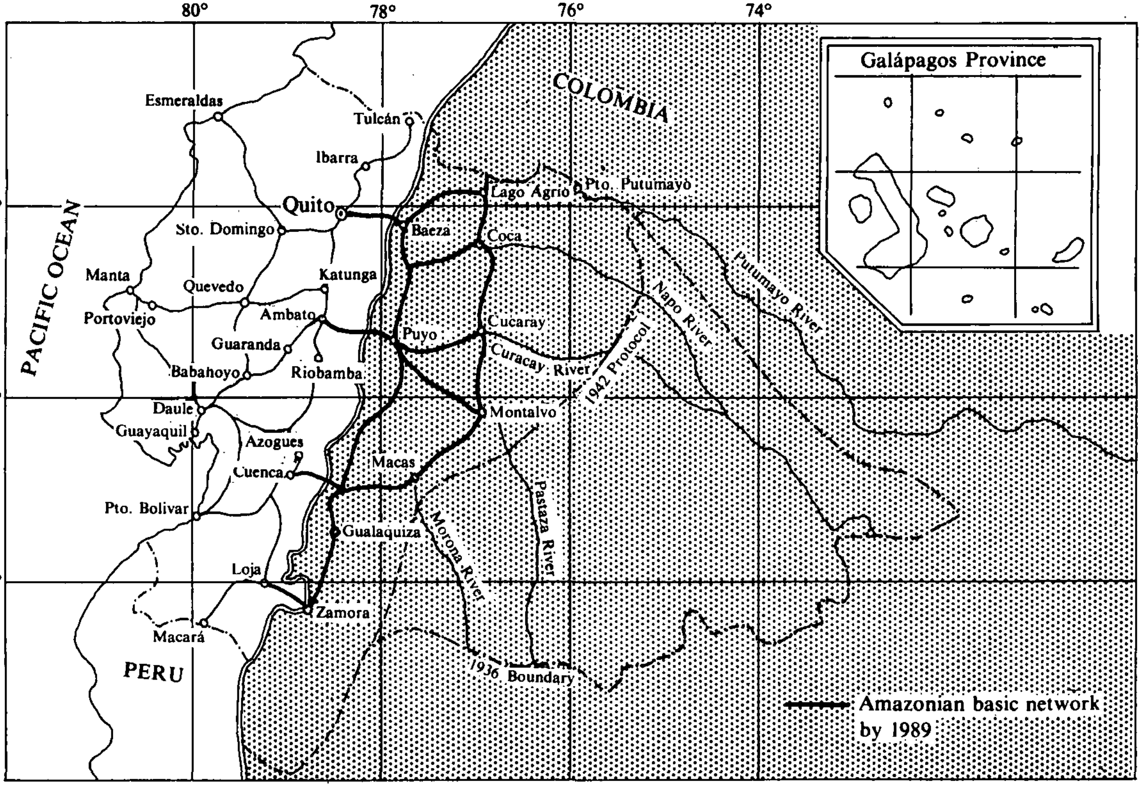

Figure 3. *Basic road network to be constructed in this decade.*
Source: Instituto de Colonización de la Región Amazónica Ecuatoriana, 1978

National Development Policies and Agencies for the Amazonia

National Development Plan

The National Development Plan, recently put into effect by the current government, has as its mandate:

> "The physical, economic, social, political and cultural integration of Ecuador; the stimulation of deprived zones; the incorporation of marginal groups; the elimination of regionalism, and the necessity of effectively occupying the national territory constitute, among others, fundamental objectives outlined in the 21 Program Points of the Government".

To achieve these basic principles, the Plan emphasized the importance of defining a policy of regional development that focuses on "the need for harmonious development, adequate settlement and utilization of the territory in relation to economic and social needs and to the soils' characteristics and use; communication among regions and provinces; complementarity between diverse territorial localities based on economic production capacity and on the types of settlements".

A fundamental strategy is to bring into production lands suitable for agriculture and livestock raising. Therefore, priority is currently given to the construction of connecting roads and to colonization, with the goal of effectively occupying all of the country's vacant areas and incorporating new lands into agricultural and cattle production. Because of its sparse population the Amazonia offers good possibilities for human resettlement through colonization programs.

The National Development Plan has conceived settlement programs for areas where research indicates a good resource base. These programs conform with existing agricultural zoning and respect territorial rights of indian communities. It is of vital importance to generate, diffuse and promote appropriate technology to assure an efficient and rational use of natural resources. For this reason, research should receive all necessary support to be able to complete its assignment.

The five-year goal of the colonization program is to occupy in a rational manner approximately 750,000 ha, practically all of them in the Amazon region. The predicted investments for the various settlement programs are given in Table 5.

In order to coordinate and execute Amazonian development programs, the national government has created new institutions and strengthened existing ones with mechanisms for directing and implementing the development plans. These mecanisms include the coordination of the ministries and delegation of responsibility for such work as road construction, technical agricultural assistance, reforestation and social programs to regional institutions. Research directed to the study of principal agricultural problems was initiated formally four years ago.

Table 5. **Investments for colonization in the Amazon region of Ecuador, for the 1980-1984 quinquennium (in millions of sucres).**

Project	Total investment in:	
	1980	quinquennium
San Miguel	2.6	60.0
Shushufindi	2.0	2.0
Payamino	3.0	12.0
San Pedro de Tena	3.0	10.3
Morona	3.2	27.6
Upano-Palora	7.7	29.0
Study for Colonization and Forestry Development of Morona	31.4	43.0

Source: CONADE, Plan Nacional de Desarrollo, 1980-84.

Amazon development agencies and programs

The following state institutions participate in distinct programs related to agricultural development of the region: Instituto Ecuatoriano de Reforma Agraria y Colonización (IERAC); Centro de Reconversión Económica del Austro (CREA), which includes the eastern province of Morona Santiago; Instituto Nacional de Investigaciones Agropecuarias (INIAP); Subcomisión Ecuatoriana para Desarrollo del Sur del Ecuador (PREDESUR), with responsibility for and jurisdiction over the province of Zamora-Chinchipe; and Instituto de Colonización de la Región Amazónica Ecuatoriana (INCRAE).

It is fitting to mention the valuable contribution of religious missions to the agricultural sector of Amazonian provinces. Besides having created technical agriculture schools where hundreds or thousands of the region's young people have studied, the missions have contributed to the process of technology diffusion.

Instituto Ecuatoriano de Reforma Agraria y Colonización (IERAC). This institute was, until 1978, the organization charged with controlling the process of land occupation and its legalization. In 1978, INCRAE was established as the directing entity for settlement and development of the Amazon region, and since then IERAC's only function has been to legalize the possession of lands assigned to the settlers.

Settlement of Amazonia has been done without a clear and defined policy. IERAC has promoted spontaneous settlement of individuals by assigning 50 ha to each settler, and the creation of pre-cooperatives and communes. IERAC has also participated in programs of directed colonization.

Three large projects of directed settlement were initiated by IERAC before the creation of INCRAE. Large capital investments have been made in the Shushufindi, Payamino and San Miguel Projects. The results obtained thus far are discouraging. The established goals have not been reached, including the number of families settled, because of constant desertion. Confusion and lack of definition on the part of project managers and settlers are generally cited as the main reasons for the difficulties.

The failure of these directed settlement projects leads one to think that those who conceived them, although having the best purposes, committed serious errors possibly because of disregard for or ignorance of the realities of the region. Frequent comments have been made about the lack of clear objectives and technical cooperation, the expense of legal backing, and, even, the ignorance about the target zone on the part of IERAC's employees who mark land boundaries before the possessions are legalized. Someone has asked, with reason, whether the high sums of money spent on these projects would have better served the interests of the country and the region if used to create several experiment centers.

Instituto de Colonización de la Región Amazónica (INCRAE). Some of its objectives are: (1) aiding the process of agrarian reform; (2) expanding the agricultural frontier by promoting the utilization of new resources; (3) executing settlement programs in agreement with requirements of territorial and military security, and of integrating development; (4) orienting and providing incentives for industrial development in Amazonia for utilizing raw materials and the labor force of the region; (5) promoting the psycho-social integration of communities of natives and settlers; and (6) conserving the economic equilibrium and the ecosystems of the regions through reforestation.

As can be appreciated, the large scope of INCRAE's activities have made the successful attainment of its initial objectives very difficult, to say the least. Very little effective work has been done satisfactorily in the last two years.

In agriculture, INCRAE has the following objectives: (1) Sponsoring technical-scientific studies to locate potential agriculture and animal production areas for increasing food production for local demands; (2) increasing the production of raw materials of agricultural origin to satisfy industrial needs; and (3) expanding the production of items well adapted to Amazonia, in order to obtain exportable surpluses and to increase financial resources for the region's economic development.

INCRAE should act as a coordinating organization for all the institutional and private research efforts in the region, and should give full support to INIAP, the institution that would directly administer the research work. In accordance with INIAP's policy of technological development for Amazonia, INCRAE adopted the strategy of sponsoring the use of production systems that most faithfully copy natural ecosystems, such as agro-forestry, pasture-forestry and agro-pasture-forestry systems.

The results obtained thus far, however, are not very gratifying. It has been stated that INCRAE needs to revise its organization and program to improve its efficiency and to achieve the objectives for which it was created.

Subcomisión Ecuatoriana para el Desarrollo del Sur del Ecuador (PREDESUR). The Ecuadorian subcomission is an autonomous entity assigned to the Ministry of Foreign Affairs. PREDESUR was created in 1971 to integrate development of the southern provinces of El Oro (on the coast) and Loja (in the inter-Andean region), utilizing the Puyango and Catamayo Rivers. In 1974, PREDESUR increased its area of action to include the province of Zamora-Chinchipe, located in the extreme south of the Amazon region. In this province, PREDESUR carries out the Rural Development Project of the Zamora Region, oriented principally to ranching development. This project has the financial backing of the World Bank (BID, 1978) of US$16.9 million, which covers 54.7 percent of the total project cost.

The project area, located in the Zamora and Nangaritza valleys is characterized by hilly topography, good soils and 400.000 ha of potentially exploitable forest. Land use in the project region is given in Table 6; 62 percent is in forest, 35 percent in livestock raising and about 2 percent in agricultural crops. Ranching is the predominant activity.

These valleys have been spontaneously colonized since the 1950's and the average land holding size is on the order of 30 ha. The larger holdings, for the most part are controlled by the Shuara Indians who hunt and farm collectively. The holding sizes are presented in Table 7. As is obvious, more than 70 percent of the land holdings are less than 100 ha.

Table 6. **Agricultural and forestry uses of land in the Zamora and Nangaritza valleys of Ecuador.**

Land use	Zamora valley		Nangaritza valley		Total	
	ha	%	ha	%	ha	%
Agricultural crops	1,792	2.0	865	8.6	2,657	2.5
Pastures	33,863	35.0	3,480	35.0	37,343	35.0
Forests	60,473	63.0	5,655	56.4	66,128	62.5
Total	96,128	100.0	10,000	100.0	106,128	100.0

Table 7. **Distribution of production units by size in the Zamora and Nangaritza valleys of Ecuador.**

Intervals (ha)	Farms		Area		Average size (ha)
	No.	%	ha	%	
0 - 10	589	26.0	2,723	3.5	4.0
10 - 20	415	18.0	6,230	8.0	15.0
20 - 50	864	37.0	29,092	37.5	34.0
50 - 100	324	14.0	21,908	28.0	68.0
100 - 200	77	3.0	9,654	12.5	125.0
200 and more	25	2.0	8,702	10.5	348.0
Totals	2,294	100.0	78,309	100.0	34.0

Within this context, the project is designed to: (a) support and rationalize the process of spontaneous settlement; (b) intensify agricultural and cattle production to increase the income of producers; and, (c) furnish the economic and social infrastructure and basic support services required to accelerate development.

The project includes activities that can be grouped into three subprojects:

1. Credit for agriculture, livestock and forestry development, requiring approximately 31 percent of the resources.

2. Support activities receiving approximately 44 percent of the resources and including land assignment and titling, agricultural

and livestock research and extension, and infrastructure development.

3. Social infrastructure, such as construction of schools, investments and rural sanitation, will receive 13 percent of the funds.

Centro de Reconversión Económica del Austro (CREA). This center is a regional development institution that has responsibility for the Palora-Gualaquiza Rural Integral Development Project in the eastern province of Morona Santiago. This project has two subprojects. One provides agricultural credit to settlers and natives to carry out infraestructure projects and provides basic inputs in support of the technical recommendations of the Project. The other promotes development through technical training to improve current production systems, with the active and critical participation of the rural population, small farmers, technicians and professionals (CREA, 1978).

The agricultural credit subproject is supposed to benefit more than 2500 families with cattle, hog and guinea pig breeders. However, the major emphasis is on credit to encourage livestock raising with the introduction of purebred Brown Swiss sires in participating farms. Genetic improvement should increase meat and milk production.

CREA has three experimental farms in the Project areas, located in Pablo VI (190 ha), Domono (190 ha) and General Proaño (25 ha).

The reasons why CREA and Project directors decided to import cattle to distribute among settlers and natives by means of financial credits under this subproject are not known. So is the technical justification for choosing Brown Swiss. One should realize that in this area, as well as in other zones of Amazonia and the rest of the country, the great majority of the rural population are small farmers of scarce economic resources, little education, and, in many cases, ignorant of proper farming methods. For these reasons, it is difficult to expect that the imported animals would receive appropriate care and management in order to fulfill the proposed goals. On the other hand, given the high price of imported cattle, it would have been advisable to analyze whether the cattle farmers were prepared to accept them and if their situation permitted them to neet the loan agreements.

The assumed technical parameters and the expected goals of the project planners are very optimistic and it is unlikely that they can be achieved. Experience demonstrates that–with the zone's ecological conditions and the human factors just described–achievable production levels are much lower than those hoped for in the present plan. For example, it is practically impossible to attain a calving rate of 88 percent, a calf mortality of only 3 percent and a daily milk production of 11 liters/cow throughout a 285-day lactation period. Perhaps it would be more useful to think in terms of a cattle development program that does not involve substantial changes in management, that does not demand high investments such as are needed for acquiring animals, and that responds in general to the socio-economic reality of the region.

In addition to the bovine component, the project plans to distribute pure Duroc hogs and to produce guinea pigs.

The development subproject will be responsible for maintaining the farms where animals will be bred for sale to the cooperators in the agricultural credit subproject. In addition, the development subproject will identify research needs and its execution, in order to determine a "realistic technological path that permits the modification of the different existing systems to adjust them to potentials and limitations."

After examining the existing production systems, a series of initial recommendations will be formulated to permit extension personnel to immediately begin their work and, at the same time, to identify research areas on local farms as well as CREA's experimental farms. In addition, it is considered essential to complement the above with a permanent program of information to the farmers and of training at all levels.

Priority will be given to research in pastures and forages, especially legumes. On the CREA farms, a grass introduction plot will be established as a starting point for a process of selection and multiplication, in which farmers would also participate by carrying out adaptation and production trials of the most promising species on their own farms. With the information obtained in this type of trial, on the experimental farms as well as in private farms, recommendations and technological adjustments can be generated for application by some of the zone's producers. However, it must be kept in mind that small farmers work in complex, mixed production systems, where the various components constantly interact. For this reason, isolated recommendations relative to the improvement of each of these components should be made only after a thorough analysis of the socio-economic reality surrounding the farmers and their limitations, and after having innovations tested experimentally confirming that they do not alter the stability of production systems.

Instituto Nacional de Investigaciones Agropecuarias (INIAP). INIAP's agricultural and animal production research officially began in 1975 with an agreement with the Summer Institute of Linguistics to utilize its installations at Limoncocha. Given the urgent need to establish a first-class permanent experiment station to resolve problems limiting Amazonia's agricultural and animal production, specialists of INIAP and of the Agriculture and Livestock Ministry (MAG) began an agro-socio-economic study of the region in 1976 in order to determine the location of such a station. The Napo Experimental Station was created in 1978. Since then, the station has replicated some of the research begun in Limoncocha and has undertaken new projects. INIAP's philosophy is based on trying to develop stable and profitable production systems for small farmers: stable in order to preserve the ecosystems and natural resources, and profitable so that settlers and natives receive the economic stimulus that permits them to stay in the zone without having to seek better opportunities in urban centers.

By focusing research on production systems of the small farmer, INIAP seeks to increase the productivity of the land (which in most cases cannot be enlarged) by determining the possible associations of species and varieties, their chronological and spatial distribution and their management.

Considering the region's realities and the research strategies needed, the following conclusions and recommendations were formulated in a seminar organized in 1978 by INCRAE on Management of Ecological Systems and Agro-Pasture-Forestry Production Alternatives (INCRAE, 1978):

-Recognize the necessity of a research program on profitable, sustained, timely production systems, to maintain the existing equilibrium or create a new, equally-balanced ecosystem.

-Production systems will have agriculture, pastures and forestry components in combinations determined by the surroundings.

-Research should give priority to the region's existing agricultural and forestry products. At the same time, species and varieties introduced to create alternative systems will be studied.

-Research should be done in accordance with the needs and priorities established in sectional development plans, with preference given to staple commodities of high national importance.

-INIAP must be responsible for conducting research on agro-pasture-forestry production systems. To accomplish this task satisfactorily, it requires support, cooperation and participation of all institutions concerned with agricultural development of the Amazon region.

-An adequate research program needs constant training for the formation of responsible technical teams.

-Links with other countries of the Amazon region need to be established in order to exchange information and experiences in diverse methods and procedures.

-Research will give priority attention to small and medium sized farmers, regardless of the associations to which they belong.

The work completed since then demonstrates that most of the recommendations have been taken into account and put into practice to some degree. The lack of coordination among institutions concerned with developing the region is still obvious. This situation is reflected in the disjointed activities and in the diversity of criteria regarding certain problems. Moreover, it is evident that various state agencies continue to dispense with the recommendations of INIAP and do not follow the principles upon which research strategy in integrated production systems is based.

Given the limitations of INIAP, it has not been possible to establish new experimental centers in other representative ecological zones, with the exception of a few farms in the areas of regional development institutions. Initial and isolated experimental work is being conducted on these farms, but the majority of the research has been confined to the Napo Experiment Station and the Limoncocha Center. Some of this research is presented in the technical paper of John Bishop elsewhere in this wolume.

Conclusions

The Ecuadorian government has identified the Amazon region as the major area for expansion of agricultural and animal production, and to this end has created a number of institutes and research centers to coordinate these activities in the Amazonia provinces. Not surprisingly, there have been numerous difficulties linked to lack of ecological information about the area, limited availability of agricultural techniques, difficulty in transferring existing information, and problems associated with institutional cooperation and definition. Because the emphasis on Amazonian development in Ecuador is relatively new, the region has not received the attention and investment it merits. However, this situation appears to be changing.

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Development Policies and Plans for Peru's Amazon Region

Javier Gazzo*

Introduction

Peru is a climatically, geologically, geographically and ecologically complex country. The total surface area is 1,285,216 km^2 distributed in four natural regions: the coast, 148,643 km^2, the sierra, 350,923 km^2, the montane jungle, 90,961 km^2 and the lowland jungle, 964,688 km^2 (see Fig. 1 in López Parodi's paper).

The estimated population in June 1978 was 16.8 million, with a growth rate of 2.8 percent for the period 1978-1980. The population estimate for 1990 is 23.3 million. The population pyramid shows that 43 percent of the total is under age 15, and 53 percent is between 15 and 64. With a population density of $13/km^2$, Peru would seem to be uninhabited. However, the population is concentrated in an area no larger than 500,000 km^2. The disproportionate relation between population and habitable territory has led to an unequal population distribution in the country. Estimates for 1990 show that 57 percent of the national population (13.3 million) will live in coastal areas, 31 percent (7.2 million) in the Sierra, and 12 percent (2.8 million) in jungle regions.

This growing population will increase the demand for jobs, energy, habitable lands, basic social services as health, education, housing, transportation, and especially for food supplies.

The current estimated population in the Peruvian Amazon is 1.4 million inhabitants, with 522,000 located in the montane jungle and 878,000 in the

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lowland jungle. Half of the inhabitants of the lowland jungle live along the rivers and work in shifting agriculture and small cattle ranches. Periodically, they work in lumber extracting industries.

In the last few years, the government has been aware of the need for regional planning and has adopted several criteria for the distribution of human and financial resources. This policy resulted in the creation of 11 new Regional Development Organizations that make decisions at the local level and that reduce the capital city's centralized power. The mandate of these organizations is to provide integrated development utilizing the country's different natural resources and regions, and to incorporate depressed areas into the economic life of the nation.

General Characteristics

Location and area

The Peruvian Amazon region, situated to the east of the Andes, occupies a large part of the Amazonian geosyncline and extends to the piedmont and Amazonian plains.

The Peruvian Amazon jungle covers 78.5 million hectares; the montane jungle is 23.11 percent of the total, and the lowland jungle covers 76.89 percent. These two zones are differentiated by their physiography, climate, soils, and river characteristics.

The montane jungle is comprised of secondary Andean ridges between 500 and 2000 m, with narrow, very long valleys that sometimes form gorges called "pongos". Large areas are covered by fluvial terraces that have up to four levels. The widest terraces are located up to 450 m above the current river beds.

The lowland jungle, also called the Amazonian plain, starts at the last Andean ridges at 500 m. The region has undulating relief covered by heavy forest.

The Peruvian jungle contains an estimated 8 million hectares of land suitable for intensive agricultural development.

Geology

The Amazon region probably began with the appearance of an eastwest geosyncline, in which a basin emptying into the Pacific Ocean originated in the Cambrian Period. Sedimentation and Andean orogeny caused the drainage of the basin to change to the east, to flow into the Atlantic Ocean. The rivers that descend from the Andes carry large quantities of sediments, that originate in the sandstones, limestones and volcanic lavas. The Amazon River carries about 3 million metric tons of sediment each day on its journey to the ocean.

Physiography

In Amazonia there are two basic physiographic units. One corresponds to the recent sediments of the Holocene Period that form low terraces and more or less floodable alluvial plains; this area covers 10 to 20 percent of the Peruvian territory. The rest of the region is located on the sediments of the Tertiary and Pleistocene Age and contains high terraces and hills that have been appreciably dissected by erosion. The topography of the Amazonian plain is undulating with average elevations of less than 300 m (CRIA, 1977).

Soils

The high terraces and dissected hills are dominated by Ultisols, or in the Food and Agriculture Organization's (FAO) classification, Nitrosols and Acrisols. These soils are highly weathered. The constant washing causes the soils to be very acid and to have low base saturation. Although the lands in the humid tropics receive between eight and 12 tons of organic matter from the natural forest, the content of organic matter in the profiles is characteristically low, due to the nutrient recycling by the forest.

In the low terraces and alluvial plains, the soils are Entisols, Inceptisols or Alfisols, or in the FAO classification, Fluviosols and Gleysols. These soils receive nutrient additions with the periodic flooding which although improving the fertility of the soils, also affects their productivity. The areas of gleization on the flood plains, distinguished by the presence of poorly drained, watering places and *Mauritia flexuosa* palms, have very acid soils of little agricultural value.

Some Vertisols are found in Huallaga Central, and Spodosols are found in the Amazon plain. The Vertisols, characterized by the presence of expandable clay minerals, have good fertility, but generally poor drainage characteristics.

The Spodosols (Podzols in the FAO classification) in Amazonia are distinguished by a deep A2 horizon and are practically free of bases. They have no agricultural value.

The Oficina Nacional de Evaluación de Recursos Naturales (ONERN) (1980) has performed 23 soil studies in different zones of the Peruvian jungle covering a total of 19,581,240 ha, and is carrying out four more as shown in Figure 1. These studies provide details on soil classification in Huallaga Central, Alto and Bajo Mayo and Jaén-San Ignacio, some 1,630,790 ha.

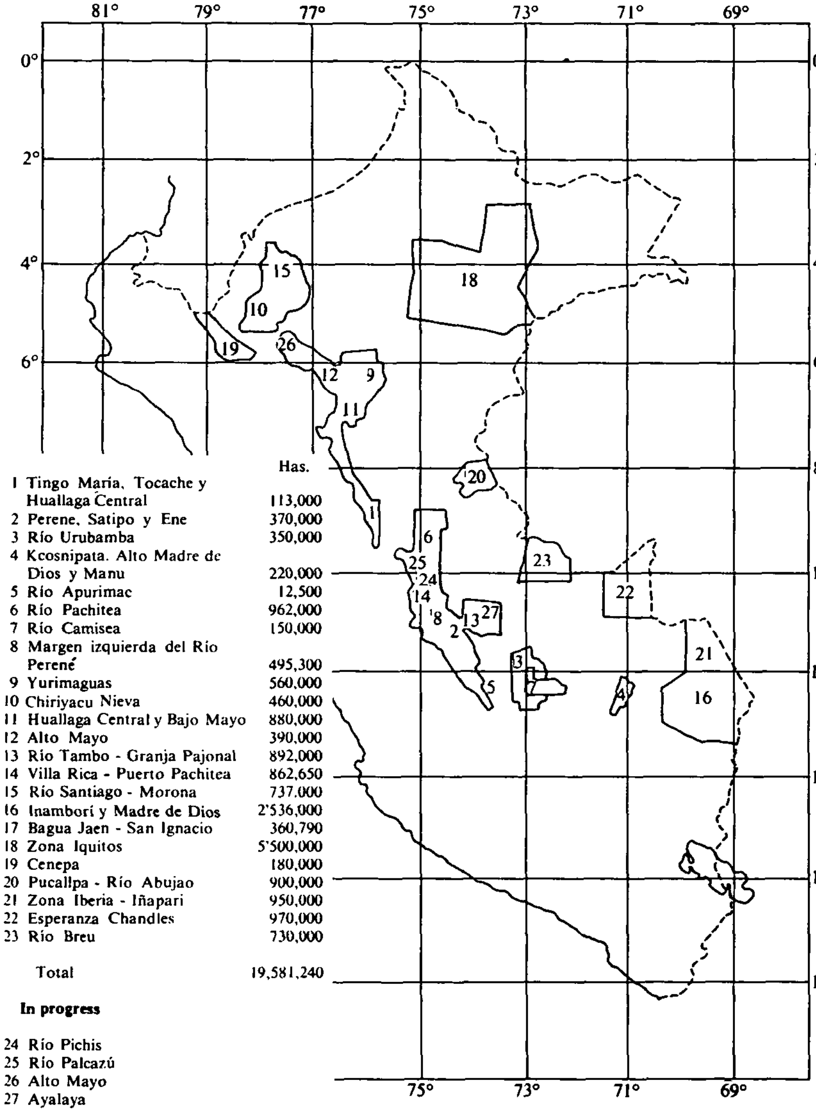


Figure 1. *Soil studies conducted or in progress in the Peruvian Amazon jungle.*

The land has been classified according to its potential for major use: cultivated crops, 4.15 million hectares (3.2%); pastures, 18 million hectares (14.0%); forests, 43 million hectares (33.5%); and protective cover, 60.17 million hectares (46.8%). These figures show that the country's lands are most apt for forests. For agricultural use, there are only 7.35 million hectares, or 6 percent of the total area of Peru. Of that total, 1.55 million hectares are located in coastal regions (21%), 1.8 million hectares in the sierra (25%), and 4 million hectares in the jungle (54%) (INP, 1979).

Ecology

According to the Holdridge System, the natural life zones of the Amazon are classed as humid tropical forests, dry tropical forests and very humid subtropical forests (Fig. 2).

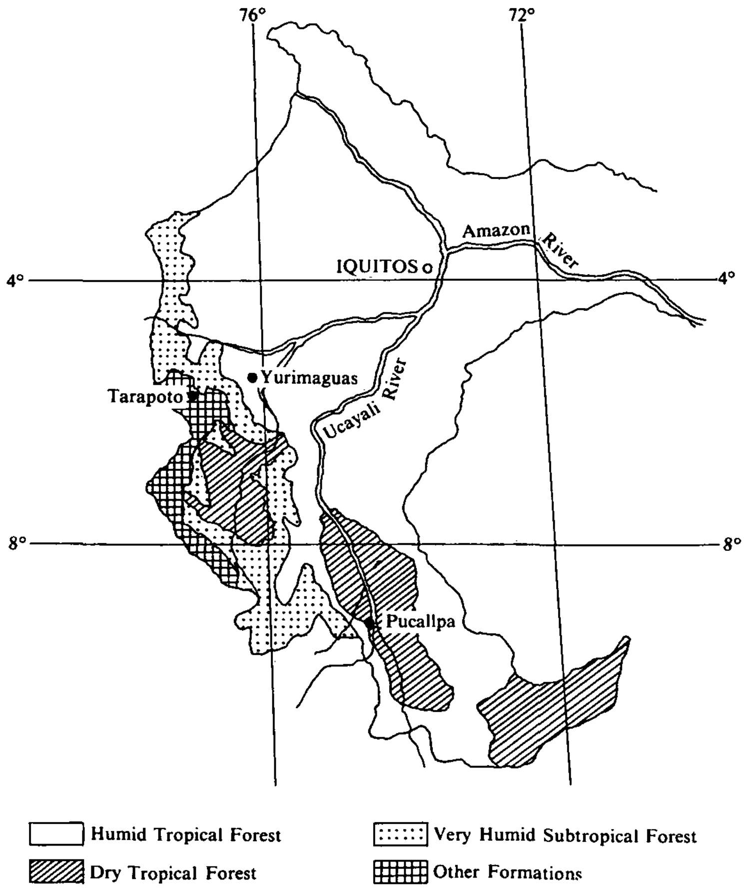


Figure 2. *General locations of the three most important natural zones in Peru.*

A great part of the Loreto Department belongs to the humid tropical forest zone. The dry tropical forest appears south of Contamana, follows the upper waters of the Ucayali River and terminates near the confluence of the Urubamba and Tambo Rivers.

The Department of San Martín, situated on the eastern slope of the Andes, shows a more varied ecology. The agricultural land of Huallaga Central is dry tropical forest. The agricultural area of Moyobamba-Rioja is of the humid subtropical forest. Tingo María, the other important base for agricultural development, is in the very humid subtropical forest. Peru's most humid zone of natural life is found between Tingo María and Pucallpa. This zone has subtropical rain forests and very humid tropical rain forests. The subtropical rain forest is also found in Moyobamba and Yurimaguas (CRIA, 1977).

The driest part is Huallaga Central, where some areas are in transition from dry tropical forests to very dry tropical forests.

Climate

The average temperature of the tropical areas is slightly higher than 24°C; that of subtropical regions is around 22°C. Precipitation is above 3000 mm annually in the very humid subtropical forest; the humid tropical forest has about 2000 mm; and the dry tropical forest has nearly 1200 mm. Figure 3 gives the rainfall for six jungle locations. The dry season appears in the middle of the year in June, July and August, although even in the dry season the rainfall fluctuates between 20 and 100 mm/month (CRIA, 1977).

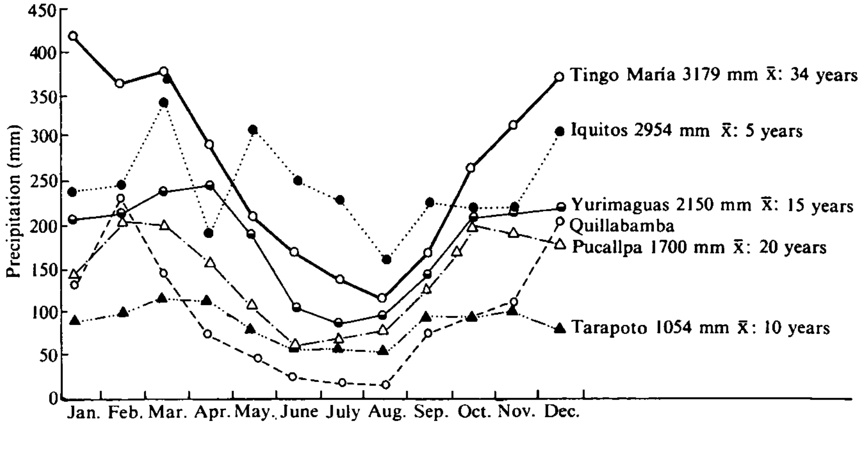


Figure 3. *Precipitation regimes for some localities of the Amazon region of Peru.*

Hydrobiological resources

The jungle is characterized by a great variety of fish, the majority of them unstudied.

Forest resources

Peru has abundant forest resources. The various types of forest associations and arable lands occupy 86.7 million hectares or 67.5 percent of the national territory. Now in existence are 28 forest reserves and 5 national forests; together they total 34.2 million hectares, or 39.5 percent of the forest lands in the nation. They are located mainly in the eastern macroregion in the Departments of Loreto and San Martín, which have 24.3 million hectares of forest lands—71 percent of the productive forests (INP, 1979).

Mineral resources

Gold is the principal mineral. It is found mainly in the southeast and in central and northern jungles.

Transport and access

A jungle highway exists although it is not passable in several stretches. It will join Tingo María with Tarapoto. There is also a highway between Tarapoto and Yurimaguas. Penetration roads include those that unite Tarapoto with the North coast, passing through Moyobamba, Bagua, Jaén, Olmos, and Chiclayo. There is also a highway that connects Pucallpa with Tingo María, leading to Lima through Huánuco, Cerro de Pasco and La Oroya. In the south, highways connect Cusco to La Convención, Kcosñipata and Quincemil (Fig. 4).

Air and river transportation are the most important means of transport in the Amazon region. There is an international airport in Iquitos, and national ones are found in Tarapoto, Pucallpa and Tingo María. Other important airports are at Rioja, Juanjuí, Yurimaguas and Puerto Maldonado. All rivers are used for transportation, with the Amazon, Ucayali and Marañón Rivers being the most important. Boats from throughout the world arrive at the river port of Iquitos.

Figure 4. *Road network into the Amazon region of Peru.*

General Considerations on Amazonian Development

Amazonia cannot be understood as a region by itself. It is an alternative with different priorities for the national development program of each Amazonian country. The humid tropics is only one of the options for national development in each of these countries. The Amazon region presents major risks and uncertainties for the investment of capital. A main factor in Amazonian development is often the demand from the developed countries. The possibilities of satisfying this demand reveal the comparative advantages of some Amazonian countries in relation to the others.

Usually the economic activities of Amazonia are based on only one type of exploitation, whether it be agriculture, ranching or extractive activities.

The perception of only one of the varied Amazonian resources as "the important one" on the part of groups of settlers is what has produced the dispersed settlement currently found in the region, which we must modify in order to improve the quality of life of the population.

Dispersed settlements make it difficult to carry out projects to improve the quality of life of the population, such as health, education and technical assistance. These improvements can be obtained by encouraging the formation of population centers of such a size that it becomes feasible to install the necessary services. Changes in the current production base of Amazonia are mandatory, and require the integration of all the productive resources of an area accessible to a population center.

The great variability of Amazonian resources over small areas demands the creation of technologies capable of benefiting from each other in the vicinity of the settlement, while the long term economic viability of the population center needs to be assured. Protection of natural resources also must be maintained or even enriched.

Current Productive Activities

Petroleum

Petroleum is the principal energy resource. Proven reserves of crude were estimated in 1975 as 549 million barrels, which represents 71 percent of the national production. Petroleum is being exploited and extraction taxes are giving the region large amounts of revenue.

The exploitation of petroleum is a transitory activity, whose intensive technology creates only an insignificant number of jobs. The revenue generated by oil production is usually transferred to the coast. It is essential that the income produced by petroleum be used to finance the development of renewable resources of the montane and lowland jungles, especially forest and aquatic resources, permanent water supply systems, etc.

Forestry

Forests are the principal renewable resource of the Peruvian Amazon and provide the highest income compared to other productive activities. The highest investment priority should be given to the extraction and forest products industry. The integration of those activities with other development programs will permit forestry development to benefit all of the rural residents and to help finance less profitable activities, such as cattle raising and agriculture.

Shifting agriculture

The original model of Amazonian agriculture, using local crops (principally cassava), is shifting cultivation. This agricultural system mimics the physical structure of forest and the mixing of crops simulates the heterogeneity of species that characterize the humid tropical forest. The fundamental limitation of the system is that it is only compatible with very dispersed settlement, a model that is inappropriate for the current demands of development.

Plantations

Other successful systems are the plantations of sugar cane, rubber, tea, cacao, African palm, bananas, etc., developed in the humid tropics of Africa and America, to meet the demand for cash crops that could not be produced elsewhere. These plantations were installed by foreign companies, which made large investments with the only goal of maximizing profits for their own benefit.

From the agricultural point of view, the plantations were a successful system of permanent monoculture. From the social point of view, they are undesirable because of exploitative conditions for workers. From the government's point of view, these foreign investments, whose profits were repatriated, were not advantageous. Finally, the large initial investments required did not produce the desired social conditions for the national development in Amazon countries. In the case of private investments, the working conditions will have to be revised to make the interests of the investors compatible with those of the government.

The development objective for the Amazonia is to increase food and high value crop production and to perfect the production structure of the region.

Given the country's current situation and the region's characteristics, as well as the basic objective for Amazonian development, some basic policies have been outlined for rational utilization of the region's resources.

General Policies

Reorganization of rural space

The regrouping of rural inhabitants now dispersed along the rivers and highways should be done in such a way that they can live in centers that are important enough to justify the installation of minimal health, housing, education, transportation and communication services.

Each population center should be large and productive enough to sustain an economic activity that will guarantee an adequate level of living for its inhabitants.

Where possible, new rural settlements should be combined with existing ones or with urban centers, in order to optimize the use of the infrastructure.

New penetration roads should not be opened before the occupation of the territory is controlled and the problems of currert inhabitants largely resolved.

Rural settlements

The development of Amazonia will be based on the establishment of socio-economic units called Rural Settlements which will have integrated production systems that attempt to maximize the income-yielding capacity of the area in social, economic and ecological terms.

Land classification studies and forest evaluations are essential before a rural settlement can be established. Several other studies will be carried out to evaluate: (a) soils suitable for agricultural use (annual and perennial crops and cattle); (b) soils suitable for forests (reforestation); (c) forests (wood and other forest products); (d) wildlife (hunting and tourism); (e) hydrobiological resources (fishing and fish farming); and (f) natural landscapes (tourism).

The original or modified forest cover should be maintained in at least 30 percent of the surface that is subject to economic uses other than forestry, especially along rivers and streams, on the slopes and in higher parts.

Reforested or degraded forests should be transferred to common ownership through reforestation contracts or through extraction contracts, if the land possesses mature, usable timber.

Individual plots should be avoided in rural settlements of small farmers. It is preferable to have production organized under collective enterprises or common ownership that can compete efficiently with settlements of medium and large farmers under a private enterprise system.

In the rural settlements, agricultural production and/or fish, forest and wildlife production-extraction will be integrated with processing activities.

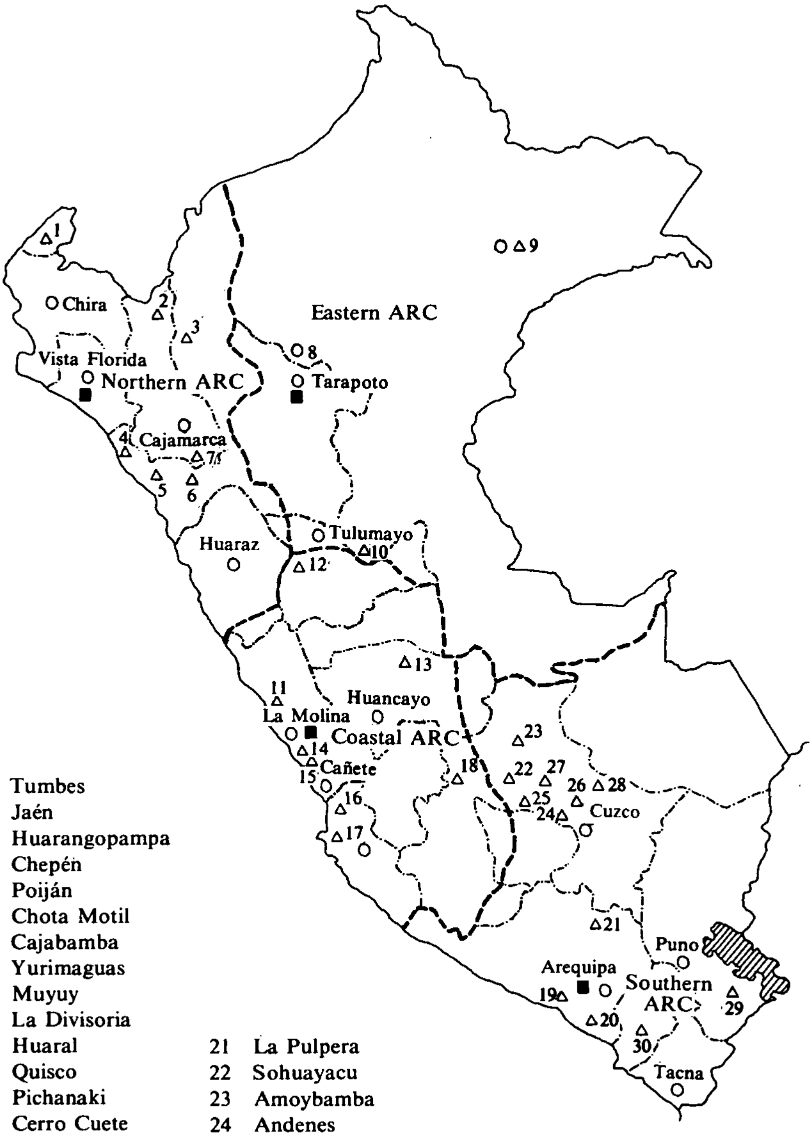
The idea that the region can be converted into an exporter of food for the rest of the country should be avoided during the first stage of rural development of Amazonia. Peruvian Amazonia is, however, capable of producing food for more people than are residing in the area. Part of the surplus would be initially directed to the Andean region where people are involved in forest activities and industries.

Dispersed settlements must be avoided, and spontaneous colonization, along highways, must be controlled through the coordination of public agencies, and the organization and training of rural residents as well as the use of the Forest Police.

Agriculture

The following land uses should be given priority: (a) Agro-forestry rotations (multistrata systems; taungya systems; sowing perennials with forest plantings; short agricultural cycles with natural forest regeneration; alternating agricultural and forest strips, etc.). (b) Animal-forest rotations (forest plantings in pastureland; forest shelters in pastures). (c) Natural forest regeneration in pasture. (d) Agriculture-animal-forest rotations. Figure 5 shows the locations of agricultural research centers and experimental stations and substations in Peru in 1979.

Horticulture should be encouraged. It is practically non-existent now but has possibilities of high yields in alluvial soils. Consideration should be given to the establishment of vegetable gardens to supply family consumption needs.



1 Tumbes
2 Jaén
3 Huarangopampa
4 Chepén
5 Poiján
6 Chota Motil
7 Cajabamba
8 Yurimaguas
9 Muyuy
10 La Divisoria
11 Huaral
12 Quisco
13 Pichanaki
14 Cerro Cuete
15 Asesor
16 Cañopay
17 Los Pobres
18 Canaán
19 Tambo
20 La Joya
21 La Pulpera
22 Sohuayacu
23 Amoybamba
24 Andenes
25 Urubamba
26 Huayoccari
27 Taroy
28 Pilcopata
29 Tahuaco
30 Moquegua

■ Agricultural Research Center (ARC)
○ Experimental Station
△ Experimental Substation

Figure 5. *Locations of agricultural research centers, and experimental stations and substations in Peru, 1979.*

Identification of flood plain agriculture in order to grow grains and devising efficient means to control sedimentation and flooding are an important development task.

Encouragement for raising hogs (based on cassava feed), fowl and buffaloes is emphasized.

Conventional mechanized clearing should be avoided due to detrimental effects on production, compared with the traditional method of clearing.

Cocaine cultivation should be eradicated for health reasons, and because this crop contributes to erosion. Only pre-determined rural settlements could raise the crop, under strict government control.

Intensive cattle ranching for meat and milk production (based on the use of rotations, forest foliage, and the new techniques of wood hydrolysis for cattle feed) should be encouraged in place of the current extensive ranching.

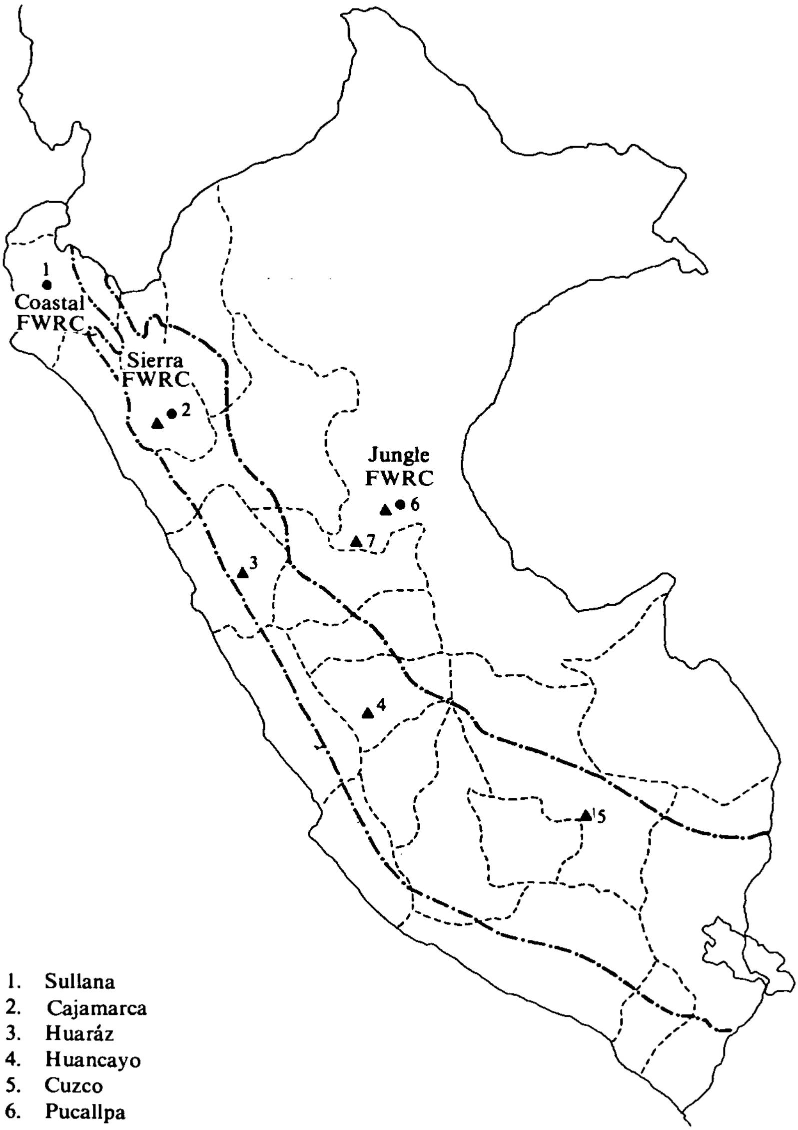
Utilization of forest, wildlife and hydrobiological resources

Priority should be given to the development by the government and by commonly-owned and private enterprises of forest projects in natural forests that integrate the commercial extractive and industrial phases. More species could also be used.

Natural forests should be managed so that the native ecosystems will not be drastically altered, and so that the area's revenue can increase. This can be accomplished by applying a combination of artificial regeneration systems in pure or mixed plantations, by stimulating natural regeneration, and protecting existing forests from uncontrolled use.

Conservation should be assured by the creation of Conservation Units (principally National Parks and Reserves) on 20 percent of the area of the montane and lowland jungles. In addition, these units would be the base for developing tourism and recreation opportunities. The Forest Policy should be implemented in Amazonia, complying with all legislation on renewable natural resources, forests and wildlife. Figure 6 shows the location of forest and wildlife research centers and forest experiment stations in Peru in 1980.

The government should not directly utilize more than 20 percent of the productive forests of Amazonia, in order to assure the participation of commonly-owned and private enterprises in the production process.



1. Sullana
2. Cajamarca
3. Huaráz
4. Huancayo
5. Cuzco
6. Pucallpa
7. Alexander von Humboldt National Forest

- ● Forest and Wildlife Research Center (FWRC)
- ▲ Forest Experiment Station (FES)
- —·— FWRC boundary

Figure 6. *Location of Forest and Wildlife Research Centers and Forest Experiment Stations in Peru, 1980.*

Areas of the montane jungle destroyed by shifting agriculture should be recuperated using potential use classification, identifying priority areas, implementing soil conservation and reforestation programs, and by the exclusion or strict control over ranching and agriculture. This recovery is essential for the economic use of the lands and preventing erosion that causes landslides and flooding, and is detrimental to river navigation and to potential hydroelectric projects.

Fish farming, as well as raising crocodiles, monkeys and other species should be supported. Extensive management systems that will be gradually transformed into intensive ones should be established for forest and aquatic wildlife.

The utilization of natural water supplies should be encouraged and the feasibility of utilizing palms and broad-leaf plants as suppliers of vegetative oils and other products should be investigated.

Social policy

The territories of native communities should be large enough for the inhabitants to live in them with dignity and in accordance with their cultures. These teritories in part can be protected forests where only such activities as hunting and extracting non-wood forest products could be carried out. The rest could include agriculture and forestry.

The transfer of rural populations from the sierra to the jungle should not be forced until the situation of the local inhabitants of the latter region has been resolved. The agricultural potential of each area should be evaluated before establishing new settlements.

Research in Amazonia

Scientific research in Amazonia should be aimed at improving the quality of life of the local population and should assure a good food supply, health and education services, etc. This research should close the gap between the region's potential and the real possibilities of investment that are limited by risks and uncertainties. Two research programs have been of particular importance:

- The Integral Settlement Project SAIS Pampa was developed in Pucallpa in 1974, with the goal of designing the production systems for integrated and intensive land use. The simultaneous achievement of the following was proposed: (1) strict maintenance of the ecological equilibrium; (2) a large number of stable work places per unit of invested capital; (3) a clearly superior level of living for settlers, including health, housing, social assistance, education, etc.; (4) permanent settlement of the colonists; (5) diversification of production that would guarantee the survival of the economic units; (6) a reasonable economic productivity that would permit "self-development" of colonization; (7) a significant increase in market production of foods, wood, etc; and (8) an easily reproducible model (Maas, 1974).

- Agronomic research has been carried out in Yurimaguas since 1972 on tropical soil management in the lowland jungle. Field work has included a central experiment called "System of Continuous Cultivation" and a series of complementary experiments designed to obtain answers to more specific questions, such as optimal rates for fertilizers (Sánchez *et al.*, 1974). This research is discussed in the paper by Valverde and Bandy.

Current Development Projects

The development plans for the Peruvian Amazon region are carried out through the Rural Settlement Projects conducted by the government and located in different places in the jungle (Fig. 7).

To date, 12 projects have been initiated. A summary of results follows.

1. **Jaén-San Ignacio Agricultural and Livestock Development,** initiated in 1971, was established with the goal of increasing the agricultural frontier with the incorporation of 400,000 ha and the settlement of 17,000 farm families. By 1979 the incorporation of 16,000 ha and settlement of 2400 families, aerial-photographic studies of 370,000 ha, soil studies of 40,000 ha, conclusion of the socio-economic study, conclusions of the forest inventory, regulation of land tenancy on 48,000 ha for 27,000 families, production assistance on 100,000 ha, support to the arrangement of 36 enterprises, and soil classification of 245,000 ha had been accomplished.

2. **Alto Marañón Rural Settlement,** established in 1979, focused on the integration and development of 2 million ha, settlement of 3000 families and titling of 100 native communities. By 1979, the preliminary study of the project, integral development on 518.000 ha with settlement of 842 families, titling of 79 native communities, cadastral survey and land classification on 434,794 ha, support to 85 rural organizations, and 1510 m^2 of infraestructure projects and 14 km of roads had already been achieved.

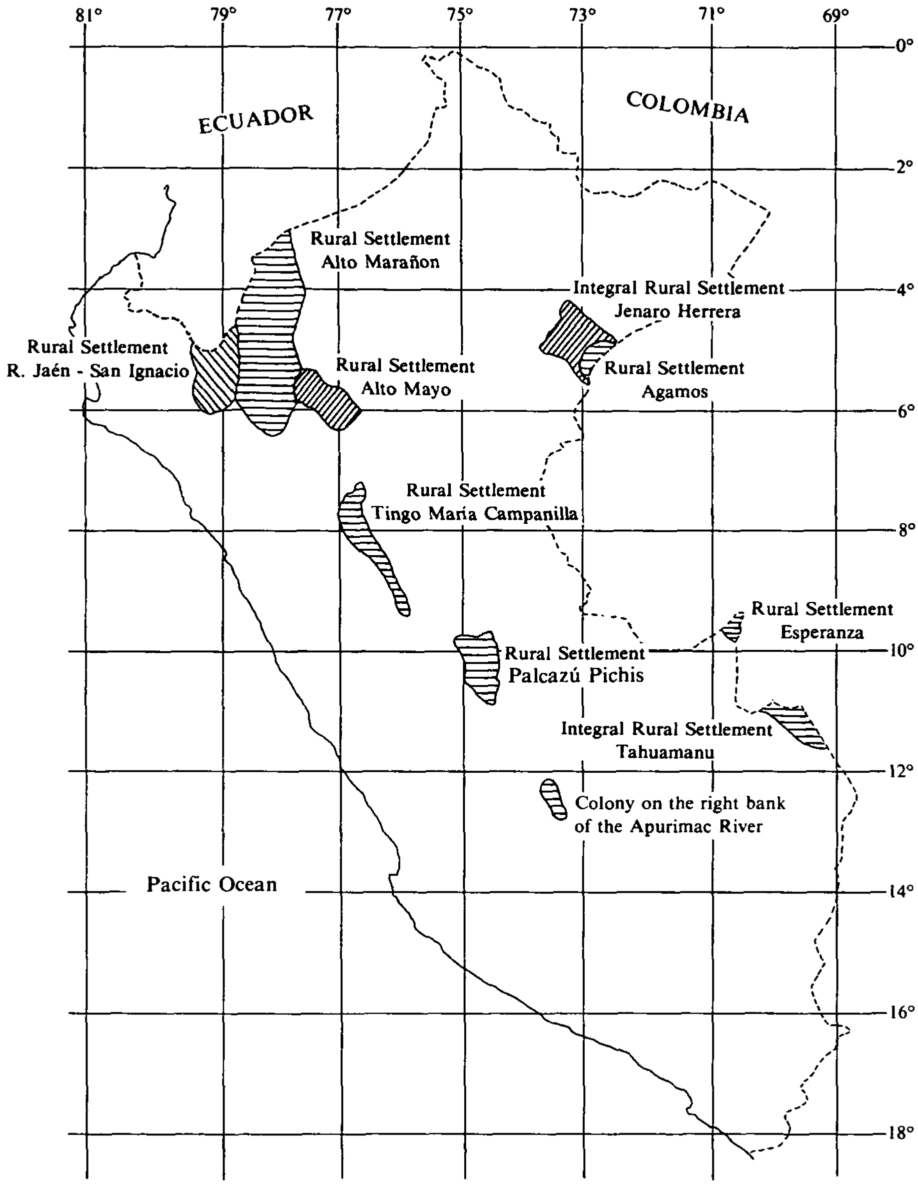


Figure 7. *Locations of rural settlements in the Peruvian Amazon.*

3. **Alto Mayo Rural Settlement,** begun in 1978, intended to plan agricultural development, rural settlement and resettlement of 7000 farm families and consolidate 100 native communities on approximately

662,000 ha. Topographic studies, cadastral survey of 245,000 ha, land classification of 2850 ha, rural resettlement of 664 families on 8000 ha, rural settlement of 71 families on 930 ha, conclusion of the preliminary study of the Project, and Nuevo Cajamarca Services Center (600 m^2) were completed.

4. **Huallaga Central and Bajo Mayo Rural Settlement,** begun in 1979, was concerned with the development of the agricultural potential of 150,000 ha and regulation of land tenancy of 15,000 families. By this year topographic work, construction of an agricultural machinery center, and construction of a storage and marketing center had begun.

5. **Tingo María-Campanilla Rural Settlement,** initiated in 1961, intended to settle 4680 farm families on 130,000 ha. By 1979 the settlement of 4680 families on 130,000 ha, completion of the agronomic and infrastructure study. two infrastructure projects, 545 km of roads, six buildings, maintenance of 275 km of roads, repair and renovation of 35 hygienic services. and 2136 m of a water system, and construction of 845 m of a perimeter wall had been achieved.

6. **Palcazú-Pichis Rural Settlement** commenced in 1969, with the intention of integrating development of 963, 510 ha and settlement of 1441 farm families. By 1979, integral development of 25,000 ha, completion of the feasibility study, and titling of 11 native communities of 377 families on 31,565 ha as well as settlement of 55 families on 4590 ha and cadastral survey of 2000 ha, were finished. The conclusion of the research and basic studies, production of 80,000 garden plants, acquisition of 140 head of breeding stock, maintenance of 60 ha of pastures, production of 4000 plant cuttings, creation of six horticultural gardens, clearing and establishment of pastures and crops on 111 ha, were also achieved.

7. **Colonization on the Right Bank of the Apurimac River** begun in 1963 and had the goal of incorporating 18,424 ha into planned agriculture and the settlement of 635 farm families. By 1979, 259 rural families had been assigned 8248 ha.

8. **Integral Rural Settlement in Tahuamanu,** begun in 1975, intended to initially settle 50 farm families in areas located within a perimeter of 325,000 ha. By 1979, the development of a pre-feasibility study, and 78 percent of the implementation work on offices and housing for technical, administrative and auxiliary personnel in Iberia were completed.

9. **Integral Rural Settlement in Jenaro Herrera.** This project is discussed in detail in Lopez-Parodi's paper.

10. **Cantagallo Rural Sttlement Project** began in 1975 and its main goals included a detailed forest inventory of 10,000 ha (scale: 1/25.000), soil study of 10,000 ha, aerial photographic survey of 100,000 ha (scale 1/25,000), and socio-economic diagnostic study of the project area. By 1979, the work of the experimental farm had advanced, with 46 ha dedicated to pastures and agricultural products.

11. **Esperanza Rural Settlement** (largely a military post) begun in 1975 and meant to settle 150 families and incorporate 2800 ha of productive lands. By 1979, the installations for its military personnel, clearing of 53 ha and sowing of pastures and grain products on 43 ha, and improvement of a landing field to allow large cargo planes to land, were completed.

12. **Angamos Rural Settlement Project** initiated in 1975 intended to incorporate 35,000 ha to agricultural production and settle 200 farm families. By 1979, the Angamos-Jenaro Herrera highway was marked out and 21 km had beed cleared; the highway to the landing field (5 km) was also completed. In addition, the construction of a military camp, instalation of fowl and hog farms, and implementation of an experimental farm with more than 20 ha of pastures and 16 ha of diverse crops were achieved.

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A Peruvian Experience for the Development of Amazonia: The Regional Development Organization of Loreto (Ordeloreto) and the Jenaro Herrera Settlement Project

José López Parodi*

Introduction

The creation of ORDELORETO (Organismo Regional de Desarrollo de Loreto) corresponds to the decentralization and deconcentration policy of the Peruvian government, with the goal of aiding integral regional development of the Peruvian Amazon.

ORDELORETO was the first Regional Development Organization created in Peru. Instituted on August 16, 1977, it began functioning October 1 of that year. ORDELORETO is defined as the "governing entity of regional development and the principal organization for multisectional coordination in the Region", according to the law creating it.

ORDELORETO has a director with the rank of State Minister and includes all of the Regional Sector Directorates that had previously been under the jurisdiction of various ministries headquartered in Lima. Its structural organization is very similar to that of a ministry; that is, it has an executive management level made up of the Director's Office and the Technical Executive Directorate; a control agent or Inspector General; support agencies such as Administration, Personnel and Communications; advising agencies such as the Regional Planning Office and the Office of Legal Counsel. Finally, it has sectional implementing agencies made up of the Regional Directorates of Agriculture, Fisheries, Industry and Commerce; Energy and Mines; Transportation and Communications; Housing and Construction; Education; Health; and Labor and Taxes.

ORDELORETO is responsible for the development of the Departament of Loreto and the Districts of Honoria and Puerto Inca belonging to the

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Pachitea Province of the Department of Huánuco (Fig. 1). This area includes some 47 million hectares (approximately 37 percent of the national territory and 60 percent of the Peruvian Amazon) located in the Amazonian plain or lowland jungle. The remainder is under other regional development organizations created recently.

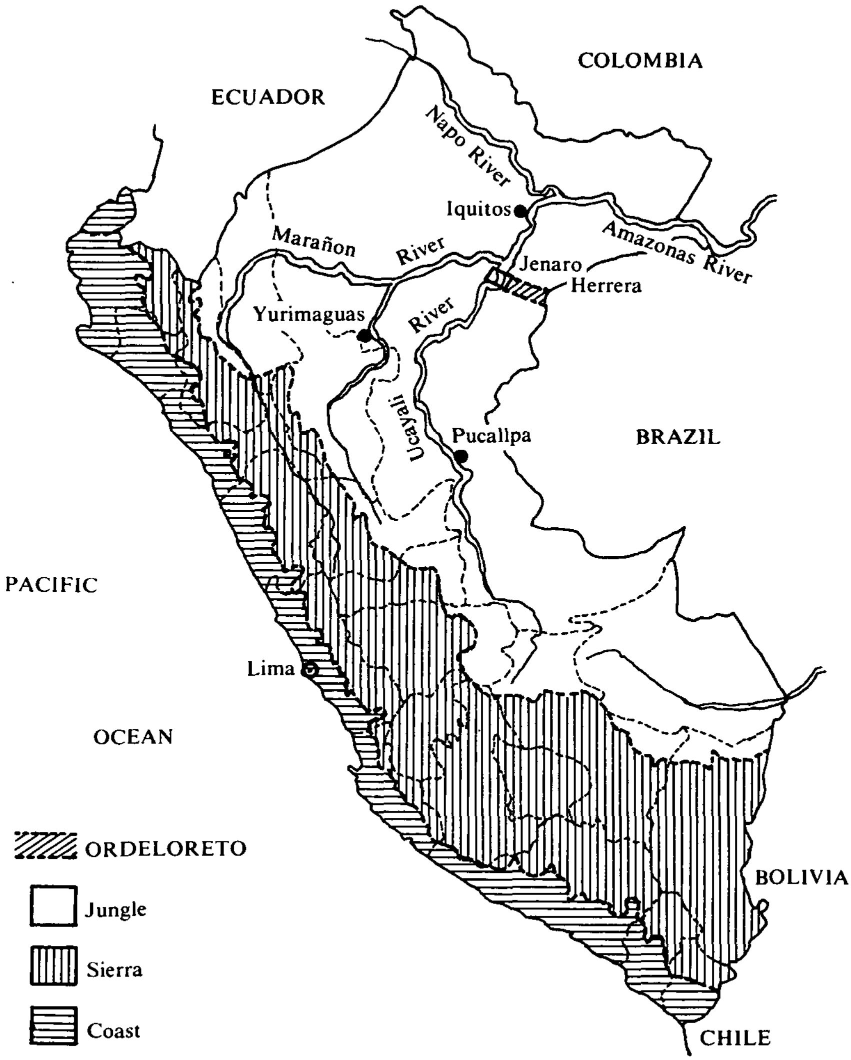

Figure 1. *Natural regions of Peru and boundaries of the ORDELORETO Project.*

The territory has some 620,000 inhabitants. Half of them live in rural areas along the principal rivers. It is important to mention that the rural population is approximately 75 percent mestizos and 25 percent indians belonging to 51 ethno-linguistic groups, which constitute an invaluable component of Peru's rich and varied cultural heritage.

Territorial Division for the Administration of Development

To avoid transfering the centralism of Lima to Iquitos, capital of the region, ORDELORETO in its two years of experience has divided the region into administrative territories in order to internally decentralize and deconcentrate the actions of integrative development. These territories correspond to five levels of administrative organization, as follows:

A) Regional level: Scope of ORDELORETO
B) Zona level: Three territories

- Provinces of Requena, Loreto, Maynal, Ramón Castilla and district of Putumayo, with headquarters in Iquitos
- Provinces of Coronel Portillo and Ucayali, headquartered at Pucallpa
- Province of Alto Amazonas, with its seat at Yurimaguas

C) Sub-Zonal level: 11 territories
D) Nucleus of development level: Approximately 60 nuclei
E) Center of development level: Population centers.

The Zonal level is responsible for implementing the various levels of territorial organization. Each Zone has its own budget and personnel resources and is responsible to the Zonal Sector Directors of Agriculture, Health, Education, Housing, Transportation, etc. The Sub-Zonal Development Committees, which pertain to the Development Zones, are being implemented.

The Nucleus of Development level has been proposed as the smallest territorial and administrative unit that allows quick action in the actual administering and supervising of one territorial extension. At the same time, the Nucleus should permit —because of its size— the operation of basic diagnostic studies of physical, biological, social and economic factors that constitute the fundamental base for defining development alternatives of the area. The nucleus is made up of the Centers of Development, which in reality are the existing population centers of the area. They can develop a system of production and local commerce based on the use of available natural resources in the area. A basic premise is that development provides for the welfare of the people, which means that the basic needs of food, housing, clothing, education, health and recreation are satisfied for the entire population. It also means that the people are able to increase family incomes and have access to a series of commodities that improve the quality of life.

To accomplish this, more and better products should be produced, which involves understanding the physical and natural bases of production (i.e., climate, soils, forests, water, wildlife). One must also understand the currently used technologies and how they can be improved, if they need to be improved. One must understand what MEN (in the fullest sense) think and how they can participate. In this sense, development should be the product of the combined efforts of public and private institutions and the people themselves. It is evident that economic resources and sources of financing are very important factors.

How can it be possible to put this idealized scheme into practice? The answer is: Testing in a defined and well-known area what we can do and how we can do it to make planning a reality. Undoubtedly, research is required, but we also need to keep development going; therefore, we must seek priorities for research and development.

This first experience is taking place in ORDELORETO, working through the already-existing Integrated Rural Settlement Project in the locality of Jenaro Herrera (IRSP Jenaro Herrera).

The Integrated Rural Settlement Project Jenaro Herrera

General characteristics

Jenaro Herrera is located on the right bank of the Ucayali River, 250 km south of Iquitos. The climate is typical of the humid tropics, with 3000 mm of annual rainfall and an annual mean temperature of 26° C. The soils are predominantly Ultisols (in higher zones or solid ground) of gently rolling topography. Entisols are found in the islands and beaches of the riverside area. Also found are Spodosols (sandy soils of 99 percent silica sands) and Gleysols in the "aguajales" (swampy areas where *Mauritia flexuosa* predominates). For the most part, vegetation is humid tropical forest, although there are homogeneous forests of *Mauritia flexuosa* (aguaje). The waters are formed by Andean rivers (e.g.,the Ucayali) and those originating in lowland Amazon areas, as well as by meandering lakes receiving the waters from both sources. The terrestial and aquactic wildlife is typical of the humid tropical forest, although overutilized. The initial project covers 250,000 hectares, with potential expansion to 450,000 hectares.

The IRSP Jenaro Herrera is an ORDELORETO Investment Project and is executed through the Regional Agricultural Directorate with Swiss Government technical cooperation. The Project has been converted into the center of operations of the Pilot Development Nucleus, which includes another 12 population centers (hamlets) located along both sides of the Ucayali River; these have a total of over 5000 inhabitants.

Current activities

Agriculture. Agricultural production is found in the várzeas (seasonally flooded, rain forests plains), including such seasonal crops as rice, peanuts, dry beans, urena (a fiber), squash, melons and watermelons. On the higher, solid ground, cassava and plantain plots are the main crops. However, a two-year old experimental plot of 3.5 hectares of associated crops and trees has such local crops as *Discorea* sp. (sachapapa) and *Calathea* sp. (dale-dale), associated with pineapple, cassava, plantain, coffee, rice, *Inga* sp. (guaba) and such forest species as *Cedrelinga cataeneformis* (tornillo) and *Chirizia* sp. (lupuna).

Cattle raising. Dual purpose cattle of Brown Swiss, Zebu and native breeds are in the area to furnish meat and milk. The pasture grasses are *Brachiaria decumbens, Axonopus scoparius* (maicillo) and *Pueraria phaseoloides* (kudzú). Water buffaloes (*Bubalus bubalis*) were introduced two years ago and their development is very good. There is one farm of 350 Landrace, Yorkshire and native hogs. Some 80 horses from San Martín (montane jungle) are doing well, especially on the *P. phaseoloides*.

Forest. The natural forest is being utilized and is reforested or managed by natural regeneration. More intensive reforestation trials for strips and open field plantations are utilizing *Cedrelinga* sp. (tornillo), *Chorizia* sp. (lupuna), *Hymenaea palustris* (azúcar-huayo) and two other species. Work with palm trees has begun.

Fish. Fish are taken from adjoining lakes. A communal fish reserve is being created to put into effect national management of the resource. There are hatcheries with *Prochylodus* sp.(boquichico) and other species such as paco and gamitana. One pond is associated with the swine facility and the other two serve as watering places for cattle.

Wildlife. Local forest animals have been evaluated and *Hydrochaeris hydrocoerus* (roncoso) and *Tayassu tajam* (sajino) are being raised in captivity.

Community advancement

Education. A campaign against illiteracy and in support of rural schools has been organized.

Health. There is a health station and 12 promoters who provide first aid and preventive measures such as vaccination and health education. The village of Jenaro Herrera has organized an Association for Development and has a 60-metric ton motorboat that makes the Jenaro Herrera-Iquitos trip twice a week. A pharmacy sells medicines at official prices.

Housing. Jenaro Herrera has an Urban Expansion Plan. An elevated reservoir, the water purification plant and home water lines are being finished. In effect, it is a research and development project for rural construction in the jungle, which emphasizes the use of regional materials and technology available to the rural resident.

Transportation. Fifteen kilometers of a highway to the Yavari River have been construçted. The road will facilitate forest utilization and settlement. Tests of a non-conventional vehicle (Tortoise-Seiga) are being conducted to find alternatives to trucks.

Medium-range Development Plan for the Nucleus of Development Jenaro Herrera

A medium-range (five year) development plan is being formulated for the Nucleus of Development. In order to give an idea of what this effort involves, some aspects of the plan follow.

The objective of the "Pilot" Nucleus of Development Jenaro Herrera is: "To sponsor integrated rural development that permits raising the socio-economic and cultural levels in the Nucleus zone, through optimal, socio-economically and ecologically reasonable utilization of all natural resources, by means of coordinated efforts of all related or to-be-related sectors, under the principles of full participation".

The "pilot" nature of the Nucleus is explained by the novelty represented by the integrated and coordinated development effort of a microzone in the lowland jungle and by the modeling function this effort will eventually acquire.

The principal development objectives of the Pilot Nucleus for the next five years follow:

A) Political-organizational:
- Obtain the district category for Jenaro Herrera and its area of influence (Santa Rosa, Carahuayte, Bagazán).
- Establish the Pilot Development Nucleus within the scope of the Jenaro Herrera District with all the necessary organisms for its full functioning.
- Assure self-organization of all the villages within the Nucleus to obtain their participation and co-negotiation in accomplishing the five-year plan.

B) Basic infrastructure:
- Provide adequate health services in all communities of the Nucleus.
- Eradicate illiteracy and provide complete educational and training services for all ages and at all levels.
- Assure that each family has a roofed house with wooden floors, and separate bedrooms.
- Provide electricity to all communities with adequate urban structures.

C) Primary production:
- At the community level, assure integrated agricultural, animal and fish production, with a harvest sufficient to guarantee all families a balanced diet during the entire year. Encourage surplus food production in order to satisfy these minimum necessities.
- Manage in a reasonable manner the forest resources that will be assigned to each community, to permit the financing of basic infrastructure needs as well as reforestation.
- Assure the necessary storage, transportation and commercialization infrastructure in order to achieve food production objectives.

D) Transformation of primary production:
- Encourage surplus primary production through adequate technology with the goal of producing added value.
- Encourage the commercialization of transformed products.

E) Research:
- Encourage, by means of adequate technology, basic and applied research on the zone's natural resources and on their utilization.

F) Evaluation:
- Continually evaluate the results obtained in fulfilling the Development Plan to assure its completion.

G) Information:
- Continually make public the results obtained in carrying out the Development Plan to make accessible the fullest possible benefits of the accumulated experience.

Conclusion

The experience of the Nucleus of Development Jenaro Herrera is novel for the Peruvian Amazon region, insofar as it groups knowledge and experiences* accumulated in different disciplines, locations and institutions of Peru and other countries. There is no "recipe" to accomplish the Plan. But we believe that research ought to go hand in hand with development. Cooperation is welcome and participation of the people is necessary because the purpose is to seek the well-being of everyone. Each person has a responsibility to preserve what exists and provide something better for the people to come.

* References, information and publications may be obtained by writing to: Proyecto de Asentamiento Integral Jenaro Herrera, Casilla 546, Iquitos, Perú.

Agricultural Development in Venezuela's Amazon Region

Sergio Benacchio*

Introduction

Venezuela is located between 0°40' and 12°28' north latitudes, and despite being a clearly tropical country, 22 life zones are found within its territory. These zones have environmental characteristics ranging from ecosystems typical of the Equatorial belt to those of the highest latitudes. In general terms, the areas north of the Orinoco River are the driest and those to the south become more humid as one approaches the Equator. For socioeconomic and political reasons, in addition to those of an environmental nature, the country's development has taken place almost exclusively north of the 6° latitude. However, since 1969, the nation has had renewed interest and concern for a more effective integration of its southern territories into the national life both because of their importance as a frontier region and for the potential that they represent for the country's economy.

According to Presidential Decree N° 478 of Administrative Regionalization dated January 8, 1980, the Amazonas Federal Territory is a constituent part of the Guiana Region, next to the Delta Amacuro Federal Territory and to the State of Bolívar, whose Cedeño District has very similar environmental characteristics. According to the disposition of April 7, 1980, emanating from CORDIPLAN, the development planning for all of the Guiana Region is the responsibility of the Corporación Venezolana de Guayana (CVG).

Because of the specific interest of this conference, this report will discus the studies conducted south of latitude 6° and, specifically, in the Amazonas Federal Territory.

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The Amazonas Federal Territory, with 178,095 km², makes up approximately 20 percent of the national territory. Its population in the 1971 census was 21,696 inhabitants, with an apparent density of 0,12 inhabitants/km². Most of the residents live in the most important centers along the western and north-central border, such as Puerto Ayacucho (10,417 inhabitants), capital of the Territory, San Fernando de Atabapo (1,537), and San Juan de Manapiare (529). Approximately 10,000 indians scattered throughout the Territory should be added to the counted population.

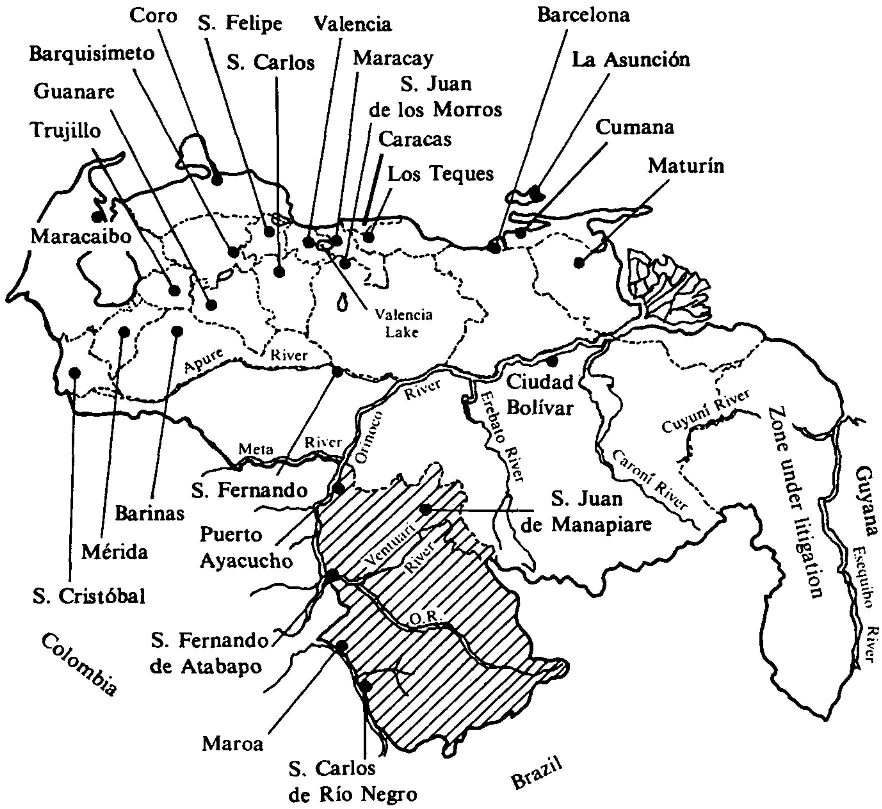

Figure 1. *Venezuela's Amazon region.*

General Characteristics

Physiography

The morphology of the region is characterized by an extensive plain, on which tabular relieves and heavily dissected granitic massifs can be observed. The Guiana shield gives geologic unity to the region and is made up predominantly of metamorphic and granitic rocks of Precambrian origin in the Paleozoic Period.

The region is crossed by rivers of major importance such as the Orinoco, the Negro-Guainia, the Ventuari, the Atabapo and the Brazo Casiquiare, which unites the Orinoco basin with that of the Amazon. Through a branch of the Negro River, 25 percent of the Orinoco waters empty into the Amazon. The Territory, as such, can be more appropriately considered as part of the Orinoco basin region and only one-fourth would belong to Amazonia.

The mountainous area, with levels higher than 500 m, is particularly extensive, covering 79,855 km^2 or 44 percent of the Territory. It is made up of the massif on the northeast, the mountain chains of the east and the rocky mountain ranges of the southeast. The highest peaks of the Amazon basin are found there: Cerro Marahuaca, 3860 m; Cerro Huachamacari, 2520 m; Cerro Duida, 2880 m; Cerro Yari, 2556 m; and Cerro Neblina, 2940 m.

The remaining 102,005 km^2 are in lower zones distributed as low plateaus (0-100 masl, 19%); higher ground (75-250 masl, 32%); and high plateaus (250-500 masl, 12%).

The existing geological conditions, the long period of erosive processes and the peculiar climatic conditions of high temperature, high rainfall and high humidity have caused the formation of landscapes and reliefs that characterize the region. The principal ones are:

Plains of erosion-alteration which have rocky outcroppings alternating with small mountainous tiers, surrounded by sandy sloping embankments and altered ridges. Included among them are the peneplains of Santa Bárbara, Ventuari and Casiquiare.

Alluvial deposits. These physiographic forms are linked to alluvial deposits produced by overflow along the main rivers. A typical example is the locality of San Juan de Manapiare.

Mountain valleys. Are generally wide but not very deep, with alluvial deposits and eroded, altered ridges.

Precambrian granitic-gneissic massifs generally are made up of ancient eroded surfaces. Examples are the Unturán-Tapirapecó Plateau and the Sierra Parima.

Massifs of the Roraima formation. These residual forms are found as high plateaus circled by almost perpendicular, very deep crags. They were formed initially as a consequence of the erosion of the Guiana shield; the enormous accumulation of sediments then underwent several transformations, and granites and diabases later intruded.

Based on climate and relief, the territory has been divided into four physical-natural subregions.

Region contacting the Plains (Llanos). This subregion, a strip 50 km wide, occupies the vicinity of the Orinoco River to near Puerto Ayacucho. The area is characterized as having a savanna climate (Aw, according to Köeppen). It is a region of fluvial plains, and because of a well-marked dry season, it has vegetation similar to the Plains (Llanos). The soils are generally sandy.

Region of transition. This subregion is formed by Sipapo and Ventuari rivers. Morphologically, it consists of undulating plains with hills and mountains separated by large rivers. It has an Am climate, with precipitation throughout most of the year. This sufficiently heterogeneous region serves as the limit between the Plains and the rain forest to the south. Anual rainfall is 2500 to 3000 mm. The vegetation is hygrophytic forest with good water drainage and great variety of plant species. However, there are also large patches of savanna.

Peneplain of Casiquiare. Physiographically this region is fairly heterogeneous, with discontinuous savannas interrupted by thicker vegetation along the large rivers or by mountainous areas that are remnants of the old massif. The average annual precipitation varies from 2000 to 3500 mm. The most important forest utilization in the Amazon Territory has been developed in this subregion: the exploitation of chiquichique *(Leopoldina piassaba)* fiber.

Parima mountainous country. The topography and general characteristics of this subregion make it the most rainy. Its vegetation has been classified as jungle or mesothermic rain forest. The sources or heads of the principal rivers are found in this area.

Climate

Latitude, altitude and winds are the fundamental factors that determine the climatic characteristics of the region, which can be summarized as follows.

Precipitation is more than 2400 mm; zones of the highest relief have more than 4000 mm. Two-thirds of the Territory has no proper dry season. The greatest rainfall occurs from May to November with a decline in August.

The average annual temperature is higher than 25°C throughout the region, with the exception of zones above 800 m, which have a temperature decline because of the altitude. According to the Köeppen's classification, the region has an "A", or tropical, climate, characterized by the coolest month having temperatures above 18°C. Three variations of this climate have been determined in the Amazon Territory.

Aw, or savanna climate. Found in the northwest zone of contact with the Plains (to the north of San Fernando de Atabapo), this climate is characterized as having a well-marked dry season during the year. This dry period occurs between December and March in the region.

Am, or tropical monsoon climate. It is found in the strip that follows the course of the lower waters of the Orinoco River, south of Puerto Ayacucho. This area separates the savanna climate from the tropical rain forest climate. This variety of tropical climate is characterized by a short dry season.

Af, or tropical rain forest climate. This climate does not have a well defined dry season. Most (75%) of the region has this type of climate, which is found in all of the area south of the Ventuari River.

Within the area of tropical rain forest (Af) climate, certain differences are found because of altitude and precipitation: (a) Region of the Sipapo and Ventuari Rivers, characterized by rainfall between 2500 and 3000 mm. This is the transition zone between the monsoon climate along the Orinoco and the rainy region of the Casiquiare. (b) The Casiquiare River Region, with heights up to 500 m and precipitation between 3000 and 3500 mm. (c) The Sierra de Parima Region, with altitudes above 1000 m and more than 3500 mm of precipitation. This appears to be a special region because of its high precipitation.

Soils

The parent material and the climate are, apparently, the most important pedogenic factors in forming the region's soils. The predominantly acid granites constitute the mineralogical base, while the high temperatures and the extraordinary rainfall aid the chemical disintegration of the soil, the transporting and depositing of sediments and continual washing and removal of the soil.

The majority of the soils developed in the region can be tentatively classified as Oxisols, with local areas of Ultisols or complexes of these orders. Entisols are also represented. The soils formed on higher ground not exposed to flooding have a characteristic oxic horizon situated at a depth between 0.30 and 2 m. This is common in humid tropical areas that do not have well-defined dry seasons.

In general, the region's soils have pH's between 4.0 and 6.2, a high C:N ratio (greater than 14) that is indicative of the high requirements of N for the development of crops, and a low cation exchange capacity. They also have a high proportion of sands and gravels, that explain the low water holding capacity and organic matter content of these soils as well as their vulnerability to erosion because of high precipitation, particularly in areas of undulating topography. These soils have very low natural fertility, as a consequence of several cycles of weathering, erosion and sedimentation that occurred in the region.

The percentage distribution of the lands by class follows:

Classes III and IV	19.3%
Classes V and VI	7.0%
Class VII	30.5%
Class VIII	43.2%

The potential agricultural lands (Class III, limited agriculture and ranching, and Class IV, very limited agriculture and ranching) are found especially in the Manapiare Valley, in the southern Orinoco sector between Santa Bárbara and San Fernando de Atabapo, between the Siapa, Pasimoni and Yatua rivers and north of the Brazo Casiquiare River to San Miguel.

Classes V and VI are principally forested lands, for reasons of poor drainage, low fertility or erosion susceptibility. If drained and improved, these lands could be put to agricultural use. The remaining 73.7 percent are lands exclusively in forests or with protective cover.

Vegetation

Because of the climate, the characteristic vegetative formation of the entire region should be of the humid tropical forest type. However, the presence of other factors —such as the soil, relief, drainage, and man, principally— has served to break the continuity of Amazonian vegetation. Thus, different types of forests and savannas are found in response to these factors.

It has been estimated that 90 percent of the region is covered with forest. The remaining 10 percent is covered with savannas, *Tepulia stiuplaris* and bodies of water. Thirty to 40 percent of the forests have been classified as humid tropical and 20 to 30 percent as very humid premontane and humid premontane.

Thirty to 50 species of trees having more than 10-cm breast-high diameters have been counted per hectare in the primary forests. The region's typical forest consists of a formation of two to four canopies in which the lower levels contain shrubs and the upper ones have well-developed trees (30-40 m) that ordinarily have smooth, straight trunks. These trees are supported by adventitious and lateral roots and by the intertwining of their upper branches. Numerous vines and epiphytes contribute to the formation of very thick growth in the lower and middle vegetative layers, which makes movement through this zone difficult.

Economy and Agriculture

The region's economy is basically one of subsistence. The production of goods is very restricted; a rudimentary, low-productivity technology is utilized. The economy is based on local consumption, with limited commercialization of extractive products.

Extractive activities include the gathering of forest products such as fruits, fibers and latex and occasionally wood products. Outstanding for their economic importance are the cutting and tying of chiquichique *(Leopoldina piassaba)* fiber, harvesting the fruit of *Yessuta batana* (seje) and harvesting latex of the *Mimusops* sp. and *Pouteria* sp. (pendare) and *Manilkara bidentata* (balatá). Some commercial activity based on the sale of ornamental fish also exists.

The region's agriculture is based on family production, directed principally toward family consumption. Very few surpluses for commercial interchange are generated. A sedentary agriculture exists near the principal population centers such as Puerto Ayacucho, San Juan de Manapiare, San Fernando de Atabapo, Maroa, Ocamo, and San Carlos de Río Negro. These small family operations supply part of the food needs of those centers. The indians have a primitive system of shifting agriculture and cultivate cassava, tobacco, dry beans, maize, rice, taro, pineapple and various bananas and plantains. Despite the Territory's extensiveness and scarce population, however, agricultural production is insufficient and products must be imported from other regions of Venezuela and Colombia.

Inventory and Research Work Completed in the Region

Exploration and prediagnostic phases

An intensive program to study the Amazonas Federal Territory was initiated in mid-1969 with the creation of the Commission for the Development of the South, first in the agencies of the Ministry of Public Works (MOP) and then in the Ministry of Renewable Natural Resources (MARNR).

The initial exploratory work examined the region and defined its problems. The resulting preliminary report served as a base for later studies. The prediagnostic studies following that phase had as their objective to determine potential resources and other socio-economic aspects of the region.

The activities developed in the second phase included: (a) preparing the preliminary map of the region; (b) providing aerial photography of the region; and (c) taking a broad-range inventory of resources.

The aerial photographic work was done in 1970 using conventional methods between latitudes 4° and 6° and longitudes 65° and 67°, on a 1:50,000 scale. Because of the characteristic cloudiness of the zone, however, it was necessary to resort to the Side-Looking Airborne Radar (SLAR) system to survey the approximately 110,000 km^2 of territory south of latitude 6°. As a result, maps with a 1:250,000 scale were produced, along with corresponding reports on the geology, hydrography, vegetation and soils of the area.

In order to quantify and assess the potential of the natural resources, the Commission carried out edaphic, hydrological and economic studies, as well as exploratory studies of the forests, and studies of population and human resources. The compiled information was published in an Atlas in 1973 and in a prediagnostic report.

Diagnostic phase

After the preparatory phases came the diagnostic phase whose object is to "carry out the required studies and research to define the use that can be given to each area of the region and the management that ought to be given to each ecosystem and each resource". Thus, beginning in 1973, the studies conducted in the region have a more specific character with objectives limited to the solution of priority problems; most of the studies also are being conducted in areas that eventually will be the probable foci of development. The following data correspond to these studies.

Soil studies

From 1973, soil inventories were intensified in priority areas such as the sectors of Puerto Ayacucho, San Fernando de Atapabo-Santa Bárbara, San Juan de Manapiare, Osita Cacuri-Parú, Tama Tama, and Santa Bárbara del Orinoco-San Antonio. Savanna soils were also studied. The inventories, most of which are in the process of being published, were performed at the sub-group level and the maps have a scale of 1:100,000. The MARNR Soils Division, within the work execution program of the National Land Inventory, has already covered all of the Amazon Territory north of latitudes 3°30' with edaphological, geomorphological and land use capacity information on a 1:250,000 scale and at the level of sub-group associations. This work is also being published. Recently initiated was the examination of 80,000 ha including the Maroa and Casiquiare sectors.

The more-detailed soil studies, conducted in the region in recent years, do confirm what was found in the prediagnostic stage. The soils present very severe limitations of agriculture and livestock raising because their natural fertility is extremely low, with the exception of recent alluvial deposits of the Orinoco and other rivers, especially the Ventuari. Unfortunately these deposits cover limited areas and are scattered along the rivers. To the condition of extreme nutrient deficiences must be added other limiting factors such as erosion and periodic flooding, affecting the majority of the soils in alluvial zones near the principal rivers. According to the estimates and studies, at this time only 2 to 3 percent of the soils are suitable for some agricultural and ranching use. All are Class II and IV soils with severe restrictions. A great majority of these soils have suffered very intense processes of weathering and leaching. Their age and the dominant climatic conditions, such as high temperature and precipitation, imply a very advanced process of "ferralitization"*, characterized by leaching of silica and other major cations and the breakdown of clays in kaolinites and hydrous oxides of iron and aluminum.

* Process of formation of ferralitic soils. (Editor's note.)

The abundance of warm rain and humid climate give a physical-chemical characterization to these soils as follows: (a) A very low cation exchange capacity, because of the kaolinitic constituents and the sexquioxides present (1 meq/100 g of soil). (b) A very low exchangeable base capacity, generally below 1 meq. (c) An acid to very acid pH (4-5). (d) A variable but low degree base saturation, around 10 percent, especially in the B horizon.

Chemically, these soils are very poor, sometimes extremely poor —true mineral skeletons that play a support role— and where only the upper horizon (horizon A, often very thin) is relatively fertile.

The presence of organic matter in the surface slightly increases the exchange capacity, and is the only element that helps to modify the poor chemical makeup of these soils. The C content in the surface layer is on the order of 0.4 percent. The pH is almost always more acid on the surface than in the lower part of the profile.

Although this study does not necessarily reflect the reality of the entire Territory, it is very indicative of an approximately 10 km-wide strip along the right bank of the Orinoco River that extends 200 km from north to south, covering a total of 371,505 ha. In the specific case of this study, soils of Classes III and IV cover 7.59 percent of the area, which is a relatively high percentage compared to other areas of the Territory.

Study of the "forest" biome

The "forest" biome occupies approximately 90 percent of the Territory. Its initial study was based principally on conventional serial photographs in the area between latitudes 4° and 6°. Later, using the satellite images of ERTS I, the vegetative communities of the Sipapo Forest Reserve (4°-6° Lat. N, 65°-67° Long. W) were studied.

Among the most abundant vegetative species, as found in the forest inventories of the Manapiare and Parucito river basins in the Sipapo Reserve, are the following: *Pouteria* sp., (temore), *Peltogyne* sp. (zapatero), *Vochysia crassifolia* Warm (salado), *Erisma uncinatum* Warm (saladillo), *Sterculia pruriens* K. Sch. (majagua), *Inga thibaudiana* D.C. (guamo), *Macrolobium* sp. (arepito), *Virola surinamensis* Warb. (cuajo), *Protium* sp. (tacamajaco), *Copaifera pubiflora* Benth. (aceite), *Enterolobium cyclocarpum* (Jack.) Griseb (caro), *Trichilia propingua* (Miq.) D.C. (cedrito), *Ceiba pentandra* (L.) Gaerth (ceiba), *Eschweilera holeogyne* A.C. Smith & Beard. (coco de mono), *Sweetia shomburki*

Benth. (congrio), *Brownea* sp. (rosa de montaña), *Jessenia* sp. (sejo), *Manilkara bidentata* (balatá) *Manilkara tridentata* (pendare), *Maximiliana* sp. (cucurito) and *Vismia cayennensis* (sangrito).

The most prominent of the latest inventories of the forest areas are the one conducted on 650,000 ha in the area of San Juan de Manapiare and the one being carried out by the Sipapo Reserve in an area of 1.215 million ha south of Puerto Ayacucho. A forest inventory of the Catariapo River basin is also scheduled. A forest nursery for testing native species and species introduced from other Venezuelan regions has been established in Carimagua, near Puerto Ayacucho. There are also phenological observation plots. No silvicultural studies are being conducted in the Territory at this time.

The Amazonas Project

Research under this project begun in 1975. Basic studies of the rain forest ecosystem have been conducted by researchers from the Instituto Venezolano de Investigaciones científicas (IVIC), with the collaboration of the Institute of Ecology of the University of Georgia (U.S.A.), the Max Planck Institute of Plon, Germany, and other North American and European scientific institutions. The researchers have studied poor sandy soils in an Amazonian caatinga*type forest in the area of San Carlos de Río Negro. This is a highly oligotrophic system, in condittions of high rainfall and temperature, where the cycling of nutrients is very efficient in minimizing losses by mineralization and leaching.

Several studies have been carried out under this project. The profiles of typical soils of the area have been characterized chemically and mineralogically. Well-defined correlations between the distribution and types of vegetation, the micro-relief and soil types have been found. Also found was a low discrimination between anions and cations during leaching, and an elevated velocity of vertical translocation was verified.

The cycling of nutrients in the rain forest was studied and the following hypotheses were confirmed: (a) the principal movement of the nutrients in these jungles is from trees to fallen leaves to trees, with the soil playing a relatively secondary role in the nutrient cycle; (b) the mycorrhizal fungi have an important function in the transfer of nutrients from the fallen leaves to the tree roots; and (c) after the forest has been cut, the nutrients

* Type of vegetation of certain areas of the Amazon forest characterized by stunted tress with rigid leaves. (Editor's note.)

are washed rapidly through the soil because the mechanisms that assure their conservation and cycling have been destroyed. Studies determined the amounts of Ca, Mg, N, P, and S in the fallen leaves, in the water that washes the foliage and stems and in the water in the soil of an intact forest. The change in the flow of nutrients after forest clearing was measured. The flow of nutrients from the fallen leaves to the roots through the mycorrhiza was quantified. Other factors measured were the rates of nitrification and denitrification, the rate of nutrient incorporation in trees and the loss of nutrients with the fall of dead leaves. Some of the mechanisms that regulate the efficiency of nutrient cycles were studied.

Ecophysiological studies of the metabolism of epiphytes were performed also.

Conclusions from research conducted by IVIC researchers on the distribution and cycling of nutrients in tropical humid forests and agrosystems can be summarized as follows: The Amazon forest ecosystem studied has a lower concentration, quantity and run-off of nutrients than other tropical and non-tropical forests over richer substrates. Thus, the hypothesis was confirmed that under oliogotrophic conditions, the nutrient conservation mechanisms are markedly efficient. Among the mechanisms found were: (a) preferential storage of nutrients in the biota; (b) a high proportion of these nutrients in the root system; (c) a direct relationship between the root system and matter that is mineralized; (d) an abundance of decomposer associations involving fungi and lower herbivores; (e) retranslocation of the senescent material; and (f) nutrient uptake from dilute solutions.

In the agroecosystems studied, based on coffee and cacao, the contribution of nutrients by the fallen dead leaves more than compensated for those lost in the harvest. In the agrosystems based on cassava *(Manihot esculenta* Crantz.), mapuey *(Discorea trifida* L.) and pineapples *(Ananas comosus* L. Merr.), the curve of nutrients in the soil showed a sharp peak following the cutting and burning of the forest, with a rapid fall in subsequent months. After a year, amounts of Ca and Mg increased, possibly as a consequence of the decomposition of the forest's root system; later, according to lysimetric data, the loss of nutrients continued. The fall and decomposition of dead leaves occurred simultaneously with the flowering and setting of fruit by the crops.

The results indicate that under the oligotrophic conditions of the soil-vegetation complexes in Amazonia, the strategies for conserving nutrients are very complex and at the same time very fragile. The modification and use of these ecosystems for production are severely limited, not only by the availability of nutrients but also by the fragile mechanisms for conserving those nutrients. In the coffee and cacao plantations, the practice of cultivating them with shade trees, has ecological advantages in addition to the traditional ones of protecting the soil and regulating the light intensity. Under conditions of low technology, the maintenance of soil fertility depends on the nutrient cycle, particularly mediated through fallen dead leaves.

Study of the "savanna" biome

The savanna biome occupies approximately 20,000 km^2, or almost 10 percent of the Venezuelan Amazonas Territory. The rest is in forested or aquatic areas.

The Ministry of Environment initiated a project in 1977 to examine the biome and determine its production potential and eventual use. This study, still not completed, established the existence in the Territory of three types of savannas.

1. **Grassy plain type.** This type of savanna is found along the banks of the Orinoco River from the Meta to the Sipapo, in patches near Santa Barbara and in the area of the lower and upper Ventuari River. The soils are sandy, for the most part; however, there are also clavey loam soils. The dominant grasses are the *Trachipogon, Axonopus* and *Paspalum* genera. Among the legumes are found several *Cassias,* a *Centrosema,* an *Eriosema* and the *Clitorias.* Nearly 2000 cattle pasture in these savannas, near Puerto Ayacucho and in Cacuri. This type of savanna is located in the areas of Tropical Am climate, with a relatively short dry season. The soils are generally very acid and of very low fertility.

2. **Floodable savanna type.** The lower savanna is inundated about nine months of the year by more than 50 cm of water. The dominant grasses are the *Paspalum* and *Andropogon* genera. In the higher parts, bushy and wooded savannas are found. This type of savanna, which makes up nearly 4000 km^2, is found mainly near San Juan de Manapiare in the rest of the Territory. About 1500 cattle, the majority living in a wild state, pasture in these savannas.

3. **Amazonian savanna type.** This type of savanna, which covers the most extensive area, is found on practically sterile quartziferous sands that are extremely poor in nutrients. These savannas have no grasses; the fibrous species are represented by Rapataceae, Ciridaceae, Eriocaulaceae and Ciperaceae, among others. In addition there are small shrubs and woody bushes. In general, it is a very endemic flora of great biological interest.

This savanna type is located in the middle and lower reaches of the Ventuari, in the middle Orinoco region between San Antonio and the Sipapo River and in the entire Department of Casiquiare. This land has no agricultural or cattle raising potential.

The study of savanna areas helped to locate three important centers of botanical diversity. Many species of pharmaceutical interest were also found.

Recently, in collaboration with the University of Gottingen (West Germany), an investigation has been planned that will help determine the origin of the Amazonas Territory savannas.

Agronomic research

Research on forage species. To better evaluate the agricultural potential in the areas of Santa Bárbara and San Juan de Manapiare, 11 forage grasses were introduced in 1976 from Guasdualito (Apure State) and sown in Trapichote near Santa Bárbara. They were grown in a soil, classified as Typic Haplorthox, that had been cleared by hand and burned a year earlier. The soils of the area planted are deep and have good drainage, a low cation exchange capacity, a pH of 4.3-4.8, and good physical characteristics (texture and structure). Annual precipitation is 3240 mm; July is the wettest month with 470 mm and February the driest with 51 mm. The region has a well-defined dry season of 3-4 months. It is an intermediate situation between the drier north and the more humid south. The grasses were *Pennisetum purpureum* (pasto elefante), *Panicum maximum* var. Guinea, var. Colonião and var. Embú (gamelote), *Digitaria decumbens* and *D. swazilandensis* (pangola), *Melinis minutiflora* (capin melao), *Brachiaria decumbens* (pasto barrera), *Brachiaria* sp. (pasto tannegrass), and *Hyparrhenia rufa* (yaraguá). After four years, the first seven species still show excellent performance, both in the rainy season and in the relatively short dry period. The *Brachiaria decumbens, Brachiaria* sp., *Hyparrhenia rufa* and *Panicum maximum* var. Colonião had only ordinary performance in comparison with the others.

Rubber research. A station for the study of rubber has been functioning in Santa Bárbara del Orinoco since 1974. A nursery has been established near Macurumo and an 11-hectare test plot is located in Trapichote. Sixteen varieties of *Hevea* were introduced in 1975. Three of them, of oriental material selected in Malaysia, came from the Ivory Coast. They are good producers but are susceptible to a fungal leaf disease caused by *Microcyclus ulei.* The other thirteen varieties that are of average production but resistant to the disease came from Brazil. The material was initially taken to Caucagua (Miranda State) and the African ones suffered a fungal attack, possibly because the Brazilian clones came from infested areas (Pará and Bahía States). In Santa Bárbara, the infection was controlled the first year with Dithane and has not appeared since then. Apparently, an ecological control occurs in the area because of the dry period that is unfavorable for reproduction of the fungus.

In general performance, the best varieties to this point have been RRIM 600, selected in Malaysia, and IAN 717, FX 567, FX 3844 and FX 3864, selected in Brazil.

Based on the first results, the zone of Santa Bárbara-San Fernando de Atabapo has a total of 80,000 ha of soils suitable for the cultivation of rubber trees. The climatic conditions of the area are favorable for the control of the fungal leaf disease caused by *Microcyclus ulei* and for good development of the plants. Other potential zones, although less favorable for climatic reasons, are the areas of Puerto Ayacucho, San Juan de Manapiare and Ocamo. A project to develop 10,000 ha of rubber trees in the Santa Bárbara regions is now being studied by CVG.

Production systems research. In addition to basic studies of shifting agriculture systems being done by IVIC researches, an inventory of small farms was conducted in the Territory. The purpose was to evaluate the farms and to initiate studies on integral production systems to supply food to the local population. The Government, through the Agricultural Development Directorate, also is promoting a development program of vegetable gardens and family farms and evaluating the needs for technical assistance and for agricultural development agencies.

Study of the widlife

The terrestial fauna of the Amazonas Territory belong to the neotropical zoogeographic kingdom, which is characterized in the tropical region by a great diversity of species.

Up to now, the following have beeen identified:

(1) 180 species of mammals including *Cacajao melanocephalus* (mono negro), *Chiropotes satanas* (macho capuchino), *Saimiry sciurus,* (mono ardilla), *Myrmecophaga tridactyla* and *Cyclopes didactylus* (oso hormiguero), *Choleopus didactylus* (la pereza), *Priodmtes maximus* (cuspa), *Sciurus gilvigularis* (ardilla), *Dasyprocta fuliginosa* (picure amazónico), *Inia geoffrensis* (tonina), *Lutra longicaudis* (nutria) and *Pteronura brasiliensis* (perro de agua). Many others, which have a wide

distribution in the rest of the country, are also found in the Amazonas Territory and should be added to this list. These include *Alouatta seniculus* (araguato), *Ateles belzebuth* (viudita o mono araña), *Agouti paca* (lapa), *Hidrochaeris sp.* (chiguire), *Coendu prentrensilis* (puerco espín), *Cerdocyon thores* (jorro), *Potos flavus* (cuchicuchi), *Felis onca* (jaguar), *Felis pardalis* and *Felis wiedii* (cunaguarus), *Tapirus terrestris* (danta), *Tayassu pecari* and *Dicotyles tajacu* (báquiros), *Odocoileus virginianurs* and *Mazama americana* (venados).

A very important group is the bats (Chiroptera) that make up more than half (about 100) of the mammalian species present in the Territory. Within these groups are species that feed on nectars, insects, fruits, fish and blood *(Desmodus rotundus).*

(2) 650 species of birds, a fact that makes the Territory one of the world's most diverse bird areas. Typical species in the Territory include: *Tinamus mayor* (gallina de monte), *Cyrturellus variegatus* (gallineta cuero), *Crax alector* (paují culo blanco) *Mitu tomentosa* (paují culo colorado), *Priphia crepitanus* (grulla), *Ara araucana* (guacamaya azul-amarilla) *Ara chloroptera* (guacamaya roja), *Rupicola rupicola* (gallito de las rocas), *Tangara chilensis* (siete colores), *Ramphastos tucanus* (diostedé) *Prarocoloni viridis* (canoto verde), *Icterus crysocephalus* (moriche) and others.

(3) 150 species of amphibians and reptiles. In this group are found herpetological elements of the pnains, of the upper Amazon and of the Guiana region, in addition to endemic species and those of wide distribution. A laboratory has been established in Puerto Ayacucho where 800 specimens, representing 120 species of savanna fauna, are being studied. A general characteristic of the whole Territory is the great diversity and low density of species.

Recently initiated was an ecological study of the reproduction of the largest fresh water turtle *(Arrau podocnemis expansa),* which can reach a weight of 40-50 kg, and whose natural habitat is in the rivers of the region.

Preliminary studies of the rivers, channels and lagoons identified a large number of aquatic species. Among the most abundant species captured in a study carried out near San Fernando de Atabapo were these edible fish: *Colossama* sp. (cachama), *Myloplus shomburkii* (pampano), *Brycon* sp. (bocón), *Pseudoplatystoma* sp. (rayao), *Metynnis argenteus* (palometa), *Rhandia* sp. (bagre), *Cichla ocellaris* (pavón). The most abundant ornamental fish were: *Potamorrhasis guianensis* (aguja), *Geophagus* sp. (vieja), *Pterophyllum altum* (escalar), *Cichlasoma festivum* (vieja), *Corydora* sp. (coridora), *Leporinos musicorum* (leporino) and *Hypbessobrycon* sp. (neón).

Agricultural Development Policies for the Area

The Venezuelan government has shown great interest in the Amazon region, both as a border territory and as a reservoir of renewable natural resources. Instead of opening up the region to development by means of transportation infraestructure which will facilitate massive outmigration and potential destruction of renewable natural resources, a conservationist policy has been preferred. For such reason, any development plan for the region must be supported by basic studies addressed both to making the inventory of resources and to the interpretation of the laws governing those ecosystems. Both tasks are being done since 1970. Up to now definite plans have been adopted for the agricultural development of the area, eventhough the possibilities have been and are being explored to develop perennial crop plantations such as rubber and cacao. Besides, there are limited agricultural exploitation plans sufficient in size to supply staple foods for the local population.

An interministerial commission is studying the policies which will guide development of the Federal Amazon Territory in the years to come, and the resulting report will be integrated into the Fourth National Plan, presently under preparation.

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Technical Reports

Ecosystem Research

Land Resources, Soils and their Management in the Amazon Region: A State of Knowledge Report

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Introduction

The purpose of this paper is to review the present state of knowledge of the land resource base and soil properties of the Amazon region of South America. When considering the problems and potentials of any particular ecosystem, its land resource base is obviously a primary consideration. In the case of the Amazon this is even more critical, because most of its soils are regarded as poor and fragile. Many authorities consider them incapable of sustaining agriculture or livestock production after the primary vegetation is removed (Gourou, 1961; Setser, 1967; Reis, 1972; Tosi, 1974; Budowski, 1976; Irion, 1978; Goodland *et al.,* 1978).

As early as 1926, however, Marbut and Manifold, reported that the well drained soils along the Amazon River are strikingly similar to the dominant soils of the southeastern United States, where successful commercial agriculture has replaced shifting cultivation during the past 150 years. Indeed, there is evidence that agriculture in well drained lands of the Amazon is possible, as evidenced by both research data and commercial experience (Alvim, 1978 a, b, 1979; Sánchez, 1977 a, b, c, d, 1979; Serrao *et al.,* 1979; Toledo and Morales, 1979).

The amount of information on soils of the Amazon has increased rapidly within the last fifteen years. The reference section lists the work available to the authors but it is by no means exhaustive. A synthesis of this information, although preliminary, is atempted in this paper.

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Methodology

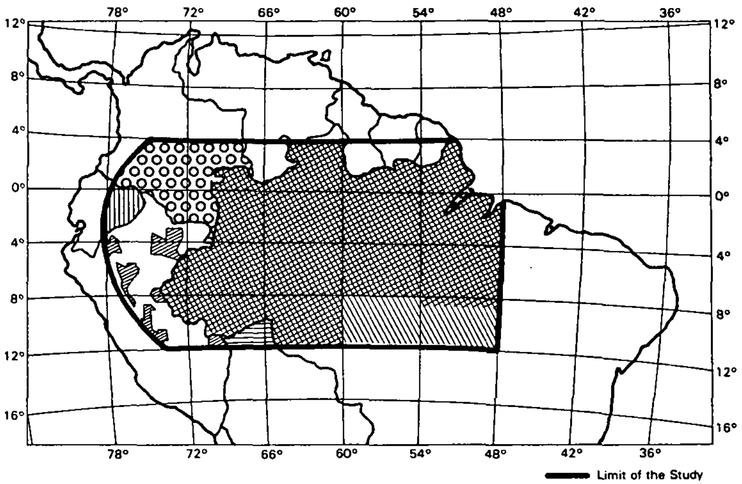
This paper is divided into two parts. The geographic synthesis of the land resource base and the interpretation of soil properties in terms of farming systems. The geographic synthesis was prepared by the first author as part of CIAT's Land Resource Evaluation Study. The interpretative section was prepared by the second author drawing on site-specific experiences. A description of the procedures follow.

CIAT, in collaboration with national agencies*, has been collating information on tropical America's land resources including Amazonia since mid 1977 (CIAT, 1978, 1979, 1980; Cochrane, 1979 a, 1980; Cochrane *et al.,* 1979). The objectives are to formulate practical guidelines for selecting appropriate cultivars of pasture legumes and grasses, beans, cassava, maize and rice for the ecosystems of major economic importance, and to provide information for crop, pasture and agroforestry production in general. Land resource information was put into a comparable geographical base by delineating land systems (areas that have a repetitive pattern of climate, landscape and soils), directly onto satellite and radar imagery. Although the work has mainly been an exercise in collating existing information, a limited amount of field work was carried out to help fill knowledge gaps and standardize criteria. Figure 1 summarizes the principal soil studies published by various organizations and authors from which information was collated. Following the collection, revision and mapping of the climate, landscape and soil information, the data are coded and recorded in a computarized data storage-retrieval-analytical map and data printout system to facilitate speedy analyses. Long term climatic data was obtained from 1144 stations throughout tropical America, including 107 stations in the Amazon, and compiled by Hancock *et al.* (1979). This limited number of stations imply that there are large areas without a reliable long term climatic data base.

Potential evapotranspiration (POT ET) was calculated to assess the amount of energy available for plant growth and to determine the water balance and growing seasons. Hargreaves' (1977a) equation was used; it is based mainly on solar radiation and temperature. The precipitation deficit (DEF PREC) is the difference between the mean precipitation and the POT ET. The dependable precipitation (DEP PREC) reflects the 75 percent probability level of precipitation occurrence, that is, the amount of precipitation that will be equaled or exceeded in three out of four years.

* Ministries of Agriculture of most South American countries and in Brazil the Centro de Pesquisa Agropecuária dos Cerrados of EMBRAPA.

The moisture availability index (MAI) is a moisture adequacy index at the 75 percent probability level of precipitation occurrence, computed by dividing DEP PREC by POT ET. Hargreaves (1977 b) recommends that MAI values lower than 0.34 define a dry month. This level, however, may be too high for soils with very low moisture holding capacities. The wet season, therefore, is defined as that part of the year with MAI values larger than 0.33. Total wet season evapotranspiration (WSPE) was calculated as the sum of the monthly POT ET values during the wet months. Wet season mean temperatures (WSMT) were calculated in a similar manner.



Area covered by the following studies:
(1) PROJETO RADAMBRASIL, Volumes 4,5,6,7,8,9,10,11,12,13,14,15,16,17 and 18 (1974-1978); includes 1198 soil profiles and 877 partially described profiles with analyses for fertility evaluation.
(2) EMBRAPA, Bull.No.17(1975); includes 97 soil profiles, plus 960 analyses of topsoil samples.
(3) SOMBROEK (1966); includes 47 soil profiles.

Area covered by a part of study No.(2) and (3) referred to above.

Area covered with a part of the study by COCHRANE (1973); includes 7 soil profiles; however a further 30 profiles were available from his original notes.

Area covered with studies by ONERN (1967-1978) Nos.8,14,17,26,39,40,46 and 49 includes 195 soil profiles.

Area covered with studies by BENAVIDES (1973), 9 soil profiles; and by CORTES et al. (1973) 19 soil profiles.

Area covered with studies by ORSTOM, INIAP and MAG of Ecuador with soil descriptions and generalized chemical data.

Area covered with more generalized soil studies; including Vol.IV, Soil map of the world. FAO-UNESCO, (1971).

Figure 1. *Principal soil studies used as sources of information.*

Vegetation classes were identified following the criteria of Eyre (1968) for tropical forest and Eiten (1972) for tropical savannas. Correlations between physiognomic vegetation types and climatic parameters were made for well drained soil sites with more than 20 years climatic data. Climatic subregions were identified as a result of such analysis.

The landscape was subdivided into land systems which were delineated onto satellite and side-looking radar imagery (U.S. Geological Survey, 1977; Projeto Radambrasil, 1972-78). Maps were collated, drawn at the scale of 1:1,000,000 and computerized in a 5-minute x 4-minute units (approximately 6800 ha) to serve as the basis for thematic map production. A limited amount of field work was carried out to help standardize descriptive criteria and study the variation of landscape features within the land systems. These variations, although not mapped because of scale limitations, were described as land facets, and the proportion of each land facet within the land systems was estimated. In this way, selected landscape features were computed on the basis of the land facet subdivision. It should be noted that as the smallest mapping unit was the land system, thematic mapping for a given characteristic, unless otherwise stated, represent the rating of the major land facet.

The subdivision of land systems into land facets was particularly useful to bridge the gap between land systems and soil units. Obviously land facets will contain soils with a variation in properties, but some level of generalization must be accepted in making an inventory of land resources. The most extensive soils in each land facet were first classified at the great group category of Soil Taxonomy (Soil Survey Staff, 1975), then described in terms of their physical and chemical properties. Areal estimates for each great group were made according to topographic division within climatic subregions.

Many physical and chemical properties of the topsoil (0-20 cm depth) and subsoil (21-50 cm depth) were recorded, tabulated and coded. Soil physical properties include slope, texture, presence of coarse material, depth, drainage estimates, moisture holding capacity, temperature regime, moisture regime and the presence of expanding clays. Soil chemical properties included were pH, % Al saturation, exchangeable Al, Ca, Mg, K, Na, total exchangeable bases (TEB), effective cation exchange capacity (ECEC) (calculated by the sum of exchangeable Al, Ca, Mg, K and Na), organic matter and available P* and, whenever possible, available Mn, S, Zn, Fe, Cu, B, Mo, free carbonates, salinity, presence of cat clays, X-ray amorphism, and additional data of importance to animal nutrition. They were classified according to the Fertility Capability Soil Classification

* Available P data using the Olsen, Troug and Vettori (1969) methodologies were approximated with the values by the Bray II method.

System (FCC) described by Buol *et al.*, (1975) and modified by Sánchez *et al.* (in press). The soil nutrient levels were further grouped into three ranges to equate crop needs in the sense: 1-adequate for most crops, 2-inadequate for crops requiring high levels of the nutrient, 3-inadequate for most crops except those tolerant to low levels of the nutrient. It should be emphasized that the quantity and quality of the available data varied considerably among regions. Minor and trace element information was seldom available. Consequently the results presented in the paper are very much subject to modification as more detailed studies become available.

The interpretation of the data generated by CIAT's Land Evaluation Study was developed by the second author in terms of soil properties, constraints, dynamics, and management under main farming systems. Site-specific results of experiments were incorporated in this portion of this state of knowledge report, and their relevance discussed.

The Land Resource Base

Figure 2 details CIAT's computerized land systems map coverage of the Amazon region, an area of 484 million hectares. It provides a convenient geographical definition for this overview summarizing some recent findings concerning Amazonian climates, landscapes and soils. This study covers the land areas of South America between 4° N and 12° S latitude east of the Andes and west of the 48° W meridian. A total of 215 land systems were identified in the Amazon.

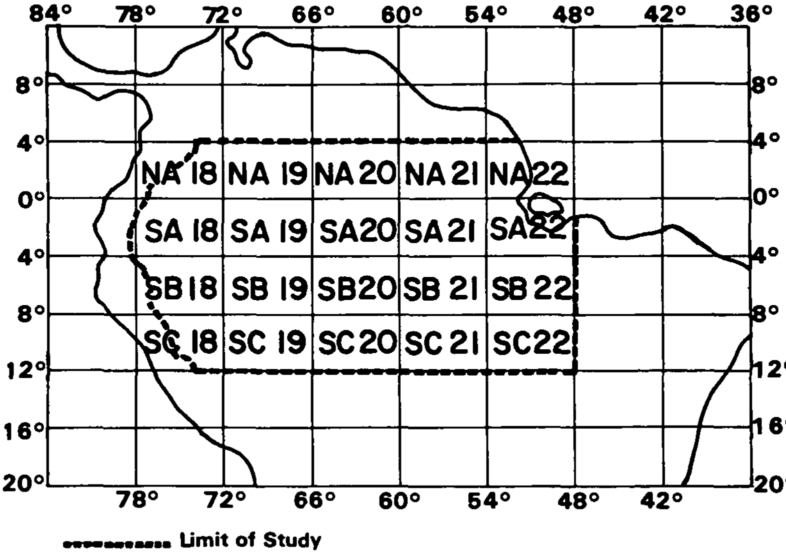


Figure 2. *CIAT's land system map coverage of Amazonia. Nos. refer to the world map on the millionth scale index.*

Climate and vegetation subregions

Figure 3 is a sketch map showing the broad native vegetation classes throughout the Amazon. The main classes shown are: tropical rain forests, tropical semi-evergreen seasonal forests, well drained and poorly drained savannas. Figure 4 compared with Figure 3 shows the relationship between the native vegetation and the number of dry months. It is evident that there is a good overall relationship, but the number of dry months overlap in the semi-evergreen seasonal forest and savanna classes. This would indicate that considerations of water balance alone cannot fully explain the vegetation differences. Cochrane and Jones (1981) have recently investigated the dependency of vegetation on a number of climatic parameters throughout the tropical South America using Hancock's data. A vegetation class was assigned to well drained soils of each of 251 sites for which long term (more than 20 years) meteorological data were available.

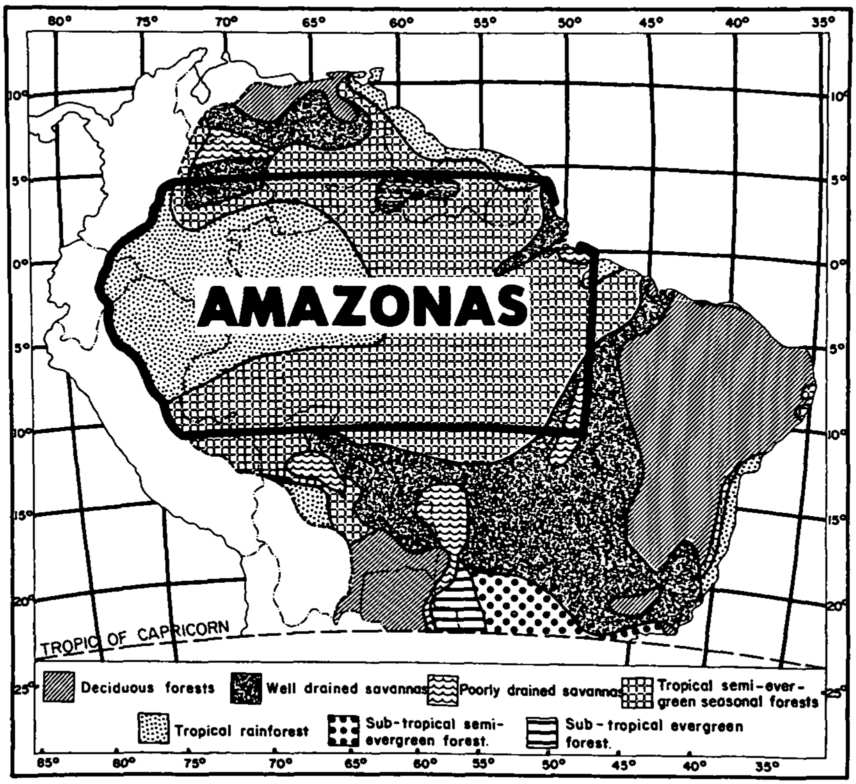
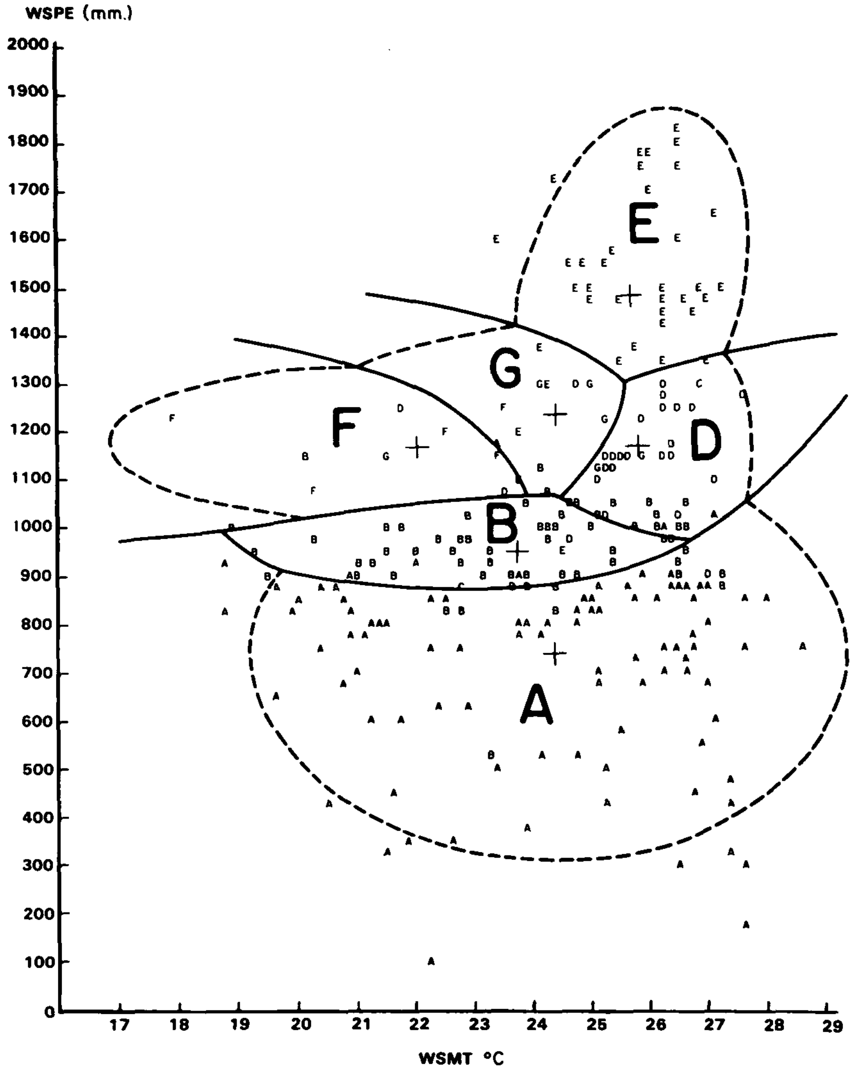


Figure 3. *Natural vegetation classes of the Amazon basin.*

Figure 4. *Number of dry months per year, Amazonia.*

As a result of a series of statistical analyses on the 251 data sets including the WSPE, WSMT, wet season radiation, number of wet months, average dry season moisture availability, mean annual POT ET, mean annual temperature and mean annual radiation, it was found that the two parameters which best differentiated vegetation were WSPE and WSMT.

The WSPE and WSMT of the 251 data sets were subjected to discriminate analyses, not only parametric but also non-parametric and computed plotted as shown in Figure 5. The clustering of vegetation classes can readily be seen. The posterior probabilities of correct assignment were estimated as: A, deciduous forests .91; B, well drained savannas .68; D, tropical semi-evergreen seasonal forests .71; E, tropical rain forests .87; F, subtropical semi-evergreen forests .67; and G, subtropical evergreen forests .60. Using the nearest neighbour classification described by Cover and Hart (1967) (12) as implemented by Barr *et al.* (1976) (13), the probabilities of correct classification were also high.



A = Deciduous forest
B = Well drained savanna
D = Semi-evergreen seasonal forest
E = Tropical rain forest
F = Subtropical semi-evergreen forest
G = Subtropical evergreen forest

Figure 5. *Cluster diagram of vegetation classes throughout tropical South America in terms of total wet season potential evapotranspiration and wet season mean monthly temperature.*

Note: Lines of equiprobability of assignments are shown solid. Dashed lines are 95% confidence elipsoids for the vegetation classes.

Source: Cochrane and Jones, 1981.

The WSPE regimes within the major vegetation zones are shown in Figure 6. Together with the length of the wet season and the WSMTs, they provide a convenient subdivision of the Amazon into the four climatic subregions, described in Table 1. WSPE approximates the total annual energy available for plant growth when the soils hold sufficient moisture to enable satisfactory growth for at least one week under the prevailing POT ET regimes.

Figure 6. *Total wet season potential evapotranspiration regimes of the Amazon basin.*

Approximately 35 percent of the Amazon falls into the tropical rain forest subregion, mainly in the western half of the basin. The tropical semi-evergreen seasonal forests, characterized by the narrow range of an eight to nine month wet season occupied 57 percent of the area, most of it in Brazil east of Manaus. The isohyperthermic savannas are natural grasslands surrounded by forest vegetation. They include the Boa Vista, Rupununi, Amapá and Cachimbo savannas; the Llanos of Colombia and Venezuela are excluded from this region because of the geographic limitation. Subregion D is actually part of the Cerrado of Brazil which differ from the Llanos in terms of a cooler temperature regime. A total of two million hectares of subregion D happens to fall within the area mapped but will be excluded from further consideration as it represents the Cerrado and not the Amazon. Table 2 shows the meteorological data from a representative site of each of the subzones.

Table 1. **Climatic subregions of the Amazon.**

Subregion	Climate*	Name	Million hectares
A	WSPE > 1300 mm Wet season>9 mo WSMT>23.5°C	Tropical rain forest	171
B	WSPE: 1061-1300 mm Wet season: 8-9 mo WSMT>23.5°C	Semi-evergreen seasonal forest	274
C	WSPE: 900-1060 mm Wet season: 6-8 mo WSMT>23.5°C	Savannas (isohyper-thermic)	37
D	WSPE: 900-1060 mm Wet season: 6-8 mo WSMT 23.5°C	Savannas (isothermic)	2
Total			484

*WSPE = Total wet season potential evapotranspiration
Wet month = MAI>0.33
WSMT = Mean wet season air temperatures.

In considering the relationship between the WSPE and vegetation, it should be noted that soil moisture stress is described in terms of the climatic potential to supply and extract soil moisture at a given location during a given period of time, based on the ability of well drained loamy or clayey soils to store and supply water. In soils that have less than this assumed capacity to store plant available water, such as sandy Spodosols, vegetation can quickly suffer moisture stress. Such situations occur in the Amazon basin. As Alvim (1978) notes, areas of "campinarana" vegetation, are prevalent on sandy soils with very low moisture holding capacities surrounded by soils with higher moisture holding capacities covered in semi-evergreen seasonal forests. Alvim and Silva (1979) in their comparison of Amazon forests with the savannas of Central Brazil, have also pointed out the value of water balance studies, and that vegetation differences can be explained on the basis of annual water balance figures. This is not in conflict with the WSPE concept, as the determination of the water balance is basic to its definition.

Cuadro 2. **Resumen climático de una localidad de cada subregión climática de la Amazonía.**

Subregion A: Bosque húmedo tropical
Yurimaguas, Loreto, Perú. Lat. 5°54' S; Long. 76° 5'0; Alt. 179 msnm

	Ene.	Feb.	Mar.	Abr.	May	Jun.	Jul.	Ago.	Sep.	Oct.	Nov.	Dic.	Anual
Temp. prom.	26.1	26.4	26.1	26.2	26.0	25.8	25.8	26.6	26.9	26.6	26.6	26.7	26.4
HR prom.	98.	98.	98.	98.	98.	98.	98.	98.	98.	98.	98.	98.	98.
% rad. solar	13.	14.	13.	13.	12.	13.	12.	12.	14.	13.	13.	12.	13.
Rad. prom.	308	309	237	287	249	263	342	324	345	379	326	309	306
Prec. prom.	214	225	212	249	177	99	90	93	159	209	210	199	2135
ETP est.	141	138	137	135	134	129	129	139	139	141	142	143	1508
Def. prec.	-73	-87	-75	-114	-43	30	39	46	-20	-68	-68	-56	-627
Prec. con	145	152	143	169	119	64	58	60	111	141	142	134	1051
IHD	1.03	1.10	1.04	1.25	.89	.50	.45	.43	.80	1.00	1.00	.94	.79

Subregión B: Bosque estacional *semi-siempreverde*
Manaus, AM, Brasil. Lat. 3°8' S; Long 60° 1'0; Alt. 48 msnm

	Ene.	Feb.	Mar.	Abr.	May	Jun.	Jul.	Ago.	Sep.	Oct.	Nov.	Dic.	Anual
Temp. prom.	25.9	25.8	25.8	25.8	26.4	26.6	26.9	27.5	27.9	27.7	27.3	26.7	26.6
HR prom.	88.	89.	89.	88.	81.	74.	71.	63.	67.	76.	78.	85.	79.
% rad. solar	38.	36.	37.	38.	48.	56.	59.	67.	63.	54.	51.	43.	49.
Rad. prom.	420.	415.	418.	404.	426.	441.	462.	525.	541.	509.	491.	443.	458.
Prec. prom.	276.	277.	301.	287.	193.	99.	61.	41.	62.	112.	165.	228.	2102.
ETP est.	132.	118.	131.	123.	135.	136.	149.	172.	173.	167.	155.	142.	1732.
Def. prec.	-144.	-160.	-170.	-164.	-58.	37.	88.	131.	111.	55.	-11.	-86.	-370.
Pre. con.	215.	215.	236.	224.	114.	64.	32.	15.	33.	75.	120.	174.	
IHD	1.62	1.83	1.80	1.82	1.06	0.47	0.22	0.09	0.19	0.45	0.78	1.22	

Subregión C: Sabanas
Conceição de Araguaia, Pa., Brasil. Lat. 8°15' S; Long. 49°15' 0; Alt. 90 msnm

	Ene.	Feb.	Mar.	Abr.	May	Jun.	Jul.	Ago.	Sep.	Oct.	Nov.	Dic.	Anual
Temp. prom.	25.1	24.9	25.2	25.6	25.6	25.1	24.9	26.0	26.7	25.8	25.6	25.2	25.5
H.R. prom.	88.	89.	88.	79.	65.	48.	44.	54.	70.	83.	83.	89.	73.
% rad. solar	38.	37.	38.	50.	66.	79.	82.	74.	60.	46.	45.	36.	54.
Rad. prom.	437.	431.	428.	453.	470.	488.	510.	530.	521.	479.	477.	427.	471.
Prec. prom.	253.	252.	263.	163.	60.	8.	7.	15.	64.	163.	196.	227.	1671.
ETP est.	135.	119.	132.	137.	147.	146.	156.	167.	162.	150.	144.	132.	1727.
Def. prec.	-118.	-133.	-131.	-26.	87.	138.	149.	152.	98.	-13.	-51.	-95.	56.
Pre con.	195.	194.	204.	119.	31.	0.	0.	0.	34.	119.	146.	173.	
IHD	1.45	1.63	1.54	0.87	0.21	0.00	0.00	0.00	0.21	0.79	1.01	1.31	

Fuente: Hancock *et al.*, 1979.

The WSPE concept has provided a fresh approach for zoning climatic subregions throughout Amazonia for non-irrigated, perennial crop production. This is leading to a better understanding of the region and has provided a basis for defining broadly comparable climatic conditions for the selection, testing and transfering of new pasture plant accessions (CIAT, 1980). Studies including those recently published by Ranzani (1978) will help to define more precisely the ability of the soils *per se* to supply soil moisture, and improve the water balance estimates for specific agricultural systems.

Landscape

The Amazon region has been subdivided into 215 land systems. Figure 7 is an example of land system mapping on sidelooking radar imagery 350 km west of Manaus. Figure 8, reproduced from computer coding of Land System 257, shows how this particular land system is subdivided into several land facets. Figure 9 summarizes the topography of the Amazon region.

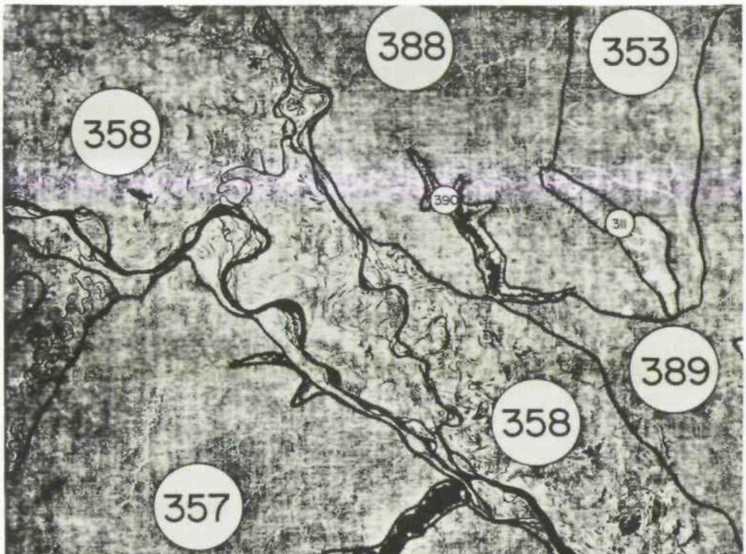


Figure 7. *Land system mapping on side-looking radar imagery 350 km to the west of Manaus, Brazil.*

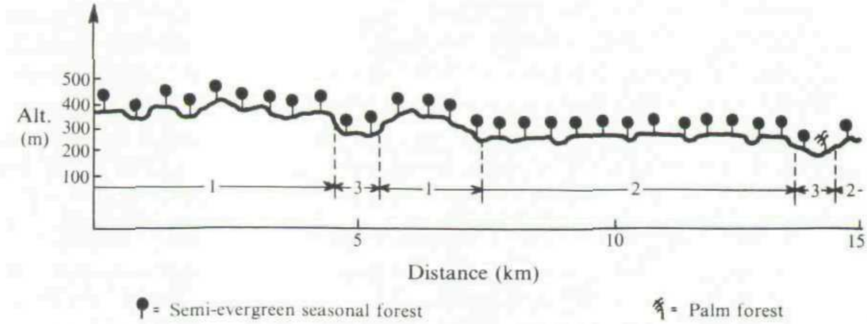


Figure 8. *Landform diagram (land system No. 257) showing the subdivision of landscape into facets.*

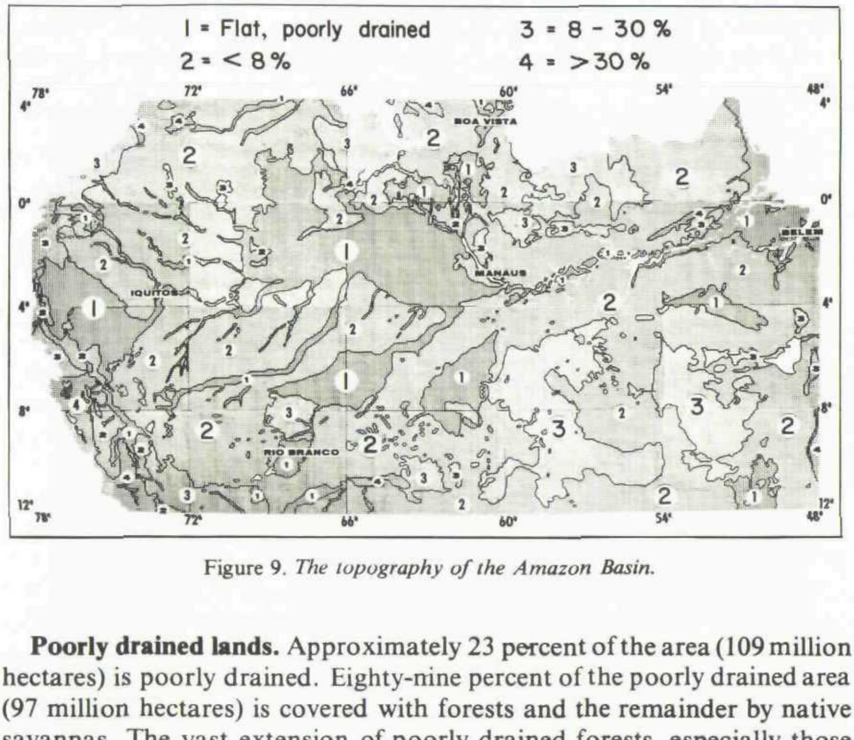


Figure 9. *The topography of the Amazon Basin.*

Poorly drained lands. Approximately 23 percent of the area (109 million hectares) is poorly drained. Eighty-nine percent of the poorly drained area (97 million hectares) is covered with forests and the remainder by native savannas. The vast extension of poorly drained forests, especially those found in the northwest, imposes a natural barrier to development. Nevertheless, the seasonally flooded land or "várzeas", of major river systems often have naturally fertile soils, and it is likely that an increasingly greater percentage of these lands will be brought into more intensive production of crops, including wetland rice, in the not too distant future.

The poorly drained savanna lands have been used successfully since colonial times for extensive cattle production; significant areas are found in the island of Marajó at the mouth of the Amazon River, the Humaitá plains south of Porto Velho in Rondônia, the Pantanal de Araguaia on the southeastern margin of Amazonia, parts of the Amapá savannas near the mouth of the Amazon and parts of the Boa Vista savannas in Roraima.

Well drained lands. About 77 percent of the Amazon region (375 million hectares) is reasonably well drained. The majority (350 million hectares) is covered by forests and the remaining 25 million hectares include the well-drained facets of the Amapá and Boa Vista savannas, together with a part of the Araguaia and Alcantillados savannas to the south and east. Approximately 64 percent of the well drained lands (242 million hectares) have slopes less than eight percent, and 36 percent (133 million hectares) have slopes greater than 8 percent. The relatively flat lands are often closely dissected by small streams. In fact, over 88 percent of the area as a whole has perennial streams at less than 10 km intervals and 63 percent less than 5 km apart.

Table 3 provides a breakdown of the topography within the broad climatic subregions. There is a significantly higher proportion of poorly drained lands in subregion A than in the rest of Amazonia. Even so, 71 percent of the tropical rain forest area is well drained; of these, 79 million hectares have slopes less than 8 percent. With the notable exception of some areas in the sub-Andean foothills such as the Florencia region of Colombia, and near the main cities in the lowland jungle of Perú, most of these lands are still covered by native tropical rain forest vegetation. Variations in physiography are common and picturesque along the narrow sub-Andean piedmont. Away from the immediate foothills, however, the landform becomes more uniform and gently undulating, although it is often interspersed with extensive areas of poorly drained lands, known as "aguajales" in Perú.

By far the largest area of well drained lands is found in subregion B, particularly in central, eastern and southern Amazonia. Here the original semi-evergreen seasonal forest is largely intact, although sizeable areas in the highway zones and Rondônia, have been altered in recent years. About 62 percent of these well drained lands are relatively flat, with slopes less than 8 percent. The landscape of subregion B is less variable than the lands found in subregion A. Nevertheless, there are major physiographic differences. Subregion B is heavily dissected by the many tributaries of the Amazon River system. The larger rivers often have extensive flood plains or "várzeas". An extensive area of poorly drained land is found to the south of the Amazon River west of Manaus.

Table 3. **The topography of the climatic subregions of the Amazon region expressed in million hectares.**

Climatic subregion	Topography (% slope)				Total
	Flat, poorly drained	Well drained			
		0-8%	8-30%	>30%	
	Million ha				
A-Tropical rain forests	50	79	30	12	171
B-Semi-evergreen seasonal forests	47	142	69	16	274
C-Isohyper-thermic savannas	12	19	4	2	37
D-Isothermic savannas	0	2	0	0	2
Total	109	242	103	30	484
%	23	50	21	6	100

The 345 million hectares of well drained lands of the Amazon with slopes of less than 30 percent represent one of the world's major and perhaps ultimate reserves for crop, pasture and agroforestry production under rainfed conditions. Their soil conditions, therefore, should be carefully examined.

Soil Geography

The areal distribution of soils of the Amazon is shown in Table 4 at the order, suborder and great soil group level. This table is considered tentative and subjected to change as more detailed surveys become available. Seven of the 10 soil orders are shown in Figure 10; only Vertisols, Aridisols and Histosols are not depicted at the scale of this study. The majority of the soils are classified as Oxisols and Ultisols, which together account for 75 percent of the region. Following in extensiveness are the Entisols, with about 15 percent, most of which are of alluvial origin found along the river network. The remaining five orders cover relatively small areas but they are locally important: Alfisols (4%), Inceptisols (3%), Spodosols (2%), and Mollisols and Vertisols with less than 1 percent. Table 4 shows that 75 percent of the Amazon's soils are included in five great groups: Haplorthox (29%), Tropudults (17%), Acrorthox (14%), Fluvaquents (9%), and Paleudults (6%).

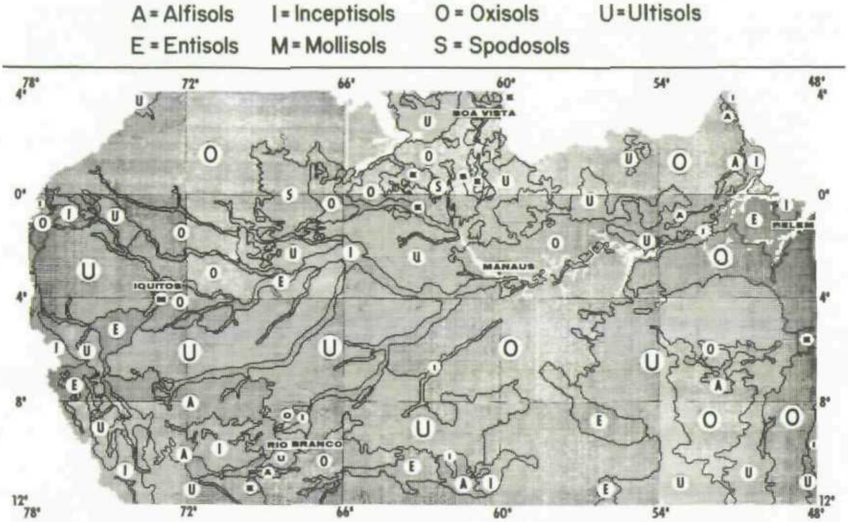


Figure 10. Soil order map of the Amazon Basin.

Table 4. **Soil distribution of the Amazon region at the great group level. Tentative classification.**

Order	Suborder	Great Group	Million hectares	% of Amazon
OXISOLS	Orthox	Haplorthox	137.8	28.5
		Acrorthox	67.5	14.0
		Eutrorthox	0.3	0.1
	Ustox	Acrustox	6.6	1.4
		Haplustox	4.8	1.0
		Eutrustox	2.0	0.4
	Aquox	Plinthaquox	0.9	0.2
	Total Oxisols:		219.9	45.5
ULTISOLS	Udults	Tropudults	83.6	17.3
		Paleudults	29.9	6.2
		Plinthudults	7.6	1.6
	Aquults	Plinthaquults	12.2	2.5
		Tropaquults	7.1	1.5
		Paleaquults	0.7	0.1
		Albaquults	0.1	0.1
	Ustults	Rhodustults	0.5	0.1
	Total Ultisols:		141.7	29.4

Table 4. **Soil distribution of the Amazon region at the great group level. Tentative classification** (continued).

Order	Suborder	Great Group	Million hectares	% of Amazon
ENTISOLS	Aquents	Fluvaquents	44.8	9.3
		Tropaquents	6.7	1.4
		Psammaquents	2.8	0.6
		Hydraquents	0.6	0.1
	Orthents	Troporthents	6.9	1.4
	Psamments	Quartzipsamments	5.5	1.1
	Fluvents	Tropofluvents	4.7	1.0
	Total Entisols:		72.0	14.9
ALFISOLS	Udalfs	Tropudalfs	16.5	3.4
	Aqualfs	Tropaqualfs	3.3	0.7
	Total Alfisols:		19.8	4.1
INCEPTISOLS	Aquepts	Tropaquepts	10.6	2.2
		Humaquepts	0.5	0.1
	Tropepts	Eutropepts	4.3	0.9
		Dystropepts	0.6	0.1
	Total Inceptisols:		16.0	3.3
SPODOSOLS	Aquods	Tropaquods	10.5	2.2
MOLLISOLS	Udolls	Argiudolls	2.8	0.6
	Aquolls	Haplaquolls	0.9	0.2
	Total Mollisols:		3.5	0.8
VERTISOLS	Uderts	Chromuderts	0.5	0.1
Total Orders			484.0	100.0

Oxisols

Haplorthox are well drained, uniform Oxisols with very low native fertility but well granulated soil structure. They are also known as Latosol Amarelo and Xanthic Ferralsols in the Brazilian and FAO classifications. Many of them have very high clay contents. Acrorthox are similar except for a lower cation exchange capacity of the clay. Oxisols of the Amazon are not generally high P fixers. These soils are mainly under natural vegetation, but considerable areas are used for extensive livestock production and permanent crops.

Ultisols

Ultisols are very extensive both in well and poorly drained landscape positions. Tropudults and Paleudults are well drained, acid infertile soils but with less desirable physical properties than the Oxisols because of a significant clay increase with depth. They are also known as Red Yellow Podzolics, Orthic Acrisols, and Podsólicos Vermelho Amarelo in other classificacion schemes. The difference between Tropudults and Paleudults is the depth of the clay bulge in the subsoil, of little agronomic importance. Table 5 shows examples of Paleudults which are fairly representative of the well and poorly drained upland positions of subregion A. The well drained member is acid, infertile and susceptible to compaction because of its low clay content. The poorly drained member shows very high exchangeable Al contents in the subsoil corresponding to a clayey, mottled layer which is a mixture of kaolite and montmorillonite. This layer appears at first glance to be plinthite, but analysis shows it is not (Sánchez and Buol, 1974). Some of these soils are devoted to shifting cultivation in the upper Amazon, but most are still under native vegetation.

Alluvial soils

Soils along the flood plains of the rivers, although less extensive, are very important because this is where the bulk of the food crop is produced in the Amazon. They show little or no profile development and are classified as Entisols (Fluvaquents), Inceptisols and Mollisols. These soils are known in other classification systems as Alluvial soils, Hydromorphics, Low Humid Gleys and Dystric or Eutric Gleysols. Periodic flooding is the main limiting factor, but it is difficult to predict because the river levels are influenced by rainfall in the Andes and other distant watershed areas.

Two examples are given in Table 5, an Entisol from Amapá in Brazil and a Mollisol on the banks of the Amazon near Iquitos, Perú. There is a major difference in native fertility, due to the source of sediments, a very variable characteristic of "várzeas" and "barriales"* soils. Consequently, it cannot be generalized that alluvial soils of the Amazon are always of high native fertility.

Spodosols

Another soil order worthy of attention is the Spodosols, also known as Podsols, Ground Water Podzols and Giant Tropical. Podzols, including their deeper variants as Psamments. These soils are derived from coarse sandy materials and are found in clearly predictable spots, especially in

* Brazilian and Peruvian terms respectively, for flood prone zones along river banks. (Editor's note.)

northern Amazon, away from the flood plains. Native forest vegetation, called "campinarana", reflect the dry season soil moisture stress, versus (on hydromorphic classes) the wet season poor drainage condition, and is lower, and often more open, than that found on Oxisols and Ultisols. The Projeto Radambrasil (1972-78) recently identified vast areas of Spodosols along the headwaters of the Negro River, which largely account for the color of this river, as water passing through Spodosols characteristically carries organic acids. Table 5 shows one example near the Dücke forest near Manaus. Being extremely infertile and very susceptible to erosion, Spodosols should best be left in their natural state. Unfortunately the Spodosols have received more scientific attention than they deserve in terms of their areal extent (2.2% of the Amazon) particularly on nutrient cycling studies. Therefore, research on tropical Spodosols published in the international literature (Klinge, 1965, 1967, 1975b; Stark, 1978; Sombroek, 1979) should be kept in perspective; under no circumstances should it be extrapolated to the dominant Oxisols and Ultisols.

Well drained fertile soils

Unfortunately only about 6 percent of the Amazon has well drained soils relatively high in native fertility. These are classified mainly as Tropudalfs and Paleustalfs (Terra Roxa Estruturada), Eutropepts (Eutric Cambisols), Tropofluvents (well drained Alluvials), Argiudolls (Chernozems), Eutrustox and Eutrorthox (Terra Roxa Legítima) and Chromuderts (Vertisols). Nevertheless, they represent a total of 31 million hectares and where they occur permanent agriculture has a better chance of success, particularly in the Terra Roxa soils, which combine high native fertility with excellent physical properties. Table 5 shows an example of a Terra Roxa Estruturada near Altamira, Brazil. Many of the successful cacao plantations are located on such soils. These excellent soils are found near Altamira, Porto Velho and Rio Branco in Brazil, and in eastern Ecuador associated with relatively recent volcanic deposits.

Laterite or plinthite hazard

The areal extent of soils with plinthite in the subsoil (Plinthaquox, Plinthaquults, Plinthudults) is limited. They total about 21 million hectares or 4 percent of the Amazon. This point deserves emphasis, given the broad generalizations that Amazon soils once cleared will be irreversibly transformed into hardened plinthite or laterite. The three plinthic great groups are the only soils where this phenomenon can occur, but as the soft plinthite is in the subsoil, the topsoil has to be first removed by erosion before hardening can take place. Since these soils occur mainly on flat, poorly drained landscapes, erosion is not likely to be extensive.

Table 5. **Representative profile samples from extensive Oxisols, Ultisols and alluvial soils of the Amazon and less extensive but locally important Spodosols and Alfisols. Suregions A and B only.**

Horizon depth	Clay	Sand	pH	Org. C	Exchangeable Al	Exchangeable Ca	Exchangeable Mg	Exchangeable K	ECEC	Al Sat.
cm	%	%	H_2O	%	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%
OXISOL[1]										
0-40	38	38	4.2	0.4	1.2	0.08	0.28	0.15	1.76	71
40-75	43	30	5.0	0.2	1.5	0.10	0.23	0.10	1.93	78
75-176	37	27	5.1	0.0	1.0	0.10	0.20	0.10	1.40	71
176-216+	38	26	5.5	0.0	1.4	0.10	0.70	0.03	1.73	81
OXISOL[2]										
0-8	76	15	4.6	2.9	1.1	1.70	0.30	0.19	3.29	33
8-22	80	12	4.4	0.9	1.1	0.20		0.09	1.39	79
22-50	84	8	4.3	0.7	1.2	0.20		0.07	1.47	82
50-125	88	7	4.6	0.3	1.0	0.20		0.04	1.24	81
125-265	89	5	4.9	0.2	0.2	0.20		0.11	0.51	39
ULTISOL[3]										
0.7	15	67	4.0	1.5	0.8	1.60	0.10	0.12	2.62	31
7-48	23	57	3.5	0.5	3.2	1.60	0.10	0.08	4.98	64
48-67	25	57	3.5	0.5	4.4	0.80	0.10	0.08	5.38	82
67-157+	29	57	3.5	0.4	5.3	0.60	0.10	0.08	6.08	87
ULTISOL[4]										
0-3	27	25	5.2	6.3	0.2	4.20	2.10	0.52	7.1	3
3-21	45	17	4.3	1.9	4.0	2.20	1.20	0.40	7.9	51
21-62	59	15	4.2	1.0	8.7	0.80	0.90	0.32	10.8	81
62+	59	21	4.1	0.5	11.6	0.40	0.70	0.24	13.1	89

[1] Tropeptic Haplustox (Latosol Amarelo) FCC: Cdaek, Km 308.8. Transamazonic highway, Marabá, Brazil. Profile 3 of Ranzani (1978)

[2] Haplic Acrorthox (Latosol) Amarelo muito pesado) FCC: Cack. EUPAE: EMBRAPA Station, Manaus, Brazil. Profile SBCS-4 of Camargo and Rodrigues (1979)

[3] Typic Paleudult (Yurimaguas series). FCC: Laek. Yurimaguas Exp. Station, Peru. Profile Y-6 of Sánchez and Buol (1974)

[4] Aquic Paleudult. (Pucallpa series) FCC. LCgh. IVITA Station, Pucallpa, Peru. Profile Pu-2 from North Carolina State University (1973).

Table 5. **Representative profile samples from extensive Oxisols, Ultisols and alluvial soils of the Amazon and less extensive but locally important Spodosols and Alfisols. Subregions A and B only** (continued).

Horizon depth	Clay	Sand	pH	Org. C	Exchangeable				ECEC	Al Sat.
					Al	Ca	Mg	K		
cm	%	%	H_2O	%	meq/100 g					%
ENTISOL[5]										
0-20	41	30	4.8	1.2	1.5	0.70	0.90	0.20	2.67	57
20-70	38	38	4.9	0.5	0.9	0.60	0.70	0.10	2.30	39
70-130	66	31	5.1	0.5	0.2	1.00	1.40	0.30	2.63	76
MOLLISOL[6]										
0-10	24	13	6.0	1.5	0.0	11.0	3.10	0.22	14.32	0
10-50	20	19	6.1	0.8	0.0	10.4	3.60	1.52	15.52	0
50-120+	10	36	6.3	0.4	0.0	6.8	2.30	0.20	4.78	0
SPODOSOL[7]										
0-3	2	89	3.8	6.3	5.4	0.30		0.16	5.86	92
3-25	2	95	4.4	0.5	0.7	0.10		0.04	0.84	83
25-50	2	94	5.0	0.1	0.1	0.10		0.02	0.12	83
50-90	1	98	5.1	0.0	-	0.10		0.01	0.11	-
90-105	5	93	3.7	1.1	3.0	0.10		0.04	3.14	96
105-125	9	91	4.7	2.2	2.9	0.10		0.03	3.03	96
125-165	16	76	5.6	0.8	0.4	0.10		0.03	0.53	75
ALFISOL[8]										
0-20	48	34	5.9	1.5	0.0	5.59	1.20	0.16	6.95	0
20-40	57	24	5.8	1.1	0.0	4.40	0.62	0.06	5.00	0
40-60	69	19	6.0	0.6	0.0	2.62	0.58	0.04	3.24	0
60-80	62	16	5.9	0.5	0.0	2.30	0.82	0.04	3.16	0
80-100	71	15	6.1	0.4	0.0	2.18	1.06	0.04	3.28	0

[5] Fluvaquent (Gley Pouco Humico), FCC: Cgh. Flood Plain Rio Cupix, Amapá Brazil. Profile p 146-147 *In* FAO-UNESCO (1971)

[6] Fluventic Haplaquoll. (ALLUVIAL) FCC: Lg. Restinga (Flood Plain) Amazon River 30 km E. of Iquitos, Perú. Profile 1-4 of Sanchez and Buol (1974)

[7] Arenic Tropaquod (Podzol Alico). FCC: Sgaek. Km 4.5 of BR-174 SUFRAMA, Manaus, Brazil. Profile SBCS 2 of Camargo and Rodrigues (1979)

[8] Orthoxic Rhodic Paleustalf (Terra Roxa Estructurada Eutrófica) FCC:Cd. Km 218.0 Transamazonic Hwy. near Altamira. Brazil. PROFILE IPEAN 9142/46 of Falesi (1972). Subgroup not provided (Profile has Rhodic, Ultic and Oxic Paleustalf subgroup properties).

Hardened laterite outcrops occur in geomorphically predictable positions in parts of Amazonia geologically affected by the Guiana and Brazilian shields, sometimes mixed with soil materials. These outcrops are an asset to development because they provide excellent low cost road building materials. The lack of plinthite or laterite in upper Amazon areas not affected by the Precambrian shields is a definite constraint to road building and construction in general. Many poorly drained subsoils of these areas have mottled colors resembling plinthite, but are in fact mixtures of 1:1 and 2:1 clay minerals (Sánchez and Buol, 1974; Tyler *et al.*, 1978).

Soils in relation to climatic subregions and topographical position

Table 6 provides areal estimates of the great group classification according to climatic subregions and topographic subdivisions. From this table it may be seen that the higher proportion of Ultisols to Oxisols in subregion A (tropical rain forest) compared with subregion B, (tropical semi-evergreen seasonal forest), is associated with the poorly drained areas where wet Ultisols are abundant. On the well drained lands in subregion A, the ratio of Ultisols and Oxisols is almost identical to those of subregion B, 0.36 compared with 0.38 in subregion B. The two main great groups of the Ultisols in subregions A and B, the Tropudults and Paleudults, are found in about the same proportion in both subregions. On the other hand, the proportion of the two most commonly found Oxisol great groups in both subregions, Haplorthox and Acrorthox, varies considerably. There is a much greater extension of Acrorthox with very low cation exchange capacity (<1.5 meq/100 g clay(in subregion B than in subregion A.

Soil Physical Properties

Soil texture

Figure 11 is a computer based map of soil textural classes to 50 cm depth according to the FCC criteria. Table 7 shows the tabular data by climatic and topographic subdivisions. The most extensive topsoil textural class is loamy (18-35% clay), and in the subsoil the most extensive textural classes are loamy and clayey (>35% clay). These L and LC classes together account for 72 percent of the Amazon's soils. Uniformly clayey profiles (C) occur in 21 percent of the area; the remainder consists of shallow soils over rock and other textural combinations. The CR and LR classes in Table 7 indicate that there is a physical barrier to root development at 50 cm or less in only 0.4 percent of the region. Sandy topsoil textures are also a minority in the Amazon.

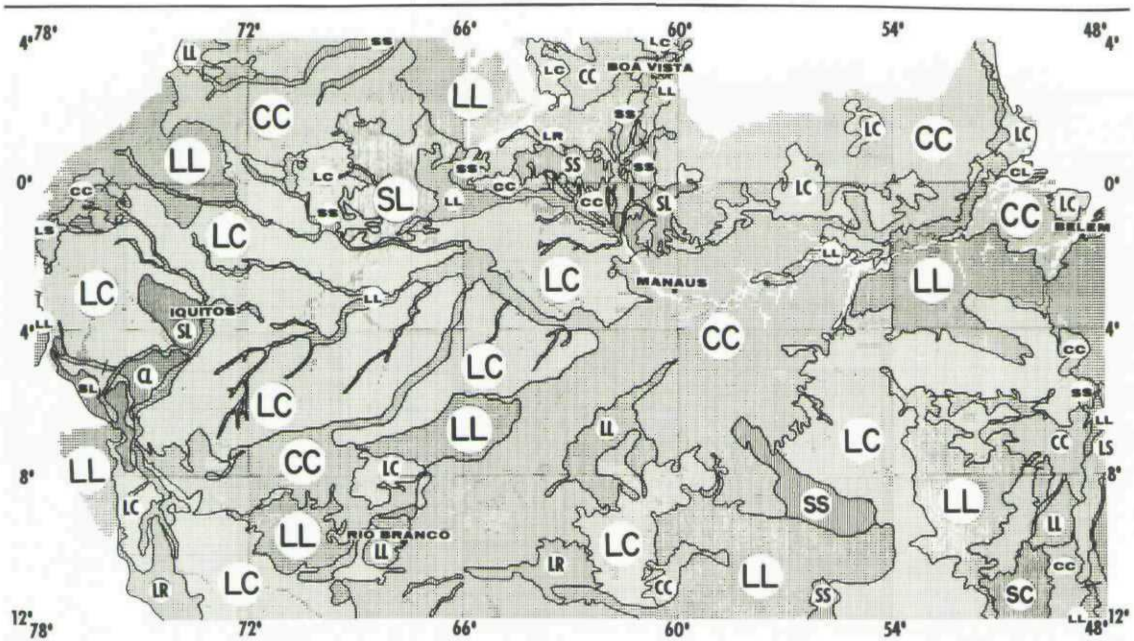
Table 6. **Distribution of great groups by climatic subregions and topographic position. Percentage figures refer to slopes. (Climatic subregion D covering 2.51 million ha excluded.)**

Order and Great Group	Total area	Subregion A - Rain forests				Subregion B - Seasonal, semi-evergreen forests				Subregion C - Savannas			
		Poorly drained*	Well drained			Poorly drained*	Well drained			Poorly drained*	Well drained		
			0-8%	8-30%	>30%		0-8%	8-30%	>30%		0-8%	8-30%	>30%
	Million hectares												
OXISOLS:													
Haplorthox	134.8	-	33.0	16.7	6.2	-	49.8	20.2	5.1		3.6	0.3	-
Acrorthox	67.5	-	1.7	1.3	0.8	-	31.6	22.0	5.7	-	3.5	0.8	0.1
Acrustox	6.6	-	-	-	-	-	-	-	-		5.2	1.2	0.2
Haplustox	4.8	-	-	-	-	-	-	-	-		3.1	0.8	0.9
Eutrustox	2.0	-	-	-	-	-	-	-	-		1.4	0.6	-
Plinthaquox	0.9	-	-	-	-	0.9	-	-	-	-	-	-	-
Eutrorthox	0.3	-	-	-	-	-	0.3	-	-	-	-	-	-
Total	216.9	-	34.7	18.0	7.0	0.9	81.7	42.2	10.8	-	16.8	3.7	1.2
%	100	-	17	8	3	1	36	19	5		8	2	1
ULTISOLS:													
Tropudults	83.0		21.2	2.4	0.1		40.8	14.9	3.6	-	-	-	-
Paleudults	29.9		7.9	1.0	-		15.0	6.3	0.6	-	-	-	-
Plinthaquults	12.2	5.6	3.5	0.2	-	0.5	0.1	-	-	2.2	0.1	-	-
Plinthudults	7.6	4.9	1.3	0.3	-	0.1	0.3	-	-	-	0.7	-	-
Tropaquults	7.1	0.8	0.1	-	-	6.2			-	-	-	-	-
Paleaquults	0.7	-	-	-	-	0.5	0.2	-	-	-	-	-	-
Rhodustults	0.5	-	-	-	-	-	-	-	-	-	0.4	0.1	-
Albaquults	0.1	-	-	-	-	-	-	-	-	0.1	-	-	-
Total	141.1	11.3	34.0	3.0	0.1	7.3	56.4	21.2	4.2	2.3	1.1	0.1	-
%	100	8	24	2	-	5	40	15	3	2	1	-	-
ENTISOLS:													
Fluvaquents	46.1	21.7	-	-	-	23.6	-	-	-	0.8	-	-	-
Troporthents	6.9	-	0.7	2.0	3.8	-	0.1	0.1	0.2	-	-	-	-
Tropaquents	6.1	-	-	-	-	0.6		-	-	5.5	-	-	-
Quartzipsamments	5.5	-	-	-	-	-	4.5	0.5	-	-	0.5	-	-
Tropofluvents	4.7	-	2.0	-	-	-	2.2	0.1	-	-	0.4	-	-
Psammaquents	2.8	2.3	-	-	-	0.1	-	-		0.4	-	-	-
Hydraquents	0.6	-	-	-	-	0.5		-	-	0.1	-	-	-
Total	72.7	24.0	2.7	2.0	3.8	24.8	6.7	0.7	0.2	6.8	0.9	-	-
%	100	33	4	3	5	34	9	1	1	9	1		

Table 6. **Distribution of great groups by climatic subregions and topographic position. Percentage figures refer to slopes. (Climatic subregion D covering 2.51 million ha excluded** (continued).

Order and Great Group		Subregion A - Rain forests				Subregion B - Seasonal, semi-evergreen forests				Subregion C - Savannas			
		Poorly drained*	Well drained			Poorly drained*	Well drained			Poorly drained*	Well drained		
			0-8%	8-30%	>30%		0-8%	8-30%	>30%		0-8%	8-30%	>30%
	Million hectares												
ALFISOLS													
Tropudalfs	6.6		0.2	-	-		4.5	1.7	0.2	-	-	-	-
Tropaqualfs	3.3	-	-	-	-	-	-	-	-	3.3			
Total	9.9		0.2				4.5	1.7	0.2	3.3			
%	100		2				46	17	2	33			
INCEPTISOLS													
Tropaquepts	10.6	4.2			-	6.0			-	0.4		-	-
Eutropepts	4.3		3.2	0.9	0.2	-	-	-	-	-	-	-	-
Dystropepts	0.6	-	-	-	-	-	-	-	-		0.6	-	-
Humaquepts	0.5	-	-	-	-	-	-	-	-	0.5	-	-	-
Total	16.0	4.2	3.2	0.9	0.2	6.0				0.9	0.6		
%	100	26	20	6	1	37				6	4		
SPODOSOLS:													
Tropaquods	10.5	8.4		-	-	2.1		-	-	-	-	-	-
MOLLISOLS:													
Argiudolls	2.8	-	1.4	1.2	0.1	-	0.1	-	-	-	-	-	-
Haplaquolls	0.9	0.6	-	-	-	0.3	0.1	-	-	-	-	-	-
VERTISOLS													
Chromuderts	0.5	-	0.5	-	-	-	-	-	-	-	-	-	-
Total	14.7	9.0	1.9	1.2	0.1	2.4	0.2						
%	100	61	13	8	1	16							

* Includes aquic and aeric subgroups.



CC = "+" CL = "@" CR = "$" LC = "•" LL = "✱" LR = "<" LS = ":" SC = "%"

SL = "O" SS = "|" Note: S = Sand; L = Loam; C = Clay; R = Rock.

Figure 11. *Soil texture according to the Fertility Capability Classification (FCC) system over the Amazon Basin.*

The first letter of the code indicates "topsoil" (0-20 cm), the second indicates the "subsoil" (21-50 cm).

Table 7. **Textural class distribution of soils of the Amazon region by climatic and topographic subdivisions, according to fertility capability classification system.**

FCC texture class	Subregion A - Rain forests				Subregion B - Seasonal, semi-evergreen forests				Subregion C - Savannas				Total	% of Amazon
	Poorly drained	Well drained			Poorly drained	Well drained			Poorly drained	Well drained				
		0-8%	8-30%	>30%		0-8%	8-30%	>30%		0.8%	8-30%	>30%		
	Million hectares													
L (Loamy)	16.8	33.9	16.5	9.1	27.9	37.8	27.5	6.9	1.3	9.6	2.4	1.2	190.9	40
LC (Loamy over Clayey)	18.5	35.7	8.5	1.2	7.2	51.4	21.5	4.3	2.8	0.6	0.2	0.2	152.1	32
C (Clayey)	2.9	6.6	4.9	2.0	7.7	43.9	15.8	4.6	4.7	5.4	0.9	-	99.4	21
S (Sandy)	4.7	1.5	-	-	2.7	4.9	0.5	-	0.4	1.1	0.1	-	15.9	4
SL (Sandy over Loamy)	5.2	1.6	-	-	1.3	4.5	1.5	-	0.4	0.5	-	-	15.0	3
LS (Loamy over Sandy)	0.6	-	-	-	0.2	0.2	-	-	-	1.3	0.4	-	2.7	-
SC (Sandy over Clayey)	-	-	-	-	-	-	-	-	2.1	-	-	-	2.1	-
CR (Clayey over Rock)	-	-	-	-	-	0.1	0.2	0.1	-	-	0.1	0.5	1.0	-
LR (Loamy over Rock)	-	-	-	-	-	0.1	0.1	0.2	-	0.3	-	-	0.7	-
CL (Clayey over Loamy)	-	-	-	-	-	-	-	-	0.5	-	-	-	0.5	-
Total	48.7	79.3	29.9	12.3	47.0	142.9	67.1	16.1	12.2	18.8	4.1	1.9	480.3	100
%	10	16	6	3	10	30	14	3	2	4	1	-	100	

Erosion hazard

Table 7 also provides a synthesis of the slope classes in the Amazon. About 72 percent of the region has level to gentle slopes (0 to 8% slopes). Topography is rolling to hilly (8 to 30% slope) in 21 percent of the Amazon and steep (more than 30% slope) in the remaining 7 percent. The presence of a textural change within 50 cm of the soil surface, such as LC, SL and SC makes the soils susceptible to erosion, particularly on steep slopes. Table 7 shows that 39 million hectares (8% of the Amazon) have soils with a sharp textural change on slopes greater than 8 percent or are shallow soils (LR and CR). The deep soils, mostly classified as Ultisols and Alfisols are generally quite susceptible to erosion unless protected by a plant canopy during periods of heavy rains. Over much of the remainder of the Amazon, erosion hazard is not likely to be a major problem because of a generally favorable combination of gentle slopes and uniform soil textures with depth.

Amoung the three climatic subregions, the seasonal forested region B has the largest proportion of highly erodible soils (10%), as compared to 6 percent in the rain forest region A and only 3 percent in the savanna region C.

These statements do not imply that erosion is unimportant in the Amazon because all soils can be eroded by mismanagement, and sheet erosion commonly occurs in nearly level well drained Oxisols and Ultisols. Most of the obvious gully erosion the authors have seen in the Amazon is caused by civil engineering, rather than agriculture, along roads, building sites and poorly constructed city sewage and drainage systems. This situation, however, could change drastically if the forest cover is removed and not replaced rapidly by another plant canopy. This seldom happens in the forested regions of the Amazon because when crops or pastures fail, weeds and secondary forest regrowth generally produce another plant canopy. Gullying along cattle trails in overgrazed pastures, however, is an increasingly serious concern.

Soil moisture relationships

The definition of great soil groups and their areal extent shown in Table 6 permits a calculation of the relative importance of soil moisture regimes in the Amazon as defined in Soil Taxonomy (Soil Survey Staff, 1975). About 75 percent of the Amazon has an udic or perudic soil moisture regime indicating that the subsoil is moist during nine or more months per year. Approximately 23 percent of the area has aquic soil moisture regime, indicating the presence of waterlogged conditions in some parts of the solum during the year. The remaining 3 percent has an ustic soil moisture regime, which indicates that the subsoil is dry for more than 90 but less than 180 consecutive days during the year.

The moisture situation is not as clear cut as these figures suggest because subregion B, which covers the largest expanse of the Amazon, includes both udic and ustic soil moisture regimes in well drained soils. Ranzani (1978) in detailed soil water balance studies done near the edge of subregion B (Marabá, Pará) classified the well drained soils as ustic.

It is relevant to point out that most soils in subregion B suffer from temporary but severe soil moisture stress during three to four months of the year, which certainly affects plant growth. The clearly defined dry season in the savannas exacerbates this situation in the well drained soils of subregion C. Even in the clearly udic soil moisture regime of subregion A, temporary soil moisture stress occurs and severely affects crops like upland rice and corn (Bandy, 1977). Thus it appears that plants growing on most well drained soils of the Amazon can suffer from lack of water during part of the year.

Compared to many other tropical forested areas, the physical properties of most Amazon soils are good. The dominance of coarse gravelly topsoils underlain by plinthite in much of West Africa's equivalent to subregion B poses major limitations to the development of permanent agriculture in that vast region (Lal *et al.*, 1975). This constraint is virtually non-existent in the Amazon. Although there are important physical limitations such as poor drainage in 23 percent of the region, severe erosion hazard in 8 percent, and widespread temporary drought stress, soil physical properties in the Amazon are generally favorable.

Soil Chemical Properties

The opposite statement can be made about soil chemical properties. The vast majority of the Amazon soils are acid and with low native fertility in their undisturbed state. As previously mentioned, only about 8 percent of the region has high base status soils with relevantly high native fertility. The main chemical soil constraints in the region are soil acidity, P deficiency, low effective cation exchange capacity, and widespread deficiency of the following nutrients: N, K, S, Ca, Mg, B, Cu, Zn, and occasionally others (Sánchez and Cochrane, 1980). Table 8 shows the areal extent of these and other chemical parameters in the Amazon. Table 9 separates the topsoil data according to the climatic subregion and topographical position. Table 10 interprets this data in terms of FCC units.

Table 8. **Summary of selected fertility parameters of the Amazon.**

Parameter and range	Topsoil (0-20 cm)		Subsoil (21-50 cm)	
	Million ha	%	Million ha	%
Soil pH:				
<5.3	392.2	81	398.9	82
5.3-7.3	91.2	19	84.7	18
% Organic matter:				
>1.5	43.9	9	405.2	84
1.5-4.5	357.8	74	77.8	16
>4.5	81.9	17	0.4	-
% Al saturation:				
0-10	81.8	17	96.2	20
10-40	37.9	8	49.8	8
40-70	78.4	16	39.4	8
>70	285.3	59	298.0	61
Exch. Ca (meq/100 g):				
>0.4	222.5	46	349.4	72
0.4-4.0	159.7	33	81.3	7
>4.0	101.2	21	52.8	11
Exch. Mg (meq/100 g):				
>0.2	185.6	38	356.8	74
0.2-0.8	185.8	38	84.7	18
>0.8	112.1	23	42.1	9
Exch. K (meq/100 g):				
>0.15	298.8	62	439.1	91
0.15-0.30	113.7	24	37.9	8
>0.30	71.1	15	6.5	1
ECEC (meq/100 g)				
<4	80.0	17	193.4	40
4-8	238.5	49	210.1	44
>8	165.2	34	80.1	16
Avail. P (ppm)				
<3	276.9	57	414.6	86
3-7	159.1	33	54.6	11
>7	47.7	10	14.4	3
P fixation				
High (>35 clay and % Free $Fe_2 0_3$/% clay > 0.15)	77.3	16	-	-
Low	406.3	84	-	-

Table 9. **The areal extent of some topsoil (0-20 cm) chemical properties within the topographical subdivisions of the climatic subregions of the Amazon.**

Parameter and range	Subregion A Tropical rain forests				Subregion B - Seasonal semi-evergreen forests				Subregion C - Savannas			
	Poorly drained	Well drained			Poorly drained	Well drained			Poorly drained	Well drained		
		0-8%	8-30%	>30%		0-8%	8-30%	>30%		0-8%	8-30%	>30%
	Million hectares											
pH (in H_2O)												
<5.3	29.1	64.2	23.2	10.9	21.0	128.8	63.6	15.1	10.0	16.5	3.3	1.2
5.3 - 7.3	20.6	14.9	6.6	1.2	25.7	13.0	3.3	0.8	2.2	2.1	0.6	0.6
% organic matter												
>4.5	16.9	12.8	2.9	0.4	14.4	15.7	5.8	1.3	8.2	1.4	0.5	0.7
1.5 - 4.5	31.5	65.6	25.8	10.1	26.1	109.3	50.3	13.3	3.7	14.7	3.0	0.2
<1.5	1.2	0.6	1.1	1.6	6.2	16.7	10.8	1.2	0.2	2.4	0.3	0.9
% Al saturation												
>70	22.8	60.1	19.7	6.0	14.4	90.7	49.4	10.6	1.7	7.0	1.6	0.9
40 - 70	5.0	2.8	2.5	2.5	3.1	33.7	13.2	4.0	2.5	5.9	0.9	0.6
10 - 40	2.8	2.1	1.0	2.3	6.3	5.3	1.2	0.7	6.3	4.6	1.1	0.1
<10	18.9	14.0	6.6	1.2	22.9	12.0	3.1	0.5	1.7	10.2	0.3	0.1
Exch. Ca (meq/100 g)												
>4.0	19.2	14.9	7.9	2.8	22.4	18.9	7.0	2.5	5.1	0.9	0.1	0.0
0.4 - 4.0	19.3	30.5	4.9	3.4	12.3	39.5	25.1	7.1	3.1	6.4	1.7	1.4
<0.4	11.1	33.6	17.0	5.9	12.0	83.4	34.7	6.3	4.0	11.2	2.1	0.4
Exch. Mg (meq/100 g)												
>0.8	19.0	13.9	8.5	5.1	21.2	23.4	9.5	0.3	7.5	1.4	0.1	0.0
0.2 - 0.8	18.8	31.9	4.5	1.2	16.2	56.7	28.0	6.8	1.3	11.3	2.5	0.8
<0.2	11.7	33.2	16.8	5.8	9.3	61.6	29.3	6.0	3.4	6.0	1.3	1.0
Exch. K (meq/100 g)												
>0.3	16.0	7.7	3.4	4.2	20.5	12.9	2.9	0.6	2.9	0.5	0.0	0.0
0.15 - 0.3	11.9	19.1	5.8	1.1	6.9	29.1	15.5	4.1	5.5	6.7	1.8	0.9
<0.15	21.7	52.3	20.6	6.8	19.3	99.7	48.5	11.2	3.7	11.4	2.1	0.9
ECEC (meq/100 g)												
>8	33.9	30.5	8.7	3.5	31.1	34.1	10.8	3.3	7.5	2.0	0.1	0.0
4 - 8	15.9	47.9	20.3	8.3	12.3	77.1	38.4	10.9	1.4	2.7	0.8	0.7
<4	0.8	0.7	0.8	0.3	3.3	30.5	17.6	1.6	3.2	13.9	3.0	1.2
Avail. P (ppm)												
>7	19.8	7.5	0.4	0.0	14.0	5.2	0.7	0.2	0.5	0.0	0.0	0.0
3 - 7	24.9	34.7	7.4	5.3	21.5	33.6	16.1	2.5	1.5	6.2	1.9	1.1
<7	4.8	36.9	22.0	6.8	11.2	102.9	50.1	13.1	10.1	12.3	2.0	0.8

Soil acidity

Tables 8 and 9 show that 81 percent of the Amazon region has soil pH values below 5.3 in their native state, indicating not only an acid reaction but the probable presence of toxic levels of exchangeable Al for many plant species. The proportion of acid soils is less in the nearly level, poorly drained topographies (55%), suggesting an equal extension of acid to non-acid soils in the Amazon wetlands.

Aluminum toxicity to plants is the main consequence of high soil acidity. Plant species and cultivars within a species differ in their tolerance to Al and this is expressed in terms of a critical percentage Al saturation. Plants very sensitive to Al suffer at levels from 10 to 60 percent Al saturation and this range is indicated by the "h" modifier in Table 10. In general, when there is 60 percent Al saturation or more within the top 50 cm, the soil is considered Al-toxic. Such soils have the "a" modifer in the FCC system. Table 10 shows that 315 million hectares or 73 percent of the soils in the Amazon are Al-toxic in their natural state. Figure 12 shows a computer printout of Al saturation levels in Rondonia.

Clearing and burning forests change this situation, because of the base content of the ash. This will be discussed later in the soil dynamics section. It is relevant to indicate at this point that soil tests must be conduced **after** land clearing if burning is to take place in order to estimate lime requirements for specific crops and cultivars. Kamprath's method applying 1.6 tons/ha of $CaCO_3$-equivalent per milliequivalent to KCl-extractable Al to neutralize most of the exchangeable Al in the topsoil works well in some acid soils of the Amazon (North Carolina State University, 1973-1978; Sánchez, 1977a, b, c, d). Using the recently published formula of Cochrane *et al.* (1980), lime recommendations can be calculated for plants of different levels of tolerance to Al saturation *per se* to be grown on the same soil. This formula takes into account the levels of exchangeable Ca and Mg in the soil and permits accurate estimation of the desired level of Al saturation for specific plant species.

There are lime deposits in the Amazon, but most of them are poorly characterized. Those in operation produce mainly slaked lime for construction purposes. Lime deposits are abundant along the eastern rim of the Andes and in the Cerrado of Brazil. Transportation is a major limiting factor and in many cases the soil acidity constraint has to be solved by other means which are described in a later section. For intensive crop production, however, liming is likely to be necessary. Although liming eliminates Al toxicity only in the topsoil, it also decreases Al saturation levels in the subsoil after one to three years in well drained Ultisols of the Amazon (Villachica and Sánchez, in press).

Table 10. **The areal extent of fertility capability classification modifier combinations of Amazon soils.**

FCC Modifier Combination*	Million ha	% of Amazon
ak	100.2	20.7
a	62.4	12.9
aik	55.7	11.5
eak	32.2	6.7
none	32.1	6.6
h	24.8	5.1
ea	15.4	3.2
hk	15.1	3.1
gak	14.5	3.0
gh	13.7	2.8
ga	12.8	2.7
ehi	9.8	2.0
ghk	7.2	1.5
d	4.6	1.0
geak	3.9	0.8
daei	4.1	0.9
gak	2.6	0.6
dehk	2.6	0.5
ai	2.6	0.5
k	2.1	0.4
hi	1.8	0.4
dea	1.8	0.4
ehk	1.9	0.4
eai	1.9	0.4
deaik	1.7	0.3
gea	0.7	0.2
gai	0.7	0.2
dehik	0.6	0.2
deak	0.5	0.1
eaik	0.4	-
dh	0.4	-
dai	0.3	-
deh	0.3	-
gehk	0.2	-
geh	0.2	-
dak	0.1	-
Totals	432.1	100

a=Al toxicity, K=low K-reserves, i=high P fixation by Fe, e=low ECEC, h=acid but not Al toxic, g=poor drainage, d=dry season.

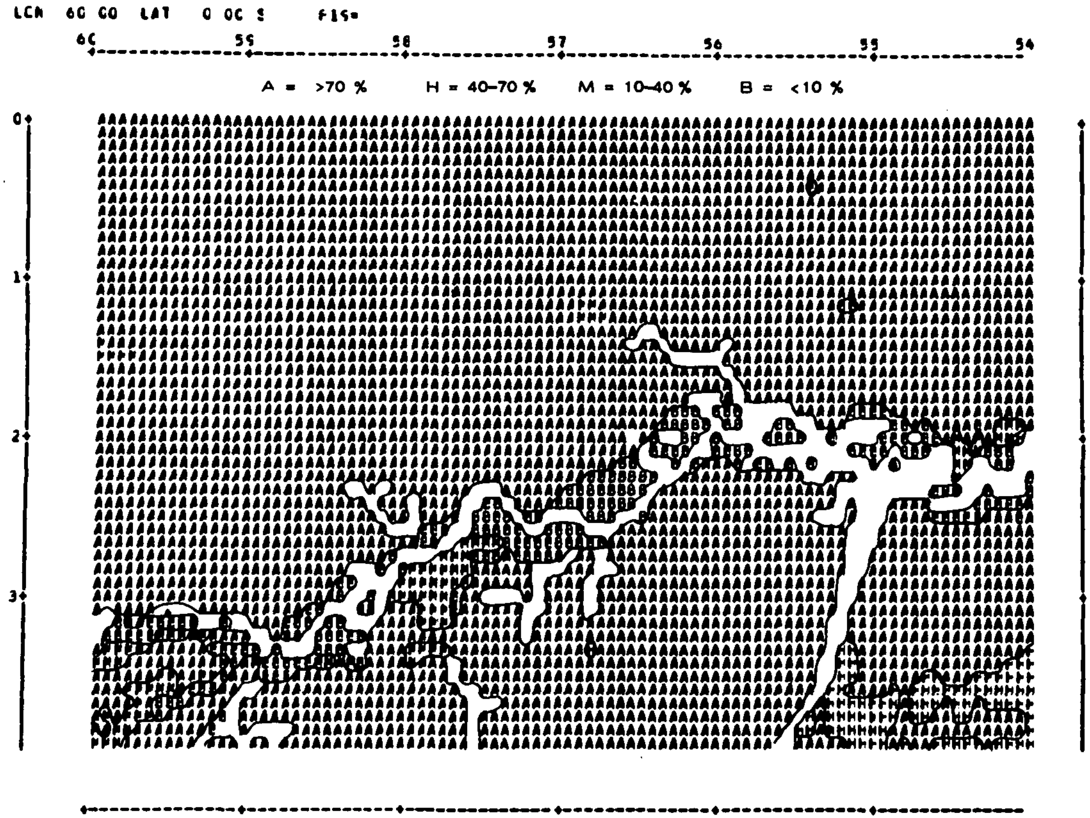


Figure 12. *Percentage Al saturation levels of topsoil, Map SA-21.*

Phosphorus deficiency

Table 8 shows that 90 percent of the Amazon soils have available P levels lower than 7 ppm P in the topsoil, according to the Bray II method. Figure 13 shows the distribution of available P levels in the same area as Figure 12. Since the generally recognized critical level for this method in Oxisols and Ultisols of Brazil is 10 ppm for crops, it is safe to state that the vast majority of soils in the Amazon are deficient in P for most annual crops. Fortunately, this widespread P deficiency is not accompanied by a widespread high P fixation capacity. Tables 8 and 10 show that only 16 percent of the Amazon have soils with a high potential for P fixation as defined by the "i" modifier of FCC. Only those toposoils with more than 35 percent clay contents and with a high proportion of iron oxides present are considered high P fixers, meaning that they will require more than 100 kg P/ha to correct P deficiency for many crops (Sánchez and Uehara, 1980; Sánchez *et al.*, in press). This situation is largely limited to clayey Oxisols and Uptisols and among them only those having the "Ci" notation in the FCC system. Phosphorus sorption isotherms conducted with some sandy or loamy Uptisols of Perú and Brazil by North Carolina State University (1973) and Dynia *et al.* (1977) confirm that their fixation capacity is low. High P fixation is not a widespread problem throughout the Amazon, although is locally important. The use of species and cultivars tolerant to low P levels is a viable alternative to decreasing P fertilization requirements in P-deficient soils.

Low potassium reserves

About 56 percent of the Amazon (242 million hectares) has soils with low K reserves as indicated by the "k" modifier in Table 10. The proportion of soils with K-deficient levels is somewhat higher than that of low K reserves, as indicated in Table 9. Although burning increases available K level in soils, this effect is short lived. Consequently, K is an important economic constraint in about half the Amazon.

Low effective cation exchange capacity

Low ECEC is an important soil constraint because of the susceptibility of mobile nutrients to leaching from the soil profile and the danger of creating serious nutrient imbalances among cations such as K, Ca and Mg. Tables 8 and 10 show that 64 million hectares (15% of the Amazon) have this condition in the topsoil and 192 million hectares (40%) in the subsoil. Low ECEC is more prevalent in subregions B and C, and occurs mainly in clayey Oxisols (Acrorthox and Acrustox), sandy textured Ultisols and Spodosols. Rapid leaching losses and serious K-Mg imbalances have been recorded in Ultisols of Peru (Villachica, 1978; Villachica and Sánchez, in press).

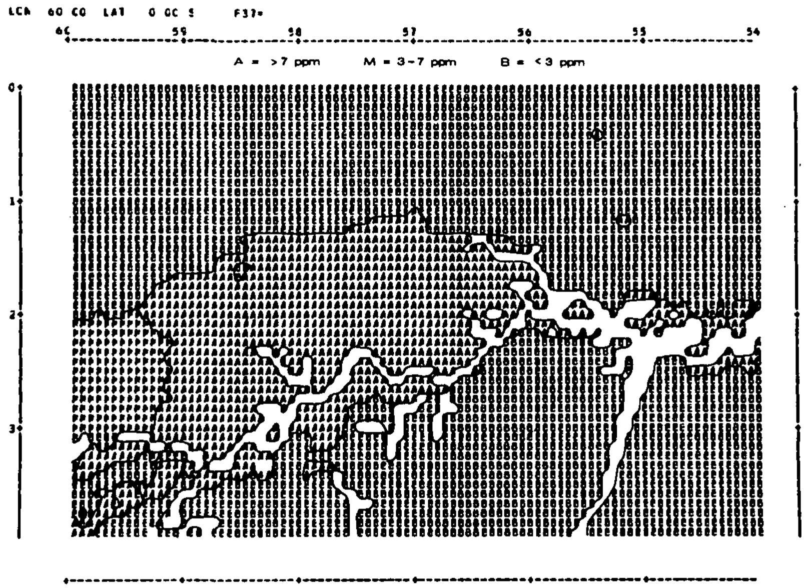


Figure 13. *Phosphorus levels of topsoil, Map SA-21.*

Deficiencies of other nutrients

The Amazon is heaven for scientists interested in nutrient deficiencies. In Ultisols of Yurimaguas, for example, deficiencies of all essential nutrient elements except for Mn, Fe and Cl have been recorded in annual crops (Villachica and Sánchez, in press). In addition to N, P and K, the most widespread ones seem to be Mg, S and Zn. The limited data base on this subject, however, impedes a geographical appraisal of where specific deficiencies occur and their relationship to soil properties.

Nutrient deficiency symptoms are frequently observed in annual or perennial crops, pasture and even forest plantations throughout the Amazon. The authors have often seen K, Mg and Zn deficiency symptoms in a wide variety of plants, in addition to the ubiquitous N and P deficiencies. Sulphur deficiencies in rice have been reported in "várzeas" along the Jari river in eastern Amazonia (Wang *et al.,* 1976). Much work needs to be done in identifying such constraints. There is a need to develop more effective soil test and plant analysis methods and carry out field fertilizer trials.

Constraints occurring together

Table 10 shows that several soil constraints occur together in the same land, as facets defined by the various FCC modifier combinations. Only about 7 percent of the Amazon showed no major fertility limitations. The rest showed various combinations of Al toxicity (a), acid but not Al toxic (h), low effective cation exchange capacity (e), low K reserves (k), high P fixation (1), poor drainage (g), and at least a three month dry season (d). The most frequent combinations involved Al toxicity, low K reserves, low ECEC and high P fixation. Examples of such FCC classes occurring together are shown in Table 5 where the seven profiles listed are classified according to the FCC system.

Soil Management

The previous sections have shown the great variability in soil properties found in the Amazon and some of the most widespread constraints. Soil management involves the manipulation of soil properties and agricultural practices for efficient plant production. The principles of dealing with soil constraints listed previously are universal; for example, the basic chemistry of soil acidity is the same whether in the Amazon or in Alaska. The management of these properties for agronomic purposes, however, is site and situation specific. Site specificity includes the actual soil properties and other attributes of land on an individual farm. Situation specificity involves the crops to be grown, and the socio-economic framework of the region, which in the Amazon usually means pioneering agriculture plus logistical and transportation difficulties.

Soil management research in the Amazon is extremely limited and has traditionally focused on one specific land use such as annual crops, pastures, perennial crops or forestry. This section summarizes the results available to the authors. Most of it is derived from a similar review prepared less than a year ago (Sánchez, 1979). There are other research projects presently ongoing but the results are not yet available.

Land clearing methods

The choice of land clearing methods is the first and probably most crucial step affecting the future productivity of farming systems. Several comparative studies conducted in the Amazon confirm that land clearing methods that involve burning are superior to different types of mechanical clearing because of: (a) The fertilizer value of the ash, (b) soil compaction caused by bulldozing, and (c) topsoil displacement in mechanized land clearing.

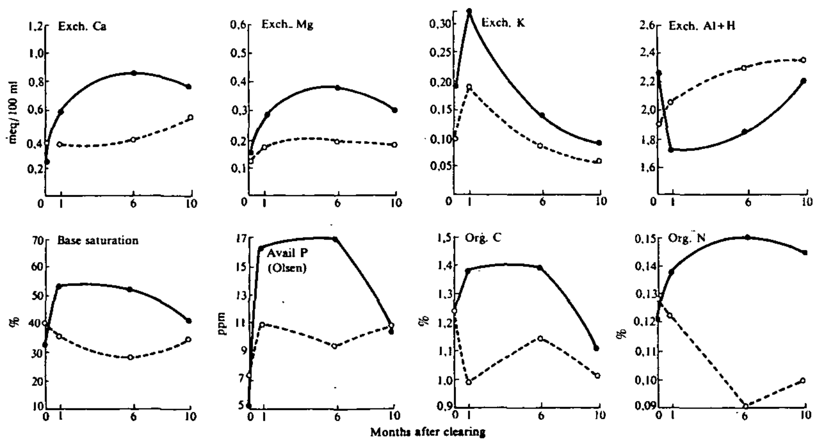
Nutrient additions by the ash

The direct measurement of the nutrient content of the ash in the Amazon has been determined after burning a 17-year-old secondary forest of an Ultisol in Yurimaguas, Perú. The data of Seubert *et al.* (1977) in Table 11 produced significant beneficial effects on soil chemical properties (Figure 14), which in turn produced consistently higher yields of a wide variety of crops during the first two years after clearing (Table 12).

Table 11. **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.



o Bulldozer clearing ● Slash-and-burn

Figure 14. *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).

Table 12. **Effects of land-clearing methods on crop yields at Yurimaguas. (Yield is the average of the number of harvests indicated in parenthesis.)**

Crops	Fertility level*	Slash and burn	Bulldozed	Bulldozed and burned
		----- t/ha**	------	%
Upland rice (3)	O	1.3	0.7	53
	NPK	3.0	1.5	49
	NPKL	2.9	2.3	80
Corn (1)	O	0.1	0.0	0
	NPK	0.4	0.04	10
	NPKL	3.1	2.4	76
Soybeans (2)	O	0.7	0.2	24
	NPK	1.0	0.3	34
	NPKL	2.7	1.8	67
Cassava (2)	O	15.4	6.4	42
	NPK	18.9	14.9	78
	NPKL	25.6	24.9	97
Panicum maximum (6 cuts/year)	O	12.3	8.3	68
	NPK	25.2	17.2	68
	NPKL	32.2	24.2	75
Mean relative yields	O			37
	NPK			47
	NPKL			48

*50 kg N/ha, 172 kg P/ha, 40 kg K/ha, 4 t/ha of lime

**Grain yields of upland rice, corn and soybeans; fresh root yields of cassava; annual dry matter production of *Panicum maximum*.

Source: Seubert *et al.*, 1977.

Variability in the quantity of ash and its nutrient content occurs because of differences in soils, clearing techniques and the proportion of the forest biomass actually burned. Silva (1979) estimated that only 20 percent of the forest biomass was actually converted to ash when burning a virgin forest on an Ultisol of southern Bahia, Brazil. Although outside the Amazon proper, the soil properties, rainfall pattern and native vegetation of this study are very similar to subregion A. Silva also analyzed the composition of ash adjacent to individual tree species and observed very wide ranges (0.8 - 3.4% N, 0-14 ppm available P, 0.06-4.4 meq Ca/100 g, 0.11-21.03 meq Mg/100 g, and 34-345 meq K/100 g). This information suggests the presence of certain species that can accumulate specific nutrients.

The fertilizer value of the ash is likely to be of less importance in fertile soils. Cordero (1964) observed that the increases in P and K availability caused by burning a forest on an Entisol of pH 7 in Santa Cruz, Bolivia, did not increase crop yields. The soil was already high in these elements.

Additional information on ash composition from different soils and clearing methods will contribute significantly to the understanding of soil dynamics. However, in addition to the nutritional value of the ash, the extent to which the ash is incorporated into the topsoil is important. Around Manaus, shifting cultivators prefer to clear loamy or sandy Ultisols on steep slopes than nearly level areas of clayey Oxisols. One reason is that the ash is not incorporated well in the Oxisols ("Latosol Amarelo textura muito pesada"), while apparently this is not a problem in the less clayey Ultisols.

Soil compaction

Conventional bulldozing has the clearly detrimental effect of compacting the soil, particularly sandy and loamy Ultisols. Significant decreases in infiltration rates, increases in bulk density and decreases in porosity have been recorded in such soils in Surinam (Van der Weert, 1974), Perú (Seubert *et al.*, 1977) and Brazil (Schubart, 1977; Silva, 1979). Table 13 shows the decreases in infiltration in the latter three sites. Slash-and-burn clearing had little effect on infiltration rates but bulldozing decreased them tremendously. Comparisons between sites are difficult because of differences in the time span used in measuring.

Table 13. **Effects of bulldozer clearing in decreasing infiltration rates in Ultisols from Yurimaguas, Peru, Manaus and Barrolândia, Bahia, Brazil.**

Clearing method	Yurimaguas	Manaus	Barrolândia
	cm/hr		
Undisturbed forest	-	15	24
Slash and burned (1 year)	10	-	20
Bulldozed (1 year)	0.5	-	3
Slash and burned and 5 years in pastures	-	0.4	-

Sources: Seubert *et al.*, 1977; Schubart, 1977; and Silva, 1978.

Topsoil displacement

The third major consideration is the degree of topsoil displacement, not by the bulldozer blade, which is normally kept above the soil, but by dragging uprooted trees and logs. Although no quantitative data are available, topsoil scraping 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 (Sánchez, 1976). For example, Lal *et al.* (1975) in Nigeria observed that corn yields decreased by 50 percent when the top 2.5 cm of an Alfisol were removed. Similar data on Oxisols and Ultisols of the Amazon are not available.

Alternative land clearing methods

The negative effects of bulldozer land clearing are becoming better known to farmers and development organizations. Government credits for large scale mechanized land clearing opperations have been sharply reduced in the Brazilian Amazon since 1978. Also, the practice of completely destroying the forest versus its partial harvesting before burning is being questioned. Silva (1979) has provided the first quantitative estimates of the possible benefits of such a practice. He compared the two extremes, slash-and-burn and bulldozing, with removing the marketable trees first, then cutting and burning the rest. All the advantages of burning on soil fertility were observed in this latter treatment, with non significant differences for the conventional slash-and-burn method, but with an important increase in income. The lack of difference is probably due to the small proportion of the total biomass that is actually burned.

Other alternatives consist of mechanized clearing followed by burning, using two bulldozers dragging a heavy chain, or large tree crusher machines which literally walk over the felled forest. The latter alternative provides a better burn (Toledo and Morales, 1979). In the case of the chain drag system, the remaining logs can be pushed away into windrows with a root-rake after burning. These combined operations capitalize on the fertilizer value of the ash, but still cause some degree of soil compaction and topsoil removal. The traditional slash-and-burn system is clearly the best unless one is prepared to add additional fertilizer and tillage operations to compensate for losses in soil fertility and for compaction. The same situation occurs when clearing forests on Ultisols in southeastern United States, but the problem is solved by additional inputs. The second author considers that many failures of large scale settlements he has observed in the Amazon and the transmigration areas of Indonesia, can be directly attributed to improper land clearing methods.

Soil dynamics after clearing

When a tropical forest is cleared and burned the following changes in soil properties generally occur within the first year: (1) Large volatilization losses of biomass N and S occur upon burning. (2) Soil organic matter contents decreases with time until a new equilibrium is reached in about one to two years. (3) The pH of acid soils increases and Al saturation decreases, all because of the nutrient content of the ash. These changes are gradually reversed with time but the time it takes varies with soil properties. (4) Surface soil temperatures increase and moisture regimes fluctuate more because more solar radiation reaches the soil surface (Sánchez, 1976).

The above generalizations vary from site to site. Most of the available data are based on sampling nearby sites of assumed known age after clearing, thus confounding time and space dimensions and increasing the already large variability in such soil samples. The available literature of this type up to 1976 has been summarized elsewhere (Sánchez, 1973, 1976). Fortunately there are five studies in which soil dynamics are being followed as a function of time: In Yurimaguas, Perú; Manaus, Belém and Barrolândia (Bahia) in Brazil, and Carare - Opón in Colombia. Most of them, however, are limited to what happens during the first year, but some report data up to 13 years after clearing. Nevertheless, they illustrate the differences in soil dynamics.

Soil organic matter

De Las Salas and Folster (1976) estimated that 25 kg C/ha and 673 kg N/ha were lost to the atmosphere when a virgin forest on a poorly drained Oxisol in the middle Magdalena Valley of Colombia was cut and burned. They measured biomass changes before and after burning, prior to the first rains. No comparable figures for Amazon ecosystems are available to determine whether such losses are representative. Nevertheless, volatilization losses accounted for only 11 to 16 percent of the total C in the ecosystem, and about 20 percent of the total ecosystem N (De las Salas, 1978). Consequently, assertions that **most** of the C and N in the vegetation is volatilized upon burning deserve careful scrutiny. Another unknown factor is whether or not a proportion of the volatilized elements is returned back to nearby areas via rainwash.

The influence of burning on the first thin organic-rich layer comprising the litter-topsoil interphase was also determined by De Las Salas (1978). The C/N ratio of this material increased from eight to 46 within five months, suggesting that the volatile losses were rich in N.

The literature has conflicting information about the losses of soil organic matter when the cropping phase begins. Larger losses will occur in soils with higher original organic matter contents (Sánchez, 1976). This effect, however, is attenuated by the topsoil clay content. Turenne (1969, 1977), for example, found an inverse relationship between organic C losses and clay contents in Oxisols of French Guiana.

Another supposedly detrimental effect of burning is a decrease in soil microbiological activity. Silva's (1979) southern Bahia study indicated that there were no significant differences on fungal flora, caused by various degrees of burning, but there was a decrease in the bacterial and actinomycetal population during the first 30 days after the conventional burn. Figure 15 shows the time trend in cellulose decomposition activity. Burning actually had a stimulating effect on the organic matter decomposing microflora, probably because of increased availability of P and other nutrients, and higher soil temperatures resulting from exposing the topsoil to direct sunlight. This, however, was not the case in the even more exposed bulldozer clearing, probably because of topsoil carryover and soil compaction. The partial sterilization effect in the conventional burn may account for the lower microbiological activity during the first 25 days after burning.

The dynamics of organic C during the first four years of continuous upland rice cropping on an Ultisol from Yurimaguas, Perú, are shown in Figure 16. There is an actual increase in organic C content immediately after burning, probably a result of ash contamination. This is followed by a plateau for the first six months, then a sharp decrease is observed after the first rice crop was harvested, and finally an equilibrium is reached during the first year. The annual decomposition rate during the first year is on the order of 30 percent, but this rate diminishes and the trend reverses during the second year of cropping at high fertility levels (Villachica, 1978). This sharp decomposition rate resulted in a very large increase in topsoil inorganic N during the first six months at Yurimaguas (80 kg N/ha in the top 50 cm), which quickly disappeared because of leaching and/or crop uptake (Seubert *et al.*, 1977). This "nitrogen flush" probably contributes to the initial lush growth of the first crop after burning.

Turenne (1969, 1977), working with fallows of known age on Oxisols in French Guiana, has made valuable observations on organic matter dynamics during the fallow period. He observed that beginning with the second year of forest fallow, the topsoil C/N ratio began to decrease while the fluvic acid composition of the organic matter increased, indicating the beginning of a N enrichment process. Turenne also observed that the litter layer reestablishes itself after four years of fallow and that it builds up as much organic matter in 10 years as is found in a 11-year old forest.

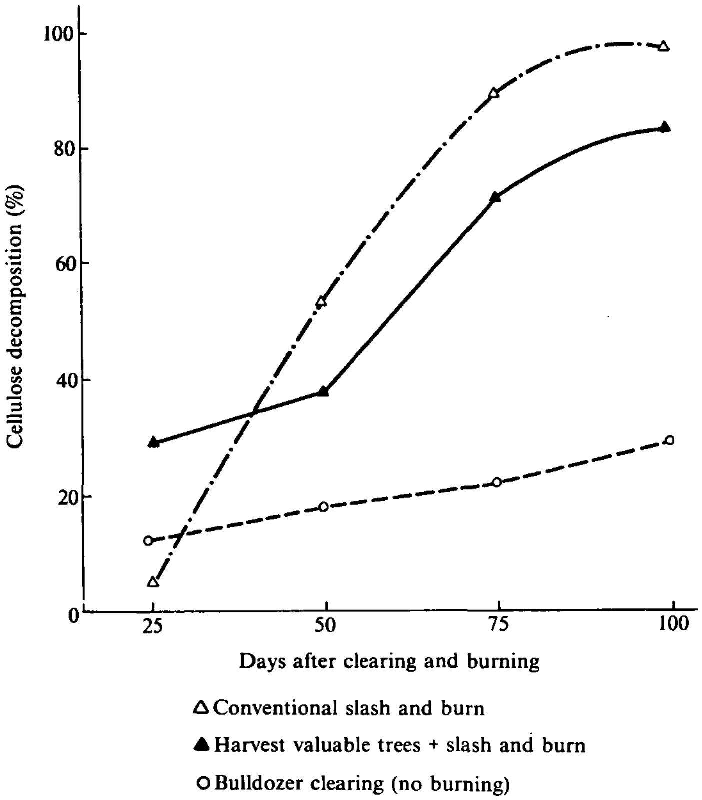


Figure 15. *Effects of degrees of burning intensity on microbial activity as measured by cellulose decomposition rates as a function of time after burning a rain forest on an Ultisol of southern Bahía, Brazil.*

(Source: Adapted from Silva, 1979).

Figure 17 shows the results of a time-space study of De Las Salas and Folster (1976) at Carare-Opón, Colombia. A sharp initial decline in organic C and N was noted, but the curve turned upward during the second year, surpassing the virgin forest levels in the 16-year old fallow. A 16-year old pasture consisting of a mixture of *Hyparrhenia rufa, Panicum maximum* and other grass species, produced topsoil organic C and N levels equal to that of the virgin forest.

Although this comparison is limited by the usual variability on small sample size (two plots in each treatment), it should cast doubt on statements asserting that grass pastures have detrimental effects on organic matter contents in tropical rain forest regions.

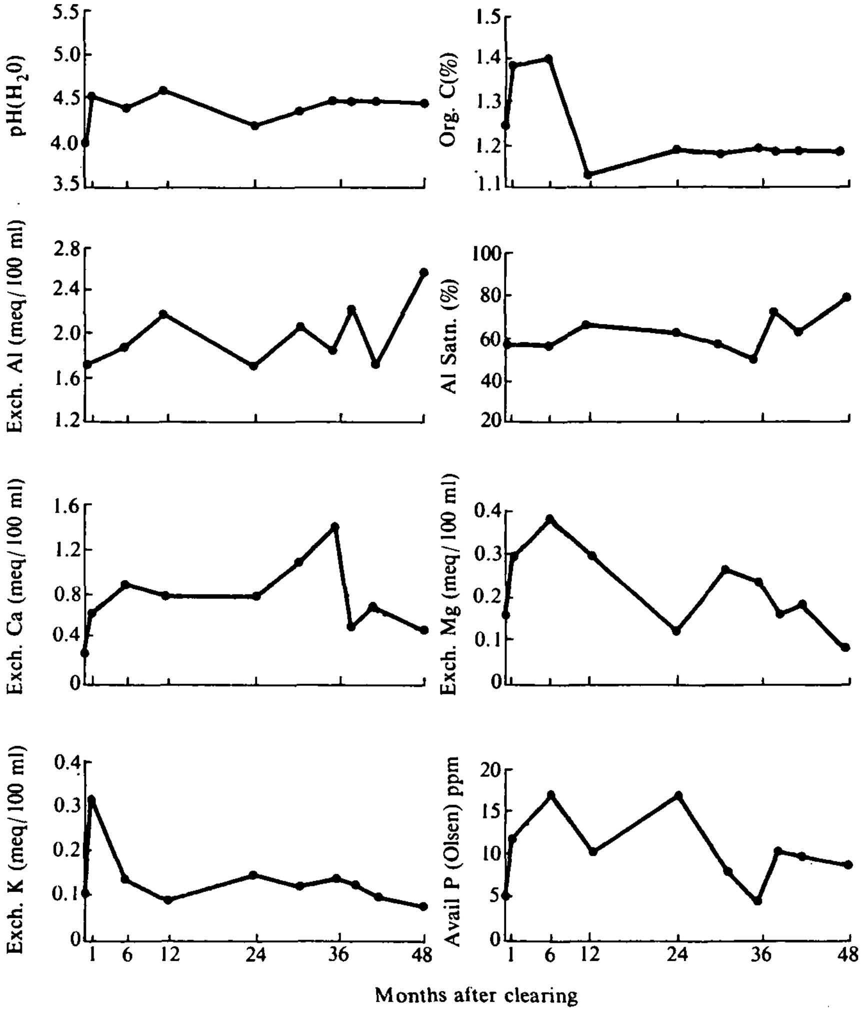


Figure 16. *Changes in chemical properties of an Ultisol continuously cropped to upland rice (8 crops), without fertilization at Yurimaguas (1972-76).* (Source: Compiled from data by Seubert **et al.**, 1977, and Villachica and Sánchez, in press.)

Changes in soil acidity and nutrient availability

The changes in topsoil properties before clearing and the first sampling after burning of several properly sampled, true time studies are summarized in Table 14. This table shows the general trends, and deviations therefrom.

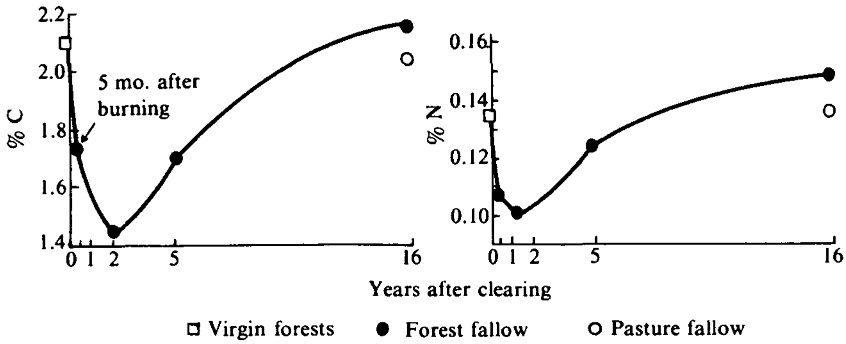


Figure 17. *Topsoil (0-10 cm) organic matter status in the Carare forest, Middle Magdalena Valley, Colombia, in nearby sites with known age and type of vegetation. Aeric Ochraquox soil pH 3.8, 3000 mm rainfall.* (Source: Adapted from De las Salas and Folster, 1976, and De las Salas, 1978.)

Table 14. **Summary of changes in topsoil chemical properties before and shortly after burning tropical forests in Ultisols and Oxisols of the Amazon.**

Soil property	Timing	Yurimaguas[1] (2 sites) I	Yurimaguas[1] (2 sites) II	Manaus[2] (X̄ 7 sites)	Belém[3] (X̄ 60 sites)	Barrolândia[4] Bahía (1 site)
Months after burning:		1	3	0.5	12 .	1
pH (in H_2O)	Before:	4.0	4.0	3.8	4.8	4.6
	After:	4.5	4.8	4.5	4.9	5.2
Exch. Ca Mg	Before:	0.41	1.46	0.35	1.03	1.40
(meq/100 g)	After:	0.88	4.08	1.25	1.97	4.40
	Δ	0.47	2.62	0.90	0.94	3.00
Exch. K	Before:	0.10	0.33	0.07	0.12	0.07
(meq/100 g)	After	0.32	0.24	0.22	0.12	0.16
	Δ	0.22	(0.07)	0.15	0.00	0.09
Exch. Al	Before:	2.27	2.15	1.73	1.62	0.75
(meq/100 g)	After:	1.70	0.65	0.70	0.90	0.28
	Δ	(0.59)	(1.50)	(1.03)	(0.72)	(0.45)
Al satn.	Before:	81	52	80	58	34
(%)	After:	59	12	32	30	5
Avail. P (ppm)	Before:	5	15	-	6.3	1.5
(Olsen in Peru,	After	16	23	-	7.5	8.5
NC in Brazil)	Δ	11	8	-	1.2	7.0

Calculated from data by:
[1] Seubert *et al.*, 1977; and Villachica and Sánchez (in press)
[2] Brinkmann and Nascimento, 1973
[3] Hecht (unpublished data)
[4] Silva, 1978.

Soil pH values increase after burning but not to neutrality. Exchangeable Ca and Mg levels double or triple, but there is considerable variability among adjacent plots on the same soils as shown by the two Yurimaguas sites. This particular difference is attributed to an initially higher base status in Chacra II and a more complete burn. Exchangeable K contents also increase but the effect is short-lived because of rapid leaching. This probably explains why there were no increases in exchanleable K in the Yurimaguas Chacra II and Belém sites, which were sampled at three and 12 months after burning. Exchangeable Al decreases in proportionate amounts to increase in exchangeable Ca and Mg, suggesting a straight liming effect. An exception to this statement occurs in the more fertile southern Bahia site. With one exception, Al saturation decreased to levels below that considered as critical (60%). Available P, commonly considered the most limiting nutrient, also increases with burning, surpassing the critical soil test P level in some cases, but again with considerable variability within sites. Regardless of these differences there is no question that the fertility of acid soils increases considerably after burning.

Fertility decline pattern

These relationships begin to reverse themselves with time. Figure 14 illustrates the changes occurring within the first 10 months after clearing in Yurimaguas. Silva (1979) has reported almost identical results in southern Bahia, Brazil. Inorganic N (not shown) and K are the first elements to be depleted, while the others show a slower decline.

Figure 16 shows the four-year trend in unfertilized plots at Yurimaguas grown to two crops of upland rice a year. Yields of the first three crops were on the order of 1.2 tons/ha, declining to 0.5 tons/ha in the fourth crop and to negligible amounts afterwards (Bandy, 1977). The soil was so infertile that not much weed growth was observed. Its surface was also heavily compacted by exposure to rains, because the poor rice growth did not provide an adequate canopy.

Shifting cultivators seldom continue the cropping period for such a long time. They normally abandon their fields when they expect less than half the yield in the forthcoming crop than in the previous one (Sánchez, 1976). Figure 18 illustrates when this would happen in different soils and with different crops. In the fertile Mollisols from Petén, Guatemala, only two crops of maize are planted, because weed control is the main limiting factor. In the fertile, but poorly drained Alfisol from Yurimaguas, more than three consecutive upland rice crops can be expected if weeds are controlled. In the infertile, well drained Ultisol at the same location, only two crops of rice or cassava, and one rotation of rice-corn-soybeans (in one year) can be expected. From Figure 18 it is apparent that weed control is the main limiting factor in the more fertile soils, while fertility decline is the main cause of yield reduction in the acid soils.

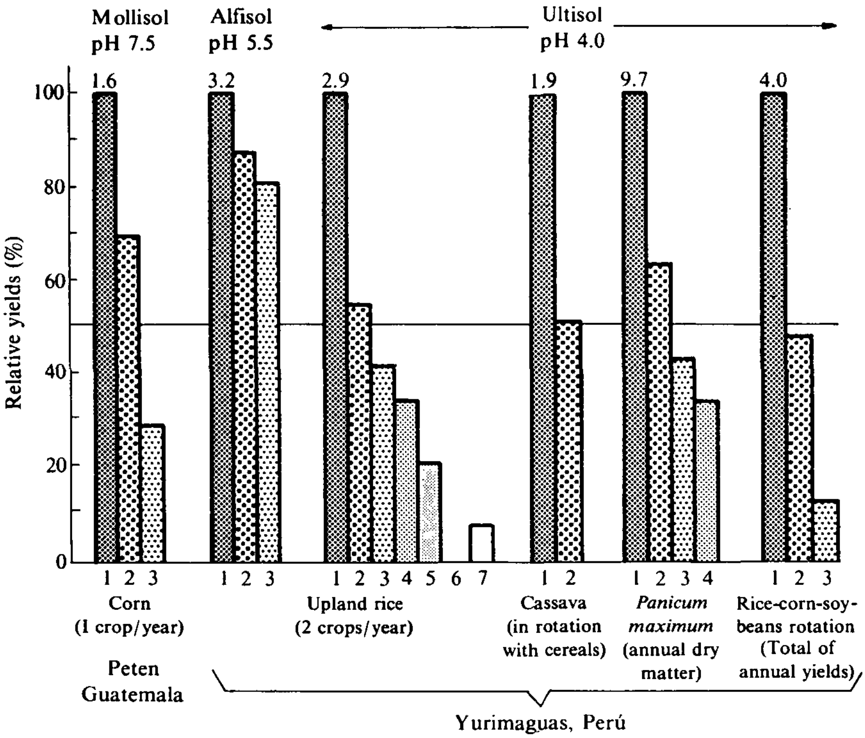


Figure 18. *Yield decline pattern in several shifting cultivation systems without fertilization; numbers on top of histograms refer to economic crop yields (t/ha). Numbers on x-axis refer to consecutive crops.* (Source: Adapted from Sanchez, 1976.)

Maintenance of soil fertility under annual crops

Farmer experience in selecting better soils: Altamira. One straightforward strategy to retard the yield decline pattern is the selection of better soils. An excellent example is given in a survey by Morán (1977) showing the ingenious selection criteria used by one type of shifting cultivator near Altamira, along the Transmazonic highway of Brazil. The "caboclos"* native to the region, select sites with trees of relatively thin trunks such as acaí *(Euterpe aleracea)*, babacú *(Orbignya martiana)* and morocó *Bauhinia macrotachia)*. The "colonos" or new settlers attracted by government colonization projects, look for virgin forest with thick tree

* Brazilian half-breed or pure blood indians. (Editor's note.)

trunks such as acapú *(Vouacapona americana)* caju-acú *(Anacardium giganteum)* and juraná *(Holopyxidium jarana).* After one year of similar slash-and-burn practices, the caboclos' soils were far superior in chemical status to those of the "colonos" (Table 15).

This suggests that caboclos were able to identify areas of Alfisols by vegetation, while the new settlers selected Ultisols and Oxisols. The caboclos also grew mostly cassava, while the colonos planted rice, corn, and beans, all without fertilization. As a result of the judicious selection of soils and adapted crops by the traditional shifting cultivators, the caboclo's farm income was twice as much as the new settler's income (Morán, 1977). Although the indicator species are likely to differ in other regions, this is a good example of accumulated experience as a way to increase production. A quantification of these differences in tree species by chemical analysis would be most useful.

Table 15. **Topsoil (0-10 cm) properties of soils selected by caboclos and colonos near Altamira, Pa., Brazil. Mean of 3 samples taken a year after felling and burning.**

Farmer type	Indicator trees (trunk width)	Moist-soil colour	pH	Org. C %	Avail. P (N.C.) ppm	Exchangeable (meq/100 g) Al	Ca	K	ECEC	Al sat. %
Caboclo	Thin	10 YR 4/4 -3/2	6.2	1.7	26	0	7.1	0.1	8.2	0
Colono	Large	7.5 YR 4/5 -3/3	4.3	2.3	2	5.5	1.1	0.2	6.8	81

Source: Morán, 1977.

Intensive continuous crop production: Yurimaguas

The fertility requirements for continuous crop production in an Ultisol from Yurimaguas after clearing and burning a 17-year old secondary forest have been investigated since 1972 using a variety of cropping systems and fertilization rates (North Carolina State University, 1973, 1974, 1975, 1976; Sánchez 1977 a, b, c; Bandy, 1977; Villachica, 1978; Valverde *et al.,* 1979).

The sequence of nutrient limitations in their approximate order of appearance is outlined in Table 16. This shows how dynamic the system is and explains the low yields obtained without fertilization. The increase in yields from the seventh crop onwards is due to the identification and solution of these fertility problems. A fertilization scheme for this situation is presented in Table 17. Maintenance fertilization as such begins with the second year and is supported by a soil testing program.

This fertilization scheme is costly (about US$875/ha/year) but the yields are high. Bandy (1977) shows that it is profitable with a net return of US$2.9 per dollar invested in fertilizers and lime at 1978 prices in Yurimaguas for the rice-soybeans-peanuts rotation. This calculation includes the high cost of transporting fertilizers from industrial areas across the Andes.

Table 16. **Time of appearance of fertility limitations in an upland rice-corn-soybean annual rotation after burning a secondary forest in an Ultisol in Yurimaguas, Peru.**

Months after clearing	Problem
1	Initial boost in pH, inorganic N, P, K, Ca, Mg, S, and micronutrients, decrease in Al saturation to below toxic levels. Effect of ash.
8	Inorganic N supply depleted. N deficiency symptoms appear. Exch. K below critical level of 0.2 meq/100 g. K deficiency symptoms appear.
10	Organic C decomposition to new equilibrium level completed. Al saturation increases, surpassing toxicity level of 60% for corn and soybeans. Available P below critical level (12 ppm P via Olsen method). Mg becomes critical at 0.2 meq Mg/100 g for soybeans and 0.4 for corn.
12	Liming to pH 5.5 and applications of 80-26-80 kg N, P, K/ha per crop except N for soybeans increases yields.
	K applications solve K deficiency but creates K/Mg imbalance when ratio < 1.2. Mg applications needed. B deficiency evident.
	S, Cu, and Mo probably limiting (S became limiting immediately after clearing in bulldozed plots). Mo deficiency depends on Mo status in seed.
24	Nutrient removal by cropping depletes soil further. Rates of N, P, K and Mg have to increase.
48	Zn deficiency appears.

Source: Villachica, 1978, and Villachica and Sánchez (in press).

Table 17. Suggested fertility maintenance scheme for intensive crop production in Yurimaguas. Three crops a year: rice, corn, soybeans, or preferably rice-peanuts-soybeans.

Months after clearing	Crop number	Fertilization
0	1	Slash and burn clearing. Short-statured-upland rice planted without fertilization. Yields 3 tons/ha. Soil tested near harvest to determine Al saturation.
5	2	Apply dolomitic lime at 1 x exch. Al and incorporate with hand tractor. Apply 50 kg P/ha as single superphosphate to correct P and S deficiencies, and 60 K/ha. If dolomitic lime unavailable add 30 kg Mg/ha per crop.
12 onwards	5	Maintenance applications (kg/ha per crop) of 50 P, 50-80 K, Mg to keep K/Mg ratio at about 1.2. One kg B and 1 g Mo/kg seed. N rates should be 80 for rice, 120 for corn and none for soybeans and peanuts. Soil testing every 6 months to check for Al toxicity, P, K, Mg and micronutrients. Apply 2 kg Cu/ha every 3 crops.
24	9	May need to add more lime. Watch for Zn becoming critical.

Source: Villachica, 1978; and Sánchez, 1979.

Low input continuous crop production: Yurimaguas

The high fertilization requirements previously described limit the adoption of an intensive system to areas with readily available credit and fertilizer, as well as a working marketing system. Other strategies were also investigated for continuous cropping at lower costs. One is a five-crop-a-year relay intercropping of cassava, corn, soybeans and peanuts, which produces 30 percent more total yield per year than if the crops were grown in monocultures (Wade, 1978; Bandy, 1977; Sánchez, 1977, a, b). Another is the use of kudzu *(Pueraria phaseoloides)* as mulch or green manure. Kudzu mulch or green manure produced yields of soybeans, peanuts, cowpeas and upland rice on the order of 80 to 90 percent of that achieved in heavily fertilized plots without organic additions for five continuous crops.

Economic analyses of these and other combinations, including the use of the traditional rice-cassava-plantain-fallow system reported by Cate and Coutu (1977) show that the net income of a small farm family in Yurimaguas can reach US$6,000 per year assuming a capital investment of US$1,000 prorated over three years. Seven hectares of continuous cropping per year were required to reach this income level. This family income level compares very favorably with the 1977 average annual rural family income of US$750 in the Yurimaguas area and US$1,500 for the top 25 percent of the families in the "barriadas" (slums) of Lima, mostly immigrants from Perú's rural areas.

Maintenance of soil fertility under pastures

Pasture-based beef production is the largest single activity of cleared land in the Amazon basin, and a major source of controversy, particularly in Brazil. There are about 3.7 million hectares of cultivated pastures in forest areas of the Amazon, according to estimates by Kirby (1976) and Serrão *et al.* (1979). Most of them consist of *Panicum maximun,* are not fertilized, and have a carrying capacity of one animal unit/ha, producing about 100 kg/ha of annual liveweight gain. After the first three to four years, pasture productivity begins to decline, secondary growth invades and the pasture slowly changes into secondary forest fallow. Serrão *et al.* (1979) estimate that 20 percent of the area planted to pastures in the Brazilian Amazon is in some state of degradation. This has raised serious questions as to the value of this important farming system in the Amazon (Goodland and Irwin, 1975; Schubart, 1977; Fearnside, 1978). The Brazilian government has reduced credits for new land clearing for pasture and is concentrating its research efforts to reclaim degraded pastures.

A series of studies conducted primarily in the Paragominas area along the Belém-Brasilia highway, in northern Mato Grosso, and near Belém has shed light on the soil dynamics through time in pasture production (Falesi, 1976; Baena, 1977; Serrão *et al.*, 1979; Fearnside, 1978; Hecht, 1978). Soil samples were taken in pastures of known age in several farms. Although sample size is small, time and space are confounded and variability is high, a clear trend has emerged from these studies: Pastures retard the rate of fertility decline, maintaining for several years some of the benefits of burning, particularly a high soil pH, elimination of Al toxicity, high Ca and Mg and, for the first four to five years, sufficient levels of P. Serrão *et al.* (1979) attribute this decline to N and P deficiency, and the poor adaptation of *Panicum maximum* to this environment.

Figure 19 summarizes the data for a clayey Oxisol from Paragominas and a loamy Oxisol from Northern Mato Grosso. The data suggest a remarkable degree of nutrient recycling and maintenance of soil fertility under pastures in the eastern Amazon. Observations on animal productivity indicate that its decline is associated with available P levels decreasing below 4 ppm. Serrão *et al.* (1979) state that the speed of this decline is faster in clayey than in loamy soils. Since P fixation in Oxisols and Ultisols increases as a function of topsoil clay content and Fe oxides (Sánchez and Uehara, 1980), it is not surprising that the clayey Oxisols show pasture degradation symptoms earlier than the loamy ones. Since *Panicum maximum* responds very strongly to P fertilization, it is also not surprising that it tends to disappear and is overtaken by jungle regrowth. Serrão and coworkers found that excessively high grazing pressures also accelerate pasture degradation.

A look at Figure 19 suggests that these pastures are periodically burned as the sharp increases in bases and available P show. It also illustrates large site-to-site variability.

The solution to this apparently hopeless situation is remarkably simple: Clear the jungle regrowth ("juquira") by hand, burn the pasture, and broadcast 25 kg P/ha, as single superphosphate and half as rock phosphate. When Serrão and coworkers (1979) did that in a 13-year-old degraded pasture at Paragominas, its botanical composition changed from 77 percent weeds and jungle regrowth to 92 percent *Panicum maximum*. Ongoing experiments suggest that animal liveweight gains will increase accordingly.

There are still questions about how persistent these regenerated *Panicum maximum* pastures will be, since their fertility requirements are relatively high, and whether nutrients other than P and S (applied in the single superphosphate) will become limiting.

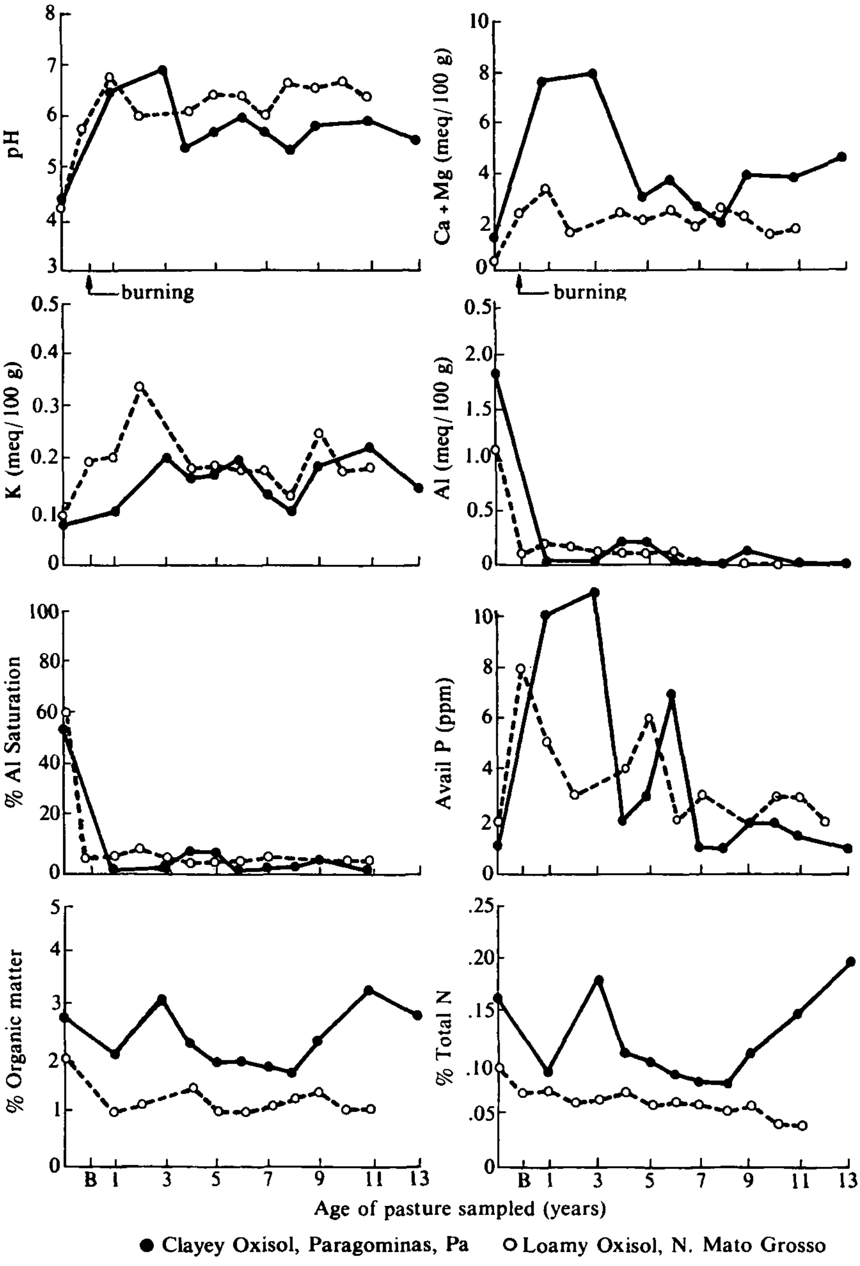


Figure 19. *Changes in topsoil properties of* **Panicum maximum** *pastures of known age in eastern Amazonia (sampled at the same time).* (Source: Adapted from Serrão et al., 1979.)

The main concerns are N and K with K levels near the critical level. Research underway is studying the adaptation of grass species that require lower levels of P, e.g. *Brachiaria humidicola* and *Andropogon gayanus,* and the introduction and test for persistence of legume species as *Pueraria phaseoloides, Desmodium ovalifolium* and many others (CIAT 1980). An additional limiting factor is the tolerance of pasture species to serious insect and disease attacks in the Amazon, such as spittlebug on *Brachiaria decumbens* and anthracnose on *Stylosanthes guianensis.* It is interesting to note that the forage value of some of the jungle regrowth species is considerable, according to a recent study by Hecht (1979).

In western Amazonia, in the semi-evergreen seasonal forest region of Pucallpa, Perú, Toledo and Morales (1979) report that productive grass-legume pastures fertilized with 22 kg P/ha/year as simple superphosphate have persisted for at least three years, producing about 377 kg/ha of annual liveweight gains with a carrying capacity of three animals/ha in mixtures of *Hyparrhenia rufa* and *Stylosanthes guianensis.* Without the legume, similarly fertilized pastures produced a maximum of 149 kg/ha of annual liveweight gain with a carrying capacity of 2.1 animals/ha.

These data are most encouraging because they indicate a very high beef production potential in Amazon jungle pastures with minimal inputs. Also the Brazilian data suggest a significant degree of nutrient recycling in extensively managed pastures. The sharp differences in fertility decline between the cropping data shown in Figures 17 and 19 probably reflect more than just the effect of nutrient recycling by grazing animals. The Paragominas area has an ustic or nearly ustic soil moisture regime with a four-month dry season, typical of subregion B. The contribution of the ash may be larger because of a more intense burn. The dry season may also decrease leaching losses and perhaps reverse the flow of nitrates, K and other cations upwards during the dry season. Also, farmers burn the weed and forage regrowth every two to three years in Paragominas, which facilitates recycling of P and bases. The situation in Pucallpa is similar to the cropping regimes of Paragominas and Manaus, but unfortunately no soil dynamics data are available from Pucallpa.

The maintenance of soil fertility under tropical pastures is not a new finding. A similar time-space study conducted by Bruce (1965) after clearing a tropical rain forest in South Johnstone, Queensland, Australia, shows a decline in topsoil organic matter content with *Panicum maximum* without fertilization, but a complete maintenance of the original topsoil organic C and N levels with fertilized *Panicum maximum - Centrosema* *pubescens* pastures of up to 16 years of age (Figure 20). The data for a 16 year-old pasture in the Carare-Opón (Colombia) study shown in Figure 17 also indicates that pastures can build up the organic matter level of soils like the fallow period in shifting cultivation.

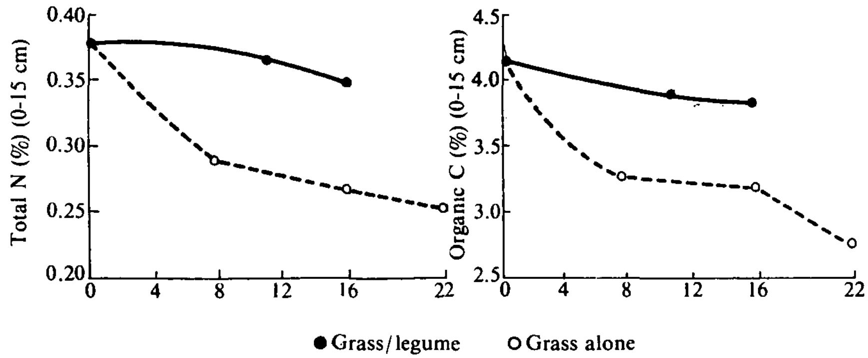


Figure 20. *Long-term effects of unfertilized guinea grass* **(Panicum maximum)** *pastures, with and without* **Centrosema pubescens,** *on the topsoil organic matter after clearing a rain forest in South Johnstone, Australia.* (Source: Adapted from Bruce, 1965).

Soil fertility maintenance under permanent crops and forestry

In these systems the original nutrient cycling between the virgin forest and the soils is replaced with another nutrient cycle. Quantitative data on this subject are scanty, but there is successful commercial evidence such as *Gmelina arborea* plantations in Jari, Brazil. The only data available on this subject are evidence of incipient nutrient recycling of several permanent crops in the southern Bahia study of Silva (1979). Table 18 shows an increase in the exchangeable base contents in the top 5 cm of the soil 34 months after burning. The increase is most marked in the young oil palm plantation with a *Pueraria phaseoloides* cover crop, followed by pasture, and to a lesser degree in the cassava-banana intercropping that precedes cacao planting.

Information on soil management in agroforestry systems in the Amazon appears to be non existent (Sánchez, 1979). This is an obvious gap that must be filled, and by doing so break the present pattern of studying Amazon soils in relation to just one kind of use.

Table 18. **Effects of cropping systems on the topsoil (0-5 cm) exchangeable bases content 34 months after clearing a virgin rain forest on an Ultisol of southern Bahia (30 months after planting crops and 18 after planting pastures).**

System	Months after clearing	Sum of exch. bases (Ca+Mg+K) meq/100 g
Virgin rain forest	0	1.15
After burning	1	2.09
Rubber-kudzu	34	2.60
Cassava-bananas	34	2.80
Pasture	34	4.00
Oil palm- kudzu	34	4.50
LSD .05	34	2.00

Source: Silva, 1979.

Conclusions

There is a close relationship between the natural vegetation classes and the WSPE regimes of the Amazon region. This indicates that unless substantial climatic changes occur, any fragility (in the sense of cleared lands not reverting back to forests if left alone), will probably be confined to areas of transition between the well drained savannas and the semi-evergreen seasonal forest. Most of the well drained lands are suited for crop, pasture and forestry production. If they are to be used for pasture production, one of the foreseeable problems will be the difficulty of controlling regrowth of forest species. The use of the WSPE parameter provides a fresh approach for defining climatic sub-regions for perennial crop and pasture production in the tropics.

As soils of the Amazon region are becoming better known in terms of their geographical distribution, morphology, classification and, to a lesser degree, management, many generalizations about their behavior should be reconsidered. The pattern of soil variability among the different climatic subregions and topographical positions can serve as the basis for orderly development. Although the knowledge of how to manage these soils emerges principally from a few research sites, the available information permits decision makers to select within a land system those soils that are apt for continuous annual crop production at a specified level of inputs, those soils best suited for pasture production, permanent crops or agroforestry. In addition, those soils that are best left in their natural state, such as the Spodosols, can also be identified.

The available information clearly shows that most of the Amazon soils have no insurmountable limitations for agricultural production from a technical point of view. More evidence on this point is presented in other reviews of this conference. The main limitations are chemical and these can be handled by a combination of fertilization plus the use of species and cultivars tolerant to some of the main soil constraints. Statements on the impossibility of cultivating these soils on a continuous basis, the dangers of laterite conversion and catastrophic erosion are clearly exaggerated. It is clear, however, that without a suitable soil management technology new agricultural systems will fail, as the direct transplantation of *Panicum maximum* pasture technology from southern Brazil to the Amazon did. Appropriate technology needs to be developed. Although there are several worthwhile research projects in the Amazon which are generating such technology, the total effort is very small compared with the magnitude of the task.

Marbut and Manifold's (1926) comparison of well drained Amazonian soils with their counterparts in southeastern United States has stood the test of time. The latter region evolved from shifting into continuous cultivation during the last century, but lack of appropriate technology resulted in widespread erosion in the piedmont region of the United States. Many of those soils are now in secondary but productive forest vegetation. Agricultural scientists can contribute to prevent a similar situation in the Amazon by the timely development and transfer of appropriate soil management technology.

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Natural Resources for Land Use in the Amazon Region: The Natural Systems

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Introduction

The object of this report is to synthesize the knowledge and research needs of the natural ecosystems of the Amazon as these relate to the development of the agriculture, silviculture and other land uses. Time and space limitations force us to focus largely on the Brazilian Amazon. This article is not a critical review of all existing literature, since it would require the team work of several ecological specializations, such as the studies carried out recently for the neotropics (Farnworth and Golley, 1974), and for the humid tropics (UNESCO, 1978). Additional information sources on tropical ecosystems are Richards (1952), Odum and Pigeon (1970), Golley and Medina (1975), and Golley *et al* (1978).

Ecological studies can contribute substantially to regional development, to the evolution of food production systems and management of renewable natural resources. If most of these production systems were supported at least in part by natural processes, maintenance costs of inputs such as pesticides, fertilizers, herbicides, etc., that are extremely expensive in the Amazon and erratically available, could be reduced. It is important to understand the process controlling the ecosystem structure and function in order to design sustainable land use systems.

Ecosystems are integrated units of living organisms composed of a biotic community plus their abiotic environment. The definition of an ecosystem is basically an operational one. Its physical limits are deliberately vague, as a bromeliad is just as much an "ecosystem" as a watershed. The ecosystem boundaries really depend on the focus of the research.

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Amazonia is a region of high biotic diversity. This diversity can correlate with differences in landscape, soils, climate as well as climatic history (Ab'Saber, 1971). In the following pages we will review:(1) The broader geologic and geomorphic areas of the Amazon in order to better understand the variety of ecosystems encountered in the region; (2) the structure and function of the rain forest of the terra firme*; and (3) the relation between the Amazon rain forest and the climate as they reflect quaternary climatic fluctuations, the current forest-climate equilibrium and the possible climatic consequences of extensive felling.

Ecological Diversity of the Amazon Region

The lowland forest ecosystems of the Amazon, though superficially uniform, encompass considerable ecological diversity. Mapping of the region has been carried out by the Projeto RADAMBRASIL (Brazil, 1973-79). This survey includes data on the geomorphology, geology, soils, vegetation, and potential land use mapped at the scale of 1:1,000,000. The study was done with radar imagery, infrared and multispectral photography, as well as "on site" samples to establish ground truth. The RADAM project is a large scale inventory and is an important information source. However, much more detailed studies need to be undertaken for land use evaluation at a given site.

Geology, geomorphology and soils

Basic geological formations

Terra firme. The Precambrian Brazilian and Guiana shields, composed largely of igneous and metamorphic rocks, are located to the north and south of the Amazon Valley. Paleozoic strips of sediments where Devonian shales predominate are found east of the 60th meridian, and near the shield borders. The central area between these paleozoic strips is occupied by the "Barreiras Formation". Formed by fluvial sediments of coarse texture, deposited from Cretaceous to Tertiary period, the "Barreiras" originated from the erosion of the Precambrian shields. Brackish-marine and some fresh water sediments occur south-west of the Brazilian Amazon, apparently formed during Andean orogeny. Using radar imagery data, Irion (1976b, 1976c, 1978) has identified vast areas of Pleistocene flood plains of the Solimões River (Amazon above Manaus) and their tributaries west of the 60th meridian. Irion estimated that these plains extend from 300,000 to 400,000 km^2, and consist of deposits laid down during various

* Elevated portions of land that are not affected by floods. (Editor's note.)

thermal periods, and interglacial episodes that correlate with periods of high sea level. The most recent deposition is atributed to the Monastirian, about 100,000 years ago. The RADAMBRASIL project includes the deposits of the southwestern Amazon and the Pleistocene plains in the "Solimões Formation" of the Plio-Pleistocene period.

The várzeas. The Holocene flood plains of the Solimões and the Amazon as well as their white water tributaries constitute the várzeas. Várzeas were formed by deposition of lakes and meandering rivers. Irion (1976c, 1978) estimates that the age of the upper 20 m of the deposits is less than 6.000 years old. The Amazon has marked geological regions with particular rock chemistries, and these have important implications for pedogenesis and soil morphology of the Amazon soils.

Soils of the shields and of the Barreiras Formation

Soils of the shields and Barreiras formation encompass 60 percent of the Amazon basin. These soils have evolved continuously on these parent materials for 20 million years. The rocks of the shields and the sediments of the Barreiras Formation are, in general, of coarse texture originally rich in feldspars; these soils are quite permeable. Under tropical weathering conditions feldspars are transformed into kaolinite (Irion 1976a, 1978). A 0.5-1.00 m wide lateritic zone with a high Fe content formed by hematite and geothite concretions, normally occurs at 3-10 m depth.

The first meters of a typical Barreiras soil profile present an ochre coloration, mainly consisting of kaolinite and decomposed quartz; these ochre clays are classified as Belterra clays and were thought to be deposits of a lake that existed during the Pliocene and Pleistocene (Sombroeck, 1966; Fittkau, 1974). A bimodal granulometric distribution and the presence of a lateritic zone accompanying the surface morphology, indicate that these clays were formed *in situ* as a result of an acid weathering process which resulted in serious impoverishment of the inorganic nutrients, critical for the biosphere and agriculture (Table 1). The cation exchange capacity of these soils is about 5 meq/100g.

The Barreiras Formation is frequently extremely dissected. Coarse eroded sediments from these acid rocks have been deposited over areas in the northern part of the Amazon Basin. This material, largely white sands, is extremely impoverished, and the vegetation on this substrate is very sclerophytic. The acid litter generated by the vegetation produces leachates high in chelating agents, which results in podzolization (Turenne, 1977). These are the famous "giant Podzol" soils.

Table 1. **Chemical composition (mean values in ppm) of clays of the Amazon region soils.**

	Na	K	Ca	Mg	Zn	Co
Barreiras Formation	160	225	350	100	27	1.5
Guiana shield	600	700	700	280	50	3
Paleozoic:						
Moderate drainage	1,125	750	375	290	38	4
Poor drainage	5,900	17,100	900	2,500	-	2
Cretaceous-Tertiary deposits of the southwestern Amazon region	1,630	15,100	1,300	5,000	126	5
Várzeas:						
Pleistocenic plains	1,650	15,200	940	5,600	115	8
Holocenic plains	3,200	17,800	9,800	11,700	-	16
Andean soils	2,680	19,080	7,360	30,120	147	15

Source: Adapted from Irion, 1976a and 1978.

Soils of the Paleozoic strips

Most of the sedimentary rocks of the Paleozoic zones are relatively impermeable and the weathering process is not as advanced as in the soils of the "Barreiras Formation" and the shields. In relatively permeable soils the first decimeters of the profile are also kaolinitc, while Mg and K increase at 0.5-1.5 m depth due to presence of partially decomposed illite. In poorly drained soils, the content of important plant nutrient elements is relatively high (Table 1), due to presence in the soil's superficial horizons of corrensite (a structure of montmorillonite and chlorite mixed layers), and rectorite (a structure of pirofilite and vermiculite mixed layers). The area occupied by this type of soils in the Amazon region is small.

Soils covering the Cretaceous and Tertiary deposits of the southwestern Amazon region

These soils began evolving one or two million years ago during the Andean orogeny. These sediments are mostly fine-grained, generating poorly drained soils. The clay fraction presents "low charge" montmorillonites. The sediments suspended in the rivers that drain these soils, contain large amounts of these montmorillonites, 30 percent illites and traces of kaolinite. The presence of feldspar in the sand fraction of the river's suspension indicates that mineral transformation is not as advanced as in the Paleozoic strip where this mineral is no longer present. These soils, athough poor in Ca and Na, are relatively high in K and Mg (Table 1) due to the high illite and montmorillonite content. The extension of these soils in the Amazon is considerable.

Soils covering the Quaternary flood plains

These soils have developed from transported Andean material. About 12 percent of the basin supplies 80 percent of the sediments (Sternberg, 1975). Montmorillonite and illite were the main minerals of the original sediments. Sudoite-type minerals are found in older deposits, which formed by accumulation of aluminum hydroxide in the intermediate layers of the original illite; abnormal kaolinite occurs probably due to the presence of K as a rare ion in the crystaline structure. The altitude of the flood plains can be attributed to varying river heights during the Pleistocene.

Table 1 summarizes the nutrient status of the various soils that we have described. We want to emphasize the relative poverty of the shield and Barreiras soils, and emphasize that they are the predominant soils type (60 percent) in the Brazilian Amazon.

Water

Amazon aquatic resources are extremely important to the region. While this work focuses on terrestrial ecosystems, we want to emphasize that both systems are strongly interrelated and should be integrated into a larger concept of regional landscapes (Hasler, 1975). A poor land use system could seriously damage aquatic resources, that are the main protein sources for most of the people who live in the Amazon.

In Amazonia, the water quality and morphology of rivers and lakes clearly reflect the geological and pedological division described above. This is stated in many papers by Sioli (*1950, 1951, 1967, 1968a, 1975b*), who describes three principal types of rivers in the Amazon region: rivers of white water, of clear water, and of black water.

Rivers of white water

"White water" rivers are characterized by their turbid waters, that have a high suspended particle content (40-300 mg/liter). Most of these rivers have their headwaters in the Andes or in the Pre-Andean regions, and carry relatively large amounts of dissolved electrolites, and clay minerals (montmorillonites and illites) in suspension (Irion, 1978a). While the Amazonas, Madeira and Purus Rivers are classic rivers of this type, the Branco River which originates in the upper regions of the Guianas shield, carries close to 90 percent kaolinite in its suspended material (Irion, 1976a) and has a low level of dissolved electrolites. The term "white rivers", however, generally refers to the rivers which carry Andean sediments.

Rivers of clear water

"Clear waters" go from yellow-green to light olive in coloration. They are clear and transparent because the load of suspended particles is never greater than 5 mg/liter. Their headwaters are located in the plateaux of the Brazilian shields, in the Guianas shield or in the Barreiras Formation, draining clay soils covered by tropical forest formations. The waters are characterized by low levels of dissolved electrolites, and pHs between 4.5 and 7.8.

Rivers of black water

The color of the water is olive, dark brown or reddish brown, transparent, with less than 5 mg/liter of particles in suspension. The headwaters are located in the plateaux, draining generally very deep Podzols (Klinge, 1967) covered by "campinaranas" (thin forest on sandy soils), "campinas" (scrub forest on white sand) and grasslands on sandy soil. These waters are extremely poor in dissolved electrolites, with pH between 3.8 and 4.7. Dissolved organic substances give their special color to the Rio Negro, Cururu River, and many small rivers and creeks; clear and black water brooklets could be found in the same area. While the former have their origin in Latosols, the latter are associated with podzolic soils.

Lakes

During the Monastirian thermal period, the Amazon shore line level was 15 m above the present level. With advancing glaciation in the temperate zone, large quantities of water stored in ice caps resulted in a drop in sea level of some 100 meters, deepening valleys of the Amazonian river basins. In the post Pleistocene period of the last 18.000 years sea levels rose, and these deep valleys were drowned by rising water levels and formed rias or ria lakes. The mouths of the Tapajos and the Negro River are very striking examples of this process. The large ria lakes when they are fed with water sediments in many cases have gradually filled in and formed wide holocene flood plains, with many smaller "varzea lakes" (Irion, 1978).

Biological productivity

The best conditions for biological productivity are found in the várzea lakes that are fed by white water, rich in electrolites. When the suspended particles settle, light penetration is good. Much of the primary productivity of these waters is due to the floating meadows. Clear water rivers, although poor in nutrients, are very transparent to light and so have intermediate productivity. Black water rivers are less productive due to extreme chemical poverty of their waters and moderate light penetration (Sioli, 1968b; Fittkau *et al*, 1975).

The water level of the Central Amazon rivers is subject to a more or less regular annual cycle of floods of considerable amplitude (10 m) and high unpredictability (Yanasse, 1979); particularly as one moves closer to the mouth. The interrelation between the aquatic and terrestrial systems is a very close one. During the overflow large extensions of the várzeas (plains flooded by white water) and igapos (plains flooded by black water) become submerged. As the river level rises there is sequential occupation of the flooded forests by aquatic animals, many of which feed upon fruits that come from forest trees (Gottsberger, 1978; Smith, 1979). The várzea forests obtain nutrients from the innundation (Irmler, 1978); however, as Walker (1980) has pointed out, the flood plain forests also contribute greatly to the secondary production of the terra firme rivers and streams.

Vegetation

There are several papers on the Amazon vegetation (Ducke and Black, 1973; Pires, 1973; Prance, 1975a and 1978). The RADAMBRASIL Project (Brazil, 1973, 1979) already mentioned, published detailed phytoecological maps related to the Brazilian Amazon, that still need to be interpreted. This paper will adopt the classification presented by Prance (1978), with the observations compiled by Brown (1979).

Table 2 shows the main vegetation types of the Amazon region, according to Prance (1978). The terra firme forests cover 85 percent of the Amazonia. In the area mapped by the RADAMBRASIL Project, which includes some non-Amazonian areas and omits small southern Amazonian strips, tropical forests cover 75 percent of the total area. Bamboo forests are found in Acre state, covering 3 percent of the mapped area. Forest in permanent or periodically flooded areas covers 5 percent of the mapped area, while open formations such as savannas, campinas, montane, coastal or riverside vegetations account for 15 percent. During the vegetation survey by the RADAMBRASIL Project in 1971, 4 percent of the region was under secondary vegetation and agricultural activities. Today, this figure must be doubled (Brown, 1979).

Table 2. **Main vegetation types in the Amazon region.**

1. TERRA FIRME FOREST (unflooded)
   a. Highland forest with abundant biomass
   b. Cipo forest (mainly in the area of Tocantins and Xingu)
   c. Lowland forest with reduced biomass
   d. Campina forest over sandy soil
   e. Dry forest of transition areas
   f. Montane and cloud forests
   g. Bamboo forest of the state of Acre
   h. Other kinds of lowland thin forest

2. FORESTS IN FLOODED AREAS
   a. Regularly flooded
      i. Floods caused by the annual cycles of rivers
         - Flood forests with white or clear water = seasonal várzea
         - Flood forest with black waters = igapó

      ii. Floods through tides
         - Salt water = mangroves
         - Fresh water = tidal várzea

      iii. Floods caused by irregular rains = forest subject to short floods

   b. Permanently flooded = swamp forests

3. TERRA FIRME SAVANNA (unflooded)
   a. Amapá
   b. Cachimbo-Cururu
   c. Madeira
   d. Roraima
   e. Trombetas-Paru
   f. Marajó
   g. Llanos-Gran sabana
   h. Others

4. VARZEA SAVANNA (flooded)

5. CAMPINAS (Low vegetation over white sand)
   a. Caatingas from upper Negro River
   b. Campinas of lower Negro River
   c. Others

6. MONTANE VEGETATION IN THE BORDERS OF THE AMAZON REGION

7. COASTAL VEGETATION (dunes)

8. RIVER BEACHES

Source: Prance, 1978.

High biomass forest is the predominant vegetation type. The RADAM-BRASIL Project subdivided these forests in some principal types whose distribution seems to be related to the geological division of the region rather than floristics. Brazilian shield vegtation is more diverse than that of the Guiana shield. Great continuous extensions of a given vegetation type exist in the Guianas shield, while in the Brazilian shield, there is a mosaic of vegetation types (for example, the high forest and open forests, with and without palm trees). This could be a transition effect between the Amazon forest lowland domains and the plateaux covered by cerrados of Central Brazil or it could be a result of climatic history.

The campinaranas, which encompass 3 percent of mapped areas, occur in wide extensions, pure or mixed with high forests in the upper Negro River. Always associated with Podzols and hydromorphic soils, they certainly contribute to the black waters formation of the Negro River (Klinge, 1967).

Structure and Function of the Terra Firme Rain Forest in the Amazon Basin

The primary productivity potential of the Amazon Basin is very high due to practically ideal conditions for photosynthesis: abundant water, solar insolation and CO_2. Lieth and Whitakker (1975) indicate that the productivity of the Amazonian area can be over 8 t/ha/year. This fact has led to perhaps overly optimistic appraisals of the agricultural productivity of the region, both for food and bioenergy production.

In spite of the very high potential productivity, the region has remained undeveloped. While there are clearly important historical, social and economic factors that are central to an understanding of the underdevelopment of Amazonia, there are also important ecological parameters that have limited human exploitation by conventional agriculture. Two aspects of Amazonian forests deserve special attention: species diversity and nutrient cycling.

Species diversity

Recent research has shown extraordinarily high species diversity in virtually all life forms found in the Basin. Klinge and Rodrigues (1975) found in 0.2 ha 505 plant species taller than 1.5 meters, encompassed by 59 plant families. Prance *et al.* (1976) identified 179 tree species with diameters greater than 15 cm in a 1 ha area. Schubart (1977) investigated the fauna of forest litter and found 425 individuals of 61 species of oribatid mites in 800 cm^3 of humus from primary forests. Many other examples could be cited.

These numerous species interact and co-exist with each other in a variety of relationships. Journals such as Acta Amazonica, Biotropica, Tropical Biology and Ecology are excellent sources for information dealing with the complex linkages among organisms in the humid tropics. We would like to emphasize that tropical food webs and resource competition are extraordinarily complex and that an organism is likely to be involved in several of the interconnections presented.

The large numbers of species that occur and the complexity of their interrelationships are a function of evolutionary history. Factors that influence this diversity have been an active area of research, as they are of considerable theoretical as well as practical interest. In this section, the general theories of diversity in the tropics are discussed as they apply to Amazonia. The evolution of the pattern of species diversity has been broadly described as a function of three main categories of factors: (a) Proximal (or geographic factors); (b) interactions within the communities themselves; and (c) dynamic instability.

Proximal factors

Climatic stability. This theory argues that regions with very moderate climates without great seasonal or diurnal fluctuations in temperature allow the evolution of finer adaptations than in areas where the climatic regimes are more erratic. A plant or animal in a stable climatic regime does not need to have the variety of behavioral responses that are needed for survival in an area of greater climatic variation. Finer specialization allows many different kinds of organisms to be accomodated (Mac Arthur, 1969).

Productivity hypothesis. The productivity hypothesis relates to two basic factors: (1) that the potential of the environment for biomass production is higher than other ecosystems (Lieth and Whittaker, 1975), and (2) only a small proportion of the energy assimilated by an organism will be used in regulatory activities (Conell and Orias, 1964), leaving a high proportion available for growth and reproduction. This can result in large populations that subsequently become isolated and speciation is the net result. Baker (1970) goes into a rather detailed critique of this hypothesis to which we refer the reader.

Spatial heterogenity hypothesis. This hypothesis claims that environmental complexity and gradients are more pronounced as one approaches the tropics. In the vast rain forest expanses of the Amazon lowlands the question becomes a bit more problematic. Pianka (1966) and Baker (1970) both argue whether at a micro level there is really that much habitat diversity. Ashton (1969) has argued convincingly, however, that part of the species diversity in Malaysian Dipterocarp forests can be accounted for by this hypothesis. It has been stated that the distribution of epiphytes correlates with microhabitat differentation. Baker (1970) feels that this theory should be given some recognition even though it will not apply equally to all animals and plants.

Climatic instability. This theory is enjoying popularity among researchers as a means of explaining the extreme diversity encountered in the Amazon. According to this theory, during Pleistocene dessications rain forest retreated to gallery forests and largely refugia located at the foot hills and coast. These remaining forest areas served as source area for rain forest species which differentiated from each other during periods of geographic isolation. Pleistocene refugia have been posited for plants, lizards and butterflies. There is also palynological and geomorphological evidence that indicates a different vegetation cover from rain forest. This hypothesis is discussed in greater detail later in the paper.

Available time hypothesis. This hypothesis implies that communities tend to become more complex with time and that older, stable communities will contain more species than younger ones. If tropical communities have existed longer than temperate ones (whose species numbers were reduced during glaciation), the high species diversity is explicable on this basis. The theory argues that tropical forests were not catastrophically affected by the ice ages and that the temperate zone was basically recolonized after glaciation, and hence has less "developed" communities.

The geographic theories explain the diversity of these environments based upon a wide array of external parameters largely linked to climatic constancy or lack of it. Underlying these theories is the idea of what Baker (1970) terms a "permissive" environment. Year round warmth and high primary productivity set the stage for a variety of evolutionary processes which result in high species diversity.

Interactions

Anocher class of theories deal with processes that are internal to the ecosystem.

Competition. The first of these is the "competition" hypothesis, first developed by Dobzhansky (1950). In the favorable and relatively stable growing conditions of the tropics, the factors that become more important in speciation are the biotic interactions. The more biological controlled nature of selection theoretically results in extreme resource partitioning.

Predation. This hypothesis suggests the predators and parasites influence biotic diversity because predation prevents any one prey species from building up its population to such an extent that it monopolizes resources (e.g., space, nutrients). Janzen's (1970) work on this topic appears to be particularly instructive. Further, pest populations act as a strong genetic sleve and are probably important in the evolution of secondary chemical compounds.

Dynamic instability

Huston (1979) has proposed that the high diversity in tropical forests is maintained by several factors including growth rates, density dependent factors (such as predation) and other aspects of community structure which prevent equilibration and dominance by any one species. He argues that more species can be maintained in a dynamically unstable configuration. In many ways, Huston reconciles the previous theories by emphasizing their importance in maintaining a dynamic disequilibrium, in which more species can be "packed".

Implications

The preceding discussion has reviewed the hypothesis used to explain forest diversity. The very dynamic nature of tropical forests means that exploitation of these ecosystems is extremely difficult. The high pest potential of weeds, insects and diseases is aggravated by the lack of a strong seasonal check such as occurs in the temperate zone during the winter; only periodic floods act in a similar manner in the várzea.

Nutrient cycling

To understand the dynamics of rain forests, it is necessary to discuss some aspects of nutrient cycling. Water, CO_2 and N all have a gaseous phase in their biogeochemical cycle that results in atmospheric and hydrospheric reservoirs. While there may be large reserves of these elements, their availability for plants may be limited by climatic factors, for example, the forest soils of Manaus are water deficient in the dry season (Franken, pers. comm.) or by other elements which limit biotic activity and uptake such as Ca, Mg, P, Na, Zn, etc., which have sedimentary biogeochemical cycles. The presence of these elements in the Amazonian ecosystems is a function of the geological substrate (which we have seen is frequently quite poor) and nutrient absorption from rainfall. Tight nutrient cycling is one of the keys to tropical forests and helps to explain many of the features of these ecosystems.

Klinge and Fittkau (1972) determined the biomass and nutrient distribution of Amazon high forest in a study site located near Manaus on yellow Latosols. The results of several publications (Klinge, 1973, 1975, 1976 a, b, c; Fittkau and Klinge, 1973; Klinge *et al.*, 1975) are summarized in Table 3. This table demonstrates that 70 percent of the N and P are present in the organic fraction of the soil while 90 percent of the remaining nutrients are found in the biomass. Klinge and Rodrigues (1971) examined litter production and element return in the Manaus forest. Litter production was on the order of 8 tons dry weight/ha/year. Other studies near Belém that evaluated litter production on terra firme, várzea and igapo sites, indicated a litter production of 8 t/ha as well. The nutrient quantities returned to the Manaus site in kg/ha were N = 106, P = 2.2, Ca = 18.4 and Mg = 12.6. In Table 4 the minerals returned to soils are compared with soil reserves to a meter depth as well as the nutrient stocks in the vegetation. While the data on mineral contents of throughfall are incomplete (Northcliff and Thornes, 1978) or unpublished (Franken, in prep.), the available data suggest that K, Mg, and Ca could be the most limiting elements.

Evidence of N fixation on legume roots or nitrogenase activity of roots has not been found in primary forests or older secondary forests on Latosols near Manaus (Sylvester-Bradley *et al.*, 1980). Soil N fixation is higher on more fertile sites with higher P contents such as the Indian Black Earths or in sandy soils where N seepage could be a problem.

These authors indicate that P might well be a limiting factor in N fixation on heavy textured yellow Latosols. Serrão *et al* (1978) have shown that one of the causes of degraded pastures is P deficiency. Another interesting aspect of N fixation in Amazonian forests is that termites fix N in the alimentary tract (Sylvester-Bradley, 1980), a finding that has rather interesting implications for the N cycle of the Amazon. The amount of N fixation by epiphylls is not known for Amazon forests.

Mycorrhiza have received a great deal of attention in humid tropical ecosystems (Went and Stark, 1968; Janos, 1975; Stark and Jordan, 1979). Singer and Araujo (1979) observed very few ectomycorrhizae in Amazonian high forests on yellow latosols, but they did find a broad array of leaf decomposing basidiomycetes. In campina forests, however, they found the reverse situation. Singer (1978) and Singer and Araujo (1979) argue that the rapid litter decomposition in the forests on Latosols is due to the broad spectrum of decomposers. In the campinas where the diversity of decomposers is lower (possibly due to secondary chemical compounds) and leaves are very sclerophytic, there is litter accumulation.

Table 3. **Distribution of organic matter, water (during the dry season) and mineral nutrients in different compartments of terra firme rain forest ecosystem on heavy yellow Latosols in the Manaus region.**

	Live vegetation				Dead vegetation		Soil				Total
	Aerial parts		Roots				0-30 cm		30-100 cm		
Plant biomass (t/ha)	406	(80.6)*	67	(13.3)	31	(6.2)	-		-		504
Humus (t/ha)	-		-		-		113	(48.2)	120	(51.5)	233
Mineral soil (t/ha) (without humus)	-		-		-		3346	(26.3)	9376	(73.7)	12,722
Water (t/ha)	279	(5.2)	188	(3.5)	33	(0.6)	1569	(29.5)	322	(61.1)	5,321
Nitrogen (t/ha)	2.43	(19.9)	0.56	(0.5)	0.29	(2.4)	4.26	(34.9)	4.66	(38.2)	12.2
Phosphorus (kg/ha)	59	(27.3)	7	(3.2)	3	(1.4)	71	(32.9)	76	(35.2)	216
Potassium (kg/ha)	434	(77.2)	62	(11.0)	8	(1.4)	58	(10.3)	0		562
Calcium (kg/ha)	424	(80.3)	83	(15.7)	21	(4.0)	0		0		528
Magnesium (kg/ha)	202	(67.8)	55	(18.5)	18	(6.0)	17	(5.7)	6	(2.0)	298
Sodium (kg/ha)	193	(66.3)	45	(15.5)	3	(1.0)	35	(12.0)	15	(5.2)	291
pH (KCl)	-		-		-		3.3-3.7		3.7-4.1		-
C/N	-		-		-		15.4		15.0		-

* Figures in parentheses are percentage values.

Source: Adapted from Klinge, 1976 c.

Table 4. **Rate of nutrient transfer from the vegetation to the soil through leaf and other fine detritus fall in relation to their supply in the soil and in the aerial parts of the vegetation.**

Component	P	K	Na	Ca	Mg
Leaf litter production (kg/ha/yr)	2.2	12.7	5.0	18.4	12.6
Soil 1 m depth (kg/ha)	147	58	193	0	23
Vegetation (aerial parts) (kg/ha)	59	434	50	424	202
% in relation to soil	1.5	21.9	2.6	-	54.8
% in relation to vegetation	3.7	2.9	10.0	4.3	6.2

The rivers and streams which drain the Barreiras Formation and the shields are very low in nutrient elements and reflect to a large degree the nutrient content of rainwater (Anon, 1972 a, b; Schmidt, 1972; Brinkman and Santos, 1973; Furch, 1976; Northcliff and Thornes, 1978). The low nutrient contents of rivers reflect that the mineral release by rock is low, and that the forest is a very efficient nutrient cycler.

Herrera *et al.* (1978) have described some of the nutrient conserving mechanisms in forests growing on low fertility sites under high rainfall conditions:

1. Dense rootmat formation with high nutrient retention capacity.
2. Direct nutrient cycling from the leaf litter to the roots via mycorrhizal fungi.
3. Nutrient conservation by plants, through:
   a. Reduction of herbivory by accumulation in leaves and roots of chemical substances from the secondary metabolism;
   b. nutrient reabsorption before leaf fall.
4. Physiological adaptation of trees to acid soils with low Ca and high Al levels.
5. Arrangement of fallen leaves on the forest soils in such a manner that residence time of water on the litter is reduced minimizing leaching.
6. The multi-strata forest structure acts as a filter to remove nutrients from rain waters; epiphyllic organisms are thought to play an important role in this process.

Forest dynamics

Forest dynamics, by which we mean the mechanism by which the forests maintain and regenerate themselves is only very poorly understood for the Amazon region. This kind of data has important implications for silvicultural practices as well as regeneration and reclamation of degraded sites and is one of the least researched areas of tropical biology. At this time we want to point out (very incompletely) some promising lines of research.

1. Reproductive biology of forest trees, including
   a. Pollination biology
   b. Phenology
   c. Germination biology
   d. Seedling ecology
   e. Mechanisms of seed dispersal

2. Ecophysiological adaptation of forest trees

3. Secondary succession

4. Insect and vertebrate population dynamics

5. Herbivory

The Amazon Forest and Climate

In this section we will briefly outline the paleoclimatic fluctuations which may have affected the biogeography of the Amazon region, the current forest/climate equilibrium and the possible climatic and hydrologic modifications generated by large scale forest destruction or forest substitution.

Paleoclimatic fluctuations

Glaciation in the temperate zone has frequently correlated with desert expansion and semi-arid periods in tropical regions (Flenley, 1979). The evidence for a dry phase in Amazonian Quaternary Paleoclimates has been compiled mainly by geomorphologists (Tricart, 1974; Journaux, 1975; Ab'Sáber, 1977) and palynologists (Van der Hammen, 1975; Absy and Van der Hammen, 1976; Absy, 1979). The presence of arkosic sand in the Equatorial Atlantic deep sea sediments suggests erosion under semi-arid climates (Damuth and Fairbridge, 1970) although this contention is disputed by Irion (1976c), who interprets these sands as unconsolidated Barreiras material which was eroded at the height of the Monastirian dry period when sea level was 100 m lower than today rather than during the more moderate Pleistocene thermals. Theoretically, during the dry period, the forests retreated to areas which could maintain a more humid microclimate. Regions that today are covered by forest are thought to have been under a cerrado or caatinga like vegetation (Ab'Sáber, 1977).

Forest fragmentation is thought to have had a profound effect on the speciation of plants and animals; true rain forest organisms tended to retreat into these "islands" of forest. In theory, the existence of refugia help explain the extraordinary biotic diversity in certain areas of Amazonia as well as the rather unusual distribution of certain species of birds (Haffer, 1969), lizards (Vanzolini and Williams, 1970; Vanzolini, 1970, 1973), butterflies (Brown, 1977, 1979) and plants (Prance, 1973, 1977). As the climate moved toward conditions similar to those of today, the gallery forest dispersed out from the rivers joining the expanding "refugia" to form a continuous forest cover. The areas where refugia meet are supposed to have exceptional diversity.

The importance of areas of high endemism and diversity has practical implications in land use. First, areas of extreme diversity and endemism ought to be preserved since the value of the gene pool of such areas is much higher than in other regions. The existence of centers of diversity also emphasizes the fact that there is a spatial as well as a structural component to Amazonian diversity which has rather interesting implications for pest management. This means we may have difficulty in predicting the kinds of pests that may shift onto a given agricultural crop, and that control mechanisms worked out in one region of the Amazon may not be applicable to another.

Climate and hydrological cycles

Climates of the world are not static. They fluctuate. The reasons for these fluctuations are not well understood but are possibly related to variations in solar activity. These climatic fluctuations have been associated with the greater or lesser extensions of principal vegetation formation (e.g., deserts, tropical forests, savannas) in other parts of the world. There is no doubt that climate in a general sense determines the vegetation of a region, and it may appear unlikely at first glance that large scale forest destruction could modify climates.

Vegetation and climate are interdependent and the ability of forests to modify microclimates is well documented (see, for example, Kittredge, 1948). The tropical forest and climate exist in a dynamic equilibrium because the forest has an important effect on the amount of water vapor in the immediate atmosphere (evapotranspiration), thus increasing the residence time of water in a given region. In the last five years there has emerged a considerable literature which quantified the Amazonian hydrological cycle and which shows the dynamic nature of the forest-climate equilibrium (Marques 1976, 1978; Marques *et al.*, 1977; Molion, 1975; Salati *et al.*, 1978, 1979; Villa Nova *et al.*, 1976). These works indicate that about 50 percent of the Amazonian precipitation originates from

Atlantic ocean vapor carried into the Amazon Basin by the trade winds. The remaining 50 percent is due to forest evapotranspiration.

Although we cannot precisely predict the consequences of forest destruction or forest substitution by other vegetation types, it is possible to infer some of the kinds of changes which might occur if the substitutions were of a radical nature:

- Massive forest felling would reduce the residence time of water in the Basin because of a decline in the waterholding capacity of the soil (Schubart, 1977). This would increase surface flow and reduce underground storage of water. Reduced permeability would be likely to cause severe river flooding in the wet season and, due to lower water volume in subsoil reservoirs, decreased flow during the dry seasons.

- Vegetation types that transpire at lower rates than the forest would reduce vapor availability in the atmosphere, and, consequently, precipitation. This effect would be most severe during the dry season.

- The Amazon area is at this time a source of water vapor for adjacent regions. There is a continuous water vapor flow from north to south at the southern boundary of the region throughout the year. It is possible that some of the rains from the central regions of South America depend on the water vapor produced in the Amazonia. Interrelations between the air masses of the Amazon and Orinoco basins are completely unknown so that the effect deforestation might have on south-north movement is highly unpredictable.

- Mean solar energy arriving in the region is about 420 cal/cm^2/day and is mostly utilized in water evapotranspiration. Fifty to 60 percent of the solar energy is used in this process. Forest felling, if it drastically changes the albedo, would modify this energy usage because a greater percentage of solar energy would probably go to air heating. The implications that this might have upon atmospheric dynamics in the Amazon Basin or in the surrounding regions is at this time impossible to assess.

- More solar radiation is absorbed in tropical regions than is lost via long wave radiation. Tropical regions have a net positive radiation balance, while in the temperate zone the radiation balance tends to be negative. One of the important mechanisms from the point of view of global climatic change might be modification of the heat transfer regime from the tropics to the temperate areas.

CO_2 and climate

The Amazon forest is not an important source of oxygen. The forest is a climax formation and thus consumes most of the O_2 that it generates in respiration. Organic matter is not being progressively accumulated. A net oxygen production would be indicated by organic matter leaving the region, perhaps in the form of organic and fulvic acids. The presence of humic and fulvic acids in black water rivers may indicate that the campinas and campinaranas could be contributing to global oxygen, and may be at a somewhat earlier successional state than other rain forest types. While no quantitative data exists, the contribution of these sources to O_2 supplies is probably small.

Forest are one of the major carbon sinks on the planet. The volume of CO_2 fixed in plants and organic matter is about three times that of the atmosphere (Woodwell, 1978; Woodwell *et al.,* 1978). CO_2 in the atmosphere is determined by interactions with the ocean, and global phytomass, that generate an equilibrium value of CO_2 at about 290 ppm. At the beginning of this century accelerated burning of fossil fuels and deforestation may have disrupted the CO_2 balance, and atmospheric carbon dioxide concentrations are increasing at the rate of about 1 ppm/year. Degens (1979), reviewing the literature, indicates that 10 billion tons of carbon are annually released by human activities. About half of the CO_2 generated in this manner is from forest destruction. Of these 10 billion tons, 2.5 remain in the atmosphere and 7.5 are absorbed by plants or by the ocean.

CO_2 concentrations absorb long-wave radiation and can reduce its radiation into space. When long wave radiation is maintained in the atmosphere it produces the "greenhouse effect" by heating the atmosphere. A doubling of the present CO_2 levels could raise atmospheric temperatures by 2°C, which would seriously affect global climates.

The Amazon forests store about 20 percent of the CO_2 of the planet's biomass.

Recommendations for Agricultural Development and Land Use in the Amazon Region

Given the variety of ecosystems present in the Amazon, development programs should be conscious of distinctive environmental attributes of proposed areas when projects are planned and implemented. Land use potential is variable and 1:1,000,000 scale surveys obscure the complexity of a given geographical area. Van Wambeke (1978) makes an interesting analysis of the limitations of resource evaluation in Amazonia based on broad scale surveys. We feel that given the poverty of the soils in most of the upland regions of the Amazon, the poor infraestructure and the difficulty of agronomic management, that priority for agricultural development should be given to other regions where infraestructure either exists or is far easier to implant and maintain, and where intensification is a real possibility. We refer not only to the cerrados but to other areas in central and southern Brazil.

Terra Firme

The poor soils of the Barreiras and shield formations are extremely difficult to manage. Substitution of forest by other vegetation covers, such as pastures, has not been particularly successful (Serrão *et al.*, 1978; Hecht, 1981). Further, purely export-oriented activities seem inadvisable even though this has been the basis of the Amazonian economy since the sixteenth century.

We object to this kind of activity mainly because the price of the extractive products in no way includes their real cost of production. Brinkman (1972) has calculated that the Brazil nut extraction resulted in a net export of 424 tons of P, 125 tons of S, 381 tons of K, 16.5 tons of Na, 143 tons of Mg, and 104 tons of Ca between 1950-1967. The price of Brazil nuts has never included the cost of replacing nutrients.

Forests

Areas on poor soils could conceivably be utilized for forestry but should avoid forest removal over large areas. Forestry is in its infancy in the Amazon, and management techniques desperately need to be worked out. We do not recommend large scale monocultures because the nutrient cycling efficiency of large scale uniform stands is unknown, and the pest potential is extremely high. We recommend caution, because a species such as *Gmelina,* which root-grafts with other gmelina trees very efectively, is excellent from the point of view of nutrient cycling but somewhat problematic in reference to root infections. We recommended forestry operations which mimic rather than replace the forest ecosystem.

We do feel that small plot production of fast growing species such as *Inga* should be included in agricultural programs to supply firewood. We also feel that more emphasis should be placed on native fruit and carbohydrate sources in development projects for local consumption.

Reserves

The Amazonian ecosystems are poorly understood (Schubart, 1979) in terms of forestry dynamics and genetic resources. Since these genetic resources are our "insurance policy" for the future, delimitation of reserves is necessary (Gottlieb and Mors, 1978; Prance and Elias, 1977). Conservation of gene pools is essential in the interfluvial regions, especially those areas of high endemism and high diversity (Brown, 1979; Watterberg *et al.,* 1976).

Indian areas also need to be defined. While preservation of Indians at a primitive stage is probable neither desirable nor realistic, the extremely destructive confrontations between Indians and settler populations must be limited. Our major source of knowledge at this time about potential use of forestry resources in the Amazonia is derived from Indian information. Delimitation of Indian reserves should be a major priority throughout the Amazon since their cultural and biological heritage is irretrievable, once destroyed. As Prance (1977) has put it, "Extinction is forever".

Várzeas

The várzeas are annually flooded with sediments from the rivers. The flooding, often considered an obstable to development in many areas, is one means of controlling pests, and also acts to renew soil fertility. Integrated development on the várzeas which would include a fishing component should be given priority. Aquatic resources have been the basic protein base for Amazonia historically and in the present (Smith, 1979; Goulding, 1979; Junck and Honda, 1976). Pleistocene flood plains which are not flooded but have higher fertility are also of interest for agriculture. Sediments from várzea lake bottoms may have potential to be used as fertilizer on adjacent terra firme areas (U. M. Santos, personal communications). These studies should be integrated with the studies of peasant economies and rural sociology of riparian peoples who have experience in várzea colonization (Sternberg, 1956), so that the most appropriate models of agricultural projects can be effectively determined.

INPA Programs

We have emphasized that Amazon development should proceed cautiously with a great deal of research. This research should be basic ecological research on natural systems, as applied to the development of agrosilvicultural, agricultural and fishing systems.

INPA (Instituto Nacional de Pesquisas da Amazônia) has been working on a number of projects towards these ends. One is the ecological management of tropical rain forests; this is a study similar to the Hubbard Brook study in which energy and water balance, and the nutrient cycle for a primary forest are being determined for a 20 km^2 watershed. In a basin adjacent to this forested one, several management techniques, both silvicultural and agricultural, are being tested to determine the impact of various production techniques; research on forest dynamics occurs in both basins.

Another project in which INPA is involved deals with the minimal critical size of ecosystems. In this study, forest islands of different sizes, in the middle of pastures, are studied for recolonization rates, extinction rates and factors maintaining ecological diversity. These are examined in relation to the reserve sizes. This project has very interesting theoretical as well as practical applications.

INPA is also working in forest management, wood technology and basic agronomic studies which include the collection and propagation of a wide variety of native Amazonian fruit trees. This planting material is also widely distributed in the region. The soils department of INPA studies the physical and chemical properties of soils and the role of microorganisms in the P and N cycle of cultivated as well as native species. Studies on nutrient cycling based on reutilization of human waste are being carried out and more emphasis is being placed on tree crop farming. A project on alternate energy sources shows that the use of charcoal, hydropower, and solar energy are particularly appropriate to the Amazon region. There are also fishery projects, including pisciculture.

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Agricultural Research

Production of Annual Food Crops in the Amazon

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Introduction

Although much has been said about the rich, luxuriant Amazon, little has been done to understand it from the viewpoint of its adaptability for annual food crops. Field crop production could support future migrations to Amazonia that will occur due to demographic pressure and the frontier expansion of countries such as Brazil, Peru and Ecuador.

The mystique of Amazonia and controversy about its food production potential are due, in large part, to contradictory predictions that have not been scientifically proven and that have led to confusion in decision-making. However, some information does exist and suggests that with adequate scientific knowledge (Sánchez and Buol, 1975; Alvim, 1978, 1979; Serrão *et al.,* 1979; Toledo and Morales, 1979, etc.), it is possible to develop gradually the Amazon's agricultural potential. Careful manipulation of the existing conditions and the generation of an equilibrium between annual, perennial and forest crops and animal management is necessary.

The information presented here is based primarily on experiments of the Instituto Nacional de Investigación Agraria (INIA) and North Carolina State University (NCSU)*** on an Ultisol soil in the Yurimaguas zone of Peru, and information obtained by the Unidade de Execução de Pesquisa de Ambito Estadual (UEPAE)**** at Manaus, on Ultisol and várzea soils (flood plains) in Brazil.

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The Yurimaguas project has edaphic and climatic conditions and socioeconomic variables that are typical of subregion A (see Cochrane and Sánchez in this volume) of Amazonia (evergreen tropical rain forests) while the Manaus zone is representative of conditions in subregion B, that is, semi-evergreen seasonal forest.

The Shifting Agriculture System

The predominant agricultural system in Amazonia is a shifting cultivation developed as an adaptation to highly weathered soils of low fertility.

Shifting agriculture in Latin America has been amply described (Popenoe, 1960; Watters, 1966; Haney, 1968; Sánchez, 1976). In Peru, farmers clear with machetes 1 to 2 ha of forest during the least rainy period; then comes cutting up of trees and brush, burning and finally planting. Crops are planted with primitive instruments such as the "tacarpo" (dibble stick) used to make openings in the soil where seeds are placed. Crops used include maize, rice, cassava and cowpeas. Farmers remain on the site until production sharply declines after two or three years; then land is abandoned, and the secondary forest regrows. Farmers return between eight and 20 years later.

Shifting agriculture is the most widely used method in the humid tropics for cultivating annual food plants. It is practiced by more than 200 million persons on some 3.6 million hectares, or approximately 44 percent of the potentially arable or grazable land of the tropics (FAO, 1957).

In spite of the fact that average yields are low, shifting agriculture can be considered efficient because of the return per unit of labor and the low use of agricultural inputs. The system conserves an ecological balance when there is a high land to population ratio. But, when population densities increase, due to spontaneous or directed migrations, any agriculture with annual crops must be permanent and continuous.

In the humid tropics, rural settlement has almost always been initially based on shifting cultivation as the colonizations Tournavista-Pucallpa (Peru), Napo (Ecuador), Caqueta (Colombia) and the TransAm (Brazil) indicate. Colonists have often converted to low cost pasture or limited cultivation of permanent crops but still rely for food on slash and burn agriculture (Kirby, 1977). The experience of colonists and local peasants (caboclos) studied by Morán (1977) on the TransAm has shown that agricultural success is intimately linked to knowledge of soils, climate and indigenous resources. Their understanding of soils permitted them to select higher fertility soils, and to use adapted species (cassava) as the main crop. Settlers, on the other hand, planted rice, corn and beans without fertilizers or adequate technologies on low fertility Oxisols and Ultisols.

Production Factors

The step from shifting to continuous agriculture with annual crops requires a careful analysis of environmental factors. The soil can be carefully managed with an adequate system of clearing, application of fertilizers, incorporation of residues and fallows.

Plant production can be manipulated through genetic selection, and by using systems of sequential intercropping and relay cropping, and control of insects, diseases and weeds.

The climate is manageable indirectly by means of the planting seasons, and judicious use of the water provided by the rains. Soils of the Amazon are amply discussed in the paper by Cochrane and Sánchez; we will limit ourselves to review our experiences in soil management for annual crops, in the Yurimaguas Project.

Climatic factors

Comparative climatic data are presented in Table 1 for the principal Amazon colonization zones in Colombia and Brazil, and for Yurimaguas. The climate of Yurimaguas is humid, tropical, with a mean annual temperature of 26°C, an annual absolute maximum of 35.8°C and an average minimum on the order of 22°C. Precipitation is about 2359 mm/year, according to 21-year data from the Corporación Peruana de Aeropuertos Comerciales (CORPAC). Climatic variation is not great and favors cultivation of rice *(Oryza sativa)*, maize *(Zea mays)*, peanuts or groundnuts *(Arachis hypogaea)*, soybeans *(Glycine max)*, cowpeas *(Vigna unguiculata)*, cassava *(Manihot esculenta)* and plantains *(Musa paradisiaca)*.

The most important climatic feature is rainfall distribution. In the case of Yurimaguas, precipitation is distributed in such a manner that the rainiest months are October to April, with more than 200 mm/month; while in the so-called "summer" months (June, July and August) average rainfall is about 100 mm/month (Table 2), a situation similar to many other Amazon sites.

Table 1. **Climatic data for the principal settlement zones of Colombia and Brazil and for the experimental field at Yurimaguas, Peru.**

Location	Rainfall occurrence (mm)	Annual precipitation (No. days)	Relative humidity (%)	Evapo-transpiration (mm)	Average monthly temperature (°C)
Caqueta, Colombia	3850 (all months surpass 100 mm)	250	84	1100 - 1500	26
Napo, Ecuador	3000 (all months surpass 100 mm)	277	86 - 93	-	24
Altamira, Brazil	1697 (dry season is June - Nov., 6-month average is 50 mm/month)	-	79	1417	26
Yurimaguas, Peru	2359 (June, July, August average 100 mm/month; other months average 200 mm/month)	160	82	1050	26

Source: Kirby 1977, adapted by Valverde.

The average potential evapotranspiration of 90 mm/month means that the soil remains damp a large part of the year and permits cultivation of annual plants throughout the year.

In spite of the high precipitation, the basic problem for annual crops is the irregular distribution of the rains. For example, of the 93 mm of rain falling in June 1976, more than 70 percent fell on three consecutive rainy days. During the rest of the month, the crops suffered from severe water deficits. On the other hand, the 382 mm which fell in January were distributed mostly over 19 rainy days and the plants suffered from an excess of water. With a judicious design of planting dates and agronomic management, these critical periods can be alleviated.

Table 2. **Monthly distribution of rainfall during 1975 and 1976 at Yurimaguas, Peru.**

Variable	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
						1975							
Total (mm)	231	235	396	53	296	182	140	87	141	177	195	360	2493
(%)	9	10	16	2	12	7	6	4	6	7	8	15	100
						1976							
Total (mm)	382	67	222	245	167	93	65	126	129	401	230	219	2345
(%)	16	3	10	10	7	4	3	5	6	17	10	9	100
						23-year average							
Total (mm)	222	218	220	240	182	102	91	94	157	216	210	206	2158
(%)	10	10	10	11	9	5	4	4	7	10	10	10	100
						1977 average temperature (°C)							
Maximum	30.8	31.5	31.0	30.5	30.6	30.6	33.1	32.0	32.6	32.1	31.7	31.1	31.2
Minimum	22.0	22.2	22.3	21.9	22.5	21.9	17.9	19.9	19.6	21.1	21.1	21.2	21.1

Methods of forest clearing

Descriptions of clearing techniques are discussed extensively in Toledo and Serrão, elsewhere in this volume. We will discuss only the clearing data relevant to annual crops.

In 1972 traditional clearing methods were compared with clearing using a bulldozer (Caterpillar D-6), equipped with an ordinary blade, on an Ultisol covered with a 17-year old forest at the Yurimaguas Experiment Station. Results of the yields of rice, maize, soybeans, cassava and *Panicum maximum* grass, all of which received treatments with and without fertilizers and with addition of a liming amendment (Table 3), showed the superiority of the traditional systems of clearing, felling and burning (Seubert *et al.*, 1977). Additional studies (Seubert *et al.*, 1977) indicated that the harmful effect of mechanized clearing using conventional machinery was due to: (a) The low amounts of nutrients, which in the traditional method had been added through the ashes; (b) soil compaction problems that lower the infiltration rate of the soil; and (c) disruption of the fragile surface layer of soil.

The ashes and partially burned material add nutrients, and soil data demonstrate an increase in the soil pH, available P, Ca, Mg and exchangeable K, in addition to a decrease in exchangeable Al (North Carolina State University, 1974). The addition of 53 kg Mg/ha with ashes on Field II is considered very important because of the serious deficiency of this nutrient in the soils under production (Villachica, 1978).

Water infiltration rates at the end of a month (Figure 1) showed an average of 10.5 cm/hour for manual clearing and about 0.5 cm/hour for mechanized clearing. 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.

The partial removal of the surface soil layer when using heavy machinery also reduces organic matter. Seubert *et al.* (1977) observed that plots cleared with a bulldozer had lower quantities of total N and organic carbon. The negative effects of mechanical clearing on the soil also have been observed in Surinam (Van der Weert, 1974).

Preliminary studies done in the district of Suframa, Manaus, on an Oxisol soil (yellow clayey Latosol) indicate that both manual and mechanized clearing do not cause marked differences in the soil infiltration rate and compaction, and that the supply of available nutrients from the ashes is similar; nevertheless, it is still necessary to add phosphate fertilizers (UEPAE, 1979).

Clearing methods also have economic implications. In Peru, the costs 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 will remain practical.

Table 3. **Effects of two methods of forest clearing on production of crops in Yurimaguas, Peru. (Yields are the average of the number of harvests indicated in parenthesis for each crop).**

Crop	Fertility level*	Method of clearing		Advantage: (bulldozer vs. burning)
		Clearing, felling, burning	Bulldozer	
		— t/ha**	—	%
Upland rice (3)	None	1.3	0.7	53
	N-P-K	3.0	1.5	49
	N-P-K-Lime	2.9	2.3	80
Maize (1)	None	0.1	0.0	0
	N-P-K	0.4	0.04	10
	N-P-K-Lime	3.1	2.4	76
Soybeans (2)	None	0.7	0.2	24
	N-P-K	1.0	0.3	34
	N-P-K-Lime	2.7	1.8	67
Cassava (2)	None	15.4	6.4	42
	N-P-K	18.9	14.9	78
	N-P-K-Lime	25.6	24.9	97
Panicum maximum (6)	None	12.3	8.3	68
	N-P-K	25.2	17.2	68
	N-P-K-Lime	32.2	24.2	75
Relative average yield	None			37
	N-P-K			47
	N-P-K-Lime			48

* 50 kg N/ha; 172 kg P/ha; 40 kg K/ha; 4 tons lime/ha.

** Grain yields of rice, maize and soybeans; fresh root yields of cassava; annual dry matter yields of *Panicum maximum*.

Source: Seubert *et al.*, 1977.

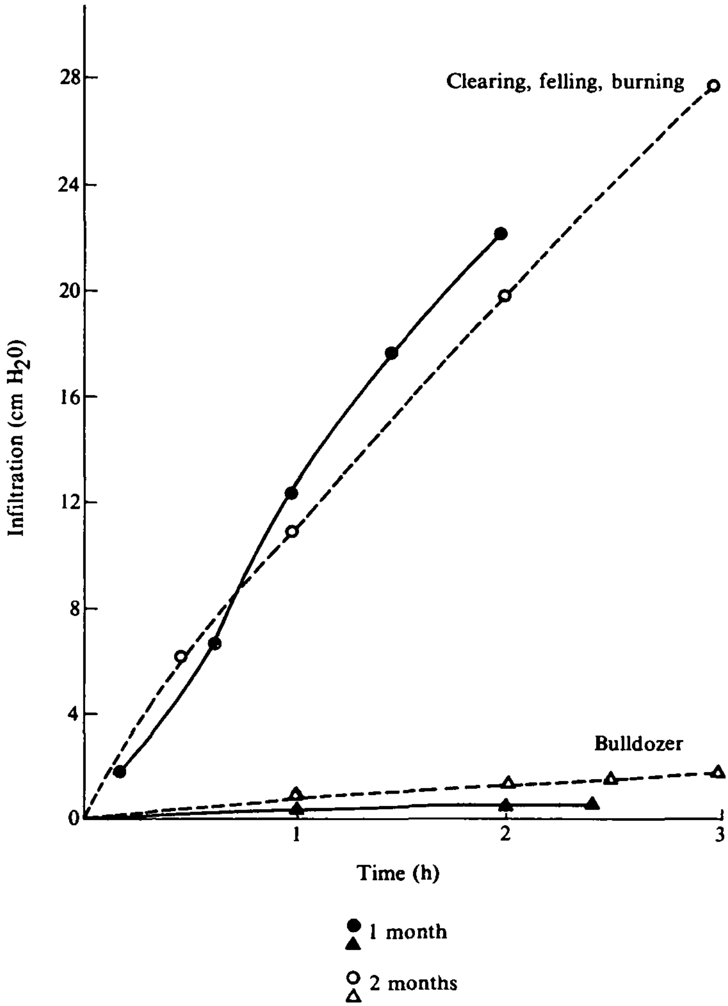

Figure 1. *Effects of two methods of forest clearing on soil infiltration rates at two periods after clearing. The humid tropical forest was on an Ultisol soil at Yurimaguas, Peru.* (Source: Seubert *et al.*, 1977).

Adaptation of Annual Crops to the Amazon

Annual crops include rice, maize, soybeans, peanuts, cowpeas and cassava. Table 4 shows agronomic characteristics, and the varietal adaptations, emphasizing interactions with the soil.

Table 4. **Descriptive agronomic characteristics of six annual crops important in the agriculture of the Amazon humid tropics.**

Crop	Species	Characteristics	Adaptation	Defects	Utilization
Rice	*Oryza sativa*	Erect, herbaceous plant; 0.6 to 1.5 m tall; vegetative period 110 to 150 days.	Has resistance to insects and diseases; does not require flooding.	Low yield potential; relatively responsive to fertilizers.	Direct consumption as food.
Maize	*Zea mays*	Erect plant; 1.5 to 2.0 m tall; vegetative period 90 to 120 days.	Little resistance to acid soils and aluminum; little resistance to high day and night temperatures.	Heavily attacked by insects and diseases.	Directly for food while green; as an industrial crop for milling.
Soybeans	*Glycine max* (L) Merr	Erect, herbaceous plant; 0.3 to 1.5 m tall; good yield potential.	Requires favorable fertility and moisture conditions.	Low seed viability; requires special *Rhizobium.*	Industrial; direct consumption; forage and mulch.
Peanuts	*Arachis hypogaea* L.	Herbaceous, trailing, climbing plant; vegetative period 100 to 180 days.	Better on sandy soils; matures during times of strong sunlight.	Susceptible to foliage diseases; difficult to harvest manually.	Industrial crop (oil and oilcake); consumed dry as food.
Cowpeas	*Vigna unguiculata* (L) Walp.	Erect, rapid grower; 0.4 to 1.5 m tall; vegetative period 65 to 180 days.	Adapted to sandy and clayey soils and to high temperatures.	Susceptible to insects and diseases.	Consumed as a vegetable green and as a forage and mulch when dry.
Cassava	*Manihot* sp.	Erect stem; 1.5 to 2.0 m tall; vegetative period of 10, 12 or more months.	Resistant to heat, acid soils and exchangeable aluminum.	Susceptible to insects and diseases; harvest is difficult.	Direct consumption or as an industrial crop (flours).

Source: Rachie and Roberts, 1974, adapted by Valverde.

Rice. The upland method is the most common system of growing rice in the Amazon region. The crop is cultivated without flooding, transplanting or formation of boundaries or dikes, and the system depends completely on the prevailing pattern of rains. Upland rice is widely planted in Amazonia in shifting agriculture. A review of upland rice for the Amazon jungle of Peru has been made by Sánchez (1972), Kawano and others (1972), and globally, by the International Rice Research Institute (IRRI).

Since 1969, hundreds of rice lines furnished by IRRI and the National Rice Program of INIA have been tested in the Yurimaguas zone. Only one introduction, IR-4-2, has continued to demonstrate good tolerance to rice blast caused by *Pyricularia oryzae.* Even under deficient soil moisture conditions, rarely has blast incidence been greater than 2 percent. Under conditions of deficient K and/or soil moisture, this variety suffers severe attacks of brown leaf spot *(Helminthosporium oryzae).* With good soil fertility and moisture conditions, experimental yields of 4.5 tons/ha have been reached in an Ultisol.

In August of 1979, nine upland rice lines with some resistance to blast were introduced from the International Institute for Tropical Agriculture (IITA), in Nigeria. They have been compared with IR-4-2 and with a tall variety, Carolino, which is traditionally grown in Yurimaguas. These. introductions have demonstrated excellent resistance to blast, good yield potential, earliness and an absence of symptoms of attack from *Helminsthosporium oryzae* and *Rinchosporium orizae* (leaf scald).

In the Amazon region, especially in Brazil, efforts have been made to grow rice on the várzeas, and the potential of these soils for the seasonal production of rice seems promising. In Peru, at the San Roque Experiment Station at Iquitos, the two varieties Chancay and Inti have been tested. Chancay has yielded 3.5 - 4.0 t/ha and Inti, 4.0 - 5.0 t/ha; both have blast resistance and vegetative periods of 120 to 130 days. In the case of Brazil, UEPAE, at Manaus, has introduced lines from the Centro Internacional de Agricultura Tropical (CIAT) in Colombia, from IRRI, and from IAC at Campinas. Preliminary results show yields between 4.0 and 5.0 t/ha. Presently, the variety BR-1 is being planted; its experimental yields have reached 5.0 t/ha.

Maize. It occupies the most area, and is the second in production of the crops planted in tropical America. In Amazonia, maize is a component of the shifting agriculture systems; however, cultivars used are of low productivity and susceptible to lodging, low soil fertility and Al toxicity.

In Yurimaguas, selection of varieties began in 1976. The objectives were to obtain: (a) Varieties of high productive potential in high and low energy production systems; (b) tolerance to prevalent diseases and insects such as brown leaf spot (*Helminthosporium* sp.), ear rot (*Diplodia* sp.) and the stalk borer (*Ostrinia nuvelalis*); (c) short plants to prevent lodging; and (d) selected populations of non-hybrids so that farmers can select and produce their own seed.

The Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) has a great deal of information about this crop. About 20 tropical selections from germplasm of the National Maize Program (Peru) and from CIMMYT have been tested, utilizing a "Yellow Short Plant" composite as a control, and the traditional varieties Polvozera and Cuban Yellow and a hybrid specifically developed for the Peruvian jungle, PMC-747. These selections have demonstrated good production, good photosynthetic distribution and good grain-filling qualities, although the tall height of the plants is one of their principal disadvantages.

In Brazil, UEPAE at Manaus is testing 20 cultivars from CIMMYT and composites improved with existing Amazon genotypes (Crioula de Roraima, Cavalo, Común, Boca de Acre and Vermelho). Results for the várzea soils show that the variety Piranao planted in September and October produces yields of 4.5 t/ha. For the Oxisols, with good fertilization, varieties Piranao, Mezcla Amarilla, Suwana OMR (Por-105), yellow dent (BR-104), Tropical Intermediate, Yellow Funky Por 21 perform well.

Soybeans. In recent years, the area in soybeans has constantly increased. Production is primarily located in Brazil and Colombia. Although soybeans evolved in humid regions (Rachie and Roberts, 1974), production has largely occurred at intermediate elevations and at higher tropical latitudes. Although ample literature exists about soybean cultivation for those conditions, information for the Amazon basin is still rather scarce.

The crop was introduced to Yurimaguas in 1974, by the Tropical Soils Program, to serve as an annual crop in a rice-maize-soybean rotation. Soybeans have shown very good adaptability and grain yields (up to 3.5 t/ha) when optimum management and soil fertility conditions are present.

The majority of the cultivars now available for the region come from the United States; the best adapted ones are Improved Pelikan, National and Jupiter. Of these three, Jupiter has shown much more tolerance to low soil fertility, and particularly to Al toxicity. Local farmers have accepted the crop and use it for domestic consumption. It is also actively sold in local markets and strong demand exists for its use in preparing milk, flour and soybean cheese.

Selection in soybeans is directed to seeking tolerance to diseases that prevent its development, especially during prolonged rainy periods. These diseases are leaf spot *(Cercospora sojina)*, pod and stem blights *(Diaporthe phaseolorium* and *D. varsojae)* and purple spot *(Cercospora kikuchii)*. All reduce yields and grain quality, especially at the grain-filling stage of development. Another important aspect is the selection of genotypes with good seed viability and storage capacity.

Selection work, in cooperation with the International Soybean Program (INTSOY), begun September 1979, resulted in tests of 16 cultivars selected for the tropics. Among those demonstrating good yield potential and agronomic characteristics are the varieties Hardee, Davis, Tunía and Improved Pelikan.

Peanuts. They were introduced in 1974 as a rotation crop within the International Tropical Soils Projects of INIA-NCSU. Peanuts show wide tolerance for planting dates and demonstrate abundant nodulation with the local nitrifying bacteria performing efficiently.

One problem with peanuts is the incidence of thrips, probably *Schtothrips dorsalis* and *Frankliniella schultzea*, which could be factors in an incipient virosis. As for peanut rust *(Puccinia arachidis)*, resistance is present in the native Peruvian cultivar Blanco de Tarapoto (PI 259747) that is being used in breeding programs around the world.

Low levels of Ca in the soil seem to be the main limiting factor, but excellent results are observed after lime applications.

Cowpeas. They are very important in the diets of Amazonian populations and are considered to be the most extensive crop planted in the State of Amazonas, Brazil. They have acquired special importance in the humid tropics because the common bean (*Phaseolus vulgaris*) is not adapted to the local ecological conditions and is very susceptible to diseases and insects. In addition, local and national demand for cowpeas surpasses that for rice.

With the assistance of IITA, 28 lines, including 19 indeterminate semierect ones and 9 determinate, have been compared in Peru with a local determinate cultivar. Preliminary results indicate that the indeterminate lines are best adapted to conditions of the area, for use as a crop in sequential rotations. One of the reasons is their better flowering and pod formation which makes them less susceptible to drought, flower abortion and thrips attack. Second, they show better use of residual N, allowing the plants to remain green through the harvest period. Thus, a greater vegetative mass can be incorporated into the soil and nodule activity is not inhibited during the critical pod-filling period. In intercropping systems, an early determinate cultivar would be most desirable because it offers less competition to the slower growth of the accompanying crop.

In Amazonas, Brazil, dozens of cultivars have been tested on Oxisols and váezea soils; the variety IPEAN V-69, from Pará, has been outstanding, with a yield of 1.5 t/ha, and great potential under humid tropical conditions.

Cassava. This crops is also known in the tropics by the names casabe, manioc and tapioca. It is a tropical root crop widely grown on infertile, very acid soils. Because it yields well under low fertility conditions, it is the last crop planted within a rotational cycle of crops.

In the past, cassava improvement received little attention, but in recent years, CIAT has been giving it the importance it deserves.

Experience in the Amazon indicates that cassava is adapted to extensive areas of Oxisols and Ultisols because of its tolerance of low levels of nutrients, high acidity and high concentrations of Al and Mn. It is tolerant to drought and performs well even in areas where the rains are not uniformly distributed.

Per capita consumption of cassava in the Amazon is approximately 65 kg/year, and the yields, even without fertilizer, vary from 8 to 20 t/ha of fresh roots.

Programs to identify the most productive cultivars seek those most adapted to the existing soil and climatic conditions. For the zone around Yurimaguas, native selections have been tested that were collected in the Huallaga Central and Yurimaguas areas. The following varieties have been determined as most promising (all yields are from 11-month growing periods): Palo Blanco - Y (yielding 45 t/ha), Amarilla- Y (30 t/ha), Motelo Blanco-HC and Motelo Rumo-HC (27 t/ha), and Rica Chica (26 t/ha). Diseases and insects do not constitute major economic problems.

In the Amazonas zone of Brazil, it has been found that the most satisfactory varieties are Aroari Grande and Olha Raxo, while for the várzea areas the best ones are Juriti (21 t/ha), Mae Joana (20 t/ha), Macazeira Amarela (18 t/ha) and Manivao or Tucuma (13 t/ha). More than 200 clones from the germplasm bank of the Centro Nacional de Pesquisas de Mandioca e Fruticultura (CNPMF) are being evaluated in order to select high yield cultivars. The major disease problem found in this area is superelongation, caused by *Sphaceloma manihoticola.*

Cropping Systems with Annual Plants

Annual cropping strategies for Amazonia were evaluated in the following production systems:

Intercropping system. The cultivation of two or more crop species that develop simultaneously in the same furrow or alternate furrows in the same area, or that occupy the same area but are not in furrows.

Relay system. The planting of a second crop before the first one is harvested; the second crop is often planted as the first one is flowering.

Sequential system. The planting of a successive crop after the first crop has been harvested. Crops may be the same species (monoculture) or different species (crop rotation).

Intercropping system

This is the most common cropping system in the humid tropics of Amazonia, including the simultaneous cultivation of upland rice, maize, cassava and plantain, or sometimes, pineapple.

Rice is the first crop normally planted, at intervals of approximately 50 to 60 cm; maize and cassava are planted at spacings between 1.0 and 2.0 m, and plantain and pineapple at 3.0 to 5.0 m, which permit their foliage to develop adequately after the rice is harvested. After cassava is harvested, shade tolerant horticultural plants or legumes can be seeded, in order to utilize the space between the plantains.

Experimental results with intercropping obtained in Yurimaguas (Wade, 1978) indicate that maize and soybeans planted in May, cassava planted in the maize furrows in July, and cassava and cowpeas growing together in September (Fig. 2), yield a Land Equivalent Ratio (LER) of 1.5. A LER value greater than one reflects the relative advantage of intercropping compared to monoculture, with the first two decimals representing the percentage difference.

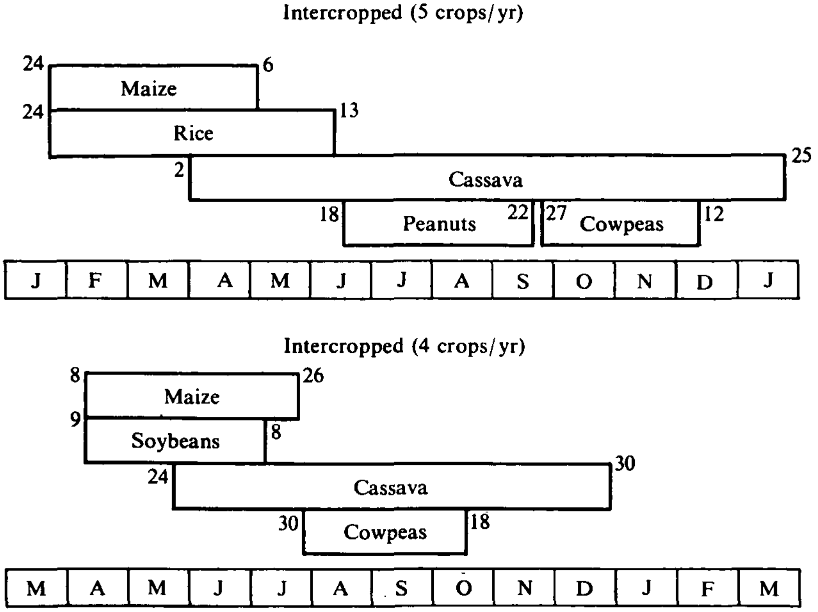

Figure 2. *Intercropped systems used at Yurimaguas, Peru.*
(Source: North Carolina State University, 1974-78.)

Wade (1978), using the scheme shown in Figure 2, increased the number of crops to five per year. Intercropping decreased the individual yield of each crop, expressed in t/ha (Table 5), but the LER calculated for the three intercropping systems was always higher than one. For example, the rice-maize combination, without applying any N, reached a LER of 1.62.

Table 5. **Yield of five intensive systems of multiple cropping, at Yurimaguas, Peru, 1975.**

Cropping system	Crop	Fertilizer levels		
		None	Low N-P-K-Lime *	High N-P-K-Lime **
			t/ha	
1. Triple crop sequence	Rice	1.78	2.37	2.34
	Maize	0.24	0.64	0.79
	Peanuts	1.59	1.72	1.43
2. Intercropped in rows, in relay	Rice	1.42	1.42	1.57
	Maize	0.10	0.30	0.60
	Peanuts	0.68	0.61	0.53
	Cassava	12.10	15.60	17.00
3. Intercropped in relay, 2 weeks of superposition	Rice	2.07	2.04	2.30
	Maize	0.68	0.77	1.05
	Peanuts	0.78	0.95	1.22
	Cowpeas	0.23	0.21	0.17
4. Intercropped in relay, 4 weeks of superposition	Rice	2.21	2.65	2.67
	Maize	0.14	0.36	0.40
	Cowpeas	0.47	0.62	0.52
5. Intercropped in rows, 3 sequences	Rice	1.31	1.40	1.57
	Maize 1	0.06	0.34	0.62
	Peanuts	1.33	1.25	1.44
	Maize 2	0.05	0.46	1.09
	Cowpeas	0.61	1.77	0.36
	Maize 3	0.53	0.55	1.79

* 0.5 tons lime/ha and 109 kg P_2O_5/ha incorporated before the first planting. Nitrogen and K were applied to each crop as follows: (kg N/ha and kg K_2O/ha), rice 30 and 23; maize 50 and 46; peanuts and cowpeas 0 and 46; cassava 0 and 0.

** Double the rates above.

Intercropped maize and rice complement each other very well; maize develops more rapidly in the first three months, and is harvested before ripening. At first, the rice grows slowly and is retarded by the maize; later it develops and matures well. In this case, the critical factor is the maturity period; the maize is harvested at 105 days and the rice 140 days after planting. In Manaus, Brazil, on várzea soils, César (1978) has shown the economic viability of intercropping jute *(Corchorus capsularis* L.), planted 30 to 45 days after maize.

The inherent advantages in this systems stem from minimizing the competition for light, water and nutrients. It is a system that better utilizes solar energy, provides more efficient management of diseases and control of insects, weeds and soils. It is better adapted to conditions of the small farmer who normally has available labor, but lacks credit for purchase of inputs and has limited areas for cultivation. Finally, it allows different crops to be grown the same year, thus permitting a better diversity of food to be available.

When only annual crops are used, these results must be extrapolated with caution because intercropping requires careful attention to details about soil type and fertility, type of plant, seeding dates, rainfall patterns, critical periods of labor, etc. However, interplanted crops are the most dynamic biologically; they allow high levels of productivity to be obtained for small farms with low levels of technology.

When the enterprise is of an intensive commercial type where better technology and higher yields of the individual crops are required, the intercropping system does not seem better than the intensive rotational cultivation system, which will be discussed next. It should be explained, however, that if the necessary capital is available, the intercropping of perennial and annual crops offers promising perspectives. For example, in Manaus, Melo (1978) has successfully designed an intercropping system of maize and cowpeas grown in areas of permanent plantations of rubber *(Hevea brasilensis)* and guaraná *(Paullenia cupana).*

Relay system

Planting of a second crop sequentially before flowering or harvesting of the first crop permits the harvest of a greater number of annual crops than those that would be obtained in sequential rotation. This system requires a small investment of capital and labor, since only one soil preparation and fertilization are needed each year. In addition, it reduces the risk of erosion and permits the adequate control of weeds; but, above all, because of a short period of competition between the crops, it yields better than those of other intercropping systems.

The relay system has been studied at Yurimaguas (Wade 1978; Bandy and Benites, 1977) and field results suggest that up to six crops per year are possible with the selective addition of fertilizers. Hildebrand (1976), in El Salvador, obtained up to seven crops in relay systems he has developed; but several factors have to be considered locally in order to obtain the correct combination of crops, varieties, spacing, planting date, and effect on succeeding crops. For example, Bandy and Benites (1977) showed that planting cassava within the maize row 20 or 30 days before maize was harvested allowed accelerated growth of cassava. However, the subsequent species to be intercropped can be affected. Table 6 shows what happened when peanuts and cassava were planted at the same time, compared with peanuts planted 20 days after cassava planting.

Table 6. **Yields of peanuts and cassava obtained in three methods of relay intercropping.**

Time peanuts planted with respect to cassava	Yield	
	Peanuts	Cassava
	kg/ha	
At the same time	1264	15,400
20 days later	596	16,800
20 days later (cassava plants cut to a height of 15 cm)	948	16,500

Monoculture

In Yurimaguas, monocultures produced drastic and continuous yield reductions for maize, rice, soybeans and peanuts. Table 7 shows reductions due to the climate, diseases and insects, for the monoculture system.

Table 7. **Reductions in yields (in metric t/ha) due to continuous monocropping at Yurimaguas, Peru.**

Crop	Sequence of monocrops					
	1	2	3	4	5	6
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
Soybeans	3.4	2.5	3.5	3.4	2.2	1.0
Peanuts	3.3	3.0	2.5	2.0	2.5	2.1

In upland rice, the principal limiting factor for continuous cropping is the lack of rain during certain periods of the year and the high incidence of brown leaf spot *(Helminthosporium oryzae)*. In low moisture periods the plant population is low, due to drought, and attacks from mole crickets *(Gryllotalpa* sp.) that devour seedlings shortly after germination.

Maize monoculture suffered during water deficits, and showed a gradual infestation by the stalk borer *(Ostrinia nuveladis)*. Crop ripening in the rainy season leads to difficulties in cob drying which can result in ear rots such as that caused by *Diplodia* sp.

In the case of soybeans, rainfall distribution has a direct relationship on the incidence of fungal diseases. When plants mature in the rainy season, both the pods and seeds are frequently attacked. On the other hand, water deficits during the flowering period affect pod formation and grain filling. Both the flowers and pods are aborted, and grains that are present are small.

There are few restrictions for monoculture of peanuts; but, yield decrease is directly related to thrips attacks and an increase in the population of nematodes *(Pratylenchus* sp.), whose control is not economical.

It can be concluded that monoculture for annual plants does not seem to be an economic alternative for the conditions studied, and that the system apparently creates favorable environments for the proliferation of pathogens; however, most of the adverse factors mentioned do not appear in a continuous rotational system.

Sequential rotational system for annual crops

The intensive continuous cultivation of annual crops practically eliminates most of the limiting factors present in monocultures at Yurimaguas. Crop rotation permits to determine the most favorable climatic conditions during the year for avoiding excesses or deficits of water, and for counteracting the proliferation and incidence of insects and diseases. Figure 3 shows the yield pattern when the cropping system was changed from a continuous sequence of rice to a rotation of rice-soybeans-peanuts. Modifications were made in the fertilization levels with the introduction of soybeans and peanuts; but, the plots that never received liming and fertilization showed yield increases that were due only to the effect of rotation.

The practical and economic feasibility of an intensive rotation system on the same area for more than seven years is also shown in the rotation (Figure 4). Once a suitable strategy was determined in 1976 for managing the soil in both rotations (rice-soybeans-peanuts and rice-maize-soybeans), it was possible to get average grain yields of 8-10 t/ha/year with these annual crops. These yields, comparable to those obtained in recently cleared fields, have been repeated for more than three years.

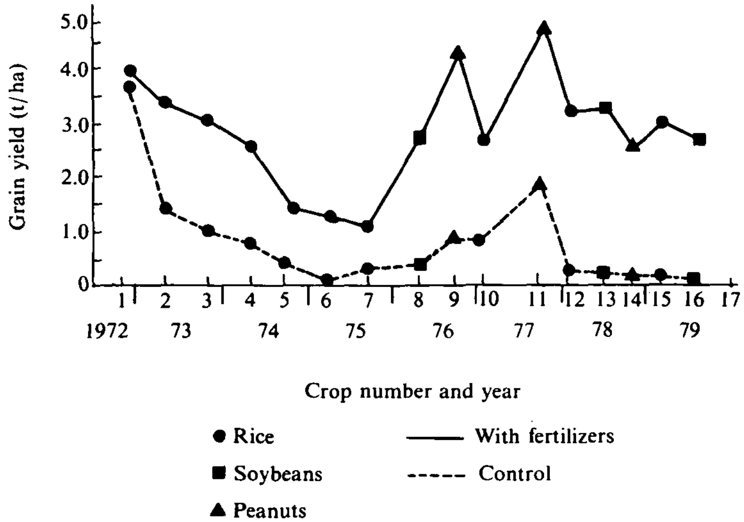

Figure 3. *Grain yields in a continuous cropping system of rice-soybeans-peanuts, at Yurimaguas, Peru, 1972-1979.*

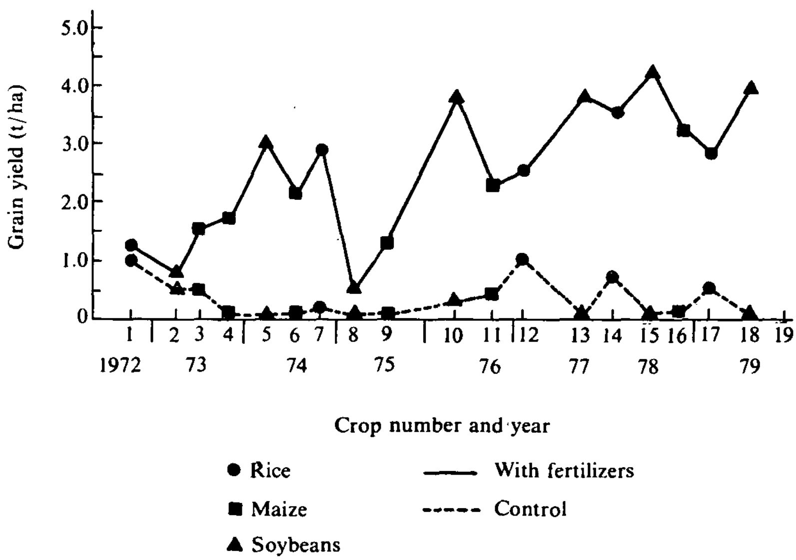

Figure 4. *Grain yields in a continuous cropping system of rice-maize-soybeans, at Yurimaguas, Perú, 1972-1979.*

Continuous, intensive cropping is possible for Ultisol and Oxisol soils in the Amazon and can be an alternative to shifting agriculture, if these areas are properly supplied with seed, fertilizers and pesticides.

Spacing, plant populations and seeding times

The traditional method of seeding and spacing between plants depends on the number of obstacles present such as trunks, branches, etc. and how they can be avoided in the field. For example, rice is sown at distances of 50 x 50 cm; maize, cassava and cowpeas are intercropped after the rice, generally alternating cassava and maize and spacing them at 4.0 x 2.0 m and 1 m, respectively. Cowpeas, a plant that grows very rapidly, is sown at random between the cassava and maize.

Experiments on spacing, populations and seeding times for each species were done to profit from the genetic potential of the new maize, soybean, peanut, rice, cowpea and cassava cultivars. The results are shown in Table 8. They indicate the best planting dates and densities for the six annual crops tested. These planting dates confirm the need for a crop rotation and the low success of monocultures.

The results reported at Manaus (UEPAE, 1979), show optimal plant densities lower than those of Yurimaguas, due probably to lower rainfall.

Weeds

There are two factors that force settlers to practice shifting agriculture: one is the gradual decrease in available soil nutrients and the other is the presence and proliferation of weeds. More than five years are necessary for regrowth to eliminate the majority of grassy-type weeds. Thus, if the farmer clears a secondary forest before weeds have been naturally eliminated, a second crop such as rice or maize does not normally succeed because of its inability to compete with and control weeds. One alternative to forest fallow could be a rotation with kudzu *(Pueraria phaseoloides)* because after one year of planting this very aggresive legume, weed development is hampered.

The weed problem is so serious that usually it is not possible to obtain good rice or maize yields with one weeding. Bandy (1979, unpublished data) more than tripled rice yields from 1.0 to 3.4 t/ha by three weedings. When weeds rather than fertility are the main problem, the success of an annual crop depends on early weed control.

Table 8. **Plant spacing and populations and planting times for annual crops at Yurimaguas, Peru and Manaus, Brazil.**

Crop	Plant spacing		Plant population		Planting period	
	Yurimaguas	Manaus	Yurimaguas	Manaus	Yurimaguas	Manaus
	cm		plants/ha		day and month	
Maize	80 x 25	100 x 40	50,000	25,000	20/ 7 to 15/10	25/10 to 15/12
Soybeans	60 x 8	(*)	200,000	(*)	01/ 9 to 01/10	(*)
Rice	25	30 x 30	25,000—100,000	30,000—35,000	15/10 to 01/02	01/10 to 30/11
Peanuts	60 x 11	(*)	150,000	(*)	01/04 to 30/09	(*)
Cowpeas	50 x 10	40 x 10	200,000	250,000	15/05 to 30/07	01/08 to 30/09
Cassava	100 x 50	100 x 100	20,000	10,000	Entire year	01/11 to 30/01

(*) No data

Source: INIA-NCSU, EMBRAPA-UEPAE.

Al Yurimaguas, the most common weeds observed with maize, peanuts and soybeans are: *Panicum trichoides* (ilusión), *Eleusine indica* (pata de gallina), *Physallis angulata* (bolsa mullaca), *Pyllantus niruri* (chancha piedra) and *Taunum paniculatum* (airambo); *Bidens pilosa* (amor seco) is usually present when cassava is grown. Other common weeds include: *Homoleasis arvesis* (paja comino), *Echinochloa crusgalli* (moco de pavo), *Leptochida filiforms* (ucsha), *Panicum virgatum* (remolina), *Cyperus diffusis* (cotadera) and *Triunfeta lappula* (caballousa), (Lewis, 1979).

Mulches

The use of mulches in annual crops in the humid tropics conserves soil moisture, controls weeds, reduces soils compaction, decreases soil temperature and increases the water infiltration rate. On the other hand, mulching is disadvantageous during the rainy season because soil moisture remains near the saturation point causing drooping problems and a micro-climate favorable for the development and spread of diseases.

Table 9 shows the variability in the effects of mulches on the yields of maize, rice, soybeans and peanuts. For four years, for 22 crops, the yield increase in most cases was minimal; and for rice, the effect was negative. There was no major effect in soybeans. Experiments on planting dates with and without mulching for soybeans (Figure 5), did not show yield increases with mulches except for the October planting date. This was due to a dry period that occurred in February 1979 which coincided with the grain-filling period of the crop.

When maize was planted in July, mulching was beneficial when there was a water deficit during the growing period. Cultivation of peanuts improved with mulches. The results showed there were advantages in certain times of the year (Figure 6).

The effect of mulches on soil temperature, weeds and soil moisture were studied by Wade (1978). He reported that mulches lowered the temperature of the upper 10 cm of soil by 2°C during hot days, and by 5°C in the afternoons.

Mulches had a favorable effect on soil moisture during dry periods of the year. But, under excessive moisture conditions, the effects were negative, especially with rice.

Table 9. **Effects of mulching on yields of several crops.**

Experiment	Crop	Yield: With mulching	Yield: Without mulching	Author	Date
		kg/ha			
System 1	Soybeans	2450	1840	D. Bandy	July 1979
System 3	Maize	3950	2710	D. Bandy	July 1979
System 3	Rice	1870	2800	D. Bandy	Feb. 1979
System 1	Rice	1850	2800	D. Bandy	Feb. 1979
System 3	Soybeans	2800	3110	D. Bandy	Oct. 1978
System 1	Peanuts	2350	2320	D. Bandy	Oct. 1978
System 3	Maize	4530	4040	D. Bandy	June 1978
System 1	Soybeans	3120	2920	D. Bandy	June 1978
System 3	Rice	2640	3000	D. Bandy	Jan. 1978
System 1	Rice	2650	2630	D. Bandy	Jan. 1978
System 1	Peanuts	2800	2200	D. Bandy	Sept. 1977
System 3	Maize	4300	3900	D. Bandy	Sept. 1977
System 3	Rice	2063	2589	D. Bandy	Feb. 1977
System 1	Rice	1298	2445	D. Bandy	Feb. 1977
System 3	Maize	2965	3610	H. Villachica	Apr. 1976
System 1	Soybeans	2213	2546	H. Villachica	Apr. 1976
System 3	Soybeans	1933	2300	H. Villachica	Sept. 1976
System 1	Peanuts	4167	4133	H. Villachica	Sept. 1976
Dead stubble	Soybeans	1000	1040	M. Wade	1974
Dead stubble	Cowpeas	640	740	M. Wade	1975
Dead stubble	Peanuts	2530	2880	M. Wade	1975
Dead stubble	Rice	2310	2740	M. Wade	1975
Average		2556	2488		

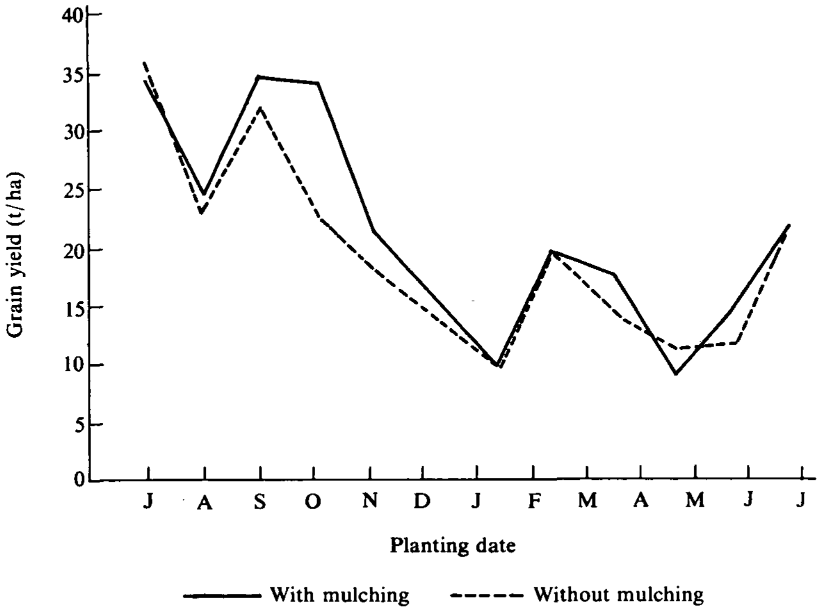

Figure 5. *Effects of mulching on soybean yields in relation to dates of planting.*

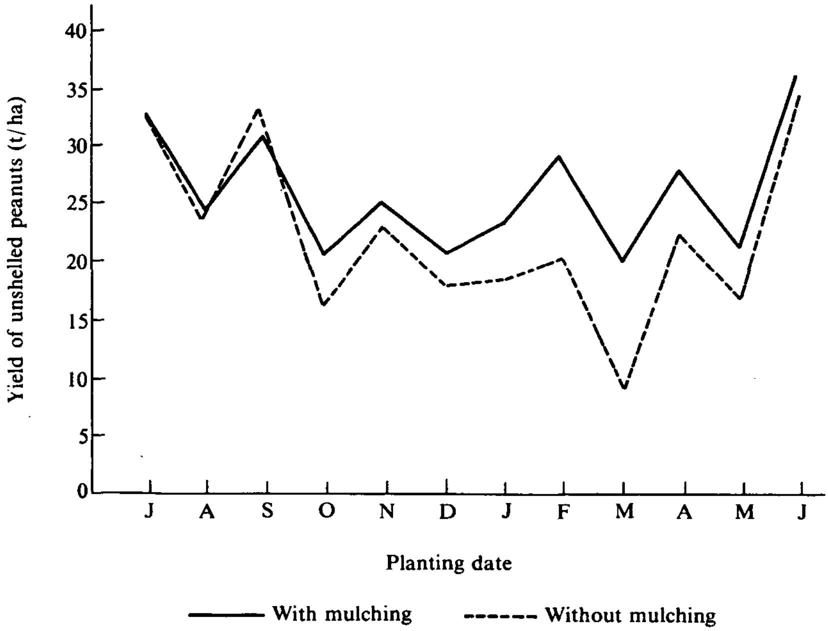

Figure 6. *Effects of mulching on peanut yields in relation to dates of planting.*

Fertilization

Research over nine years on an Ultisol in Yurimaguas indicates that it is feasible to have adequate continuous yields of rice, maize, soybeans and peanuts. The key to success depends on soil management, and knowledge about the fertility changes.

Requirements for maintaining an adequate fertility level have been investigated since 1972, using different cropping systems (see Figs. 3 and 4) and fertilizer and amendment rates (North Carolina State University, 1973, 1974, 1975 and 1976; Sánchez, 1979; Bandy and Benites, 1977; Villachica, 1978; Bandy, 1979, unpublished data). The data indicate that soil nutrient changes can be defined. Cleared and burned forests (Figure 7) provide the necessary nutrients for the first planting of rice or cassava, and good yields are generally obtainable. If no nutrients are available from ashes, an application of fertilizers is absolutely necessary, especially if the first planting involves a crop —such as maize, peanuts or soybeans— which is less adapted to acid soil conditions.

After the first crop, N deficiencies are evident due to the decrease of organic matter during the first growing year. Generally, the level of K is less than 0.2 meq/100 g considered critical for growth and normal development, especially for maize, and Al saturation increases to toxic levels for maize, soybeans and peanuts. P also reaches critical levels (12 ppm - Olsen) as does exchangeable Mg.

These events make it necessary to apply N-P-K fertilizers and to supply Ca and Mg to lower the Al saturation to non-toxic levels and to raise the pH. Using neutralization curves for acidity and P (Fig. 8), and after conducting dozens of field experiments, it has been determined that by applying 80-50-80 kg N-P-K/ha, plus the addition of 2-4 t lime/ha, it is possible to obtain acceptable yields of rice, maize, soybeans and peanuts. Due to N fixation in soybeans and peanuts, it is not necessary to apply N to these crops.

Without adding calcareous amendments, Wade indicates (1978) that the soil becomes extremely acid with a high Al saturation. Crops give maximum yields when the Al saturation is reduced to 30 percent or when the combination Ca + Mg is increased by more than 2 meq/100 g of soil, clearly suggesting that liming is reducing the Al toxicity and that the crops are responding to the supply of Ca.

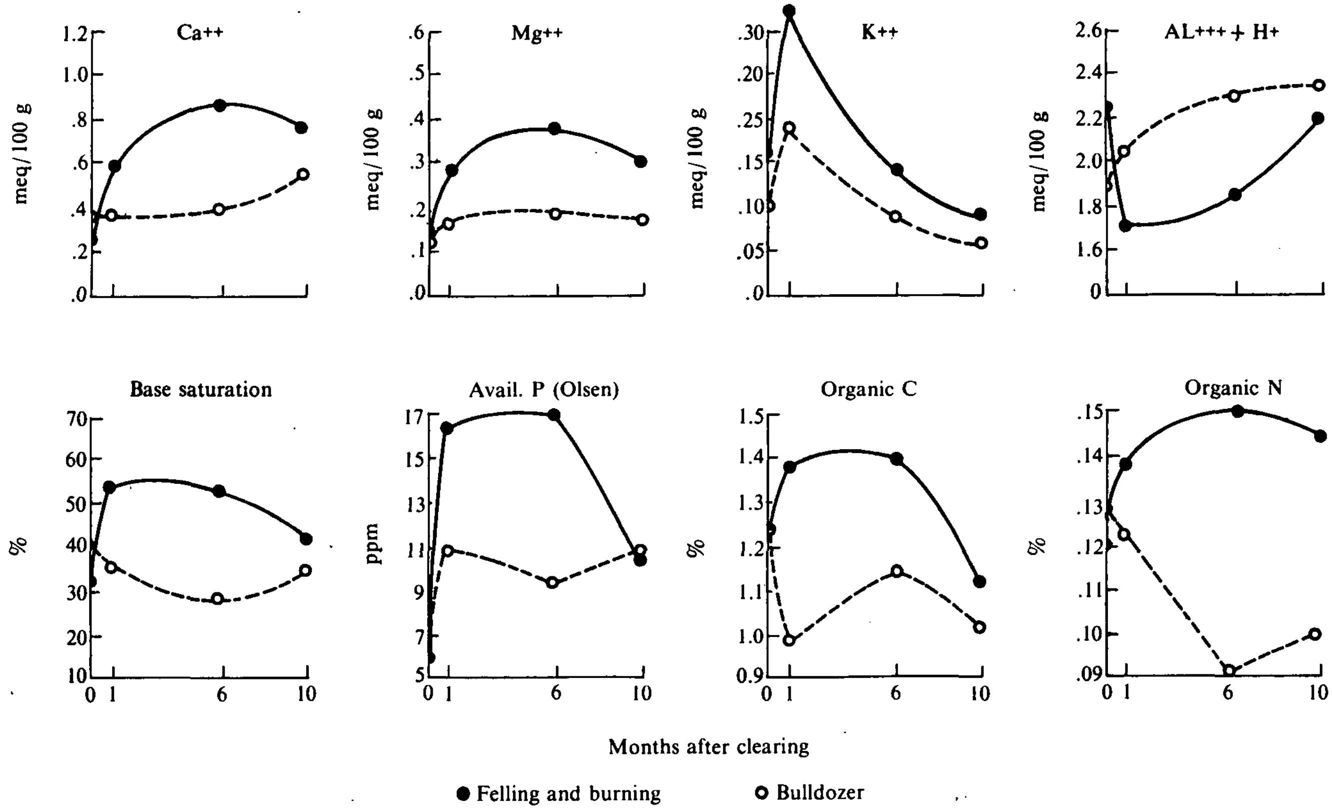

Figure 7. *Chemical changes in the plow layer of a sandy Ultisol soil as function of time and the method of clearing in Yurimaguas, Peru.* (Source: Adapted from North Carolina State University, 1974).

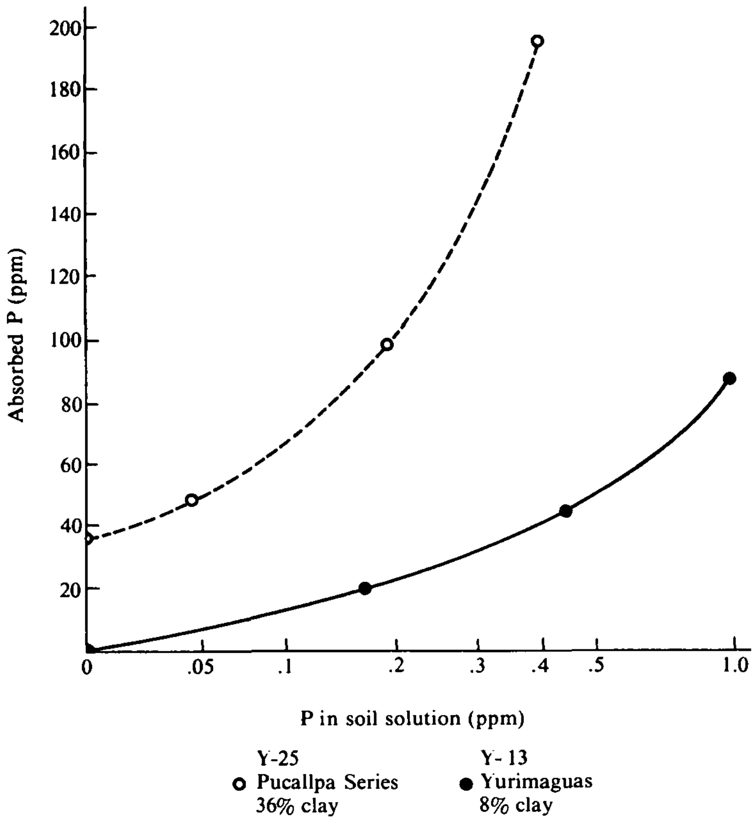

Figure 8. *Phosphorus fixation curves for soils of the Yurimaguas and Pucallpa Series, Peru.* (Source: North Carolina State University, 1973.)

Due to low levels of S and minor elements such as B, Cu and, in some cases, Mo and Zn, field and greenhouse experiments were conducted that showed responses to the application of these elements (Villachica, 1978). S deficiency can be controlled by using simple superphosphate. Microelement deficiencies are controlled by applying 1 kg/ha each of Cu and B to the crop, and 1 g of Mo to each kg of seed (Villachica and Sánchez, 1980, unpublished data). Zn deficiency has been observed primarily after the third year of continuous cultivation; presently, applications of 1 kg Zn/ha/crop are being made.

The rate of N application for rice and maize planted after the second and successive years varies from 80-120 and from 120-160 kg N/ha, depending on whether the crop was planted after a legume or a grass. The application of 30 kg/ha of N, or the inoculation of soybeans, is enough to maintain good yields.

The application of K fertilizer should be based on the K/Mg relationship. An application of 120 kg K_2O/ha and 30 kg MgO/ha provided good results in most cases where deficiencies of both nutrients were a problem. The use of dolomitic lime to supply Mg is possible. Table 10 shows the design of a fertilization program for the continuous production of three annual crops in the sequential rotation system.

Table 10. **Scheme for a fertilization program for continuous production of three annual crops (rice-maize-soybeans or rice-peanuts-soybeans).**

Months after forest clearing	Crop	Fertilization schedule
0	1	Forest clearing: Clearing, felling and burning. Grow small rice without fertilizers. Yield of 3 t/ha. Analyze soil to determine aluminum saturation.
5	2	Apply dolomitic limestone at 1.5 times exchangeable aluminum level and incorporate manually. Apply 100 kg P/ha as simple superphosphate to correct P and S deficiencies. Apply 60 kg/ha; if no dolomitic limestone is used for liming, add 30 kg Mg/ha for each crop.
12 later	5	Apply maintenance fertilizer at the following rates for each crop: 50 kg P/ha; 50-80 kg K/ha; Mg at rate to maintain K:Mg ratio at about 1:2. Apply to seed: 1 kg B/kg and 1 g Mo/kg. For rice, apply 80-120 kg N/ha and for maize, 160 kg/ha. Use no N for soybeans and peanuts.
		Analyze soils every six months to check for aluminum toxicity, P, K, Mg, S and micronutrient deficiencies.
		Conduct foliage analyses to check nutrient levels and other deficiencies. Apply 2 kg Cu/ every three crops.
	9	Liming, soil and foliar analyses, micronutrient checks and P:Zn ratios may all be necessary. Zinc could become critical.

Source: Villachica, 1978; Sánchez, 1979; Bandy, 1979.

On an Oxisol (Yellow Latosol) at Manaus, Wilms *et al.* (1979) have developed fertilization levels for a rotation of cowpeas and maize. To obtain yields of 1.5 t/ha of cowpeas and about 4 t/ha of maize, it was necessary to apply P (300-200-150 kg P_2O_5/ha over three years), K (90 kg K_2O/ha each year) and lime (2 t dolomitic lime/ha at the beginning) to maintain a minimum level of 5 ppm P, 0.15 meq K, and 30 percent base saturation in the exchange complex. P was the principal critical element.

With suitable management and efficient use of fertilizers, yields of annual crops in Amazonia are equal to or better than those in other tropical zones. For example, upland rice that is agronomically well managed consistently produces 2.5-3.5 t/ha; soybeans 1.5-2.5 t/ha; peanuts 3-4 t/ha (in shells) and cassava, between 20-30 t/ha of fresh roots. The exception is maize whose yields do not surpass 5 t/ha, even under optimum conditions.

Technology Transfer

In order to increase traditional yields, it was necessary to conduct a program of technology transfer in small farmers' fields. The objective was to demonstrate how to maintain a permanent, economical agriculture and to determine the best practical management for the Ultisols at Yurimaguas under field conditions.

Three levels of technology were determined and these were compared in 11 different localities. The three levels were: (I) Traditional, using farmers' own seed; (II) low technology, including the use of improved agronomic practices such as improved seed, correct spacing, weedings and, when necessary, application of insecticides; and (III) medium technology, which is basically the same as low technology but also uses medium levels of liming and fertilizers.

The results of the first year for maize, rice, soybeans and peanuts using the medium technology showed stable yields (Figs. 9 and 10). The use of only improved seed in the traditional system and the correct spacing and plant populations for maize increased yields from the first to the third harvest, despite a decrease in the availability of soil nutrients.

The settlers responded positively to most of the technology components, adopting improved seed (100%), insecticides (100%), correct spacing and plant populations (90%), weedings (60%), fertilizers (50%) but not liming.

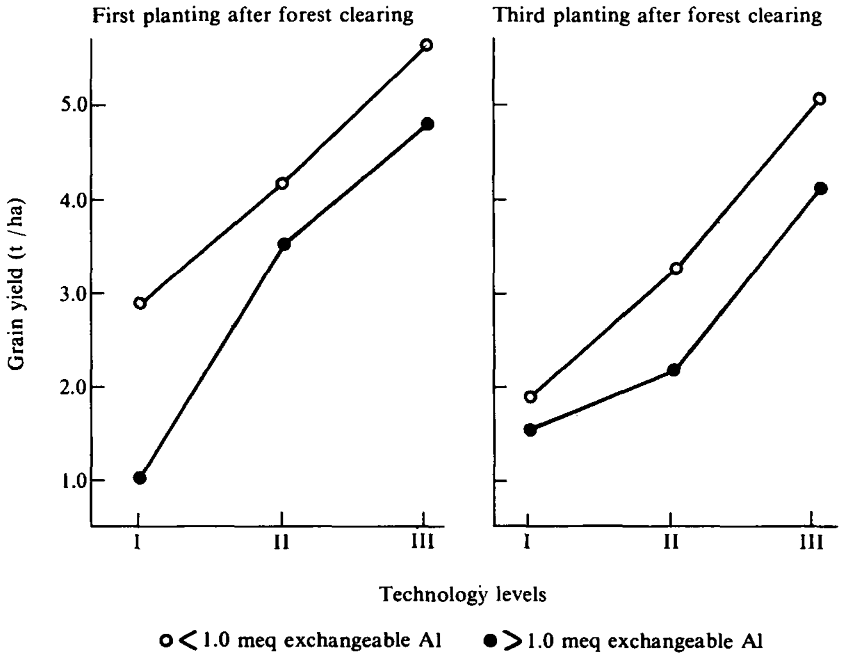

Figure 9. *Response of maize to three technology levels and to exchangeable Al.*

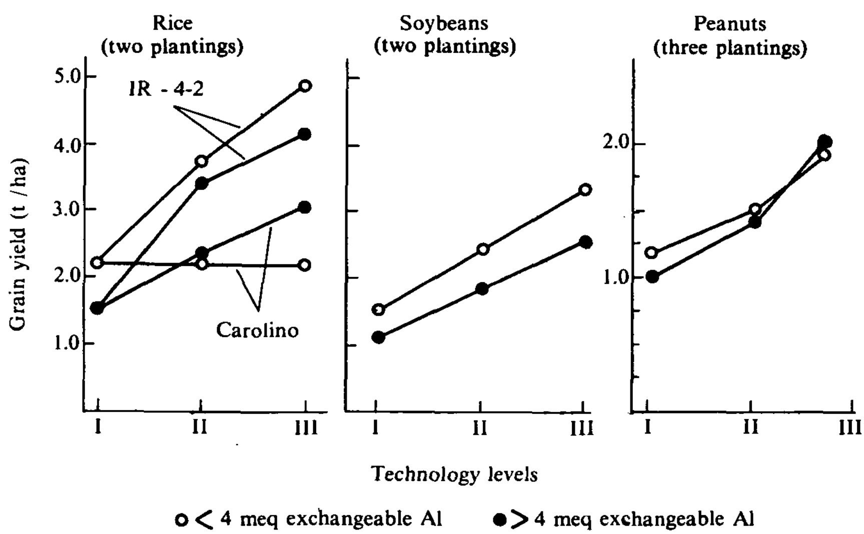

Figure 10. *Responses of rice, soybeans and peanuts to three levels of technology at Yurimaguas. (Average of 11 farmers' fields.)*

Weeding is an important practice if the settler accepts the reality of continuous agriculture. After one year 60 percent of the farmers understood the need to continuously control weeds. The farmers also recognized the increase in growth and vigor between systems (I) and (III) but they were not sure whether these were due to using fertilizers or using improved seed. None of them understood the necessity for liming.

Table 11. **Preliminary economic analyses for the use of three technology levels on eight farmers' fields, at Yurimaguas, Peru, 1979.**

Field location	Technology level	Yield (t/ha)	Value of harvest *	Production costs/ha**	Profit	Advantage of system (%)
			— 1,000 of soles		—	
Km 15	I	2.9	258	0	258	0
	II	4.6	445	53	392	52
	III	7.2	580	119	461	79
Munichis	I	2.4	204	0	204	0
	II	6.8	510	53	457	124
	III	8.6	658	119	559	164
Callao	I	2.2	216	0	216	0
	II	5.2	465	53	415	92
	III	7.6	675	119	556	157
Km 8	I	4.9	366	0	366	0
	II	7.2	553	53	500	37
	III	9.2	691	119	572	56
Km 22A	I	2.8	219	0	219	0
	II	4.9	422	53	369	69
	III	7.9	562	119	443	103
Km 28	I	5.3	389	0	389	0
	II	8.7	600	53	547	41
	III	10.5	791	119	672	73
Shucshuyacu	I	4.9	340	0	340	0
	II	7.7	629	53	576	69
	III	9.9	737	119	618	82
Km 22B	I	3.7	274	0	274	0
	II	4.8	385	53	332	34
	III	6.3	329	119	410	50

* 1979 market prices: maize, S$30/kg; rice, S$75/kg; peanuts, S$120/kg; soybeans S$120/kg.
** Purchased inputs included fertilizers, lime, insecticides, herbicides, seed, labor.

Source: Bandy and Mesias, 1979, unpublished.

Conclusions

The following conclusions were reached:

- Continuous and intensive cultivation of annual food plants such as cassava, rice, soybeans, peanuts and cowpeas is feasible in the different agricultural systems on Ultisol soils of Amazonia, especially when they are grown in rotation.
- Interplanted crops are the most biologically dynamic and are rather well-adapted to low technology levels. The total production from an area in interplanted crops can be greater than from monoculture, under conditions of the humid tropics of Amazonia.
- Broad genetic diversity now exists in annual plants discussed in this paper. This diversity permits the selection and/or adoption of suitable cultivars for conditions in Amazonia. Genetic work for obtaining resistance, principally to soil acidity, insects and diseases still remains to be done.
- Yields of annual crops are superior on fields cleared by the traditional method of clearing. Reasons for this superiority are: (a) the fertilizing and liming value of the ashes; (b) the absence of soil compaction; and (c) no disturbance or removal of the surface layer of soils, as occurs with mechanical clearing.
- Continuous and intensive agriculture results in a decrease in soil fertility if nutrients are not supplied. This can be prevented with proper fertilization and application of calcareous amendments, in accordance with properly correlated and continuous soil analyses.
- The response of annual crops to nutrients varies according to the species, variety, soil nutrient availability, and cultural techniques.
- A direct relationship has been shown between the agronomic performance of the crop, and rainfall distribution. In addition to influencing the physiology of the plant, rainfall affects the incidence and degree of insect and disease attacks, especially in the sequential monoculture system.
- In the annual crops studied, cassava and rice are tolerant to high acidity and the presence of exchangeable Al. Rice is most sensitive to climatic variations, especially rainfall.
- Traditional agronomic practices besides fertilization, like the timely, preventive use of herbicides, insecticides, fungicides and weed control adequately protect plants in the monoculture systems.
- The use of mulches slightly increases yields of maize, soybeans, and peanuts, but not those of rice. The favorable effects are due to lower soil temperature, weed control, protection against formation of surface crusts and, especially, soil moisture conservation during dry periods of the year.

The only manner by which a farmer accepts new practices is when he has sufficient income to permit him to assume the risk of expensive inputs. On the average, system (II) had a rate of return 65 percent better than the traditional system (Table 11). With the application of lime and fertilizers, farmers increased their returns more than 90 percent.

Need for Research

There is a large number of aspects about the cultivation of annual crops in an intensive form in the humid tropics of Amazonia requiring research. However, only those that we think are of a general character and of a priority nature will be listed. They are:

- Systematic and detailed studies of the climatic conditions of the humid tropics, with emphasis on determining the rainfall distribution patterns.
- Detailed, quantitative studies of soil classification and land use potential, with emphasis on soils' possibilities for annual crops.
- Alternatives for annual crops in production systems that include pastures, perennial, and forest crops.
- Study of the genetic diversity of cultivated annual plants for Amazonia.
- Genetic studies and suitability of other annual food plant crops such as Irish potato *(Solanum* sp.), sweet potato *(Ipomea batata),* and tropical plants such as pigeon peas *(Cajanus cajan),* yams *(Dioscorea* sp.), taro *(Colocasia esculenta),* etc.
- Genetic selection of (a) plants less susceptible to exchangeable Al, and (b) early-maturing plants with high photoperiod insensitivity.
- Integrated control of insects and diseases, and residual effects from applications of herbicides, insecticides, fungicides and nematocides.
- Greater emphasis on plant nutrition through studies of the nutrient requirements of each species, cation balance, critical levels of elements, and productivity correlations with soil fertility.
- Design and/or utilization of mechanical equipment, either manual or animal powered, for soil preparation, planting, fertilizing, cultivating, and herbicide and pesticide application using minimum tillage.
- Studies on new sources and forms of applying fertilizers with greater residual power, and the viability of the use of phosphate rocks for direct application.

- Application by small farmers on their fields in Yurimaguas, Peru, of the two levels of technology developed, proved them to be superior to the traditional system practiced in shifting agriculture.

Recommendations

The expansion of the agricultural frontier by growing annual food crops in the humid tropics of Amazonia requires the use of modern technology that has to be developed *in situ,* and that has to be sensitive to the local socio-economic conditions. This will be possible only with integrated research, which requires infrastructure, resources, and a critical mass of scientists of a multi-disciplinary character.

We recommend that national and international efforts be united for the development of coordinated policy of research and experimentation, adapted to the conditions and socio-economic needs of the farmer and/or settler of Amazonia.

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Pasture and Animal Production in Amazonia

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Introduction

Two extreme positions are being taken about the Amazon region. One proposes the settlement and extensive use of the region, using production methods developed for conditions in other ecosystems and disregarding the limitations and problems that are present. The other extreme calls for the preservation of Amazonia as a "living museum", asserting that the region will not be capable of maintaning a greater population than that which it supports today.

The understanding of Amazonian ecosystems and production alternatives is still superficial, due to the isolated efforts of official and private institutions on national and international levels that, almost secretly, carry on incomplete research that often is unintegrated, poorly focused and lacks adquate technical and/or economic resources.

Given the meager information on Amazonia today, there is no doubt that the wisest decision would be to preserve rather than to modify the ecosystem. The question is: How long will it be possible to prevent human occupation of the region? It is already too late. Amazonia is being invaded by man, because of socio-economic and demographic pressure in such countries as Colombia, Ecuador and Peru, and because of Brazil's strong policy of territorial integration.

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In the confusion created by the preservationist and expansionist views, both with slanted conceptions of the Amazonian problem, the funding of research in the region has been almost nil in relation to the size of the task. Given the controversy about Amazonian development, international funding institutions have preferred not to finance research, thereby losing many years in the serious advancement of knowledge about this region.

This paper presents some results of research conducted on pasture and animal production in the Amazon region.

Characteristics of the Amazon Region

Soils

A description of the environmental conditions (climate, soil and vegetation) of the Amazon is given elsewhere in this volume (Schubart and Salati), but some aspects of the soils are reiterated here. First, the diversity of the soils is compounded by the drainage characteristics. More than 23 percent of the soils exhibit poor drainage (Table 1). Moisture retention capacities are also quite variable. Only 2 percent of the soils have a high water holding capacity. About 56 percent have a medium, and 41 percent have low soil moisture storage (Cochrane, 1980, pers. comm.).

Table 1. **Drainage quality and moisture holding capacity of soils of the Amazonia (in areas and proportions).**

	Area (millions of ha)	Proportion (%)
Drainage		
Good	354.4	73.3
Sufficient	14.8	3.1
Poor	114.4	23.7
Moisture holding capacity		
High	9.3	2.0
Medium	274.6	56.8
Low	199.0	41.2

Source: Cochrane, T.T., 1980, pers. comm.

As Table 2 shows, most of the Amazon soils are acid, deficient in P, have low base saturations, and high Al levels. There are some high fertility Alfisols (terra roxa) and Inceptisols (várzea*) soils.

* Brasilian term for areas along river banks that are inundated part of the year. (Editor's note.)

Table 2. **Frequency of occurrence of different levels of selected chemical characteristics, at two depths of Amazon soils.**

Chemical characteristcs	Soil depth*	
	0-20 cm	21-50 cm
	----------%----------	
pH		
Acid (>5.3)	18.9	17.5
Very acid (<5.3)	81.1	82.4
% Al saturation:		
Very high (>70)	59.0	61.6
High (40-70)	16.2	8.2
Medium (10-40)	7.9	8.2
Low (<10)	16.9	19.9
Exchangeable cation capacity (meq/100g):		
Medium to high (>4.0)	20.9	10.9
Low (0.4-4.0)	33.0	16.8
Very low (<0.4)	46.0	72.9
% Organic Matter:		
High (>4.5)	17.0	0.1
Medium (1.5-4.5)	9.1	83.8
Low (<1.5)	74.0	16.1
P (ppm):		
High (>7.0)	9.9	3.0
Medium (3.0-7.0)	32.9	11.3
Low (<3.0)	57.3	85.7

* Proportion of total area of 484.3 million hectares.

Source: Cochrane, T.T., 1980, pers. comm.

The soils of the Amazon basin are extremely heterogeneous, and, therefore, different potentialities exist for forestry, ranching, intensive agriculture and plantations. Areas should be surveyed and land use potential evaluated before developing settlement programs.

Recycling of nutrients

The profuse vegetation of Amazonia appears to contradict the low fertility of the soils. The abundant vegetation is possible because of the very tight nutrient cycling that occurs in tropical forest ecosystems. For a tropical rain forest in Ghana (on an Alfisol), Nye (1961) found that elements cycled involved 268 kg of N, 15 kg of P, 303 kg of K, 332 kg of Ca and 75 kg of Mg/ha/year. Other nutrient cycling information is given in

Salati and Schubart. The last 10 years produced several large scale nutrient cycling studies in Latin America, such as that of Odum and Pigeon in Costa Rica (1970), Golley in Panamá (1976), and Herrera *et al.* in Venezuela (1978).

Figure 1 shows schematically the three deposits of nutrients in the tropical rain forest ecosystem: The soil deposit with a low proportion of the total nutrients present and the deposits of the biomass and the detritus (fallen leaves and forest residues) that contain the majority of the ecosystem's nutrients.

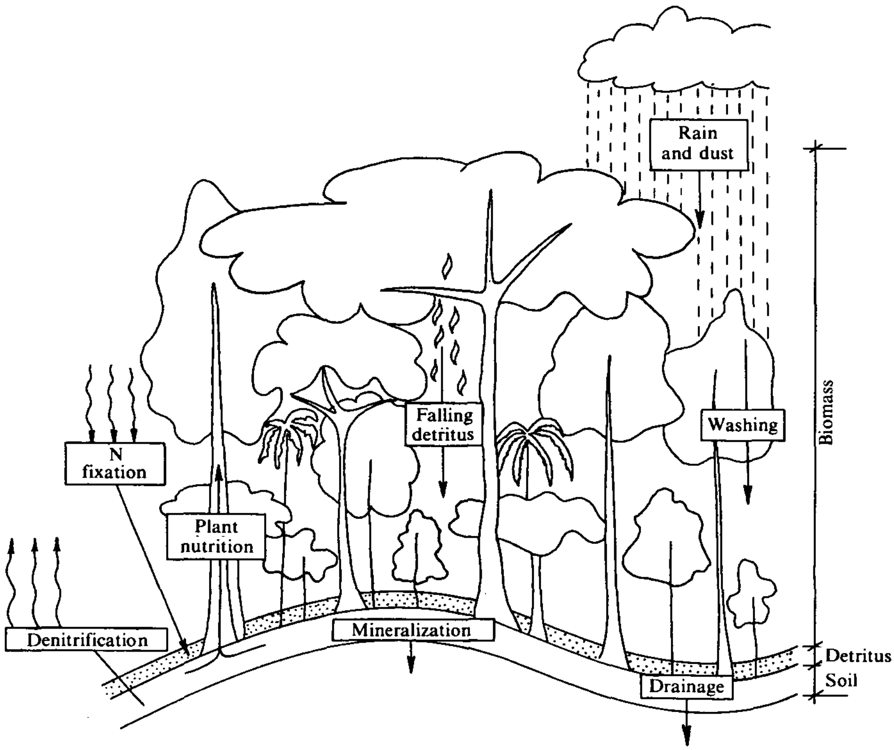

Figure 1. *The nutrient cycle in a tropical forest ecosystem.*

This diagram also indicates the most important processes in the recycling of nutrients. As rain falls on the vegetation it carries away dust and atmospheric N, which enriches the ecosystem. At the same time, the rain washes the leaves and transports nutrients to the soil. Part of these nutrients and those already in the soil are lost by seepage or by leaching, depending of the physical conditions of the soil.

At the same time, the leaves and detritus fall and accumulate on the soil. This material undergoes the process of mineralization, degrading the organic matter to more simple compounds that plants can assimilate, and contribute to the enrichment of the fertility of the top-soil layer. Forest plants, which have a very superficial root development, utilize these nutrients for their growth, rounding out the cycle.

The process of symbiotic fixation of N by the action of *Rhizobia* and other microorganisms with the roots of the plants also occurs. Part of this N can be lost by denitrification.

When this system of recycling is interrupted by felling of trees and burning the forest, a large part of the ecosystem's nonvolatile elements in the ashes remain on the surface of the soil. This produces a decrease of the percentage of Al saturation, an increase in pH, and the addition of exchangeable bases, as reported by Seubert *et al.* (1977) in an Ultisol of Yurimaguas, Perú, and by Ferreira da Silva (1978) in an Oxisol in southern Bahía, Brazil.

This initial fertility, augmented after burning, decreases rapidly by leaching of nutrients, especially if the forest is replaced by highly extractive systems and if the surface has a sparse or temporary covering.

However, the replacement of the forest by production systems with lower levels of nutrient extraction and with a denser and more effective covering guarantees a recycling process similar to that of the native forest, maintaining soil fertility and producing food or industrial materials for man's benefit. One can say that when they are well-managed, plantations and pastures are alternatives that can fulfill this need. Figure 2 shows the recycling that occurs in a well-managed pasture.

In this production system, one can count on three deposits of nutrients. The biomass (plants and animals), the detritus (fallen leaves and residues from pastures and animals) and the soil. The rain carrying dust and atmospheric N washes animals and plants and adds nutrients to the soil. Some of the nutrients are lost by drainage (seepage and leaching). When a legume is associated with grasses, the fixation of N by symbiosis with *Rhizobia* occurs. Part of N is lost by denitrification, which also occurs in the forest. At the same time, the plants take up nutrients from the soils, and these are transferred to the animal through grazing. Part of these nutrients go to man as meat or milk. The rest returns in a non-uniform manner to the soil through feces and urine. On trampling the pasture, the animal tears the aerial parts of grasses and legumes. These organic materials, together with the dead roots (a product of the reaction of the plant to defoliation as well as plant senescence), are mineralized and some are taken up again by the plant.

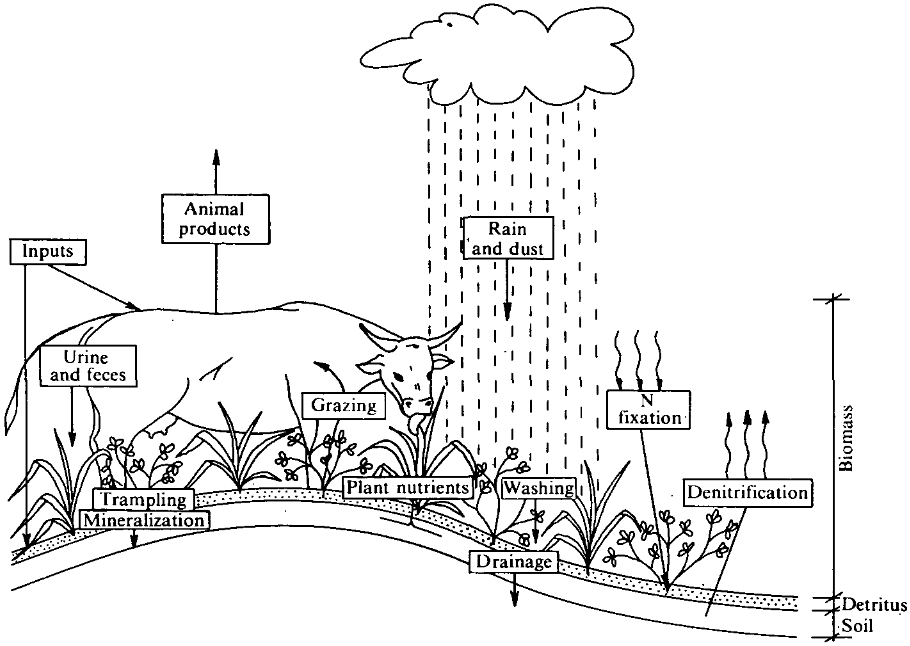

Figure 2. *The nutrient cycle in a legume-grass pasture.*

In addition to these natural processes of recycling nutrients, man must "pay" or return to the system those high-value elements that he took. He can do this by applying inexpensive nutrients directly to the soil and to the animal. Also, man must use management practices to assure the effective recycling and productive stability of the system, or the existing resources will deteriorate causing the degradation of the pastures.

Proposed Model

Toledo and Ara (1977), Serrão *et al.* (1978) and Alvim (1978) concur basically on the model that shows the dynamics of soil fertility when the Amazonian tropical forest is changed to pasture. However, they "disagree", although in theory, about the magnitude of the changes in soil fertility and the speed with which they occur after burning. The authors' criteria were made compatible by modifying the model. The new model shows a stable soil fertility level, owing to the nutrient recycling under the forest ecosystem. Fertility of the soil is rather low because a great part of the nutrients of the ecosystem is found in the biomass and the layer of detritus over the soil.

This stable cycling is interrupted by the clearing and burning of the forest, which adds the nutrients of the ecoystem to the soil surface, raising thereby the fertility to levels adequate for intensive agricultural production (Fig. 3).

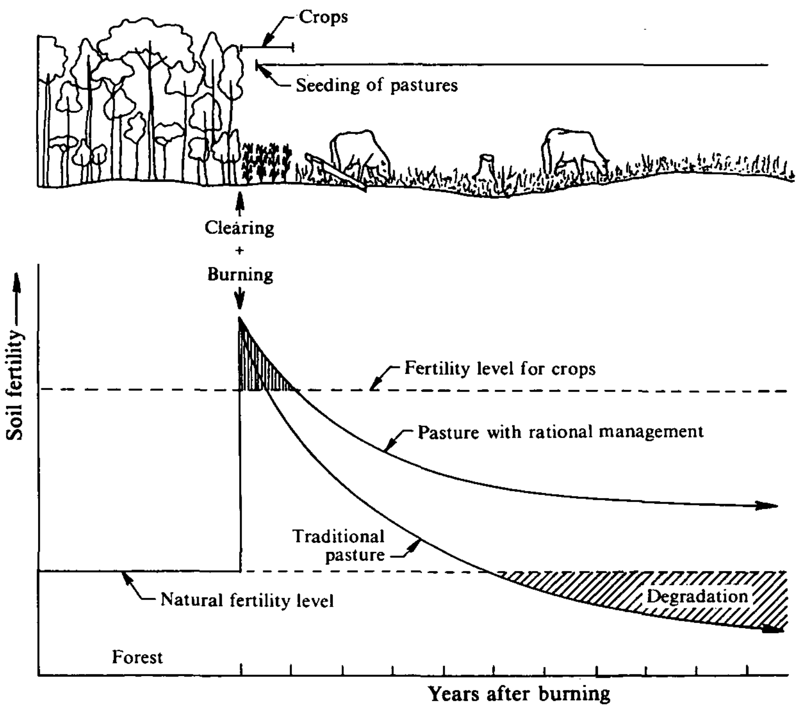

Figure 3. *Model showing the probable trends in soil fertility upon changing from a forest vegetation to a pasture.*

Source: Toledo, 1977; Serrão, 1978; and Alvim, 1978.

This high initial fertility is used normally by the settler to obtain one or two short harvests which help to pay the cost of clearing the area and which furnish a quick covering to protect the soil from erosion. Seeding of the pasture should be done while the crops are still growing so that when the crops are harvested, the pasture has covered the ground sufficiently to prevent or diminish risks of erosion.

If the pasture is poorly established and badly managed, the soil will probably lose its fertility rapidly, as the traditional pasture model shows. This leads to levels lower than the original fertility level of the forest.

If pasture establishment is good, using adapted species of grasses and legumes, and is followed by adequate management (grazing pressure and inputs), the fertility decreases more slowly and stabilizes at a level higher than the natural fertility of the soil under forest for some elements.

During the first year after clearing the forest, management options are limited by the impossibility of mechanization because of unburned residues such as trunks and stumps. Although it is possible to clear the area and initially clean it with a bulldozer, this is unadvisable because of the compacting and movement of the top soil containing the majority of the nutrients (Seubert *et al.*, 1977; and Ferreira da Silva, 1978).

Nevertheless, after six to 10 years, depending on the original forest, the trunks and stumps will have decomposed and will be incorporated into the soil, whether by microbial action or strategic burnings of the pasture. When the ground is free of obstacles so that mechanization can be used, it will be possible to intensify management (especially mechanical), increasing the productivity per unit area.

Methods of Clearing the Forest

The operation of clearing is critical to the future of whatever production system replaces the forest.

The traditional method of clearing is that of the ax and machete, which has been improved lately with the use of chain saws. In addition to this method, Toledo and Morales (1979) reported on two mechanized systems tried and evaluated in Tocache and Pucallpa, Perú.

Table 3 compares the labor needs, efficiency and operating costs of different methods of clearing the forest (ax and machete, bulldozer and tree crusher).

Table 3. **Efficiency and comparative costs for different methods of clearing the forest of the Peruvian Amazon.**

Method	Efficiency		Cost
	Men/ha	Hours/ha	(US$/ha)
Ax and machete (Tocache)	50.00	8.00	96.00*
Bulldozer (Tocache)	3.00	9.92	204.00*
Tree crusher G-40 (Pucallpa)	0.25	0.84	55.00**

* Costs in 1966

** Costs in 1971

Source: Saco Vertiz and Bravo, 1967; Valdivieso, 1973.

Table 4 compares the range of pressures exerted on the soil by different compacting agents, including man and the machinery used in the three methods evaluated.

Table 4. **Weight and pressure range over the soil produced by various compacting agents.**

Compacting agent	Weight (t)	Pressure range on the soil (kg/cm^2)
Bulldozer (180 HP)	18.30	0.67-0.51
Bulldozer (270 HP)	28.10	0.95-0.68
Bulldozer (385 HP)	38.80	0.95-0.76
Tree crusher G-40 (475 HP)	45.00	1.03- <1
Tree crusher G-60 (475 HP)	65.00	1.37- <1
Horse	0.40	4.00-1.00
Cow	0.35	3.50-0.88
Man	0.07	0.47-0.23

Source: Toledo and Morales, 1979.

Manual clearing

Clearing the forest with ax and machete requires the most manual labor, with the cost of the operation depending largely on the salary levels and the availability of personnel in the region and country in question (Table 3).

This relatively slow method is suitable for opening forest limited in area. It also causes minimal changes in the soil, because, as seen in Table 4, man produces the least soil compaction.

On the other hand, this method leaves the stumps in the soil, and many of them sprout with the secondary forest if burning is not effective, as it often happens.

However, this is the most widely used method at the present time. It provides work to native people, when present, and can be very effective depending on the forest, the opportunity for felling and burning, and the ability of the workers to reduce the thickness of the felled matter and burn it efficiently.

Clearing with a bulldozer

This system of clearing (Table 3) requires less manual labor but higher levels of specialization (tractor drivers, mechanics, helpers, etc.). It utilizes bulldozers of more than 270 HP, with KG blades for cutting and shoving. The method consists of cutting the trunks even with the ground and pushing and piling them in rows to be burned. Repiling and burning are repeated until the ground is free of forest residues, and ready for immediate mechanizable agricultural operations.

Bulldozers of 385 HP with KG-type blades can open a hectare in approximately 10 hours. This relatively slow method requires several machines to clear a medium sized or large area.

This method is also the most costly (Table 3) and the one that modifies the soil to the greatest degree. Clearing with bulldozers unevenly distributes the nutrients in the biomass and burned detritus, removes the top shallow soil containing the majority of the nutrients (in the poor Amazonian soils such as Oxisols and Ultisols), and produces strong compaction in spite of the relatively low levels of pressure exerted on the soil (Table 4). This compaction is due to the frequent passing of the tractors over the soil when cutting and stacking the trunks. Figure 4 shows the effect of compaction by bulldozers on an Ultisol in Yurimaguas, Perú, and an Oxisol in Bahía, Brazil, after clearing and piling up the forest residues. The effect of the bulldozer is clear; its use reduces the infiltration rates in both soils, but the Oxisol (Haplorthox) appears less subject to compaction than the Ultisol (Paleudult).

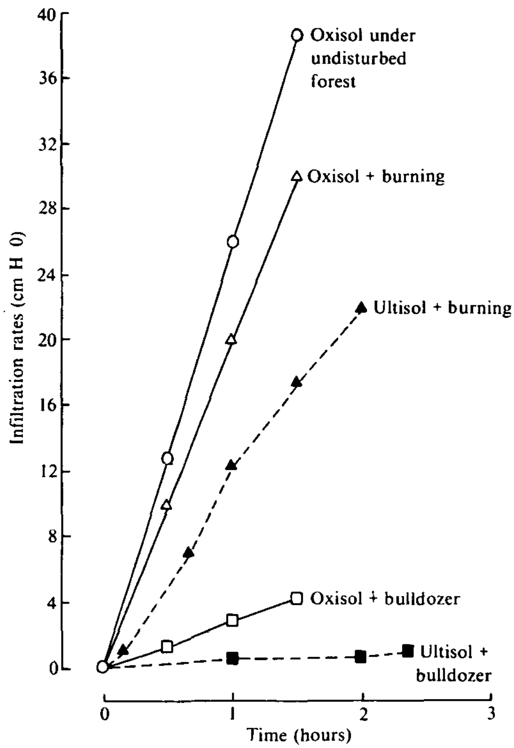

Figure 4. *Effect of land clearing method on the infiltration rates of two soils of the Amazon.*

Source: Adapted from Bandy and Benitez, 1977, and Ferreira da Silva, 1978.

This method of clearing is definitely harmful to the majority of Amazonian soils. However, in conditions where the soil is deep and of high fertility, as in some Inceptisols of the "várzeas", this method permits an immediate, intense, mechanized utilization of the area after clearing.

Clearing with tree crushers

As with bulldozers, this system of clearing requires qualified personnel, but due to its rapid operation (Table 3) the number of persons per hectare is greatly reduced.

The cost of clearing is also reduced because of the high efficiency of the operation. The tree crusher (Fig. 5) which weighs 45 tons, has three rollers with blades in the manner of a tricycle. It functions by electrical transmission, having a diesel generator in the center of the machine. Clearing is done by pushing down the tallest trees with a boom and the smaller ones with a T-shaped horizontal bar. The machine fells the trees and rides over them, then fells the next ones. In this manner, its weight is distributed over a greater area (Table 4) than just the soil surface that is in contact with its rollers, which reduces the level of total soil compaction.

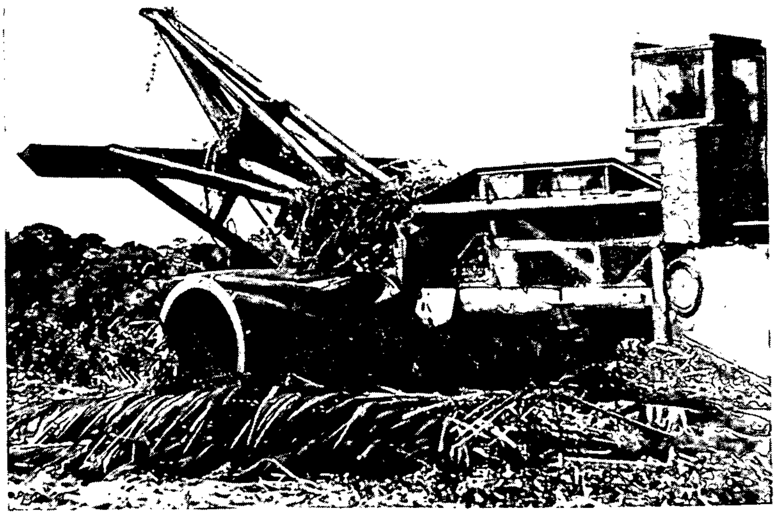

Figure 5. *Tree crusher used in Pucallpa, Peru, for forest clearing operations.*

Experiences in Pucallpa, Peru, showed that the burning of the forest residues felled by a tree crusher was more effective than the burning of those felled with ax and machete, because more uniform drying takes place in material cleared very rapidly (8-10 ha/day). In addition, the straight, uniform piling of the biomass resulting from the passage of the machine over the trees permits a better continuity of burning.

This is a method that disturbs the soil by raising the surface roots of the tress and leaving them exposed on the soil. It produces moderate compaction because the machine passes over the surface only one time and distributes its weight over a large surface area of already-felled material. Due to its rapidity, efficiency in burning and low operating costs, this method must be considered for clearing large forests. It is not, however, an economically feasible system for operations of less than 1000 ha.

Pastures and Cattle

No current figures exist for the Amazonian cattle population but a population of 7 - 10 million cattle and 0.7 million buffaloes is estimated.

Even more uncertain is the amount of forest areas presently in pastures. However, an estimation can again be made, considering that 60 percent of the cattle are in forest areas and that one hectare supports an estimated 1.0 animal, on the average. This estimate indicated that 4.2 - 6.0 million hectares of pastures are in the forest areas. Almost all of the buffaloes in Amazonia are found on native pastures of floodable lands, such as those existing in the island of Marajó and the lower and mid Amazon River in the State of Pará (Serrão and Falesi, 1977).

Unofficial reports gathered personally from officials and cattle farmers of different Amazonian countries indicate that of these areas, nearly one million hectares of pasture are now in the process of degradation, principally in Brazil, Colombia and Perú.

In the process of settlement, which is very active in different countries of the Amazon, establishing pastures and raising cattle is the cheapest and most stable system of exploitation to replace the forest.

However, the settler cannot count on appropriate forage species of grasses and legumes nor on management technology to establish and maintain the pastures at economically and ecologically justifiable levels of productivity.

Pasture persistence

The Amazonian settler relies only on one or two species of grasses to establish his pastures. In the secondary Andean ridges of Amazonia, where there is no dry period, *Axonopus scoparius* and *Axonopus micay* predominate; in many cases they are sown after clearing the forest without burning it. In the rest of the Amazon, *Panicum maximum* and *Hyparrhenia rufa* traditionally have been planted not always after an effective burning. Both species have limited adaptation to varying levels of soil fertility after burning. These species, according to the results of Simão Neto *et al.* (1973), do not persist well (Fig. 6). Other species, such as *Brachiaria decumbens* and *Brachiaria humidicola,* appear to tolerate the fertility changes that gradually occur, as shown in the model in Figure 3, which is supported by Serrão and others (1979) (Figs. 7-10). Figures 7, 8, 9 and 10 show the changes in organic matter, Ca+Mg, K and P that the soil undergoes as a result of burning and later utilization with *P. maximum* in the different soils of Brazil's Amazonian region.

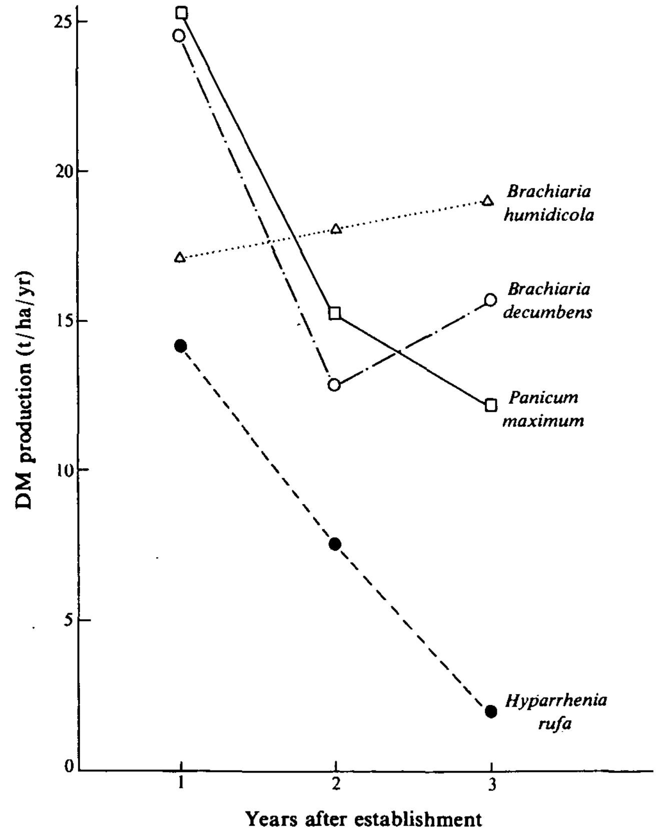

Figure 6. *Productivity of some grasses during the first three years after establishment on an Oxisol at Belém, Brasil.*

Source: Simão Neto *et al.*, 1973.

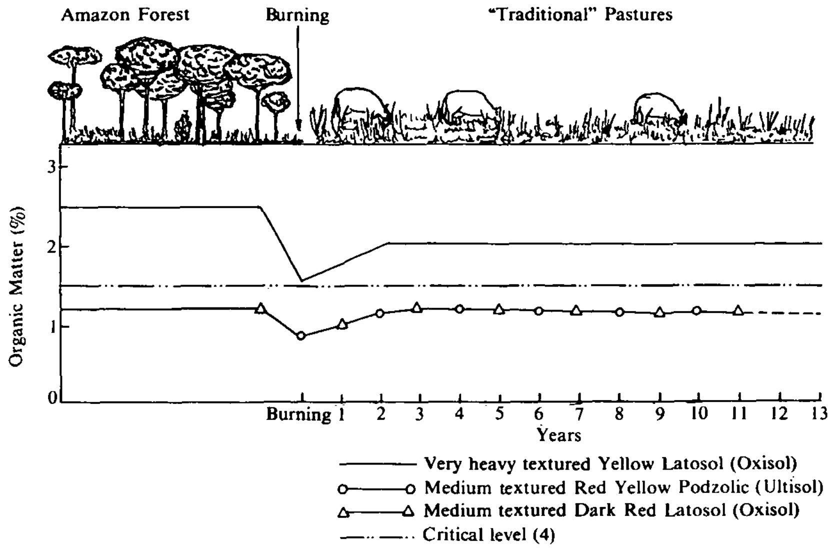

Figure 7. *Changes in organic matter values in soils under forest and* **Panicum maximum** *pastures of different ages.*

Source: Serrão *et al.*, 1979.

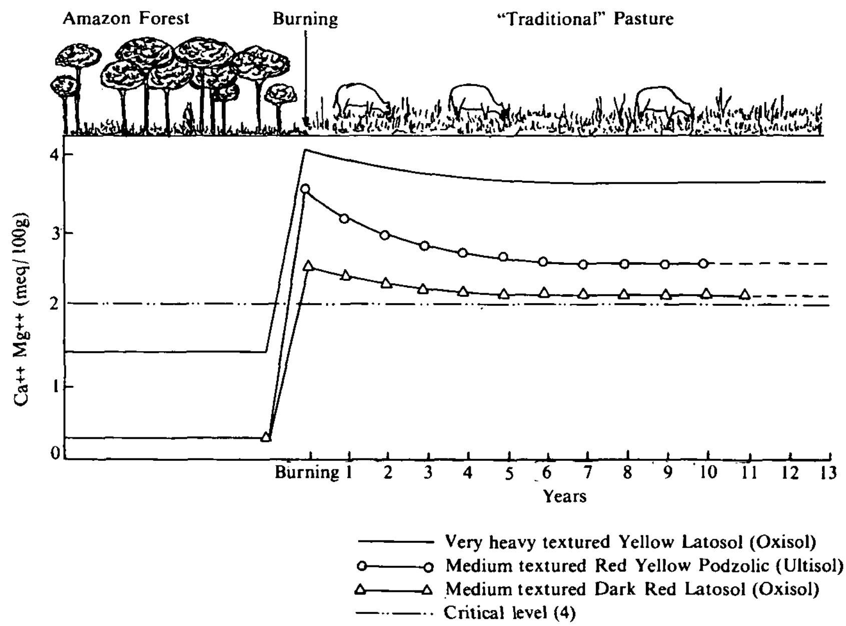

Figure 8. *Changes in contents of* Ca^{++} *and* Mg^{++} *in soils under forest and* **Panicum maximum** *pastures of different ages.*

Source: Serrao, *et al.*, 1979.

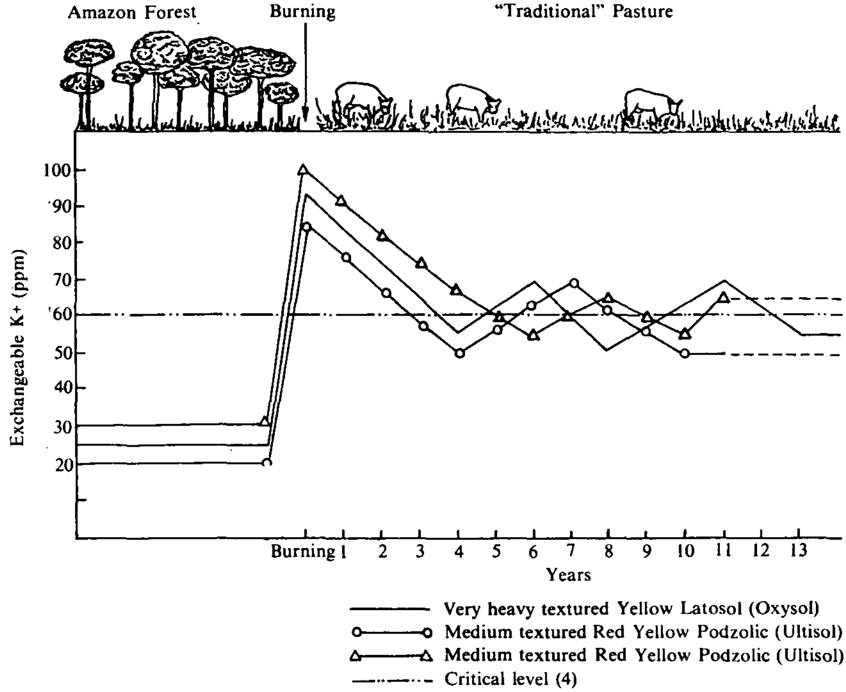

Figure 9. *Changes in the contents of exchangeable K+ in soils under forest and* **Panicum maximum** *pastures of different ages.*

Source: Serrao *et al.*, 1979.

From Figures 7-10 one can conclude that part of the organic matter of the soil is destroyed by burning, but the covering by pastures in a short time incorporates sufficient organic matter to at least elevate its contents, although it is not fully recovered. Amounts of Ca^{++} + Mg^{++} are greatly increased by burning and then tend to decrease in the early years, but stabilizing at values higher than those of forest soils. The initial low level of K in the forest soil is increased greatly by burning and then decreases to levels acceptable for grassland production. The available P that normally is found in very low levels in the original soils also is greatly increased by burning. After conversion to pasture,the area can hardly maintain the high levels of available P of the first year and decreases very rapidly to levels tremendously deficient for any pasture production, and especially one with legumes.

Phosphorus, a rather immobile element in the soil, is not lost by leaching or superficial washing. P is absorbed by the Fe and Al oxides on the surfaces of the clays and precipitated by Fe and Al cations to form insoluble Fe or Al phosphates.

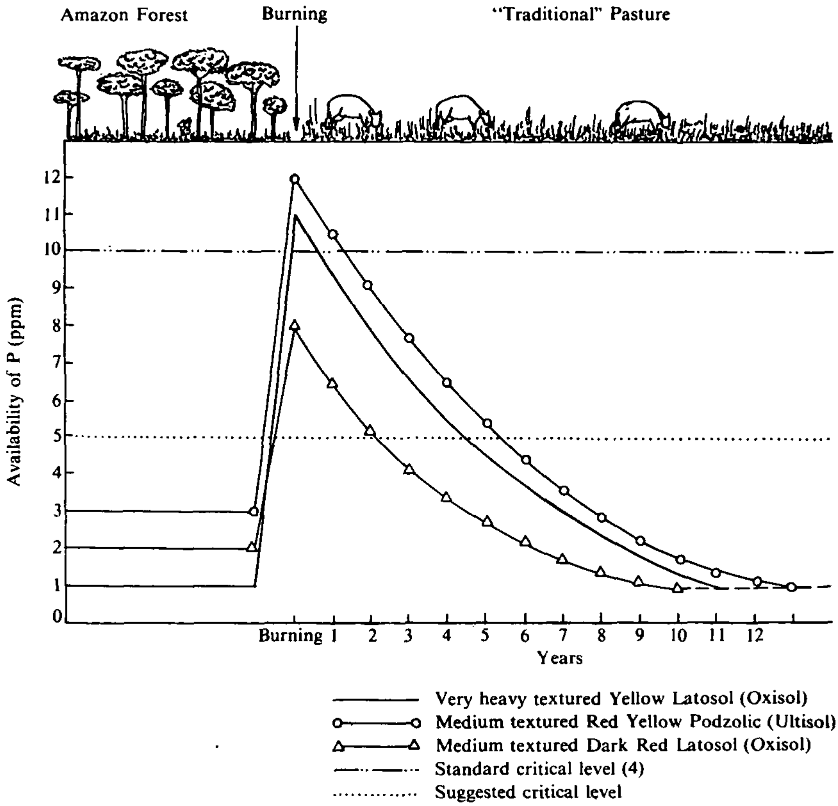

Figure 10. *Changes in the contents of available P in forest soils and under* **Panicum maximum** *pastures of different ages.*

Source: Serrão *et al.*, 1979.

Phosphorus as a limiting factor

The importance of P as a limiting element is supported again in Table 5, which shows the results of fertilization tests on four Amazonian soils. Using the missing element technique, the tests compare yields of pastures (*P. maximum* in Manaus, Sul de Pará and Paragominas and *H. rufa* in Pucallpa) receiving complete fertilization with yields obtained without applying one of the elements at a time. It can be observed in Table 5 that, in all cases, yields were the lowest when P was lacking, and when no fertilizer was used, being always less than 45 percent of the yield obtained when a complete fertilizer was applied.

Without a doubt, P is the nutritive element of plants and animals that, to a major degree, limits cattle production in the region.

Table 5. **Proportion of production with complete fertilizer attained by grasses when any one or all of the elements was not applied, on four Amazon soils.**

Treatment	Manaus-Itacoatiara Oxisol (8)*	Sul de Pará Oxisol (12)*	Paragominas Oxisol (13)	Pucallpa Ultisol (3)*
	%			
Complete	100.0	100.0	100.0	100.0
- N	120.0	90.1	101.3	26.0
- P	36.0	37.0	45.3	29.0
- K	84.0	61.7	74.7	85.0
- S	106.0	74.1	86.7	58.0
- Ca	84.0	84.0	90.7	84.0
- FTE**	104.0	74.1	85.3	-
No fertilizer	41.3	33.3	33.3	21.0

* Soil order and number of years after forest clearing
** Fritted trace alement.

Source: Serrao *et al.*, 1979; Toledo and Morales, 1979.

This problem can be corrected by applying commercial phosphate fertilizers, such as simple superphosphate or triple superphosphate, or with the more efficient application of rock phosphates that, due to their low solubility, slowly free the P into the acid soil solution.

Another procedure is to apply lime to increase the pH, displacing the Fe^{++} and Al^{++} cations from the clay particles and precipitating them from the soil solution as insoluble hydroxides, which eliminates or slows down the processes of P fixation.

Figure 11 shows the effect of different lime equivalent levels on the Al saturation level of an Ultisol in Pucallpa. One can see that the level of lime gradually modified the pH in a linear form, although its effect was rather higher at four than at six months following its incorporation into the upper 15 cm of soil. This indicates the low residual effect of liming.

On the other hand, the effect of liming on the percentage of Al saturation is greater at lower levels of application, and is maintained, following its incorporation.

Another solution is to use grass and legume species adapted to acid soils with high levels of Al saturation and that have the capacity to utilize the insoluble P. Figure 12 shows the null effect of liming at low and medium levels of fertilization and its very limited effect on an adapted species as *B. decumbens,* even without fertilization.

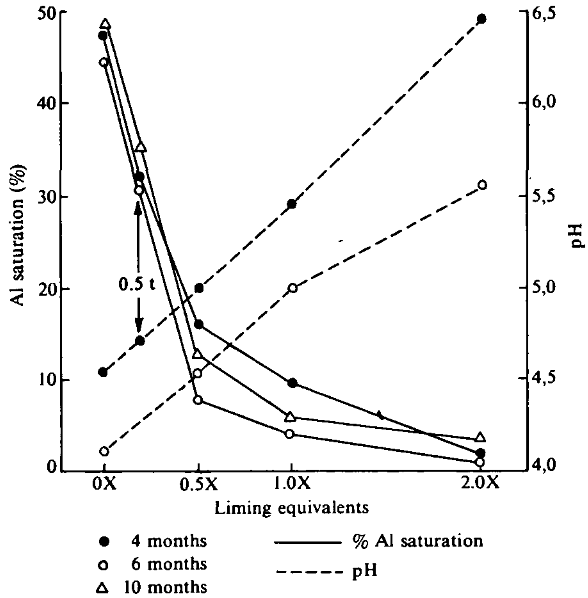

Figure 11. *Effect of liming on the percentage Al saturation and the pH, four, six and 10 months after incorporating lime into the top 15 cm of an Ultisol in Pucallpa, Peru.*

Source: Ara and Toledo, 1979.

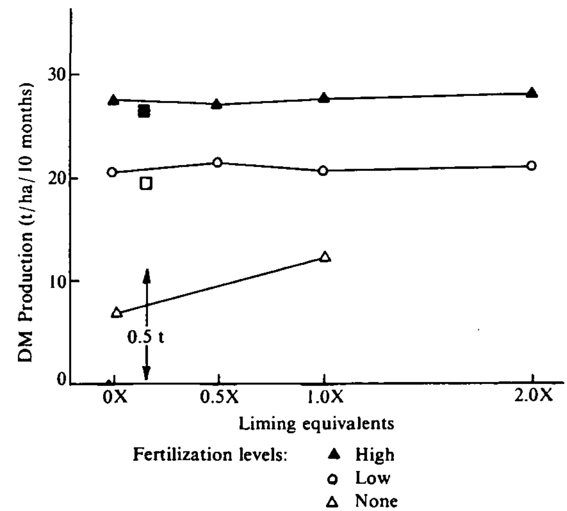

Figure 12. *Effect of liming on production of* **Brachiaria decumbens** *in Pucallpa, Peru.*

Source: Toledo, 1979.

The selection of species and ecotypes of forage grasses and legumes adapted to the range of conditions in Amazonia (climates, soils, insects and diseases) should give excellent results that increase productivity and guarantee pasture stability.

In the last 40 years, state experimental stations and farms have introduced several grasses and legumes in various parts of the region. But their presence has not produced significant results because these introductions never passed from being mere collections or plots where the few accessions were never evaluated systematically. Table 6 lists the genera and number of species and cultivars introduced in the region.

Amazonian cattle ranches commonly have pastures with nonadapted species, and instability problems caused by soil fertility changes, weeds, insects and diseases. Logically, animal performance will be limited by these pasture problems.

Table 6. **Improved forage grasses and legumes introduced in the Amazon region.**

Grasses		Legumes	
Genera	Species and cultivars	Genera	Species and cultivars
Andropogon	2	*Cajanus*	1
Azonopus	10	*Centrosema*	22
Brachiaria	10	*Calopogonium*	1
Chloris	2	*Canavalia*	4
Cynodon	9	*Cassia*	1
Digitaria	6	*Clitoria*	1
Echinochloa	2	*Desmodium*	7
Eragrostis	2	*Dolichos*	1
Eriochloa	4	*Galactia*	9
Hemarthria	1	*Glycine*	5
Hyparrhenia	1	*Leucaena*	10
Melinis	2	*Lotononis*	1
Panicum	22	*Macroptilium*	2
Paspalum	11	*Macrotiloma*	2
Pennisetum	35	*Periandra*	1
Saccharum	10	*Phaseolus*	1
Setaria	14	*Pueraria*	2
Sorghum	7	*Rhynchosia*	1
Tripsacum	1	*Stylosanthes*	25
		Stizolobium	1
		Teramnus	2
		Zornia	1
Totals	151		101

Source: Serrão and Simão Neto, 1975; Serrão and Falesi, 1977.

Animal production

Cattle. Livestock production can be increased greatly by solving the management problems in regard to the P necessary for the stable growth of grasses and especially legumes, which are able to incorporate N into the system by symbiosis.

Toledo and Morales (1979) reported six-year averages of an experiment that compares the "traditional" pasture with only *H. rufa,* with an improved pasture that includes *H. rufa, Stylosanthes guianensis,* and 100 kg of simple superphosphate applied annually.

Table 7 shows that the inclusion of legumes and fertilization with P, S and Ca provided by the simple superphosphate produced an improvement of 44 percent in the stocking capacity of the ranch, doubled weight gains per animal and tripled meat production per hectare.

Table 7. **Animal performance and meat production per hectare on traditional and improved pastures at Pucallpa, Perú. Average over six years.**

Treatments		Weight gain	
Type of pasture	Stocking rate (head/ha)	Per animal (g/day)	Per hectare (kg/yr)
Hyparrhenia rufa (traditional)	1.2	160	70
	1.5	169	92
	1.8 (100%)*	227 (100%)*	149 (100%)*
	1.9	215	149
	2.1	169	129
	2.3	203	170
	2.6	160	151
Hyparrhenia rufa+ *Stylosanthes guianensis* + 100 kg/ha/yr Simple Superphosphate (improved or "pioneer")	2.1	403	308
	2.4	401	351
	2.6 (144%)*	495 (218%)*	469 (314%)*
	2.7	340	335
	3.0	345	377
	3.1	439	496
	3.6	350	459
	4.1	286	428

* Comparative percentage between treatments resulting in the best weight gains per animal and per hectare.

Source: Adapted from Toledo and Morales, 1979.

De la Torre and others (1977) noted that a pasture of *B. decumbens* in an Ultisol—with an annual application of 280 kg of N, 18 kg of P and 42 kg of K per hectare and managed intensively in rotation with 23-day intervals—

supported a stocking rate of 3.45 cows/ha and gave a daily milk production of 8.75 liters/cow, for a total of 30.5 liters of milk/ha/day with only the mineral supplementation (Table 8).

Table 8. **Milk production and management of lactating Zebu x Holstein cows grazing fertilized *Brachiaria decumbens* pastures at Pullcapa, Perú. Average of two years.**

Parameter	Average per season		Annual average
	Rainy (8 months)*	Dry (4 months)*	
Grazing:			
Average interval (days)	22.75	22.20	22.57
Average stocking rate (cows/ha)	3.80	2.75	3.45
Milk production:			
Average per cow (kg/cow/day)	9.00	8.20	8.75
Average per hectare (kg/ha/day)	34.40	22.75	30.52

* Lenght of the season.

Source: De la Torre *et al.*, 1977.

These results give an idea of the potential of Amazonia for animal production on pastures. Conspicuous here are the larger stocking rates that pastures established in the forest ecosystem are capable of supporting, in comparison with the stocking capacity of native savanna or cerrado pastures.

Buffaloes. The domesticated water buffalo is an interesting alternative for animal production that could take advantage of the resources in extensive areas of floodable lands. Most of the current population in South America is found in Brazil's Amazon region.

Nascimento and others (1970) report production indices for the buffalo to be superior to those for cattle (Table 9). The water buffalo produces meat, milk and work Zebu cattle cannot produce on comparable low-quality pastures.

Table 10 presents digestibility coefficients for dry matter (DM) and crude fiber (CF) of overmature *Melinis minutiflora* hay. In this test, ruminal fluid was extracted from buffaloes, Zebu and European cattle, and the normal process of digestion proceeded *in vitro*. Results showed that the digestibility coefficients of DM and CF are generally low, because of the poor quality hay. However, the ruminal fluid of the buffalo gave a

DM digestibility that was slightly superior to that obtained with fluids of the other two species. This difference was even greater in the case of CF. This suggests more effective cellulolytic ruminal flora in the buffaloes, which explains their better utilization of the region's coarse forages and, under Amazonian conditions, their greater productivity compared to the of Zebu and European cattle.

Table 9. **Predominant productive indices for water buffaloes and bovines in Amazonia.**

Parameters	Water buffaloes	Bovines
Calving rate (%)	60-70	40-50
Mortality (%)		
First year	5-6	10-11
First and second year	3-4	6-7
Adults	1-2	2-3
Culling rate (%)	6	9
Slaughter age (years)	2-3	3.5-5.0
Slaughter weight (kg)	300-400	300- 350
Milk production (kg/lactation)	1000-1400	800-1200

Source: Nascimento *et al.*, 1979.

Table 10. *In vitro* **digestibility coefficients for overmature** *Melinis minutiflora* **hay, using ruminal inoculants from buffalo, Zebu and European breeds.**

	Digestibility coefficients	
Species (breed)	Dry matter	Crude fiber
Buffalo (Jafarabadi)	34.0	31.6
Zebu (Gir)	31.1	24.7
European (Holstein)	30.6	23.1

Source: Nascimento *et al.*, 1979.

The advantages of buffaloes over bovines are presented in Tables 11 and 12. Table 11 compares body weights of the two species at birth and at 24 months, obtained from animals of different breeds grazing on native pastures in Belém, Brazil. Under the conditions of the evaluation, the weight of the buffaloes at birth was consistently greater than that of the bovines. Likewise, buffaloes weighed more at 24 months.

Table 12 shows data on animal performance and pastures for buffalo and Zebu steers, under rotational grazing on *Echinochloa pyramidalis.* Initially, buffalo steers at 24 months weighed more than Zebu, and their weight gains/animal/day also were higher. Nevertheless, the stocking capacity of the ranches was greater in terms of Zebu animals, which in this case compensated for the advantage of the buffaloes, when expressing production in weight gain/ha.

Table 11. **Weight averages at birth and at 24 months for water buffaloes and bovines on native pastures, at Belém, Brazil.**

Species (breed or type)	Birth weight		Weight at 24 months	
	No.	kg	No.	kg
Buffaloes:				
(Mediterranean)	71	36.8	19	369.0
(Carabao)	32	36.8	10	322.7
(Jafarabadi)	26	36.2	8	308.3
Bovines:				
(Canchin)	13	30.9	16	281.8
(Nelore)	28	24.5	22	264.7

Source: Nascimento *et al.*, 1979.

Table 12. **Weight gains and management of bovine and water buffalo steers on *Echinocloa pyramidalis* under rotarional grazing.**

Parameter	Nelore Zebu	Mediterranean buffalo
Beginning age (yr)	2	2
Initial weight (kg/animal)	187.3	300.7
Final weight (kg/animal)	305.8	483.8
Weight gain (g/animal/day)	353.0	545.0
Stocking rate (animals/ha/yr)	3.4	1.9
Weight gain/ha (kg/ha/yr)	404.0	382.1

Source: Nascimento *et al.*, 1979.

Milk production of the buffalo is reported by Nascimento (1979) as higher than that of bovines. Milk produced by both species also differs in composition. The higher content of solids makes the buffalo milk richer and more productive for cheese making. Undoubtedly, the buffalo is a promising animal and should play an important role in future Amazonian ranching.

Research Needs

Given the conditions of the ecosystem, Amazonia demands medium to high intensity levels of management. One cannot think of extensive management because changing the natural forest to pastures is very costly, both economically and ecologically. Neither can one justify clearing the forest, using the high initial fertility after burning, and once it becomes limiting, simply decrease the grazing pressure in degraded areas while clearing new forest areas.

The priority in research should be placed on technological components that solve the problem of unstable pasture production, after clearing and burning the original forest.

Suggested research priorities are:

- Selection, by use capacity, of Amazonian areas suitable for the establishment of pastures and cattle ranches.
- Selection of species adapted to the different conditions of the Amazonian ecosystems (climate, soil, diseases and insects, and low P in the soil).
- Studies *in situ* of recycling of nutrients in different types of forests and pastures under different management.
- Determination of the most efficient methods to apply P (sources, frequencies, residual effects, etc.).
- Microbiological studies of soils in relation to microorganisms that increase the absorption of P by forage plants *(Mycorrhiza,* etc.).
- Studies of deficiencies of other elements and their correction for the varied soil conditions in Amazonia.
- Development of techniques for recovering degraded cattle ranches.
- Management of grass and legume species grown in association, under grazing, in floodable and nonfloodable conditions.
- Agroforestry systems (pastures and forests, pastures and plantations, etc.).
- Development of productive, dual purpose cattlee types or breeds for low-latitude/low-altitude areas.

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A Perspective Appraisal of Perennial Crops in the Amazon Basin

Paulo de T. Alvim*

Introduction

Perennial crops have played an important role in the economies of countries in the humid tropics. They have been grown very successfully and for a very long time in many regions ecologically comparable to the Amazon in terms of climatic and, to a lesser extent, edaphic conditions. Today the most important producing regions are found in southeast Asia, some African countries and a few scattered areas in tropical America outside of the Amazon basin. It is worth pointing out that where perennial crops are successfully cultivated, the cultural practices evolved by farmers are highly advanced and in line with the good agronomic techniques demonstrated by research.

Two of the most important tropical perennials—rubber and cacao— are native of the Amazon, but until recently Amazonian countries had given very little attention to research on these crops and the development of commercial farming. The same applies to other major tropical crops, such as oil palm, coconut, banana, etc. History shows that scientific agriculture in the tropics has always been started by industrialized countries interested in promoting the cultivation of some export crop in their former tropical colonies or where they could get better returns from their investments. Coffee in Brazil is probably the only exception to the rule. It may well be imagined that research activities with tropical perennials in the Amazon would probably have started much earlier if the region had been politically dependent on some industrialized country interested in tropical agricultural commodities in the past.

There are now good indications that inadequate agronomic research and lack of technical assistance to farmers were, in the past, the main reasons

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for many unsuccessful attempts of growing some traditional perennial crops in the Amazon. These problems are now receiving more attention in some countries. A few woody perennials, such as cacao, oil palm, rubber and pepper, are now being grown quite successfully in a few areas of the Amazon, especially in Brazil, thanks to better agronomic practices developed by local research. It is recognized that much research is still needed with such crops, not only to decide which one of them should be recommended for specific sites but also what cultural practices and production systems are more advantageous, both from the economic and ecological points of view. Research is also needed on many useful perennial plants native of the Amazon which appear to offer the possibility of becoming important commercial crops in the future.

This paper is an attempt to summarize and assess what is presently known on the subject. For a general review about the ecological requirements of the best known tropical crops, reference can be made to the book edited by Alvim and Kozlowsky (1977). As in many other publications dealing with agriculture in the Amazon, some information included in the present paper is based on theoretical assumptions more than in well documented case studies.

Advantages and Limitations of Perennial Crops

Perennial crops, grown in association with forestry plantations, are considered the most appropriate type of land use for tropical regions, such as Amazon, where rainfall is high and soils are predominantly poor. From an ecological point of view, they have some obvious advantages over annual crops. The most important one is the good protection they offer against soil degradation caused by leaching, erosion and soil compaction. Leaching is perhaps the most serious enemy of agriculture in the wet tropics. To use a teleological "explanation", nature seems to have "invented" trees mainly to do the job of recycling soil nutrients, thus preventing leaching. It is no wonder that trees are always the predominant component of natural ecoystems in all regions where leaching is bound to become a problem (i.e., where rainfall is higher than potential evapotranspiration during most of the year).

Another important advantage of perennial crops over annual crops is their lower demand for soil nutrients often coupled with higher tolerance to soil acidity and/or aluminum toxicity, problems commonly found in most tropical areas of Latin America. The lower demand for soil nutrients does not seem to be due only to mineral recycling—a function annual crops cannot perform efficiently—but appears to be related also to the fact that the products harvested from perennial crops usually have lower content of soil nutrients than those from annual crops. Indeed, tropical products such as rubber, sugar, vegetable oils, fibers and starchy foods are basically composed of carbon, hydrogen and oxygen with only a small fraction of mineral elements extracted from the soil. In other words, tropical perennials "export" from the field mainly elements extracted from the air (carbon and oxygen) and water (hydrogen) through the process of photosynthesis.

Although we can be optimistic about the possibility of using perennial crops in developing programs for the Amazon, there are some obvious constraints which must be taken into account. These constraints will vary according to the crop, but the main one is that there are relatively few perennials which can be recommended for commercial plantation in the area. In addition, some of these perennials have limited market potential and cannot be planted on a very large scale. As the problem stands today, not only there are few options to offer to potential farmers, but the total area to be planted with some known appropriate crops will be relatively small in relation with the enormous size of the Amazon basin. Within the next 20 or 30 years, a total area of two or perhaps three million hectares could be planted with traditional plantation crops, such as rubber, oil palm, cacao, coconut, and a few others. If semi-perennial crops (e.g., sugar cane, banana, pineapple, etc.) are included, the total area would obviously be larger, perhaps twice as large, but even so it would not occupy more than 1 percent of the Amazon. Within this context, perennial crops would appear at present suitable to promote selected development poles in the Amazon, but are not to be considered a panacea for the development of the region as a whole.

Among the various land use alternatives for the region, the commercial production of timber, pulp and other forest products (charcoal, methanol, etc), either by forest plantations or by self-sustained management procedures applied to natural forest, appear to have better possibilities for large expansion in the Amazon than the relatively few perennial crops about which agronomists have sufficient knowledge at present.

Another problem with plantation crops is the lapse of time between planting and production of economic returns. This is particularly inconvenient for small farmers, who obviously need other sources of income during the initial years of their plantations. This problem is partially solved by growing cash crops, as banana, yams, cassava etc., prior to and during the initial phase of the plantation, but this practice is not always feasible or sufficiently attractive to the small farmer. It may also retard growth of the permanent crop by competition.

Some government oriented settlement programs, as the Federal Land Development Program (FELDA) of Malaysia, seem to have been able to solve this problem by financing the establishment of perennial crops during the first four to six years and only settling the small farmers in their own lots when harvest is nearly starting. During the initial phase of the project, prospective settlers usually work as hired labor in the establishment of the new plantations. This would appear to be a good system to be tested in the Amazon for some perennial crops, especially rubber and oil palm.

Perennials and Semi-perennials for the Amazon

At present, the major plantation crops which appear to offer better possibilities for expansion in the Amazon are rubber, oil palm, cacao and possibly sugar cane (especially for alcohol production). Coffee *(Coffea arabica)* is another crop now being planted with promising results in a few areas of the Brazilian Amazon, particularly in Rondonia at altitudes above 300 m, where temperature is not too high and soils are Alfisols. Depending on future market opportunities, robusta coffee *(Coffea canephora)*, which is more tolerant to equatorial temperatures, may also have a place for commercial farming in other regions of the Amazon, but currently does not seem as promising as the previously mentioned crops. Other crops such as coconut and banana, which also seem to be ecologically suitable for the Amazon, are not presently attractive from a commercial point of view, although they both could possibly be used in combination with shade-tolerant species such as cacao.

Rubber

The history of the Amazon is closely linked with the history of rubber *(Hevea brasiliensis)*. Indeed it was rubber that first attracted world's attention to the Amazon region. Due to its economic and strategic importance, rubber deserves to be discussed before we consider other perennial crops.

About a century ago the world only knew rubber as a product collected from wild trees found in the Amazon forest. Today the Amazon region represents less than 1 percent of a total world production of about three million tons per year.

Rubber became known as a commercial product in 1838, when the vulcanization process was developed by Charles Goodyear. This started the search for wild rubber and increased migration of people to the Amazon. However, it was the invention of the pneumatic tire in 1888 and of the automobile that greatly increased the demand for the product and caused the so called "rubber boom" period of the Amazon, which lasted until 1912. In that year, production of planted rubber in Southeast Asia overtook that of the Amazon, bringing in a sharp decline in price with serious economic consequences for the Amazon countries, especially Brazil, which was the largest rubber exporter. However the "beginning of the end" really started in 1876, when Henry A. Wickham, a British citizen, was allowed to take 70,000 *Hevea* seeds from the Tapajós Region to Kew Gardens in London. From these seeds 2397 seedlings were raised, of which about 1900 were sent to Ceylon, a number to Malaysia and two to Buitenzorg, West Java. They were the origin of the rubber plantations in Southeast Asia.

Early attempts to cultivate rubber in the Amazon met with little success. The ill-fated experiment of Henry Ford in Tajapós area, near Santarém, is the best known example. In 1926 Ford purchased about one million hectares of land to plant rubber in Fordlandia, later Belterra. Practically nothing was known in those days about the very serious leaf disease called "South American leaf blight" (SALB), caused by the fungus *Microcyclus ulei*. This disease is endemic in all tropical regions of Latin America, but is not present in other continents where rubber plantations are successful. Other disease (e.g. the panel disease caused by *Phytophthora palmivora*) and also some insect pests (the most troublesome one being the leaf-eating caterpillar *Erinnyis ello*) of rubber also occur in the Amazon, but *Microcyclus ulei* has been by far the main constraint and was undoubtedly the main cause of Ford's defeat. In 1939 the project was abandoned, and in 1944 the area was sold to the Brazilian government for a symbolic price.

Efficient methods of controlling *Microcyclus ulei* have become available to farmers in recent years, opening new possibilities for expanding rubber plantations. One important achievement was the selection in Brazil of several clones showing resistance to SALB, such as IAN 3087, IAN 2903, IAN 3193, Fx 3899, which are now being extensively planted. In the State of Bahia the resistant clones Fx 9851, Fx 3844, Fx 4163, Fx 2261 and Fx 3864 are now being recommended.

The largest commercial plantings of rubber in Brazil were established about 30 years ago in the State of Bahia, where there are at present about 25,000 ha under cultivation. Most of the original plantings were made with clone Fx 25, which was at the time rated as resistant to SALB. In the mid-sixties, a serious outbreak of the disease occurred in Bahia causing severe damage to all plantings with that particular clone. This initiated a research program carried out by CEPLAC to control the disease by fungicide sprays, using aircraft as well as ground operated high-pressure spray machines. Good results were obtained, and today fungicide spraying is a common practice in the State of Bahia, especially in areas planted with Fx 25. An average of about 5,000 to 6,000 ha have been sprayed every year during the months of August and September, when new leaves, which are the ones susceptible to the fungus, begin to develop.

Research in Brazil has also demonstrated that damage by SALB can be minimized and even completely avoided when rubber is planted where leaf renovation or "wintering" occurs during well defined dry periods (Moraes, 1974).

In the Amazon region, about three consecutive months with rainfall below 50 to 60 mm per month* appear sufficient to prevent serious damage by SALB. It has also been demonstrated that the disease causes little damage in plantations located near large water bodies (oceans, lakes, or wide rivers), due to reduced dew formation, apparently because of higher net radiation or increased air turbulence in such sites.

Another method of controlling SALB, which is now being recommended in Brazil for areas with no dry season (Subregion A) or where there is no chance for the young leaves to escape the disease, is the use of grafted plants with canopy of *Hevea pauciflora* and trunk of high yielding clones of *H. brasiliensis*. The former is not a very productive species but has proven to be completely immune to SALB. When grafted on high yielding clones of *H. brasiliensis,* the disease is avoided and yields are reasonably good (Moraes, 1974).

At present Brazil imports about 75,000 tons of natural rubber per year and produces only about 25,000 tons, 90 percent of which is obtained from tapping wild rubber trees. The predicted annual increase in consumption in Brazil to 200,000 tons by 1980, instigated an ambitious program (PROBOR-Programa de Borracha) to plant 120,000 ha of rubber by 1982. A Rubber Research Center was established by EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) near Manaus and planting is stimulated by a generous credit program now available to farmers. So far only about 30,000 ha have been planted, the main limiting factor being the production of propagating material in sufficient quantity to meet the farmers' demand. As a result, the program has been revised and the target will be reached by 1984.

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* This corresponds to Subregion B of Cochrane and Sánchez's paper in this book. (Editor's note.)

Oil palm

The African oil palm *(Elaeis guineensis)* is recognized as the most efficient oil producing plant cultivated by man. With good cultural practices it produces from 4 to 6 t of oil ha/year, compared with 1.5 to 2.5 t by coconut, about 1 ton by soybean and sunflower and less than 0.7 to 0.8 t of oil by peanut and cotton.

Most commercial plantings of oil palm are located in areas with an annual temperature of 24 to 27°C, a mean annual rainfall of 1800-2500 mm, and above 1500 sunshine hours (preferably 2000) per year. For optimum yield, rainfall should be fairly well distributed throughout the year. In regions where a pronounced dry season occurs or where the wet season is heavily overcast, yield can be drastically reduced.

Climatic data on the Amazon basin shows that suitable conditions for growing oil palm are found almost everywhere, but the best regions, in terms of rainfall distribution, appear to be located between the Rio Negro and the Andes of Colombia, Ecuador and Peru and in a relatively small area around Belém (Moraes and Bastos, 1972). The middle portion of lower Amazon (Subregion B) has the inconvenience of having a relatively long dry season.

With regard to soil, it is well known that oil palm is not a very exacting crop. The plant is tolerant to soil acidity and/or aluminum toxicity, apparently with no need for liming. Most commercial plantings have been established in soils with pH between 4 and 6 and many examples are known of successful oil palm plantations in chemically poor kaolinitic clays, with relatively modest fertilizer requirements (Ferwerda, 1977).

From the above considerations, it seems clear that oil palm is one of the most promising crops for the predominantly poor Amazon soils. From an economic point of view, this crop appears also to be very attractive because of the increasing demand for vegetable oils. Present world consumption of vegetable oils is increasing at an annual rate of 3 percent, very likely doubling within the next 20 years. In addition, oil palm like many other vegetable oils, can successfully replace Diesel oil. Therefore, with the increasing fossil fuel shortages, the possibility of growing oil palm as an alternative source of transportable energy has been suggested by some authors (Alvim & Alvim, 1979). Other oil crops do not seem to be as promising for this purpose, not only because of lower productivity but also because of higher soil fertility requirements.

The technology for growing oil palm is well known and is already being utilized in a few scattered areas in the Amazon. Near Belém, for instance, a 1,500 ha plantation established about 15 years ago is giving excellent results with an average yield of 4 t of oil/year. The main bottleneck for expanding the planted area in Latin America has been the lack of locally produced improved propagation material. A few Latin American countries including Ecuador, Venezuela and Brazil, are now producing a small quantity of high yielding hybrids known as *tenera*, crossing the genetic type *dura* (thick endocarp) with selected *pisifera* (thin endocarp). This is the standard method for developing improved material commonly used in all major producing countries of Southeast Asia and Africa. Most commercial plantings recently established in Latin America have used *tenera* seeds imported from the Ivory Coast (Institut de Recherches pour les Huiles et Oleagineux, IRHO), under the assumption that envirommental differences will not greatly alter their performance. The need for strengthening local breeding programs is generally recognized, but very little has been accomplished so far.

A very promising line of research is the selection of the Amazon oil palm, known in Brazil as "caiaué" *(Elaeis melanoccoca = E. oleifera)*. Some crosses with *E. guineensis* have already been made with good results but many years of research are still needed before superior planting material from such hybrids can be produced.

Recent work carried out by Rebéchaud and Martin (1976) has led to the development of a new technique for propagating oil palm by means of tissue culture using leaf disks as propagating material. This is an important breakthrough which offers the possibility of rapid multiplication of superior planting material on a large scale, even in the Amazon, where the breeding program has just started. Unfortunately, full details about this new propagation method have not been released and are apparently protected by patent held by the IRHO.

Cacao

The center of origin of cacao *(Theobroma cacao)* is believed to be in the foothills of the Andes. Small quantities of seeds have been exported from the Amazon for almost three centuries through the exploitation of wild trees, but the region has never become an important cacao producing area. Even today its total production represents less than 1 percent of Latin American production, and only about 0.2 percent of the world's total annual production of 1.5 million tons.

Until quite recently very few planted cacao groves existed in the Amazon, and production came almost exclusively from natural groves commonly found along the "várzeas" (seasonably flooded rain forest plains) where soil fertility is higher. Depending on plant density, these groves are estimated to yield only about 20 to 50 kg/ha, or approximately 5 percent of the average yield commonly obtained in commercial farms.

Cacao is not as tolerant of poor soils as rubber and oil palm. It cannot be cultivated in the poor Oxisols and Ultisols of theAmazon without fertilizer applications (especially phosphorus) and liming. This has probably been the main reason for the failure of many past attempts of growing cacao in the Amazon. Some farmers were able to establish cacao in the more fertile "várzea" soils, where yields have always been disappointedly low because of periodic flooding.

Soil surveys carried out in the Amazon of Brazil have indicated the existence of relatively extensive areas of fertile soils (Alfisols), similar to the best cacao soils found in the State of Bahia, which is the main cacao producing region of Brazil. There may be between 8 to 10 million hectares of such fertile soils in the Brazilian portion of the basin. Some of the most extensive areas are located in Rondonia, southern Pará (Altamira and Sao Felix do Xingú), and Northern Mato Grosso. Experiments carried out by the Cacao Research Center of CEPLAC demonstrated the possibility of obtaining very high cacao yields in such areas without the need of fertilizers or liming. Based on these results a government plan (PROCACAU) was launched in 1975 to plant 160,000 ha of cacao in the Amazon within a period of 10 years. It is estimated that the plan will generate approximately 80,000 new jobs, with indirect benefits to about 400,000 people. Up to December 1979 almost 50,000 ha had already been planted and it is expected that the 160,000 ha target will be attained within the next five years. The plan includes also 15,000 ha of cacao to be planted in Oxisols and Ultisols near Manaus and Belém, where fertilizers and lime are more easily available to farmers.

The main limiting factor for cacao production in the Amazon is the incidence of witches'broom, a disease caused by the fungus *Crinipellis perniciosa.* This disease causes serious yield losses in many traditional cacao zones of Ecuador, Colombia, Venezuela and Trinidad. Brazil is planting hybrids which show some degree of resistance to witches'broom but this resistance may be lost with time as it seems to have happened in Ecuador. Removal of infected material combined with fungicide spraying can reduce the incidence of the disease, but experience in other countries has demonstrated that such practices are not always efficient or economic. It is generally recognized that much research is needed in order to develop efficient control measures against this disease.

Several plant collection expeditions have been organized in different regions of the Amazon (especially in Ecuador, Peru and Brazil) in search for new genetic material resistant to witches'broom. In recent years these expeditions are becoming more frequent, particularly in Brazil, in connection with breeding programs for higher yields and disease resistance. Current research in Brazil is also emphasizing epidemiology and mechanisms of resistance to witches'broom.

Sugar cane

From a climatic point of view there is no question that it is possible to grow sugar cane *(Saccharum officinarum)* in the Amazon. For sugar production, preference should be given to areas with a well defined dry season, as this is essential for sucrose accumulation or "ripening" of the canes before harvesting (Salter and Goode, 1967). For alcohol production, there is practically no climatic limitation for growing sugar cane in the Amazon, as a period of moisture stress is not essential for proper maturation.

High yields (about 80 t/ha/yr) have been obtained with sugar cane grown in Alfisols near Altamira, in the Transamazonic highway, where a three month dry season occurs from August to October. Good productivity has also been reported in Oxisols near Manaus, with the use of fertilizers. Inelastic markets, high cost of production (especially fertilizers) and distance from consuming centers have been the main constraints for sugar production in the Amazon in the past. The ambitious alcohol program of the Brazilian Government is now offering new possibilities for sugar cane as well as cassava all over the country, including the Amazon region. With increasing costs of fossil fuels, it seems likely that sugar cane will be planted in large scale in the near future in many scattered areas of the Amazon region for the local supply of alcohol.

Intensive crops

There is a wide range of perennials and semi-perennials, usually cultivated at a small scale, that could find a place in commercial farming in the Amazon. In Brazil, the best known examples are black pepper *(Piper nigrum)* and papaya *(Carica papaya)*, both grown very successfully in the State of Pará. Citrus is also commonly grown in small orchards near urban centers for local consumption. These crops, as well as several other spices and fruit trees traditionally cultivated in other tropical regions, always require more intensive management than the high volume tropical perennials. They are better suited for small farmers than plantation crops.

Some of these crops have a rather inelastic market, and research is obviously needed to define which are the most promising ones from a commercial point of view.

Black pepper

The most important crop of the Brazilian Amazon is black pepper *(Piper nigrum)*. This crop was brought from Singapore by Japanese settlers who introduced it in the State of Pará in 1933. Cultivation is concentrated mainly in the region of Tomé-Açú, and in the vicinity of Belém. More recently the crop has been sucessfully introduced in some areas along the Transamazonic highway and in the State of Amazonas. Total production of Brazilian Amazon at the present time amounts to 50,000 t/year, which places Brazil as the third pepper producing country, after Malaysia and India. Total area under cultivation is estimated in 20,000 ha.

Practically all pepper plantations in the State of Pará have been established in well drained Oxisols of low fertility, using high rates of fertilizers. Nearly 70 percent of production costs correspond to inputs and labor. Nevertheless, because of high prices in the international market, pepper cultivation is one of the most profitable activities in the Amazon.

The main constraint is the high incidence of a root rot disease caused by *Fusarium solani* f. sp. *piperi.* A small research station especially dedicated to study this serious disease was established in Tomé-Açú three years ago in conjunction with the Japan International Cooperation Agency, but so far no efficient control method has been developed.

Because of root rot disease, most pepper plantations in the Amazon have an average productive life of only eight to 10 years, after which the area has to be abandoned. The Japanese farmers developed an interesting system of replacing the crop with cacao, which is giving very satisfactory results and is now becoming widely adopted in the region. Taking advantage of the residual effects of fertilizers previously applied to pepper, cacao is planted with no additional fertilizer application in the same area as the pepper plants start dying because of the disease. The same system is also being used with other crops, usually rubber, papaya and passion fruit.

Papaya

Commercial production of papaya *(Carica papaya)* is relatively recent in the Amazon, but it is becoming a quite successful activity especially in the State of Pará and in parts of the Peruvian Amazon. The total area planted is still relatively small (around 500 ha in Brazil), and is largely concentrated in the Castanhal region, near the city of Belém. Recently the crop has been expanded to other areas, especially Tomé-Acu. The cultivar Sunrise Solo is practically the only one extensively planted (in Oxisols commonly utilized for growing black pepper) using high rates of fertilizer applications as well as herbicide treatments. In heavy soils, it is common to grow the crop in cambered beds, with a drainage ditch between every two papaya rows. A few farmers near Belém are using papaya as a temporary shade in establishing new cacao plantations, with promising results.

As in the case of black pepper, although cost of production is high, papaya cultivation in this region is proving to be a very profitable business thanks to good price of the product as well as to very high yields usually obtained by farmers (about 40 t/ha/yr). Part of the production is locally consumed but most of it is exported to southern Brazil, especially to Rio de Janeiro and Sao Paulo.

Potential New Crops

Considering the vastness of the Amazon basin and the richness of its flora (nearly 100,000 species), the number of indigenous plants domesticated by man and presentlty cultivated as commercial crops seems surprisingly small. Apart from rubber and cacao, which have already been mentioned, there are only three other Amazon species widely cultivated in the tropics: cassava *(Manihot esculenta)*, pineapple *(Ananas comosus)*, and cashew *(Anacardium occidentale)*. Cassava is grown practically everywhere in the Amazon, mainly by shifting farmers. Pineapple and cashew are traditionally found in home gardens, and only a few commercial plantings have been established in some areas of the Amazonia, for instance, near Belém.

The National Academy of Sciences of the United States has recently sponsored a worldwide survey on underexploited tropical plants showing good promise for improving agriculture and quality of life in tropical areas (Nat. Acad. Sci., 1975). Based on the experience and judgement of a panel of experts, a list of 36 plants was selected from a total of 400 species nominated by plant scientists around the world in response to a written inquiry. It is interesting to observe that 12 plants out of the selected 36, or 1/3 of the total, are indigenous in the Amazon. Many other promising species are listed by different authors, such as Le Cointe (1947), Froes (1959), Calvacante (1976), and Schultes (1979). Excluding timber species, which apparently can be counted by the hundreds, the following native perennials are seemingly the most promising ones for wider exploitation, depending on future agronomic research.

Bertholletia excelsa **(Brazil nut)**

Attempts to cultivate this important tree, which grows wild throughout the Amazon basin, have thus far given disappointing results. A disadvantage is the long period (15 years) needed for the trees to enter production after planting. A large plantation established near Manaus about 25 years ago has practically been abandoned because of low productivity. It is suspected that monocrop plantations of this species offer no breeding sites for the natural pollinating insects *(Bombus* spp.) commonly found in the forest, but this hypothesis has not been experimentally demonstrated. The low productivity of the Manaus plantation could also be attributed to inadequate cultural practices (too close planting distance, use of unselected material, etc.). Some studies carried out in Brazil (Moraes, 1974) indicate that selected clones propagated by grafting not only resulted in increased yields but greatly reduced the time between planting and harvesting (from about 15 years for seedling to four to six years for the grafted plants). This is an important breakthrough for the domestication of this valuable plant.

Paullinia cupana **(guaraná)**

This woody vine may be considered as partially domesticated, since it has been cultivated by Amazon indians for centuries. It has a good market potential in Brazil, where the seeds are used to prepare a popular soft drink known as "guaraná". There are about 500 ha under cultivation in Brazil, mainly in the State of Amazonas, and the planted area is rapidly expanding in response to the increase in demand for the product and good internal price.

Bixa orellana **(achiote or urucum)**

Like guaraná, this popular Amazon plant may also be regarded as partially domesticated, as it is already cultivated on small scale throughout the tropics. The dye extracted from the orange-red pulp that covers the seeds is widely used for coloring foods such as rice, soup, butter, cheese, margarine, processed meat, etc. The plant is known to be very tolerant to acid infertile soils.

Guilielma gasipaes **(pupunha, chontaduro, pejibaye, pijuayo)**

Also partially domesticated and grown usually in home-gardens, but some small plantings of this species are also found in Amazonia and in Central America (Johannessen, 1966). This valuable palm also known as "peach palm" produces not only a very nutritious fruit (served after cooking) but the shoots can also be harvested for "hearts of palm" (Camacho and Soria, 1970).

Euterpe oleracea **(palmito)**

Traditionally exploited for hearts of palm, the fruit of this species is also widely used to prepare a much appreciated beverage known as "açai" in the State of Pará. It is already under cultivation using primitive methods in some areas.

Jessenia **spp. (seje or patauá)**

There are three species of particular interest: *J. polycarpa* (Colombia and Venezuela), *J. bataua* (Brazil, Venezuela and Colombia) and *J. weberbaueri* (Peru). The fruit of these little-known palms produces an edible oil of high quality almost identical to olive oil. It is estimated that adult plants of *J. polycarpa* are able to produce 30 kg of fruit/year, from which 22 kg of oil (24 liters) can be extracted.

Caryocar villosum **(piquiá)**

The fruit of this tree, like that of oil palm, yields two types of edible oils, one from the pericarp and the other from the kernel. The kernels are considered to be one of the best edible nuts in the tropics. This species was introduced in Malaysia by Henry A. Wickham (the same person who introduced rubber), but only preliminary studies have been made with the plant (Lane, 1957). Research can contribute greatly to increase the productivity of this interesting plant.

Couma **spp. (sorva)**

Besides producing a latex commonly used for making chewing gum, the fruit of these trees is much appreciated and may have commercial value. The best known species are *C. macrocarpa, C. utilis* and *C. guianensis.*

Mauritia flexuosa **(buriti)**

This palm grows throughout the Amazon basin, mostly at low altitudes in groves near swamps or damp soils that are useless for agriculture. Its fruit has a thin edible pulp, rich in vitamin A and C. The seeds yield about 50 percent of edible oil. Other potential products are "hearts of palm" from the shoots, a sago-like starch from the pith of the trunk, and industrial fibers from the leaves.

Copaifera spp. (Copaiba, palo de aceite)

Several species of this genus produce an oleoresin (also known as balsam), which is extracted from the trunk. The most productive species appear to be *C. officinalis* and *C. langsdorffii,* both native of the Amazonia. The oil has been used mainly for making varnish and photographic paper. It was also formerly used in medicine as a disinfectant. It is extracted by making a perforation with a drill at the base of the trunk which must be closed and renewed yearly in order to sustain production. In general, one tree produces an average of 3 to 5 lt/year, but some trees have been reported to produce as much as 20 to 30 liters. It has recently been demonstrated that *Copaifera* oil is a good substitute for diesel oil, which makes it an interesting crop for future research.

Another interesting Amazon tree, apparently promising as a source of oil to replace diesel, is *Ocotea barcellensis,* locally known as "louro mamorim" or "árvore do querosene". Oil from the trunk of this tree has been traditionally used by natives to replace kerosen (Correa, 1969), but there are no references about the productivity of the plant.

Agroforestry Systems

In recent years there has been much interest in research to develop appropriate agroforestry systems for the humid tropics. These systems sometimes are called "multiple cropping" or "multi-storeyed" agriculture. They are defined as sustainable land management systems which offer the possibility of optimizing the overall yield of an area by combining different crops (especially perennials), simultaneously or sequentially, with forest plants and/or pastures, using the same area (Kind and Chandler, 1978).

From an ecological point of view, the advantages of agroforestry over conventional forms of agriculture are well recognized (King and Chandler, 1978; Budowski, 1978; Huxley, 1979). They mimic the natural forest ecosystem and are considered to be more efficient than monocrop plantations in preventing soil degradation due to leaching and erosion. However, as pointed out by Huxley (1979), there is relatively little hard data from actual research that can be used to implement or recommend specific agroforestry models to farmers. Experiments on agroforestry require an integrated approach, being much more complex than conventional field experimentation with single crops.

Interactions between different plant species are usually site specific, making it difficult to generalize from isolated studies. As the problem stands today, agroforestry is then to be regarded as a promising field of research to be strongly encouraged and supported, particularly in the humid tropics, but it is by no means a system ready to be widely recommended for promoting agricultural development.

Some experiments on agroforestry have been recently started in some areas of the Amazon (Alvim and Dias, 1975; Andrade, 1979). In the case of some shade tolerant species (e.g., cacao and pepper), it appears that good possibilities exist for developing efficient multi-storeyed systems using economic plants such as coconut, "pupunha" *(Guilielma gasipaes),* Brazil nut, and several valuable timbers as shade plants (Alvim, 1979). The association of cacao and coconut is already a common practice in Malaysia. In India, Nelliat *et al.* (1974) proposed a multi-storeyed system combining coconut, pepper, cacao, cinnamon and pineapple. The recent review by Dubois (1979) and other works in this volume give a general appraisal of potential agroforestry systems that could be tested in the Amazon.

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Forestry and Agroforestry

Agroforestry in the Amazon Basin: Practice, Theory and Limits of a Promising Land Use

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Introduction

This paper explores the potentials for agroforestry in the Amazon Basin. Agroforestry systems are "sustainable land management systems that combine the production of crops including tree crops, forest plants and/or animals simultaneously or sequentially on the same unit of land, applying management practices that are compatible with the cultural practices of the local population" (King and Chandler, 1978). Agroforestry is a term that covers an enormous range of land uses at all scales of tenure and investment, ranging from susbsistence to plantation farming, and from dozens of species (Conklin, 1957) to only two or three. Agroforestry usually involves multiple canopies, either in space or time, and more than one harvestable stratum.

Agroforestry has received a great deal of attention in recent years. In 1979, three major conferences dealing exclusively with agroforestry were held, one sponsored by CATIE (Centro Agronómico Tropical de Investigación y Enseñanza) in Costa Rica (de las Salas, 1979), one by ICRAF (International Council for Research on Agroforestry) in Kenya (Mongi and Huxley, 1979), and another by ICRAF and DSE (Deutsche Stiftung Für Internationale Entwicklung) in Nigeria (Chandler and Spurgeon, 1979). Many national agricultural research programs are beginning to include agroforestry experiments as indicated by country and research reports in this volume. Although research interest is new, the farming systems themselves are not. Agroforestry, particularly as related to shifting cultivation, is the foundation of agriculture throughout the

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lowland tropics, and has been the basis for the development of several market and cash crops industries, including that of Nigerian oil palm (Obi and Tuley, 1973), and several Asian cash crops cited in Kundstater *et al.* (1978). King (1979a, b) points out that some of the world's most valuable tropical hardwood plantations were developed using shifting cultivation and agroforestry techniques. While not all shifting cultivation is agroforestry, many shifting agriculturalists purposely plant or protect woody perennials for subsequent harvests. Species commonly planted in Amazonia include inga *(Inga edulis)* used for fruit and fire wood, papaya *(Carica papaya)*, genipa *(Genipapo americana)*, and peach palm *(Guilielma gasipaes)*; the latter is also known as pejibaye, pijuayo and pupunha. Such types of shifting cultivation systems have served as the prototype for many agroforestry systems that incorporate successional features (Hart, 1980; Dubois, 1979; Bishop, 1978). The presence of shifting agriculture throughout the tropics suggests that many attributes of such systems can be modified and integrated into commercial agriculture.

Forests and Agroforestry

In the rush to colonize the Amazon, the importance of forest resources to Amazonian economies has often been overlooked, both in terms of value and labor absorption and forest mediated benefits like flood control (Godfrey, 1979; Guess, 1979; Gentry and Parodi, 1980). For example, the Banco do Brasil reported that in 1979 the State of Pará exports were valued at 234 million dollars. Wood products, black pepper, Brazil nuts and palm hearts accounted for 70, 43, 32 and 15 million dollars, respectively (O Liberal, July 28, 1980). Therefore, over half of Pará's export dollars were gained from three strictly extractive products: wood, nuts and palm hearts. Table 1 shows the magnitude of the production and values of forest products. Table 2 lists numerous latexes, oils, resins and medicinals, many native to the Amazon, that could be introduced into agroforestry systems.

Estimates of the potentially exploitable wood volume in Amazonia range from 60 to 120 m^3/ha on the uplands (terra firme) and from 30 to 90 m^3/ha on the várzeas or floodplains (Pandolfo, 1978). While seven species (two *Virola* species, two *Carapa* species, *Swietenia macrophylla, Octea cymbarum,* and *Cedrela odorata)* comprise most of the timber trade (Palmer, 1977), over two hundred Amazon species have been studied in various Brazilian, British and American laboratories, and the properties of a wide variety of woods are relatively well known (Carvajal, 1978). The silvics of several species are being studied (SUDAM, 1979), including many for which there already exist comparative data from other tropical Latin American sites (e.g., *Cedrela odorata, Cordia alliodora)*.

Table 1. **Brazilian Amazon forestry and forest products: Production and value 1974-1976.**

Commodity	Production in tons			Value in US$1,000		
	1974	1975	1976	1974	1975	1976
Acai fruits[1]	n.a.	17,474	18,743	n.a.	2.068	2,104
Andiroba[2]	325	252	302	14	21	11
Babacu nuts[3]	1,354	1,227	1,784	204	223	124
Balata[4]	274	283	512	166	189	516
Caucho[5]	162	327	319	130	348	268
Copaiba[6]	160	23	26	378	22	19
Cumaru[7]	24	13	13	21	15	17
Hevea latex[8]	19,086	13,060	14,678	20,127	12,483	14,723
Hevea liquid[8]	1,027	887	1,016	476	442	512
Jatoba[9]	32	33	21	10	13	5
Macaranduba[10]	526	496	541	248	237	235
Murumuru[11]	107	44	41	6	2	2
Palmito[12]	24,342	192,182	197,671	723	9,352	11,598
Sorva[13]	3,787	3,294	6,197	1,465	1,235	1,909
Timbo[14]	19	6	15	5	1	3
Ucuuba[15]	111	110	109	13	10	9
Brazil nuts[16]	35,776	51,719	61,043	8,597	12,619	16,286
				32,583	39,280	48,340
Wood production*		1975	1976		1975	1976
Logs		7,684,395	8,770,955		136,481	650,580
Charcoal (m^3)		33,789	36,497		3,706	3,839
Firewood		16,333,375	16,620,382		294,440	366,463
					176,672	1,020,882

1 = *Euterpe oleraceae*, 2 = *Carapa guianensis*, 3 = *Orbynea speciosa*, 4 = *Manilkara bidentata*, 5 = *Castilloa ulei*, 6 = *Copaifera multijuga*, 7 = *Dipteryx oderata* 8 = *Hevea brasiliensis*. 9 = *Hymenea coubaril*, 10 = *Manilkara huberi*, 11 = *Astrocaryum murumuru*, 12 = *Euterpe edulis*, 13 = *Couma utilis*, 14 = various lianas, 15 = *Virola* sp. 16 = *Bertholettia excelsa*.

* Wood values include parts of Mato Grosso and Goias. During this statistical period, forest clearing in the Central Western region of Brazil was concentrated in the Amazon regions of these two states.

Source: Annuario Estatistica do Brasil, 1977, 1978.

Table 2. **Amazon species as sources of latex, oils, resins and medicinals with existing markets.**

Genus and species	Family	Use
Latex		
Hevea brasiliensis	Euphorbiaceae	Rubber
Hevea genera	Euphorbiaecae	Rubber
Castilloa ulei	Moraceae	Rubber
Sapium sp.	Euphorbiaceae	Rubber
Manilkara bidentata	Sapotaceae	Isomers of rubber but not elastic Natural plastic of industrial interest
Pouteria gutta	Sapotaceae	Natural plastic of industrial interest
Landolphia elata	Apocynaceae	Natural plastic of industrial interest
Ecclinusa balata	Sapotaceae	Natural plastic of industrial interest
Actras sapota	Sapotaceae	Chicle
Oils		
Acromia sclerocarpa	Palmae	Edible and soap oil
Orbynea martiana	Palmae	Kernels contain 60% oil
Oenocarpus sp.	Palmae	Edible oil
Carapa guianensis	Meliaceae	Analgesic and soap oil highly productive (200 kg/t)
Caryocar brasiliensis	Caryocaraceae	Soap, industrial oil
Licania rigida	Rosaceae	Industrial uses
Resins		
Hymenea coubaril	Leguminosae	Varnishes
Eperua sp.	Leguminosae	Lacquers and varnishes
Dye Plants		
Bixa orrelleana	Bixaceae	Edible red dye
Aromatics		
Dipteryx oderata	Leguminosae	Source of coumarin and dicoumeral anti-coagulants
Croton	Euphorbiaceae	Linalool (rose aromatic)
Medicinals		
Chondodendron	Menispermaceae	Curare
Abuta	Menispermaceae	Curare
Telitoxica	Menispermaceae	Curare
Strychnos	Loganaceae	Curare
Rauwolfia (12 sp)	Apocynaceae	Reserpine
Croton sellowil	Euphorbiaceae	Antibiotics
Capraria biflora	Scrophulariaceae	Antibiotics
Thevetia peruviana	Apocynaceae	Cardiac glycosides
Asclepias currassavica	Asclepidaceae	Cardiac glycosides
Chenopodium ambrosoides	Chenopodiaceae	Ascaridole (vermifuge)
Stevia rebaudiana	Compositae	Stevioside (sweetener 300 as powerful as sucrose)
Dimorphandra mollis	Leguminosae	Source of rutin

Source: Mors and Pizzinni, 1966.

In spite of the large forestry potential, at the moment only three woods dominate the trade: ucuuba (various *Virola* species), mahogany *(Swietenia macrophylla),* and andiroba (assorted *Carapa* species). These species are often found in relatively uniform stands, and probably could be managed for sustained yield. Unfortunately, harvesting has not been sufficiently monitored or controlled, allowing the *Swietenia* and *Virola* stocks to be over-exploited (Fox, 1976; Rodriguez, 1976; Godfrey, 1979). Amazon forestry has been described by Fox (1978) as a "huge uncontrolled mess." Detailed analyses of the area's forestry industry are beyond the scope of this paper, but are discussed in Muthoo (1977), MA/IBDF/COPLAN (1977), FAO (1976), Bruce (1976), Glerum and Smit (1960, 1962), PRODEPEF (1977), Pandolfo (1978), and Palmer (1977). One possible means for rationalizing forest management could be the integration of forest plantations with subsistence agriculture, one of the oldest and most developed forms of agroforestry.

Deforestation

International concern about tropical deforestation has sparked polemics on both sides of the issue, prompting the US National Academy of Sciences to commission a report (Myers, 1980). This document was subsequently criticized by Lugo and Brown (in press) who argued that its conclusions overstated the rate and degree of tropical forest alteration. There is no concensus yet on this question, but various estimates of the rates and magnitudes of deforestation in the Amazon countries are given in Table 3. While these figures are at best only approximations, it is not unlikely that over 15 million hectares have been cleared within the last decade in the Amazon Basin. Detailed estimates for the Brazilian Amazon based on ERTS satellite data are presented in Table 4. Between 1976 and 1978, some two million hectares of forest were cleared in the Brazilian Amazon alone. If current clearing rates are extrapolated (ignoring the tendency of the rates to increase in many areas) one may estimate that over 11 million hectares of the Brazilian Amazon have been cleared, most of it within the last 10 years. In zones where cutting has been particularly pronounced, Tardin *et al.* (1979) showed that almost one-third of the forests have been replaced by other land uses, particularly ranching.

The debate over the magnitude of clearing has been colored by several allied concerns. First, much of the wood cut was simply burned. Though infrastructure and sufficient price incentives for forest use were lacking, the waste of millions of cubic meters of timber by burning cannot be simply dismissed, especially since many very valuable forests have often been replaced by unstable land uses. This has occurred in the state of Acre where natural rubber forests were cleared for pasture and in Pará, where grasslands supplanted mahogany and Brazil nut forests (Godfrey, 1979; Bunker, 1980a). The collapse of some agricultural systems and the subsequent land abandonment after forest removal, as well as the speculative nature of much of the land development process, argues for a re-examination of clearing, and the land uses that supersede forests. It is environmentally destructive land use, rather than deforestation per se, that is at issue.

Table 3. **Tropical lowland forests of the Amazon Basin: Approximate area of forest clearing rate, and dominant replacement land use(s).**

Country	Amazon forest area (millions ha)	Current clearing* (ha/yr)	Dominant Land Use
Brazil	280	1,000,000[1]	Cattle ranching (95+)
Peru	65	No data on rates but 10% thought to be cleared[2]	Subsistence, cash crops, cattle(15%)
Bolivia	51	3,000[2]	Cattle, citrus, cacao, coffee
Colombia	31	150,000+[2]	Cattle, rice
Guyana	13	10,000[2]	Subsistence
Surinam	13	3,000[2]	Subsistence, forestry
Venezuela	13	No data on rates	Subsistence, cattle
Ecuador	10	No data on rates	Cattle (81%)[2]
French Guiana	8	Negligible	Subsistence
	484	1,166,000	

* Clearing here implies total replacement for and alternate land use. Selective logging etc. is not included. All these figures are at best only approximations.

Sources: 1) INPE/IBDF, 1980; 2) Myers, 1980.

Agroforestry is no panacea, but it is widely and successfully practiced throughout the Basin and has many features that moderate some of the environmental stresses placed on agricultural systems in the Amazon. Agroforestry systems can maintain forest resources while increasing food production, making the expansion of agriculture into forest economies an integrative rather than a substitutive process.

Table 4. **Estimates of deforestation in the Brazilian Amazon.**

State	Area cleared in 1975 (ha)	Area cleared in 1976-1978 (ha)	Increase in clearing 1975 to 1976-1978 (%)	Total cleared as of 1978 (ha)	Cleared area 1980* (ha)
Mato Grosso	1,012,425	1,823,075	180	2,825,500	5,085,900
Pará	865,400	1,379,125	159	2,244,524	3,575,528
Maranhâo	294,075	439,325	149	733,400	1,092,766
Rondônia	121,650	296,800	243	418,450	1,016,833
Acre	116,550	129,900	111	246,450	273,559
Amazonas	77,950	100,625	129	198,575	230,361
Roraima	5,500	8,875	161	14,375	23,000
Amapa	15,250	1,800	11	17,050	20,119
TOTAL	2,859,525	4,857,650		7,717,175	11,318,060

* Estimate calculated by multiplying the % increase in clearing with the deforested totals of 1978.

Source: INPE/IBDF, 1980.

Agroforestry Systems in the Amazon

Amazonian land uses are outlined in Figure 1. The forests are the foundation of virtually all the production systems, providing extractive products, fallows, and ash. Land uses can be divided into those that supply industrial raw materials and those that supply food. As enterprises become more capitalized, plant species diversity tends to be reduced. The size of land holdings tends to increase where cash crops predominate (IBGE, 1975). Recently established cattle operations in Brazil are essentially corporations and occupy large land areas, hence they are included in the more capitalized "plantation" end of the spectrum.

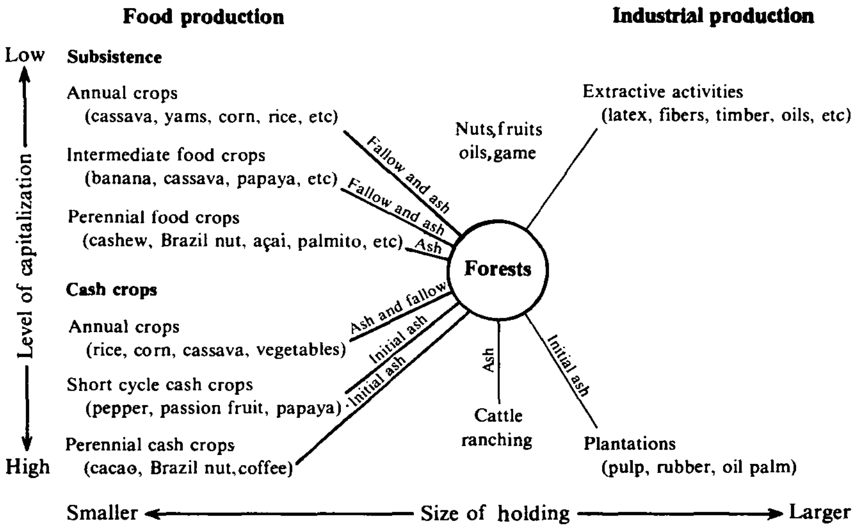

Figure 1. *Production systems in the Amazon*

As Okigbo and Greenland (1976) indicate, mechanization and the use of agricultural chemicals of various kinds have been essential to the replacement of multicrop agricultural systems by monocultures, but the heavy use of energy and chemicals is often uneconomic in the Amazon. When agricultural inputs of various kinds are lacking or erratically available and expensive, and where labor (in commercial ventures) becomes economically prohibitive, multispecies cropping becomes prevalent. For example, high weeding costs have influenced the shift from monoculture to agroforestry (tree pasture) systems even in the highly capitalized Jari pine and Pirelli rubber plantations in the state of Pará.

The definition of agroforestry cited earlier encompasses numerous subcategories that refer to distinct agricultural systems.

Agrosilviculture is the concurrent production of agricultural crops (including tree crops) and forest crops.

Silvo-pastoral systems integrate tree production and livestock production.

Agro-silvo-pastoral systems include animal, tree, crop, or forest products production.

Multipurpose forest tree production, often cited as a separate category (King, 1979a), involves managing trees not just for timber production, but also for site amelioration, fodder, fruits, and firewood.

Multipurpose species are common in agroforestry agriculture and in this article are considered in the context of specific production systems.

Agrosilvicultural systems

Subdivisions of agrosilviculture are best determined by whether the systems include a successional phase or not. Clearly, a cacao x *Cordia* agrosilvic system differs profoundly from a "Taungya" (subsistence crops, planted commercial timber species and fallow) production system in several basic ways. For convenience, we discuss successional and simple cash crop agrosilvic systems separately.

Successional agrosilvicultural systems

Successional agrosilvic systems include several forms, depending on the purpose and degree of utilization of the fallow. Characteristically, successional systems are harvested for wood or fruits after the first few years of annual cropping. These may be continuously harvested (as in some shifting cultivation and natural system analogs) or essentially "abandoned" until timber harvest at the beginning of a shifting cultivation cycle (Taungya).

Natural system analog. When plants are purposely introduced into the fallow, the succession is manipulated and is the prototype for what Hart (1980) terms the "natural system analog." Hart further emphasizes that this system is not just a simple chronological sequence of crops, but one where each successional stage contributes to the physical requirements of the next crop. Instead of planting perennials and continuously removing weeds until the crops reach maturity, annual crops and short lived perennials are substituted in the understory. Planting systems of this type are described elsewhere in this volume (see Bishop). They have also been developed by Dubois (1979) for specific Amazon situations, where agricultural plots are cleared manually, burned and planted to traditional subsistence crops like rice, cassava, and beans. After initial establishment the components for a more stratified system are introduced, including peach palm, bananas, cacao, coffee or small fruit trees. When the last harvest of annual crops is completed these perennial plants have grown enough to permit the introduction of a productive understory composed of *Marantha arundinacea, Calatha alluia* and species of *Xanthosoma, Colocasia* and *Cajanus.*

Taungya. Taungya is the best documented of commercial successional agroforestry systems. Practiced in South America mainly in Surinam, and experimentally in Colombia and Peru, it focuses on harvesting timber species interplanted with annual crops. The forest is cleared, burned and planted with annual food crops. Commercial timber species are then planted into the plot. After harvesting the annuals, the system proceeds through succession. At the end of the rotation period, the commercial trees are harvested and the land cleared, and put into crops and timber seedlings once again. Many of the teak and mahogany plantations in Africa and Asia have been developed using this technique.

Shifting cultivation. Small scale agroforestry systems are some of the most successful continuous farming systems in the tropics in spite of the frequent criticism leveled against shifting cultivators, blaming their demographic increase for land degradation (Galvão, 1979; Myers, 1980).

Shifting cultivation systems have been misperceived by many observers of the Latin American tropics. Most of the discussion and description of shifting agriculture in South America has occurred within the last 20 years (Watters, 1970; Sánchez, 1973), a period when vast population dislocations have taken place. These have been associated with changes in access to land, such as the relative decline of tenant farming (Sawyer, 1978), tenure laws and jurisdiction (Bunker, 1979, 1980a; Sawyer, 1978; Pompermeyer, 1979) and colonization projects (Nelson, 1975; Mahar, 1979; Bunker, 1978). Populations unfamiliar with lowland tropical environments, like the migrants from the Andean Sierra, or the Brazilian Northeast, were thrust into rain forest areas at the same time that government subsidized corporate groups and land speculators were becoming active in the same regions. While the Amazon area was perceived as "empty," in fact many lands are often occupied, and legitimately claimed (Ianni, 1978; Durham, 1977). The migratory and ephemeral nature of much of the shifting cultivation easily observed in Amazonia (along roads) has its roots not in intentional land mismanagement or lack of understanding of effective fallow lengths, but in the land conflicts, speculation, human displacement and power dynamics at the frontier areas (Pompermeyer, 1979; Godfrey, 1979; Schmink, 1977; Nelson, 1975; Ianni, 1978).

While shifting cultivation systems frequently are understood as ecologically rational at low population densities (Sánchez, 1973, 1976), they are described as destructive when demographic increases reduce the land area per family or individual and fallow times are shortened, resulting in land degradation. Such an analysis, focusing on only a small part of the picture, ignores the context in which most shifting cultivators must operate. On the average, the person/land ratios are extremely low in Amazon areas for all the countries discussed in this volume. Before "blaming the victim" it is worthwhile to examine tenure arrangements. In the state of Amazonas, Brazil, for example, 96 percent of the agricultural establishments had holdings of less than 100 ha, but controlled merely 15 percent of the land. Meanwhile, of the area in private domain maintained as forest or classified as non-utilized productive land, 77 percent was held by only 28 of a total of 92,741 agricultural properties surveyed (IBGE, 1979). While reduced fallow times will clearly affect the productive capacity of land, the underlying problem in shifting cultivation often is not only technical or demographic but related to land distribution and control.

Successional agroforestry systems are low input, species diverse systems. They are oriented toward small farmers and focus on supplying food crops as well as some timber and cash crops. Such systems have been successful in developing cash crop industries in many areas of the tropics (Obi and Tuley, 1973; Kundstater *et al.*, 1978; Okigbo and Greenland, 1976). Further, existing fallow systems can be made economically attractive by incorporating commercial species into the subsistence crop complex.

Cash crop agrosilviculture

Cash crop systems using agroforestry techniques have a long history in tropical agriculture. In the Amazon, however, incentive programs for cash crops (with the exception of cacao) do not include funds for silvicultural components, in spite of the prevalence of agroforestry systems throughout the Amazon Basin. Many fruits and truck crops are already grown in mixed plot cultivation such as papaya intercropped with vines of maracuya (passion fruit). These systems, though important for the local food supply, are inconsequential when compared in area and revenue with the major plantation crops, black pepper *(Piper nigrum)*, cacao *(Theobroma cacao)* and rubber *(Hevea brasiliensis)*.

Pepper. The cultivation of black pepper in the Amazon has been plagued by attacks of *Fusarium nigrum* and *F. solani* that limit the productive life of pepper plants to five to seven years (Alvim, this volume). When heavy infestation of *Fusarium* occurs in a field, the agriculturalists near Belém generally switch into cacao, and in this manner profit from the residual effect from intensive fertilization applied to black pepper. Peck (1979) points out that this substitution process of cacao for pepper is flexible and is generally accompanied by the introduction of leguminous trees (usually *Erythrina* sp.) to provide shade for the young cacao plants. In such a system where replacement of one cash crop by another occurs sequentially, the possibilities for the introduction of forestry species are excellent. Further, pepper plants are more shade tolerant than was initially realized. Research at INATA (Instituto Agronômico de Tomé-Açu, Pará, cited by Peck, 1979) indicates that pepper can tolerate 20 percent shading without a decrease in production. It is then feasible to introduce some interesting economic species with light canopies in pepper fields. Leguminous tree species such as *Erythrina* and *Gliricidia,* that tolerate pruning and thus allow the cultivator to control the degree of shading (Budowski, 1978; Urquinhart, 1965), can be especially effective. Another alternative might be the selection of legumes of moderate height that do not require pruning, such as some *Inga* and *Pithecellobium* species, as well as commercial species like *Cordia alliodora.*

Cacao. Latin American cacao cultivation has traditionally developed with the "cabroca" technique whereby the forest understory is cleared and cacao is planted underneath the tree canopy. The use of commercial timber species in conjunction with cacao is better developed than with almost any other cash crop.

Cacao yields are higher in certain climatic regimes and with heavy fertilizer applications when grown without shading. However, in many Amazonian environments where dessicating winds and a strong dry season occur, the microclimate buffering produced by shade trees may be highly desirable.

During the first three years, shading and planting density are critical for the cacao plant (Entwhistle, 1972; Mabey, 1967). Shade at this stage affects the height at which the plant bifurcates. In full sun, this bifurcation occurs at a low height causing subsequent management problems. Murray (1965) believes that the optimal bifurcation occurs with 50 percent shading. Beyond the physiological influences on cacao development, shade can reduce damage caused by insects by reducing physiological stress, as well as creating habitat for pest predators, and can diminish weed populations (Cunningham and Burridge, 1960). Cacao is a rather nutrient demanding species, and requires heavy N additions. Some of the N requirements can be met by interplating cacao with legumes such as *Erythrina* (Peck, 1979).

Species selected for interplanting with cacao should reach commercial dimensions within 25 years. In humid tropical conditions, it is possible to achieve wood volumes on the order of 200 m^3/ha/rotation with species such as *Cordia alliodora*. This represents a substantial economic gain if one considers that the value of this commercial timber is on the order of US$10 to 20/$m^3$. This kind of financial return helps promote renovation of cacao plantations, because the wood becomes harvestable at the time when cacao production is declining (Peck, 1979).

Coffee. Amazonian coffee production is still essentially a largely montane crop, but is increasingly being planted in Rondônia. This crop is traditionally grown with shade trees such as *Erythrina* and *Gliricidia*. Promising native species for interplanting include *Cordia goeldiana*, *Schizolobium amazonicum* and *Pithecolobium saman* (Peck, 1979).

The characteristics of desirable species for intercropping agrosilvic systems depend on the goals of the agriculturalist, and the needs of the farm and the agro-ecosystem. Nitrogen fixation, supplemental animal feed, firewood, fruits, soil protection, economic return, wind breaks are all legitimate considerations for species selection. In general, tree species for use in multi-strata cropping systems should have these atrributes (Peck, 1979):

- Apical dominance and good form, and relative tolerance to pruning when established at low densities.

- Rapid growth, with a rotation period appropriate to the renovation of the other interplanted species.

- Good quality wood with an established market.

- Canopy characteristics that permit the passage of light.

- A root system that is relatively deep, and that allows the tree to resist wind and that does not result in intense competition with the associated crops.

- Deciduous species are preferable because of the reduced transpiration and organic matter addition during the dry season.

Cattle ranching and agroforestry systems

Of all the agricultural land uses in the Amazon, cattle ranching is the most important in both area and investment, particularly in Brazil and Colombia. Livestock production has rapidly expanded throughout the Latin American lowland tropics (Parsons, 1970, 1976), but the success of this land use in converted forested areas of the Amazon remains variable (Koster *et al.,* 1977; Fearnside, 1978; Serrão *et al.,* 1979; Hecht, 1981). Productivity declines due to losses of soil fertility (Falesi, 1976; Koster *et al.,* 1977; Serrão, *et al.,* 1979; Hecht, 1981) and weed invasion (Hecht, 1979; Dantas and Rodrigues, 1980) are frequent. Serrão *et al.* (1979) estimated that the area of degraded pastures in the Brazilian Amazon was close to 500,000 ha. Hecht (1979) suggested that aproximately 50 percent of Amazonian pastures in Brazil are seriously damaged, an estimate corroborated by Tardin's (1979) Landsat and ground truth study of the Barra de Garças region, one of the major cattle development areas in the Amazon, and often considered the most successful. Pasture is defined as "seriously damaged" if weed invasion covers more than 50 percent of the basal area, when available soil P levels drop below 1 ppm and soil bulk densities are 30 percent higher than forest. Livestock production in plantation systems in the Amazon and elsewhere, however, has proved quite successful (Thomas, 1978; Bene *et al.,* 1977; Rios, 1979), suggesting that livestock systems are less ecologically damaging and more economic when they are developed as part of an agroforestry complex. Toledo and Serrão (elsewhere in this volume) argue, however, that the use of unadapted species and inappropriate technologies, rather than the ecological structure of pastures, is responsible for the failure of many pastures converted from forest.

Pastures that include trees fall under the heading of "agro-silvo-pastoral" systems, an unfortunately ponderous generic term. Also under this rubric are "integrated farming systems" such as those described by Bishop (elsewhere in this volume), which include animals, crops and useful tree species. Forest grazing, or "silvo-pastoral systems" describes a situation where animals graze a ground cover crop grown under plantation trees. "Agropastoral" systems are those that encompass livestock as well as trees grown for food (human or animal), or site protection including firebreaks, windbreaks, living fences, soil nutrient ameliorators, watershed management, shade or any combination of the above (Combs and Budowski, 1979). In the Amazon, forest grazing schemes are the most developed in area and management, and seem to be reasonably economic, but still remain relatively unexploited in spite of their potential in maintaining already developed sites, and recuperating degraded areas. This author estimates that less than 60,000 ha of Amazonian pastures are incorporated into agroforestry systems.

Existing silvo-pastoral systems in the Amazon

The best known forest grazing scheme in the Amazon is Jari's *Pinus caribea* x *Panicum maximum* system. Over 20,000 ha of pine plantations have been overseeded with grass mainly to lower the exorbitant cost of weed control. Extensive grazing in the plantations produced about 50 kg/ha/yr of meat and has substantially diminished weed management costs. While beef cattle reduce the pine growth by some 5 percent, the savings in brush control costs after two years is sufficient to pay for pasture establishment and fencing (Toenniessen, 1980).

At the Pirelli rubber plantation in Marituba, Pará, cattle graze a cover crop of kudzu *(Pueraria phaseoloides)* as well as a shade tolerant native herb in an intensively managed rotation. The cattle gain some 75 kg/ha/yr, a figure competitive with conventional grazing in pastures converted from forest. Costs of controlling kudzu and weeds have been greatly reduced (Castagnola, personal communication). Plantation operators find that the productive ground cover aswell as shading, diminishes weed establishment and invasion. The increased expense in animal management and infrastructure is offset by the reduced labor costs of weeding, and the return on the calves and meat.

Forest grazing in the Amazon is in its infancy due to the rarity of plantation agriculture, but has the potential to be integrated into current programs expanding or developing new plantations, such as the PROBOR program for rubber (described by Dr. Maia-Rocha elsewhere in this volume). Agroforestry techniques for oil palm plantations are well developed in Asia and Costa Rica (Thomas, 1978), and could be adapted to the Amazon for oil palm, and possibly peach palm plantations where cover crops such as kudzu or *Desmodium ovalifolium* can be effectively grazed. Many forestry plantation species have been successfully grown with forage crops. These include species such as *Cordia alliodora, Cedrela odorata, Eucalyptus deglupta, Leucaena leucocephala, Sesbania grandifoilia, Acacia mangioa, Schizolobium amazonica, Tabebuia* spp., *Octea* spp., *Caryocar* ssp., and *Parkia* spp. These are species with well developed national and international markets. Further, the silvics of these species are relatively better known compared to that of most Amazonian species. The potential for mixed plantations of native trees with cover crops grown underneath, is an unexplored, but interesting possibility in the Amazon. Plantations of diverse species are emphasized because

> "The adoption of monocultural systems has lead directly to an increase in the number and severity of pests and diseases on forest crops .... There seems to be evidence that much of this is due to the uniform and

crowded conditions that plantations provide, and that cultural operations in plantations have often accentuated". (Gibson and Jones, 1977).

A partial list of tree species that occur naturally in Amazon pastures and that are also used in the Amazon timber industry is presented in Table 5.

Table 5. **Amazon timber species recorded in pastures.**

Scientific name	Family	Common name (Portuguese)
Bagassa guianensis	Moraceae	Tatajuba
Psidium guianensis	Myrtaceae	
Siparuna foetida	Monimeaceae	
Inga sp.	Leguminosae	Inga
Cordia goeldiana	Moraceae	Frejo
Enterolobium schombergii	Leguminosae	Tamboril
Hymenea coubaril	Leguminosae	Jatoba
Hymenolobium sp.	Leguminosae	Angelim de mata
Pithecolobium racemosum	Leguminosae	Angelim rajado
Stryphnodendron pulcherimum	Leguminosae	Angelim
Goupia glabra	Celastraceae	Cupiuba
Didimopanax mororoti	Araliaceae	Mororoto
Protium sp	Burseraceae	Breu
Octea sp.	Lauraceae	Lauro/Arapira
Bertholetia excelsa	Lethycidaceae	Castanha do Pará
Cedrelinga catenaeformis	Leguminosae (mimosoid)	Cedronan
Brosimum sp.	Moraceae	Garotte
Vismia guianensis	Guttiferae	Lacre
Nectandra sp.	Lauraceae	Louro preto
Manilkara huberi	Sapotaceae	Massaranduba
Qualea paraense	Vochysiaceae	Mandioqueira
Jacaranda copaia	Bignoniaceae	Para Para
Tachegalia sp.	Leguminosae	Tachi
Pouteria sp.	Sapotaceae	Abiurana
Platonia insignis	Guttiferae	Bacuri
Vochysia sp.	Vochysiaceae	Guaruba

Sources: Dantas and Rodrigues, 1980; Hecht, 1979, 1981.

Agropastoral systems

The practice of grazing cattle in orchards is a common one in much of the Amazon. The orchards are not generally commercial, however, and are used to supply fruits for family, relatives, friends and workers on a ranch. Species that have commercial potential and that can be easily introduced into pastures include cashew *(Anacardium occidentale),* mangoes

(Mangifera indica), jambo *(Eugenia jambos)*, avocado *(Persea americana)*, *Annonas* of various kinds as well as some Brazil nut *(Bertholletia excelsa)* cultivars. These orchard products are highly prized in national markets, and with some processing can be introduced into international ones. Brazil nuts and cashews already have a large market in North America and Europe.

Forage trees

Trees are widely used as forage resources in the arid, semi-arid and subtropical world (Piot, 1969; Gray, 1970; McKell, Blaisdell and Goodwin, 1972; White, 1974; Baker, 1978), and their use has always been essential to livestock production in tropical Africa, the Brazilian Northeast, and Asia. Ranching development in Amazonia has generally overlooked arboreal sources of calories and protein for animals in spite of the importance of shrubs to animal diets (up to 64% of the protein in the dry season) in natural grasslands such as the Cerrado (Simão Neto *et al.*, 1977). The tendency of livestock development research organizations in South America to work mainly with improved grasses and herbaceous legumes and only the odd shrub such as "leucaena" and "guandú" has resulted in the neglect of the potential of trees as a major fodder source. There is a wide variety of native species within the Amazon that are browsed (Hecht, 1979); numerous fodder species are known in Africa and Asia (NAS, 1980) and the Cerrado might also supply species for use on degraded sites.

In most of the Amazon, *Leucaena leucocephala* (leucena) and *Cajanus cajan* ("guandú" or pigeon pea) are the only forage shrubs of which seed is commercially available. In unfertilized sites leucena is difficult to establish and must be planted as seedlings. What few treelets survive are usually obliterated by zealous grazing in the usual extensive system found in the Amazon. Guandú, while not as palatable as leucena, can be easily established by mixing in the legume with grass seed when establishing a pasture. Guandú is not particularly fire tolerant, but is rarely eliminated with burning. Schaafhausen (1965) has shown for São Paulo that in 90 days with no rain, young Nellore steers fed on guandú had weight gains of 0.57 kg/day for a total dry season weight increase of almost 46 kg. Cattle on Oxisols and Ultisols generally lose weight during the dry periods in eastern Amazonia. Browsing of many native shrubs that invade pastures is well documented (Dantas and Rodrigues, 1979; Hecht, 1979; Serrão *et al.*, 1979), but the use of shrubs for forage in most of the Amazon occurs not by intention, but desperation. In many of the weedy and degraded pastures where improved grasses and herbaceous legumes have been outcompeted by the regenerating vegetation, shrubs are often the only source of food for cattle.

The use of arboreal forest species with ranching is quite well developed in Central America, and their use in agropastoral systems in the Amazon is a research area of great importance. The quality and quantity of grass is not uniform throughout the year in Amazonia, especially in the semi-evergreen areas of the eastern Amazon (Cochrane and Sánchez, this volume), and feed shortages and overgrazing are common. The uses of arboreal forage sources could make a major contribution to animal diets. Fodder in the Amazon should also include the possibility of using edible fruits produced by trees. The fruit of species such as *Prosopsis juliflora, Pseudocassia spectabilis, Parmentiera cereifera* and *Cassia grandis* contain reasonable protein levels (Peck, 1979). Table 6 lists a number of species that provide edible foliage or seeds that have been used in pasture systems in South and Central America and might, with testing, be extended to Amazonian pastures. Arboreal forage species can provide ancillary benefits such as shading, wind breaks, and can potentially intercept raindrops, reducing the erosive impact of rains.

Site amelioration

The use of trees for site amelioration is an agroforestry technique according to the definitions of Combs and Budowski (1979). Site amelioration includes fire and wind breaks, living fences, shade and the improvement of soil properties.

Wind and fire breaks. Wind and fire breaks are rare in the Amazon, in spite of the dessicating winds that scour many regions during the dry season, particularly in eastern Amazonia. When the native vegetation is cleared for pastures. maintenance of a 200 to 500 meter strips of forest at the perimeter of 1000 ha of pastures provides relatively good wind and fire control.

Wind breaks have been planted in southern Pará using fast growing species, such as *Gmelina,* and some *Acacias.* Wind breaks composed of species of *Sesbania, Leucaena, Inga, Gliricidia, Cassia,* and *Albizia* can be used for a variety of purposes including fodder, fire wood, and food, and are interesting possibilities for Amazon pasture areas.

Grassland burning is one of the few management techniques that ranchers use to control pests, especially in eastern Amazonia. Burning at the end of the dry season (both intentional and accidental) is widespread and often uncontrolled. Some ranches in the Amazon leave swaths of natural forest as fire breaks (ranging 200 to 500 meters) and this has proved to be reasonably successful.

Table 6. **Forage trees with ancillary benefits for agropastoral systems.**

Species	Fodder		Soil improvement	Shade	Wood production		Other comments
	fruits	foliage			fuel	construction	
Acacia albida	x	x	Probable	moderate	x	x	Coppices well, tolerant to grazing
Albizia lebbek		x	Probable	moderate	x		Regrews rapidly, foliage has high N
Brosimum alicastrum	x	x	Probable	moderate	x		Regrows rapidly
Cassia spectabilis	x	x	Probable	light			
Cajanus cajan	x	x	Probable	light			Can serve as a source of human food
Desmanthus virgatus		x	?	moderate			Tolerant of heavy grazing. Foliage has high N
Enterolobium schomerkii		x	?	light		x	
*Leucaena leucocephala**	x	x	Yes	light	x	x	High levels of mimosine Not acid tolerant, but rapid growth
Prosopsis palida	x		Probable	light	x		
Pithecelobium saman	x		Yes	light			
Parkia sp.		x	?			x	
Sclerolobium paniculatum		x	Probable	moderate			
Stryphnoderdron pulcherrimum	x	x	Probable	moderate		x	Fire tolerant
Sesbania grandiflora	x	x	Probable	moderate	x	x	Living fences, green manure

* Except for **Leucaena,** which does not tolerate acid soils well,the response of these trees to acid conditions is not known.

Source: Compiled from NAS, 1980; Peck, 1979; Combs and Budowski, 1979, Hecht, 1981.

Living fences. This practice, which is widespread in Central America, is largely neglected in the Amazon region. In most Amazon environments, fences must be replaced in four to eight years, even when posts are treated to retard decay. Most species used as living fences are quickly established and also provide a number of auxiliary benefits such as shade, fodder, small scale wind breaks, and wildlife habitat. Sauer (1979) has documented 57 species that are regularly planted as living fences in Costa Rica. *Gliricidia sepium, Erythrina poepegiana, Sesbania* spp., *Colubrina* spp., *Jatropha* spp., and some *Bursera* are some species that might be successfully used in the Amazon. The adaptability of these species to the more acid soil conditions in the Amazon, however, must be tested.

Soil amelioration. In Amazonia, where forest clearing results in rapid nutrient decline of most elements within a year after clearing, plants that accumulate or fix nutrient elements are of great significance. Restoration and maintenance of soil fertility in tropical environments should be a priority in the design of agricultural systems for these zones.

While the importance of herbaceous legumes is well understood, and the bulk of research is oriented to them, leguminous trees may be a better choice for many reasons. First, as Jones (1972) has indicated, many herbaceous tropical legumes are not very tolerant of grazing. Secondly, with the tendency to use aggressive grasses such as *Brachiaria humidicola*, establishment and persistence of herbaceous legumes is problematic. The problem of persistence is a general one of climbing tropical legumes (except kudzu) even with relatively non-aggressive grass species such as *Panicum maximum* (Halliday. 1979).

The use of trees believed to be soil ameliorators throughout the tropics is widely discussed (see, for example, NAS, 1980; Mongi and Huxley, 1979; De las Salas, 1979) but concrete data (e.g., the amount of N fixed) is lacking. Trees are generally grown for the other benefits that they may provide, and the fixing of N or the accumulation of P or K is usually seen as an incidental side effect. Trees that are valued as possible nutrient accumulators are intentionally planted in Africa and include such species as *Acioa barteri, Alchrornia cordifolia, Anthonotha macrophylla, Albizia* sp., to mention a few (Okigbo and Lal, 1979).

Use of soil-improving species in Central and South America is not well documented, but certainly exists (Chacón and Gleissman, in press). Deccarrett and Blydenstein (1968) have studied some of the more widely used shade trees that are also N fixers. Their data suggest improved soil and forage N contents with pasture tree legumes.

Numerous native leguminous species will nodulate in agricultural conditions. In fact, the improved pH after burning probable favors rhizobia. Numerous *Ingas, Cassias, Tephrosias,* have been observed by this author to nodulate in pastures after burning. This is a research area that deserves a great deal more attention, as means of countervailing the tendency for N reduction in pastures.

Ecological Aspects of Agroforestry

Agroforestry systems exist in almost every kind of Amazonian agriculture, but the question remains, "Why do they work?" In this section, some of the possible mechanisms are discussed.

In the Amazon, monocropping practices frequently have been associated with declines in production and eventual collapse of virtually every kind of agricultural activity. The devastating economic losses due to pests and soil deficiencies or toxicities is documented for almost every type of agriculture practiced in the basin, as the reports in this book attest. Conventional monocrop agriculture channels virtually all ecosystem energy, nutrients, and cultural practices toward short-term enhancement of yields. This is usually achieved by energy and nutrient supplements, as well as through the use of pesticides. When technical skill is available and agronomic inputs are cheap enough, this agricultural model has been successful throughout the world, even though its rationality in the face of energy scarcity and costs has been questioned even for the United States (Pimentel *et al.*, 1973). Skilled management and agricultural inputs are expensive in the Amazon, and are neither uniformly effective nor available. The environmental stresses placed on production systems in the Amazon may require that agricultures incorporate more structural complexity. More ecosystem energy may need to flow into protective functions that improve nutrient cycling or reduce herbivory.

Amazon ecosystems and pest dynamics

About 85 of the Basin is covered by high biomass, extremely species-rich forests (Prance, 1978) that are characterized by a plethorà of subtypes (Pires, 1973, 1978; Heinsdjick, 1960; RADAM, 1974; Schubart and Salati, this volume). Forests of the Amazon are more usefully perceived as mosaics of relatively analogous structure, rather than a species-diverse, but essentially uniform formation. The variety of forest types has several implications for pest problems in the Amazon. Many planners do not realize that pest communities of most Amazonian agricultural systems are not only extremely heterogeneous, but also differ dramatically from region to region. Strong (1974, 1977), showed that in cacao and sugarcane, most insect pests are recruited quickly and independently from the native biota with pest numbers rising asymptotically. In his cacao study (1974) only 1.5 percent of the pests were classified as widespread. He also found that the size of the area under cultivation was the best predictor of the number of pest species of a particular crop. Kellman (1980) points out that pest communities in tropical areas change rapidly with time and with cultivation techniques.

Weed communities in the Amazon seem to follow the pattern of invasion by endemic pests. While weed surveys are in their infancy, sufficient data exist for a preliminary analysis. In Brazil, Dantas and Rodrigues (1980) surveyed pasture weeds in three experimental stations, one of which was located at a várzea site near Manaus, and the others in Paragominas and the Araguaia region, the main upland cattle areas of Pará.

The Itacoatiara site near Manaus reflects the overall lower species diversity of várzea. There were only 43 species recorded compared to 106 in Southern Pará, and 176 in Paragominas. Of all the weed species Dantas and Rodrigues recorded, only 20 percent were common to more than one of the three sites. Species overlap between any two sites was less than 10 percent. Of the total of 266 species recorded, only 10 were documented for all three localities and these are cosmopolitan species such as *Emilia sonchifolia, Euphorbia hirta, Panicum bolivense, Sida micanthra, Physalis capsifolia,* and *Stachytarpheta cayenensis.*

Such empirical studies suggest several principles important for pest management in Amazonian agriculture:

1. The diversity of pest organisms affecting a crop is probably greater than in the montane, seasonal, or drier tropics.

2. The pest diversity or intensity may correlate with the diversity of forest sites cleared for agriculture.

3. Organisms invading Amazon agricultural sites are largely endemic. This implies that:

   a. pest organisms and outbreaks are not easily predictable,

   b. many species in the basin can perform similar functions;

   c. control techniques devised in one area may be difficult to extrapolate to another.

Given the extraordinary heterogeneity of Amazon ecosystems, and the difficulty of predicting and controlling pest outbreaks in the area, a cultivation system that incorporates means of reducing the economic effect of pests is highly desirable.

Agroforestry and pest dynamics

Heterogeneous crop mixtures can function in a variety of ways to buffer pest populations either by environmental alteration or through the ecological dynamics within the field. Environmental changes initiated by multi-species cropping can modify the agricultural crop system so that: (1) it becomes difficult for a pest to enter, and (2) it becomes undesirable for a pest species. Multiple crop systems have been shown in many cases to reduce the attractiveness of a crop to its pests by reducing visual or olfactory stimuli (Norton and Conway, 1977; Pimentel, 1961a, b) and by diverting the pest away from the target crop or physically interfering with colonization. The increased ground cover and shading which characterize multicrop agroforestry systems reduce the ability of many weeds to establish themselves, or to compete effectively after establishment. It has also been suggested that polycultural cropping systems are less susceptible to pest and disease outbreaks because noxious organisms spread less rapidly in mixed agriculture (Apple, 1972; Ruthenberg, 1971).

Species diversity

The spatial heterogeneity of multicrop systems, as well as microclimate variations, provide habitats for pest predators and parasites that can control outbreaks. Further, the multiplicity of species can provide food during the nonentomophagous instars of a pest predator's life cycle, as well as alternate prey for the entomophagous stages when the pest density is low. While heterogeneous cropping theoretically might exacerbate pest problems by providing an important habitat requirement for the pest, or by diverting a pest predator into another food item in the field (Way, 1977), the prevalence of agroforestry systems suggests that this is not a common occurrence (Wood, 1974).

In monocanopy, single crop ecosystems, the environment is structurally quite homogeneous, nutrient enriched and occupied by genetically uniform, same-age organisms designed for high yields. In most tropical arable crops, reinvasion and pest buildup occur each subsequent season. Once classic "pest" species that are highly invasive with high reproductive rates enter a monoculture, particularly of field crops, appeals to the stability of the natural ecosystem are foredoomed to failure, since there are not enough natural ecosystem components to control outbreaks

(Southwood, 1977). Rather quickly, pest organisms swamp the agricultural crop in question. Hence the poor track record (over the long run) of most Amazon monocultures, particularly those of annual crops. Chemical additions become necessary to maintain the agriculture.

Agroforestry systems incorporate many features that can serve as a basis for pest management by manipulating processes that affect economic injury levels. The widespread use of agroforestry techniques at all scales of capitalization in Amazonian agriculture suggests that while it may not be known yet exactly how agroforestry systems work in pest management, they often do. Clearly, the pest dynamics of agroforestry systems are a critical research area.

Soil conservation and agroforestry

The role of vegetation in nutrient storage is important for most Amazonian ecosystems (see Schubart and Salati; Cochrane and Sanchez, this volume). When forests on poor soils are cleared and nutrient cycling mechanisms are destroyed or interrupted, most of the nutrients in the vegetation are released to the soil, where they are vulnerable to loss by erosion and leaching.

Table 7 compares forest/soil nutrient storage with that of *Panicum maximum* pasture/soil systems. Vegetation storage falls dramatically with continuous cultivation. Soil nutrient declines expressed in meq/100 g or in ppm have been documented under pasture after forest clearing (Falesi, 1976; Serrão *et al.*, 1979; Toledo and Morales, 1979, Hecht, 1981). The high soil nutrient storage values for pasture that appear in this table reflect in part the nutrient additions from ash and wood decomposition, and the increase in bulk density of soils under pasture. This change in soil density is suggested by other researchers such as Schubart (1976).

Effective fertility conservation may require that nutrient cycling components and mechanisms be introduced into agricultural systems. Systems without nutrient conserving management, such as fallows, heterogenous crop mixtures, sequential cropping, or complex structure will require large nutrient, energy, and pesticide inputs.

Agroforestry systems are potentially far more nutrient conserving than monocanopy herbaceous field crops (Okigbo and Greenland, 1976; Dubois, 1979; Bene *et al.*, 1977; Wilkin, 1978) especially at low input levels. The structural complexity and different nutrient requirements of components of multi-species systems contribute to soil conservation.

Table 7. **Nutrient storage in vegetation and soil (to 1 m depth) in humid forest and Amazonian artificial pasture ecosystems.**

Ecosystem	Biomass (m/ha)	N	P	K	Ca	Mg	Location	Source
		kg/ha						
Mature forest	504							
Vegetation		3294	67	500	528	274	Manaus, Brazil	Fittkau and Klinge (1973)
Soil		12200	216	61	0	23		
Mature forest	462							
Vegetation		1088	62	1470	849	253	Merida,	Fassbender (1977)
Soil		4638	626	239	446	113	Venezuela	
Mature forest	184							
Vegetation		740	27	277	431	133	Carare-Opón,	De las Salas (1978)
Soil		1811	180	107	22	35	Colombia	
Mature forest	n.d							
Vegetation*		956	17	367	595	255	Paragominas,	Hecht (1981)
Soil		3170	13	62	71	51	Brazil	
Panicum maximum								
1-year old pasture	10							
Vegetation								
Soil		385	7.6	87	397	145	Paragominas,	Hecht (1981)
		3400	22.5	269	564	452	Brazil	
Panicum maximum								
10-year old pasture	2							
Vegetation		60	1.2	19	58	22.5	Paragominas.	Hecht (1981)
Soil**		4610	8.9	268	1002	420	Brazil	

* Vegetation storage values for Paragominas forest site are estimates. They were calculated by using the mean relative forest/soil nutrient storage ratios derived from the forest-soil systems presented in this table. These ratios are published elsewhere (Sánchez, 1979). Soil values are derived from field data (n = 20).

** These high storage values reflect the doubling in soil bulk density after 10 years in pasture.

Agroforestry and erosion control

Latin American pedologists have justifiably focused on the chemical aspects of soil fertility. Much of the current data on the effects of soil physical parameters on cultivation are derived from African and Asian researchers (Lal, 1979; Aina *et al.* 1977; Aina 1979). In this section we focus largely upon erosion. Readers interested in soil moisture or temperature dynamics for tropical soils in general are referred to Lal (1975, 1979), Lal and Cummings (1979), Wood (1977), and Wolf and Drosdoff (1976).

High intensity storms, large drop size and high energy load are characteristic of tropical rains (Lal, 1979) and result in a potentially highly erosive and compactive rainfall (Okigbo and Lal, 1979). Under continuous cultivation the deleterious effects on soil structure and consequent problems of nutrient decline due to soil erosion are intensified. Sánchez and Cochrane (1980) indicate that 29 percent of the acid infertile soil areas of tropical America have severe erosion hazards. While serious erosion potential is usually confined to montane zones, Table 7 demonstrates that even on moderate slopes, erosion can be severe, if the soil is devoid of a plant canopy.

Continuous cultivation with poor soil protection can reduce the productive capacity of a site when progressive deterioration of soil structure results in compaction, reduction in infiltration and soil erosion (Wood, 1977; Lal, 1975). Sánchez (1979) has pointed out that the bulk of the gully erosion in the Amazon is associated with road building and construction. Sheet erosion is common in the Amazon and will be particularly pronounced after burning and at the onset of the first rains (Smith, 1976; Fearnside, 1978; Scott, 1978) before the canopy has leafed out sufficiently. Scott (1978) has documented the reduction of sediments in streams by over 60 percent after vegetation covered swidden plots and by 85 percent once the canopy of chac-chac (a *Pteridium aquilinum* dominated deflected succession in the premontane Peruvian Amazon) recovered from burning. The manner of cultivation and amount of weeding also affect sediment loss.

Pasture, even on steep slopes, is very effective in erosion control, but it is important to remember that the pasture experimental plots do not include the grazing animal, and caution should be used in extrapolating pasture erosion results.

Several beneficial effects of a closed vegetation cover (especially if it involves multiple canopies) are possible in agroforestry systems. Canopies break the impact of raindrops. Rooting habits of plants differ and are important in maintaining soil porosity. The constant organic matter additions onto the soil surface buffer raindrop impact and improve soil structure.

Soil organic matter levels increase and equilibrate rapidly under forest fallow (Cochrane and Sánchez, this volume). Rapid biomass accumulation (Snedaker, 1980) during early succession, as well as the relatively greater proportion of leafy components in the biomass in the first years of fallow (compared with mature forest), are probably responsible for the rapid rise in soil organic matter. Organic matter accumulation in agroforestry systems is likely to be similar to successional systems, but this question still requires research.

Organic matter additions to soils are of interest for maintaining soil structure and tilth. Litter is also an important cycling locus for the vegetation (Stark and Jordan, 1978). Agroforestry systems, whether in sequential cultivation (with a fallow or modified fallow) or in continuous cultivation with a well developed tree component, are more likely to conserve soil structure and reduce erosion than conventional production systems where the soil surface is periodically exposed to harvesting and/or burning.

Soil nutrient dynamics

Certain agroforestry systems have the potential to maintain higher levels of ecosystem nutrients, and to recuperate nutrient losses after cultivation. Lal (1979) reports that in Nigeria no herbaceous cover was as efficient in regenerating overall soil fertility as woody vegetation. There are a number of reasons for this. A diversity of plant species will have somewhat varying requirements and differential rates of nutrient uptake. Mechanisms of nutrient accumulation probably similar to rainforests may occur through a variety of pathways including capture of nutrients in rainfall (Jordan *et al.*, 1980; Bernhard-Reversat, 1975), enhanced absorption through physiological mechanisms (Odum, 1970), structural features (Klinge and Fittkau, 1972), and symbiotic associations, both microbial and fungal (Stark and Jordan, 1978). The structural complexity of rooting systems in a diverse agroforestry plot implies absorption of nutrients at variable depths. Nutrient retention is accomplished through increased evapotranspiration that reduces leaching (Bartholomew, 1953; Harcombe, 1977) and promotes nutrient cycling. Kellman (1970) has suggested that secondary species may cycle nutrients at higher rates than climax species. Because many components of agroforestry systems are members of early to intermediate successional communities (*Cordia*, mahogany, etc.), rapid cycling could occur.

After clearing and burning forest, values for most elements except N and C are initially increased in the soil (Nye and Greenland, 1960; Zinke *et al.*, 1978; Seubert *et al.*, 1977; Falesi, 1976; Serrão *et al.*, 1979; Sánchez, 1979; Hecht, 1981). Higher soil P levels are due to additions from the burned biomass, and occasionally enhanced availability through pH modification. Potassium is also released from the burned vegetation. These impressive soil modifications reverse themselves after the first few years of cropping (Falesi, 1976; Serrão *et al.*, 1979; Sánchez, 1979; Cochrane and Sánchez, this volume). When most of the nutrients in the ecosystem are held in soil organic matter and forest biomass, the elimination of the forest destroys a critical storage site, and transfers these nutrients to the soil where they are more vulnerable to leaching and erosion. Analyses of only soil nutrients obscures the fact that **total** ecosystem nutrient stocks have changed. Ecosystems with a woody component (tropical forest and successional forest) accumulate larger amounts of N, P and K.

Uptake patterns encountered in various successional species are quite diverse as one can see in Table 7. Selection and protection of nutrient accumulators in fallows are easy to effect and an important research area (see Bishop, this volume; Tergas and Popenoe, 1971; Hecht, 1979; Lal, 1979). A great deal of research remains to be done on the soil dynamics in agroforestry systems in the Amazon, but results from African and successional systems suggest that more efficient nutrient cycling and storage could occur in agroforestry systems.

Factors affecting Agroforestry Expansion

The expansion of agroforestry in Amazonia is limited in part by lack of technical experience with these systems, and a view that species-diverse agricultural fields are somewhat less "developed" than monocultures. More critical, however, are the contradictory processes that characterize Amazonian occupation.

A variety of development goals in the Amazonian countries has accelerated clearing and agricultural colonization by both corporate entities and individuals (Nelson, 1975; Mahar, 1979; Durham, 1977; Goodland and Irwin, 1975; Pompermeyer, 1979; Ianni, 1978). Since the early 1960's several trends have accompanied deforestation; one is that land itself rather than its production has become a highly negotiable commodity. Land values have soared above inflation rates even where the productive capacity of the land is declining (Mahar, 1979). When land is treated strictly as a commodity, careful management often becomes of secondary importance. Further, development decisions (at least in the

Brazilian Amazon) are frequently made by economic groups outside of Amazonia. As many as 90 percent of the land titles in the state of Amazonas, Brazil, are held by individuals or corporations outside the region (Pires and Prace, 1977). These groups, generally lacking in tropical experience and primarily interested in land speculation can use destructive land clearing and development methods. For example, the widespread use of mechanical forest clearing methods by corporate ranches in the southern Amazon can severely reduce soil productivity (Seubert *et al.*, 1977; Serrão and Toledo, this volume).

Land ownership in much of Amazonia has been confused by contradictory land statutes, byzantine titling procedures, multiple agency jurisdiction over land, fraud and corruption (Ianni, 1978; Pompermeyer, 1979; Sawyer, 1979; Bunker, 1978; Rodrigues and da Silva, 1977). The virulence of land conflicts throughout the Amazon suggests serious problems of speculation and land tenure, and these often interfere with rational resource use, leading to short-term, and often destructive exploitation.

Agroforestry is a land use that does not reach fruition quickly, and in a speculative economy there is little incentive to establish and maintain such systems. A further constraint is the view that dramatic physical alteration of a landscape is a proof of progress. Ultimately planners must come to view forests not as obstacles to development, but as one of its end products.

Conclusions

While agroforestry is widely practiced in the Amazon, it is the least studied of all tropical agricultural systems. Research in agroforestry will require an interdisciplinary ecological approach that must include agronomists of all kinds, anthropologists, geographers, rural sociologists as well as economists. It also implies a perceptual change, for a sustained yield agriculture necessitates an integrative rather than a substitutive orientation.

Several basic research areas need to be addressed if agroforestry systems are to receive the emphasis in development programs that they deserve. These include:

- Large scale, comprehensive surveys of indigenous agricultural systems determining when, how, why, and which species are used, and what role these can play in different agricultural systems.

- Basic research on the agricultural ecology of pests in tropical crops.
- Nutrient cycling and dynamics in tropical agroforestry systems.
- Research on components for agroforestry systems (e.g., *Inga,* commercial wood species, food producing trees) and their interactions with food crops and pastures.
- Research on the social relations of production systems is also necessary, since different agricultural paths can exacerbate or ameliorate the economic and social inequalities that exist within the Amazonian countries.

In closing, it seems appropriate to cite one of the first Western thinkers who addressed problems of deforestation and agricultural development, as a cautionary note for today's Amazon developers:

> "The very signs from which we form our judgement are often very deceptive; a soil that is adorned with tall and graceful trees is not always a favorable one, except of course, for those trees." (Pliny, Natural History, Book 17, Chapter 3.)

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Forest Research Activities and the Importance of Multi-strata Production Systems in the Amazon Basin (Humid Neo-tropics)

Robert B. Peck*

Introduction

Although the greatest land use and economic activity in the Amazon Basin has been and still is based on the natural forest cover, its frontiers have been eroding away at an ever-accelerating rate due to increased social and economic pressures for more agricultural production and uncontrolled spontaneous colonization in advance of or with penetration roads (Smith, 1977; Sioli, 1973; Morán, 1977; and Goodland *et al.,* 1978).

Since the early years of colonization, the Amazon forest has been exploited for timbers such as rosewood (*Dalbergia spruceana*) and mahogany (*Swietenia macrophilla*) by highgrading (cutting the best trees) the natural forest. More recently, *Virola* has been harvested from the várzeas (flood prone rain forest plains). But managed forests, either natural or artificial, have not been established after exploitation to any extent in any of the countries composing the Amazon Basin (Loureiro, 1979).

Only in the Brazilian Amazon where forest products are the major export item, and in Peru and Bolivia, are portions of the forest resource processed by the forest industry as the forest cover is felled for agricultural and ranching activities. The eastern region of Ecuador and the Amazonia of Colombia completely lack any significant forest industry enterprises.

There is one notable exception regarding forest management in the Amazon, that being Jari Forest Products, the industrial complex on the lower Amazon, made possible by the financial resources of Ludwig and the determination of the Jari staff. Fast growing exotic species *Pinus caribaea, Gmelina arborea* and recently *Eucalyptus deglupta* have been planted for pulp wood products, substituting the natural forest in more than 100,000 hectares (Briscoe 1978 and 1979).

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Forest Research

Efforts to study forest management systems appropriate for the humid neo-tropics of the Amazon by national and international agencies should be considered in light of historical limitations. For years, the only school in Latin America offering a graduate degree in forestry was Turrialba, in Costa Rica, established in the late 40's.

It was only in the late 60's that Brazil established its first forestry school, Curitiba, most of whose students were drawn to southern Brazil to work with pine and eucalyptus plantations.

Several attempts to establish experimental forests have been started with the help of FAO, such as those at Curua-Una and Belterra plantations near Santarém, Brazil, and the Von Humboldt National Forest near Pucallpa, Peru. The Ducke Forest Reserve near Manaus, managed by INPA (Instituto Nacional de Pesquisas da Amazônia) for some 20 years, is also important. Unfortunately, all of these efforts are still in the stage of species selection and have not evolved to the degree of verification with field trials on an industrial or commercial scale (Dubois, 1971; Pitt, 1969; Carvalho and Tavares, 1979; Schmidt and Volpato, 1972; Volpato *et al.,* 1973).

The lack of continuity by research personnel due to institutional reorganizations, erratic funding and lack of provisions for long term career development has resulted in the dispersion of research personnel and interruption of research careers. The lack of continuity has hampered the academic development of qualified personnel and has limited the number of researchers and foresters with an understanding of the dynamics of the humid tropical forest (Wadsworth, 1972). As a result, few researchers have had the opportunity to travel throughout the humid tropics to see the range of natural distribution of the most promising forest species found in the Amazon, such as *Cordia alliodora,* a shade species for cacao whose seed was imported into the lower Amazon from Costa Rica. Natural regeneration of *C. alliodora,* capable of bearing seed, can be found less than two kilometers from the research area.

Lack of communication between some research centers within the Amazon basin and in adjacent countries having humid tropical forests, which will be mentioned later, seriously limits the transfer of new knowledge being generated. Researchers usually work with only portions of a production system, and are often not informed of research development at other sites.

Multi-strata production systems

Several notable exceptions to the present status of forestry research in the Amazon basin are the efforts in multi-strata production systems being conducted by agricultural institutions and private industry. These programs include trees in combination with agricultural and cattle production systems for improved land use and diversified sources of income.

Multi-strata production systems are defined here as the occupation of land with agricultural crops in combination with trees (agroforestry), or the combination of forage crops (grasses and/or legumes) with trees (pasture-forestry systems). In other words, a multi-strata production system is the association of agricultural or forage crops with trees, each component occupying a different part of the vertical space available, whereby the combined benefits of the association are greater than either system individually.

Multi-strata production systems can be considered as a complement to existing production systems, provided the latter have proven to be successful enterprises. Benefits of introducing trees into cropping systems can vary depending on species selection from the production of commercial timber, shade, a source of fuel wood, forage and improved soil management through nutrient cycling and increased organic material.

The following institutions have been working with multi-strata production systems in the Amazon:

Brazil

Instituto Experimental Agrícola Tropical Amazônico (INATAM). It is a research and technical assistance program for the Japanese colonies in Tomé-Açu, located south of Belém do Para. This institute recognized the great importance of the forest biomass as the basic source of initial soil fertility when forests are felled, burned and converted to pastures.

Unidade de Excução de Pesquisa de Âmbito Estadual (UEPAE). Located in Manaus, it carries out extensive work with the perennial guarana *(Paullina cupanal)*,an important fruit crop used as a component in multi-cropping systems in Central Amazon (Melo and Teixeira 1979).

Instituto Nacional de Pesquisas da Amazônia (INPA). Also in Manaus, it carries out research on development of indigenous subsistence farming systems, selecting tree species with edible fruits (Pahlen *et al.,* 1979).

Ecuador

Instituto Nacional de Investigaciones Agropecuarias (INIAP). Through the Centro Amazónico Limoncocha (Napo), it has six years experience developing indigenous farming systems appropriate for colonization and sustained pasture-forestry systems for commercial cattle and timber production (Bishop, 1979 a,b).

Peru

Von Humboldt National Forest. It has established plantation trials using Taungya systems in cooperation with colonists (Ramirez, 1977).

Instituto Veterinario de Investigación Tropical y de Altura (IVITA). This institute, located in Pucallpa, has developed integrated grazing systems and recognized the importance of introducing trees into rational pasture systems (Toledo and Morales, 1979).

Venezuela

Instituto Venezolano de Investigaciones Cientificas (IVIC). It has conducted studies at San Carlos on the Rio Negro, including nutrient cycling, biological productivity and soil characteristics of undisturbed rain forests, along with a comparison of these characteristics following various types of forest modification or removal.

Outside the Amazon basin, but in the humid neo-tropics:

- The **Centro Agronómico Tropical de Investigación y Enseñanza** (CATIE)(Budowski, 1978), formerly IICA, in Turrialba, Costa Rica;

- the **Corporación Nacional de Investigaciones Forestales** (CONIF) (Leguízamo, 1979), the Secretariat of Agriculture of the Department of Valle (Molina, 1972), and the Coffee Federation (Venegas, 1971), in Colombia.

These agencies are also working with forestry species as a component of multi-strata production systems.

Agroforestry systems

Beyond these institutional research efforts on multi-strata production systems, there are numerous examples of farmers who have incorporated trees into their production systems providing what appears to be improved economic returns. These systems have developed spontaneously based on the continued observation by the farmers who have realized that the benefits of multi-strata production systems are greater than the efforts expended to create the system.

Table 1. **Distribution of *Cordia alliodora* established by natural regeneration growing in association with agricultural crops in the humid neo-tropics.**

Country	Location	Crop	Approximate extension (km^2)
Colombia	Tumaco	Cacao, plantains	500
	Interandean region	Coffee	1500
Panama	Boca de Toro	Annual crops, pasture and cacao	500
Ecuador	San Lorenzo	Cacao, platains and pastures	500
	Santo Domingo de los Colorados	Cacao, pastures and banana	1000
	Oriente-Napo	Annual and perennial crops and pastures	500
Surinam	- -	Cacao, banana and annual crops	50
Venezuela	- -	Coffee, banana	500
		Cacao, banana	500
Costa Rica	Limón, Cahuita	Cacao	1000
	San Carlos	Pastures and plantains	1500
	Turrialba	Coffee and pastures	500
Central América		Coffee, pastures and cacao	1450
Brazil	Boa Vista (Fordlandia)	Secondary forests	1
			10,101 km^2 or 1,000,000 ha

Source: Adapted from Peck (1979).

Probably the most outstanding example of a forest species incorporated by farmers into multi-strata production systems is *Cordia alliodora* (locally known as laurel) that is grown in association with a wide variety of tropical crops and grasses on approximately 1,000,000 hectares (Table 1).

Found primarily in association with coffee, cacao, plantains and some pastures, *Cordia alliodora* provides a substancial source of income to farmers, particularly in Costa Rica, Colombia and Ecuador where unprocessed logs can provide road side cash values ranging from US$10 to US$20 per cubic meter. Preliminary studies in Costa Rica and Colombia indicate that *Cordia alliodora* grown in association with coffee and cacao reaches commercial volumes of 200 m^3/ha in 20 to 25 years (Peck, 1977).

Pasture-forestry systems

Benefits from the introduction of trees into pasture systems vary from production of commercial timber, wind breaks, natural barriers for sanitary control on large ranches, and shading, to additional sources of forage during the critical dry season when pasture production is often reduced (Daccarett & Blyndenstein, 1968; Eberson & Lucas, 1965; Gomez, 1977; Hecht, 1979; and Kirby, 1976).

The introduction of tree species bearing edible fruits provide important sources of supplement forage as indicated by recent preliminary studies conducted in the Cauca Valley, Colombia (Table 2) and in Piura, Peru, with the establishment of algarrobo plantations *(Prosopis juliflora)* for forest grazing (Valdivia and Cueto, 1979).

Table 2. **Analysis of tree species bearing edible fruit in the Cauca Valley, Colombia.**

Scientific name	Common name	Raw fiber* (%)	Crude protein (%)	Carbohydrate (%)
Prosopis juliflora	Algarrobo	25	7	79
Pseudocassia spetabilis	Flor amarillo	44	14	73
Parmentiera cereifera	Velo or candle tree	20	3	16
Cassia grandes	Cañafístula	40	6	79

*Analysis of whole fruit samples including seeds.

Source: Study conducted by the author, analysis performed at the University of Valle, Cali, Colombia.

Within the Amazon Basin, the role of trees in integrated pasture systems has been recognized by researchers working in multi-disciplinary teams at CPATU (Centro de Pesquisa Agropecuária do Trópico Umido).

However, to propose the introduction of forage trees to the rancher who cannot control the invasion of woody weed species would be an obvious mistake. It would be necessary to first show him how to successfully control woody weeds and sustain forage production (Standley, 1979).

Species selection

Promising tree species for multi-strata production systems that by definition include agricultural crops and pasture range systems are shown in Tables 3 and 4. These should be considered in the context of local ecological conditions for any given areas within the Amazon basin or other portions of the humid neotropics. Just as the local soil and climatic conditions change from one area to another, so do agricultural practices and the suitability of tree species to a particular site.

Table 3. **Promising tree species for agro-forestry systems in the Amazon basin (humid neo-tropics).**

Species	Common name	Commercial value (Cr$/m³)*	Silvicultural status
Cordia goeldiana	Freijó	2000	Silvicultural techniques have been successfully demostrated. Confirmation of these species in multi-strata production systems on a commercial scale is required.
Cordia alliodora	Louro	–	
Swietenia macrophilla	Mogno	3300	
Cedrela odorata	Cedro	2500	
Carapa guianensis	Andiroba	1300	
Didymopanax morototoni	Morototó	850	Silviculture techniques are being developed, requiring confirmation on a commercial scale before being widely recommended.
Bertholletia excelsa	Castanha	–	
Vochisia maxima	Quaruba	1000	Silvicultural techniques require further testing before they are field tested on commercial or industrial scale.
Bagassa guianensis	Tatajuba	1100	
Spondias spp.	Taperabá	–	

* Commercial log value located at mill site, Belém, October, 1979, when Cr$32=US$ 1.

Table 4. **Promising tree species for silvo-pasture systems in the Amazon basin (humid neo-tropics).**

Species	Nitrogen fixing	Edible fruits	Commercial production	Production of shade
Native				
Stryphnodendrum pulcherrimum	yes	yes	fuel wood	medium
Cassia fastuosa	yes	yes	fuel wood	light
Pithecolobium saman var. *acutifolium*	yes	yes	special use	medium
Cedrelinga catenae-formis	yes	no	good	medium
Cordia alliodora	no	no	excellent	light
Cordia goeldiana	no	no	excellent	light
Cassia grandes	yes	yes	firewood	light
Enterolobium spp.	yes	yes	good	light
Hymenea coubaril	yes	yes	good	light
Inga spp.	yes	yes	fuel wood	medium
Exotic				
Artocarpus hetero-phyllus	no	yes	–	heavy
Leucaena glauca var. caucana	yes	forage	poles	light
Parmentiera cereifera	no	yes	–	medium
Prosopis juliflora	yes	yes	charcoal	light
Pithecolobium saman	yes	yes	special use	medium
Sweetia *brachystchya* (from Minas Gerais)	yes	no	—	light
Pinus caribaea var *handurensis*	no	no	long fiber pulp wood	medium

Table 5. **Actual and potential land use production systems in the Amazon basin.**

Agricultural production	Crops	Production systems
1. Annual crops	Corn Rice Beans	Subsistence agriculture crop production alternated with secondary forest cover (shifting field agriculture).
2. Semi-permanent crops	Banana Plantains Cassava	
3. Backyard orchards	Fruit bearing trees having nutritious value; avocado, bread fruit, pejibaye palm	Sedentary agriculture*
4. Perennial crops	Coffee Cacao Black pepper Guarana	
5. Cattle production	Forage Grass Legume Supplemental forage	Commercial agriculture*
6. Plantations	Production systems	
1. Forest trees: 2. Rubber 3. African palm 4. Brazil nut 5. Cashew nut	1. Homogeneous plantations 2. Line enrichment planting 3. Anderson groups 4. Taungya**	Implemented by industry or governmental agencies.
	5. Agro-forestry 6. Silvo-pasture	Implemented by the agricultural sector in multi-strata production systems*.

*Suitable for multi-strata production systems.

**Taungya is distinguished from agro-forestry systems by the fact that the tree component is only associated with annual or biannual crops during the establishment phase. After one or two years the farmer leaves the planting site permanently and the responsible institution takes charge of it. In agro-forestry systems, to the contrary, the farmers are continuously managing the association and, needless to say, are the beneficiaries of the timber production.

Dominant crops and average farm size vary from region to region. Each area may have its own variation of multi-stata production systems. Local cultural practices must be considered individually. The selection of species should take into account the needs of each local production system. For example, in the lower Amazon, Paragominas region, the average cattle ranch size is over 1000 ha, whereas in the Napo region of the Ecuadorian

Amazon, cattle farms average less than 50 hectares each. Under similar cattle raising systems, the selection of tree species in Paragominas is related to incorporating trees as a necessary source of shade and as a protection against wind, while in Napo the selection is related to maintaining soil fertility. In Table 5 distinct agricultural production systems found in the Amazon basin are presented.

Potentials for increased forestry activity in the Amazon

Multi-strata production systems, especially in agro-forestry are a particularly important alternative for land use planning for regional development based on forest industrial complexes. These systems are particularly interesting for directed colonization projects that could be located sufficiently near potential markets and areas that are planted to perennial crops such as coffee and cacao, which are partially documented in Table 1.

The use of trees could contribute to the development of stable cattle production systems in the Amazon improving the conditions for continued long-term production and the welfare of local populations.

Research is needed on the development of conceptual models determining the limiting parameters of these multi-strata production systems. Only by determining these parameters can the range of economic benefits of multi-cropping be studied effectively and more systematically demonstrated.

Conclusion

The need for new research centers in the Amazon Basin is not as great as the need for reinforcing existing national institutions. The creation of research opportunities for agro-forestry in the Amazon Basin is fundamental to the continuity of such programs seeking new and improved land use development. It can be concluded, then, that establishing multi-disciplinary teams to complement the understanding of agro-forestry production systems is basic to improved management and productivity. The complexity of multi-strata research requires contributions from many specialities. The determination of multi-strata parameters, along with the development and refinement of higher productivity models, is basic for the establisment of successful production systems. Integrated multicropping production systems should be considered as necessary biologically and socially urgent alternatives for land management in the Amazon Basin.

To help accelerate the development of agro-forestry, technical assistance should not be limited to short term consultancies, or even short-term projects of two to three years duration. Technical assistance, particularly in multi-strata research, needs to be long term, consisting of repeated consultancies so as to help modify the conceptual framework of the basic models over time.

An example of the need for this type of assistance can be seen in a reforestation program in Santo Domingo de los Colorados in Ecuador. In the Pacific coastal lowlands of Ecuador the plantations of Cordia were established at close spacing like pine or eucalyptus planted in the temperate highlands. Farmers believed that the time for thinning would occur when the trees reached a minimum commercial size. After 20 years they are still waiting to thin and mortality has set due to the lack of growing space. Without understanding the minimal silvicultural requirements of promising fast growing tropical species, large scale projects should not be attempted for the Amazon Basin.

Multi-cropping production systems, with the simultaneous association of trees and agricultural (agroforestry) or forage crops (pasture-forestry), actually provide promising land management alternatives for the Amazon Basin. Some of these associations have been recognized and implemented on a limited base by individual farmers, and more recently by national agricultural research centers. However, it is clear that a more appropriate, multi-disciplinary approach is needed in the complex field of agro-forestry, especially if real economic progress is to be achieved. The potential of multi-strata production systems in the Amazon is believed to be at least as great as traditional agriculture, which has had over a century of organized research support. Fortunately, today the many interrelationships between agriculture and forestry management are increasingly complementary and will dramatically reduce the lag in progress observed in agro-forestry.

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Forestry and Agroforestry Research in Colombia

Juan E. Valencia*

Introduction

The Corporación Nacional de Investigación y Fomento Forestal (CONIF) is a civilian, non-profit corporation created by forest and timber enterprises as private members and by INDERENA (Instituto de Desarrollo de los Recursos Naturales Renovables) as the official member. CONIF was chartered on July 11, 1974, and its legal representation was formalized by the Ministry of Justice through Resolution 5029, September 1974.

The national forest policy, directed by INDERENA, rests on six principal strategies: (1) zonation of forested areas of Colombia; (2) protection of forest resources through the rationalization of migration and colonization; (3) appropriate management of existing forest resources; (4) industrialization of forest resources; (5) education of the public about forests; and (6) promotion of silvicultural research (CONIF, 1977).

The last strategy has been considered fundamental, since through the careful planning and implementation of research, the technical base required for the application of the other five strategies can be enlarged and improved.

CONIF's mandate is to decisively urge silvicultural research, to promote reforestation, and to encourage social and economic development in current areas of forest utilization.

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The official and private members of CONIF are working to restructure the corporation. This restructuring includes the following major points:

- Amplifying the scope of the corporation to cover all of Colombia's territory.

- Increasing the number and competence of its members.

- Organizing a system of agreements and contracts in order to carry out certain research activities, in accordance with IDERENA's requirements and policies.

Conif's Research and Amazonia

Although CONIF does not really work in the Amazon,both Colombia's Pacific Coast and the Amazonian region are in the humid tropics. They have many problems in common including socio-economic constraints, lack of infraestructure, technical limitations, soil problems, subsistence agriculture with similar products (cassava, beans, rice, plantains, maize), and cash cropping (sugar cane, cocoa, oil-producing palms).

The diversity of difficulties demands a suitable and rational use of resources, especially of forest and soils, in order to avoid environmental deterioration. Research on the most suitable systems that protect resources is essential and cannot be postponed. Current research is based on techniques for silvicultural management, as well as the integration of agricultural, ranching and forestry use through agroforestry or pasture-agro-forestry systems. Table 1 shows promising forest species common in various types of forests, in different countries.

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Table 1. **Promising forest species common in various types of forests in different countries.**

Colombia	Brazil	Ecuador	Surinam
Brosimum utile	*Brosimum* sp.	*Brosimum utile*	*Carinaria pyriformis*
Carapa guianensis	*Calophyllum brasiliense*	*Carapa guianensis*	*Cedrela angustifolia*
Cedrela odorata	*Carapa guianensis*	*Cedrela odorata*	*Cedrela odorata*
Cedrela fissilis	*Cedrela odorata*	*Cedrela fissilis*	*Cordia alliodora*
Cordia alliodora	*Cedrelinga cataeniformis*	*Cordia alliodora*	*Cordia aporensis*
Dialyanthera gracilipes	*Didimopanax morototonii*	*Dialyanthera gracilipes*	*Goupia glabra*
Genipa americana	*Goupia glabra*	*(Dialyanthera gordinifolios)*	*Jacaranda copaia*
Hieronyma chocoensis	*Jacaranda copaia*	*Genipa americana*	*Virola surinamensis*
Jacaranda copaia	*Simarouba amara*	*Hieronyma chocoensis*	
Simarouba amara	*Virola* sp.	*Jacaranda* sp.	
Swietenia macrophylla		*Simarouba amara*	
Virola dixonii		*Swietenia macrophylla*	
Virola reidii		*Virola dixonii*	
		Virola reidii	

The Corporation's research program covers the following areas:

- Plantation silviculture
- Natural forest silviculture
- Agroforestry
- Insects and diseases of forest species
- Forest economics
- Utilization of forest products
- Basic studies
- Forest maps

This paper deals only with research related to natural forest silviculture and to agroforestry systems.

Characteristics of the region studied by CONIF

According to Baracaldo (1976) "The major part of the Pacific Coast was formed during the Cenozoic era of the Tertiary Period (Eocene, Pliocene) and a small part of the Quaternary Period (Pleistocene). Most of its soils are acid, clayey and of low fertility; in small areas of the alluvial zone, crops are cultivated under extremely difficult conditions. Precipitation averages 7400 mm annually, the average annual temperature is 26°C, and the average annual relative humidity is 88 percent. The southwest winds predominate; cloudiness and large amounts of rainfall are frequent."

From west to east, the landscape is formed by the mangrove swamps influenced by tides, the alluvial plains with gentle slopes that make up the Guandales, and low hills up to 50 m that form the border of the western range of the Andes—an area of uneven topography.

Natural forest silviculture

Research on natural forest silviculture takes place in the following regions: (a) Pacific Coast, at La Espriella Station in Tumaco on the Ecuadorian border and the San Isidro Station near Buenaventura; (b) Lower Atrato region, at Sautata Station in the Darién area; and (c) Middle Magdalena region, at Carare-Opón Station (Campo Capote) in the Department of Santander (Fig. 1).

Types of forests included in the program are as follows:

The "Guandales" which are periodically flooded with a mixture of fresh and salt water and whose forest components are principally *Campnosperma panamensis* (sajo), *Dialianthera gracilipes* (cuangare) and diverse species of the genus *Virola.*

.... International boundary
–·–·–·– Department boundary
• Department capitals
○ Silvicultural stations

	Station	**Department**
①	Sautatá	Chocó
②	San Isidro	Valle
③	Espriella	Nariño
④	Campo Capote	Santander

Figure 1. *Locations of CONIF's silvicultural stations in Colombia.*

Forests of this type are homogenous and their most suitable treatment is the management of the abundant natural regenation. These forests are found mostly in the Southern Pacific region in the Departments of Nariño and Cauca.

The "Cativales" are also homogeneous forests, periodically flooded by fresh water. Located in the region of the Lower Atrato River and its main tributaries, these forests contain *Prioria copaifera* (cativo), *Carapa guianensis* (guiño), *Anacardium excelsum* (caracolí), some species of *Virola* and others of the genus *Leythis*. Their most appropriate treatment is also the management of the abundant natural regeneration; to accomplish this, it is necessary to have a very integrated utilization of the forest.

This type of forest is considered to be one of the most productive of the tropics with yields from 300-350 m^3/ha, comparable only to Dipterocarp forests of the Philippines and Malaysia and to the mature secondary forests of *Terminalia superba* in the Mayombe, Zaire.

Mixed forests on low hills or terraces, which are being studied in all of CONIF's work areas-La Espriella, San Isidro, Sautata, and Carare-Opón.

The research is focused on finding the best techniques for their management through: (a) treatment of the secondary forests resulting from integrated utilization such as is occurring in the Lower Calima (near Buenaventura) and the forests of Carare-Opón in the Middle Magdalena; and (b) the management of natural regeneration, after taking diagnostic samples to determine secondary forest potential and to decide if these forests should be enriched when they have been degraded by a system of selective logging.

Research priority has been given to the management and treatment of certain forest species, based on their great industrial use, their rapid growth and their abundance in the target regions. A summary is given in Table 2.

Table 2. **Forest species considered of high priority for research, in Colombia.**

Common name	Scientific name	Type of forest and location
Cativo	*Prioria copaifera*	Catival
Sajo	*Campnosperma panamensis*	Guandal
Laurel - Mono	*Cordia alliodora*	Low hills and terraces
Vainillo	*Jacaranda copaia*	Low hills and terraces of Tumaco and lower Atrato

Table 2. (continued).

Common name	Scientific name	Type of forest and location
Tangare - Guino	*Carapa guianensis*	Low hills and terraces of Tumaco, lower Atrato and Cativales
Laguno - Soroga	*Vochisya ferruginea*	Low hills and terraces of Tumaco and Carare-Opón
Chaquiro	*Goupia glabra*	Low hills and terraces of Lower Calima and Carare-Opón
Cedro	*Cedrela odorata*	Low hills and terraces of Tumaco, lower Calima and Lower Atrato
Cedro	*Cedrela fissilis*	Low hills. and terraces of Tumaco, lower Calima and lower Atrato
Chalviande	*Virola reidii*	Low hills and terraces of Southern Pacific coast
Chalviande	*Virola dixonii*	Low hills and terraces of Southern Pacific coast
María - Aceite	*Calophyllum brasiliense*	Low hills and terraces of Tumaco and lower Calima
Mascarey	*Hieronyma chocoensis*	Low hills and terraces of Tumaco, lower Calima and lower Atrato
Roble	*Tabebuia rosea*	Low hills and terraces of lower Atrato
Piedrita	*Casearia oblongifolia*	Low hills of Carare-Opón and Tumaco
Peinemono	*Apeiba aspera*	Low hills and terraces of lower Calima, Tumaco and lower Atrato
Mora	*Miconia minutiflora*	Low hills of lower Calima and Carare-Opón
Jaboncillo	*Isertia pitierii*	Low hills of lower Calima and Tumaco
Chillalde	*Tricospermun mexicanum*	Low hills and terraces of Tumaco and lower Calima
Tornillo	*Cedrelinga catenaeformis*	Low hills and terraces of Tumaco and Carare-Opón
Achapo	*Simaruba amara*	Low hills and terraces of Tumaco and Carare-Opón

Agroforestry Research

The establishment of agroforestry systems seeks to optimize the land's production through the practice of intercropping annual, biennial, perennial and forest crops.

CONIF's agroforestry research emphasized the following aspects among others:

- Better alternatives for integral production in community areas.
- Development of multistrata systems that optimize the utilization of the soils, precipitation and available sunlight.
- Reduction of pressure on the natural forest and in areas of second growth forests.
- Development of agroforestry technology for agricultural, ranching and forested areas.

CONIF bases its agroforestry program on the following criteria (Baracaldo, 1976):

- That the "man-tree unit" be the central crux of the projects, because the final objective of the program is the recovery of the forests where the natives live.
- That the projects be carried out in organized communities or in communities that can be organized.
- That the projects include complementary units that allow the communities to improve their income and increase short and middle-term employment, while receiving income over the long-term from trees.
- That the projects also have three basic social components: education, nutrition and health.
- That physical infrastructure, marketing infrastructure and other technical, economic and social services are added to the projects by governmental agencies.
- That the research, development and social programs of the Corporation form a logical and practical unit in each of the regions.

The Corporation's work with organized communities provides 50 to 70 percent of the region's wages. The work is done on the people's own properties by local residents with traditional crops.

The projects

CONIF selected the species for the agroforestry research program that were commonly grown in the region and which could meet basic food and cash crop needs (Table 3).

It was necessary to install agricultural nurseries for the reproduction and selection of varieties. Included were 15 varieties of bananas, 14 varieties of plantains, 42 of beans and 5 of cassava.

Four projects were established: fruit trees, palms, agricultural products and special studies.

Each project has a title, an objective, methodology and trials. To provide an example: "Project 03: Agricultural Products" is included as an annex to this paper.

Preliminary results

All of the initial results are considered to be important, because of the diverse difficulties in the region. Principal findings are: (a) Excessive precipitation makes the work very difficult; (b) scarcity of specialized entities in the region forced CONIF to assume tasks belonging to other agencies (like the Instituto Colombiano Agropecuario - ICA, and the Secretariat of Agriculture), such as handling and treatment of cassava, plantains and other agricultural crops; (c) natives have to be occasionally transferred to work in forest extraction, fishing or other activities because there is a most appropriate period for each one of them during the year (e.g., summer for timber extraction); and (d) although training of labor is a slow process, it leads to better results because of the practice required.

The most outstanding findings in agroforestry are:

- Wide acceptance by the communities and individuals, as shown in the broadening of programs, requests for material from the nurseries and requests from new communities.

- A very satisfactory development of timber trees in their first year (growth from 1.5 to 3.0 m/year), and a less satisfactory, but promising, development in fruit trees.

Table 3. **Plant species under investigation by CONIF.**

Fruit trees	Timber trees	Palms	Food plants
Arbol del Pan *(Artocarpus communis)*	Cedro *(Cedrela* sp.)	Coconut *(Cocos nucifera)*	Papachina *(Colocasia esculenta)*
Borojó *(Borojoa patinoii)*	Mascarey *(Hieronyma chocoensis)*	Chontaduro *(Bactris gasipaes)*	Cassava *(Manihot* sp.)
Citrus (various)	Peinemono *(Apeiba aspera)*	Guerregue *(Astrocarium standleyonum)*	Plantain *(Musa paradisiaca)*
Avocado *(Persea* sp.)	Chaquiro *(Goupia glabra)*	Mil pesos *(Jessenia policarpa)*	Maize *(Zea mays)*
Caimito *(Chrysophyllum caimito)*	Sorogá *(Vochisya ferruginea)*	Naidí *(Euterpe cuatrecasana)*	Bean *(Phaseolus vulgaris)*
		Taparo *(Orbingia cuatrecasana)*	

- Increase in the production of *Colocasia esculenta* (papachina) from 10 to 14 tons/ha, and in cassava from 6 tons/ha (with the regional cultivar Llanera) to 13 tons/ha with a variety provided by CIAT.

- Technological development for application in other regions of the country.

- Important conclusions in graduate theses on *Bactris gasipaes* (chontaduro) and *Colocasia esculenta.*

As far as silvicultural research is concerned, the main results are:

- Very good growth of the selected species (up to 3 m/year).

- Understanding of the management techniques of approximately 20 forest species in nurseries and plantations.

- Second growth forests offer optimum characteristics for management, with yield increases above 13 m^3/ha/year, in 13-year-old forests.

- In the case of homogeneous forests, appropriate exploitation allows suitable management during natural regeneration.

Collaboration

Outstanding collaboration was obtained from different organizations, among them the Matía Mulumba Institute, ICA, CIAT, INDERENA-FAO Project, the Agriculture Secretariat of the Department of Valle and the Fondo de Fomento Agropecuario.

Annex 1

Project 03: Agricultural Products

Title:Studies on the association of agricultural products with forest, fruit or palm trees.

Methodology:

Research on the possibilities of agroforestry begins with simple models for specific situations. The models become more complex as experiences are gained. In other words, the models result from both studying data of earlier trials and thinking creatively.

The complexity of the problems make the cooperation of experts and institutions from other specialized research fields indispensable; such fields include agronomy, soil sciences, biology, food technology, economics, etc. The models have to be as standardized and systematic as possible. It is preferable to use products known in the region in natural or cultivated form.

Harvesting and planting dates of the various crops have to be scheduled in accordance with other types of work normally done (e.g., lumbering) and the available labor.

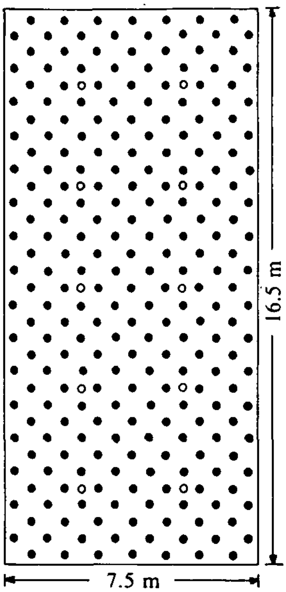
Crop competition for light, water and space for root development has to be taken into account. Initially, changes in traditional methods (planting during low tide, etc.) should be minimal.

It has to be clearly stated whether the system is directed to forestry production, to agricultural and animal production, or to the recovery of degraded lands.

The research is divided into the following combinations:

03:00: General, literature studies, reports
03-01: Planting in association with forest trees
03-02: Planting in association with fruit trees
03-03: Planting is association with palm trees
03-04: Planting in association with forest and fruit trees
03-05: Planting in association with forest and palm trees
03-06: Planting in association with fruit and palm trees
03-07: Planting in association with forest, fruit and palm trees.

Annex 2. Project 03-01-Pm-Y



Location: Guadual (Lower Calima)
Date of initiation: August 23, 1979
Seed source: San Isidro
Number of treatments: Three

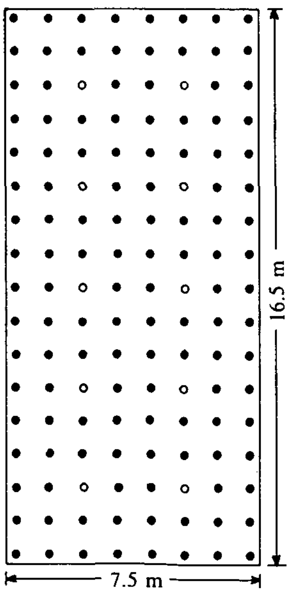
Planting distance:
Cassava to peinemono: 0.50 m
Peinemono: 3 x 3 m
Cassava: 1 x 1 m

Total of 3 replications (A_1 - A_2 - A_3)
3 x 10 peinemono
3 x 247 cassava stakes

- • Cassava stake
- o Peinemono

Scale 1:100

Treatment A. Influence of the planting distance of cassava *(Manihot utilissima)* and peinemono *(Apeiba aspera)* on the rate of growth of both crops. (The effect of distance will be assessed taking into account cassava production and peinemono growth.)



Annex 2. Project 03-01-Pm-Y

Location: Guadual
Date of initiation: August 23, 1979
Source of peinemono: San Isidro
Source of cassava: CONIF variety

Planting distances:
Cassava to peinemono: 1.0 m
Peinemono: 3 x 3 m
Cassava: 1 x 1 m

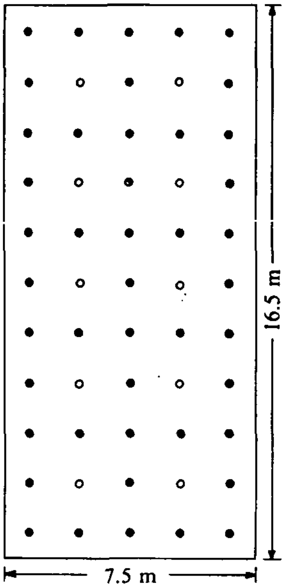
Total of 3 replications (B_1- B_2- B_3)
3 x 10 peinemono
3 x 126 cassava stakes

- • Cassava stake
- o Peinemono

Scale 1:100

Treatment B. Influence of the planting distance of cassava *(Manihot utilissima)* and peinemono *(Apeiba aspera)* on the rate of growth of both crops.

Annex 2. Project 03-01-Pm-Y



Location: Guadual
Date of initiation: August 23, 1979
Source of peinemono: San Isidro
Source of cassava: CONIF variety

Planting distances:
Cassava to peinemono: 1.50 m
Peinemono: 3 x 3 m
Cassava: 1.50 x 1.50

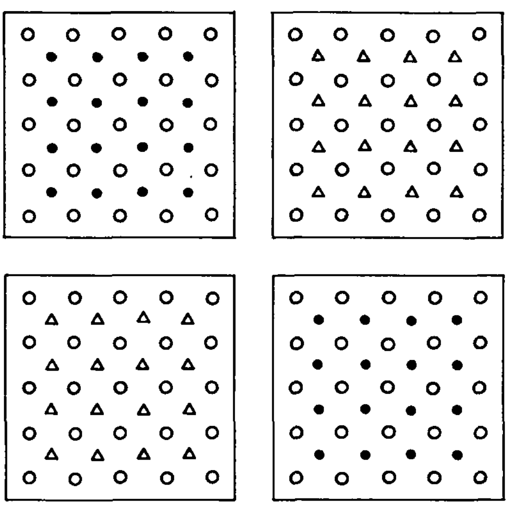
Total of 3 replications (C_1 - C_2 - C_3)
3 x 10 peinemono
3 x 45 cassava stakes

• Cassava stakes
o Peinemono

Scale 1:100

Treatment C. Influence of the planting distance of cassava *(Manihot utilissima)* and peinemono *(Apeiba aspera)* on the rate of growth of both crops.

Annex 3.



O Timber trees
● Fruit trees
Δ Chontaduro palms

Distance between trees: 6 x 6 m
Distance between palms: 6 x 6 m
Distance between fruit trees: 6 x 6 m

Total plots: 8
Number of treatments: 2

Planting trial of timber trees with chontanduro palms (*Bactris gasipaes*) and fruit trees.

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Agroforestry Systems for the Humid Tropics East of the Andes*

John P. Bishop**

Introduction

Each region of the developing world has unique nutritional demographic problems and potentials. Such problems are compounded in the central Andean region because its population has the highest density and birth rate in South America while consumption levels of protein and calories are among the lowest in the Western Hemisphere. Traditionally most people of Colombia, Ecuador, Perú and Bolivia have lived in highland areas.

These countries also contain vast humid tropical lowlands east of the Andes into which highways are being built as a result of petroleum discoveries and colonization plans. Such highways are leading the poorest of the rural poor away from over-populated areas to establish small farms in the eastern lowlands (Crist and Nissly, 1973). A sizeable part of each family farm is utilized for products of primary need such as foodcrops, swine, chicken and fuelwood.

A shifting form of agriculture is practiced by small farmers (Sánchez, 1973 and 1977; Watters, 1971). As human populations and expectations increase, rest periods in shifting cultivation are shortened, accelerating in an alarming rate soil deterioration and weed/pest invasion, and critically decreasing yields precisely as needs are increasing.

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* Agro-forestry systems are increasingly part of Amazon research programs, as the country reports in this volume attest. Dr. Bishop's models, developed in Ecuador for small farming systems, are but two of a number of possible agricultural systems incorporating agro-forestry techniques.(Editor's note.)

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The humid tropics east of the Andes are also undergoing deforestation in favor of cattle ranching. Forests are replaced with pasture after a period of short-term cropping. This kind of development has provoked severe criticisms due to the soil deterioration that occurs. Few pastures persist, and today many are adandoned.

This paper discusses some possible solutions for rationalizing these two dominant land uses by incorporating them into integrated production systems. For the shifting cultivation system, the fallow is intensified with swine, chicken and fuelwood production. In the cattle system, forage legumes and timber production provide a means of maintaining pasture productivity.

Swine, Chicken and Fuelwood Production

The American lowland tropics have the highest per capita swine population in the world (Table 1), more than five times that of tropical Africa and Asia (Williamson and Pyne, 1975). Most swine and chickens in the tropical lowlands east of the Andes are produced on small farms utilizing an open range production system with banana as the principal swine feed and corn as the supplemental chicken feed. Given the importance of pigs and chickens in small shifting cultivation holdings, a technique for increasing agricultural output during the rest period involves using small stock in conjuntion with fuelwood production (Anon, 1978; Bishop, 1978 a, b and 1979; Bredero, 1977; Breitenbach, 1974; Kirby, 1976; Masefield, 1965; Nye and Greenland, 1960; Ochse *et al.,* 1971, Sprague, 1974).

Table 1. **American countries with large swine populations.**

		No. of people/hog
1.	Brazil	2.3
2.	Ecuador	2.7
3.	Haiti	2.8
4.	Nicaragua	3.3
5.	United States	3.9

Source: World Almanac, 1978.

Forage and fuelwood legumes increase soil aeration, organic matter, nitrogen and available phosphorus, and control soil erosion and leaching (Bredero 1973 and 1977; Moore, 1967; Singh, 1967). Swine also improve soil fertility by depositing organic matter which stimulates legume/*Rhizobium* symbiosis and by supplying fecal microorganisms which mineralize crop residues (Bredero, 1977). In addition, swine can improve small farm income (CIAT, 1971) and produce low cost animal protein without cereal grains (Thomsen, 1978).

In Amazonian Ecuador, studies are being realized to intensify open range swine husbandry utilizing the following mixture of perennial species in a multi-strata production system: *Desmodium ovalifolium* (trébol tropical), *Canna edulis* (achira), *Musa acuminata* x *M. balbisiana* ABB (orito) and *Inga edulis* (guaba).

The legume *Desmodium ovalifolium* constitutes the ground cover (Masefield, 1965) as forage legumes are more palatable and more efficiently utilized by swine than are grasses (Eyles, 1963; Jones and Wallace, 1974). The root forage *Canna edulis* and banana *Musa acuminata* x *M. balbisiana* ABB are local perennial crops with low labor and soil fertility requirements and produce low-cost feeds for direct consumption by swine (Herklots, 1972; Kay, 1973; Kurita, 1967; Le Dividich, 1977; Purseglove, 1972; Walker, 1953; Williamson and Pyne, 1975). The fast growing native legume tree *Inga edulis* improves soil fertility and structure (Ochse, 1961) as well as produces fuelwood (Anon, 1978; Bishop, 1978 a, b) on an eight-year rotation cycle (Fig. 1).

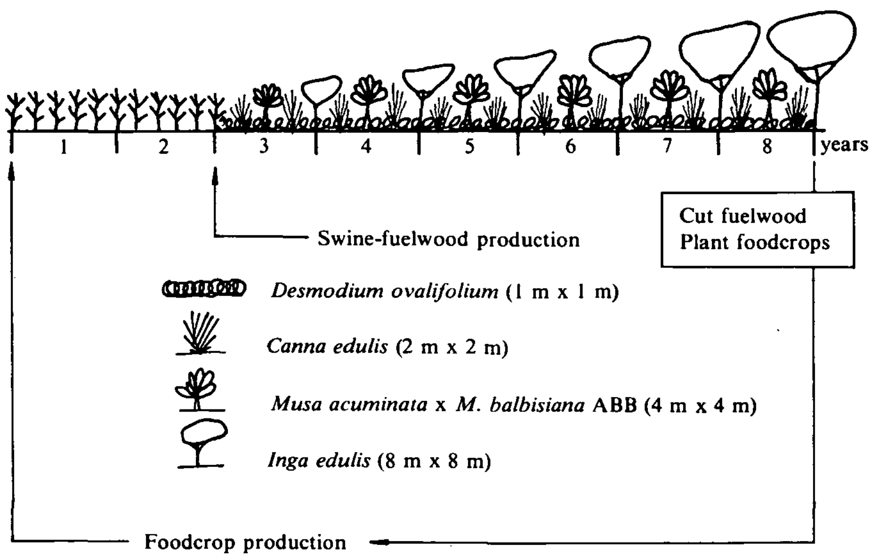

Figure 1. *Integrated foodcrop, swine and fuelwood production.*

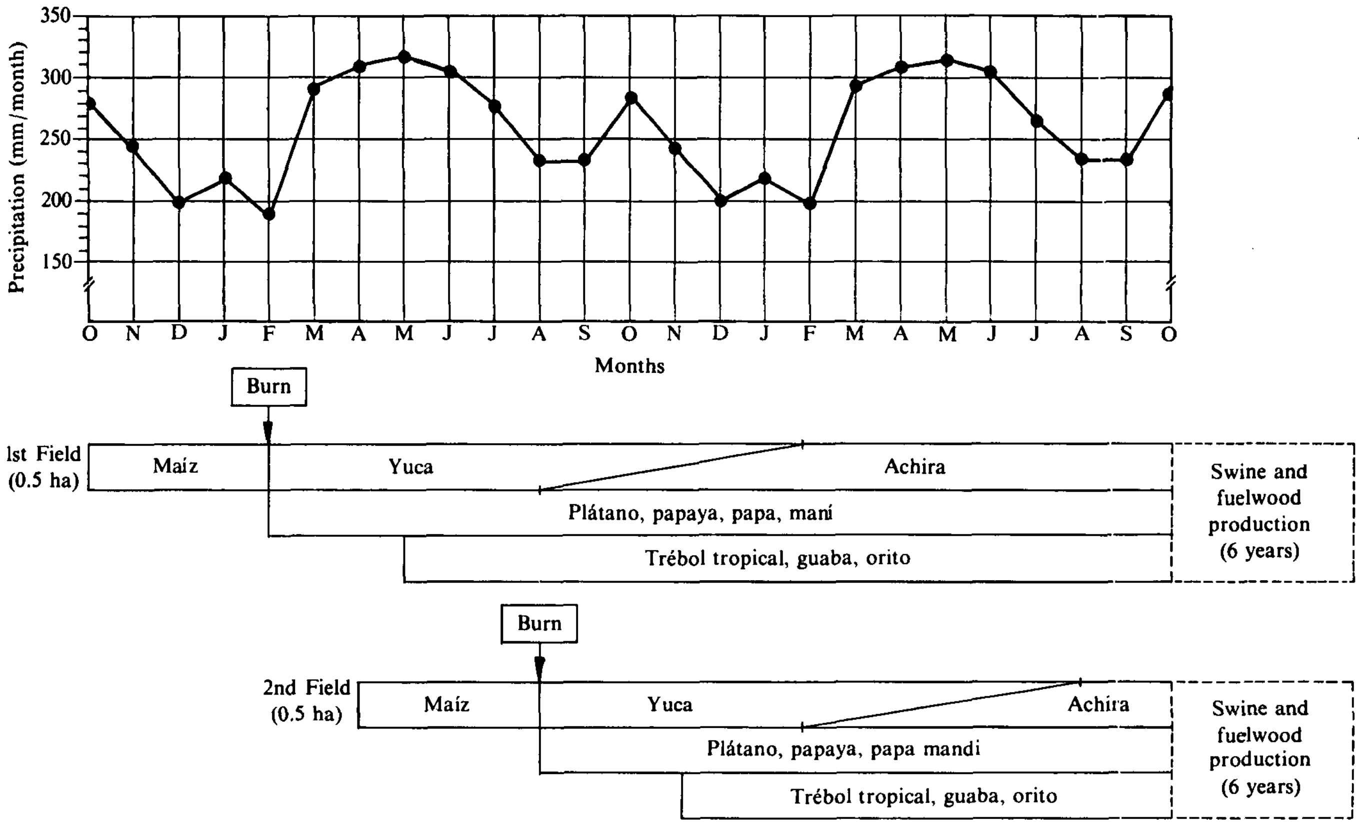

Figure 2. *Average precipitation (15 years) and cropping practices in the Centro Amazónico Limoncocha (lat. 0° 24'S; alt. 243 masl).*

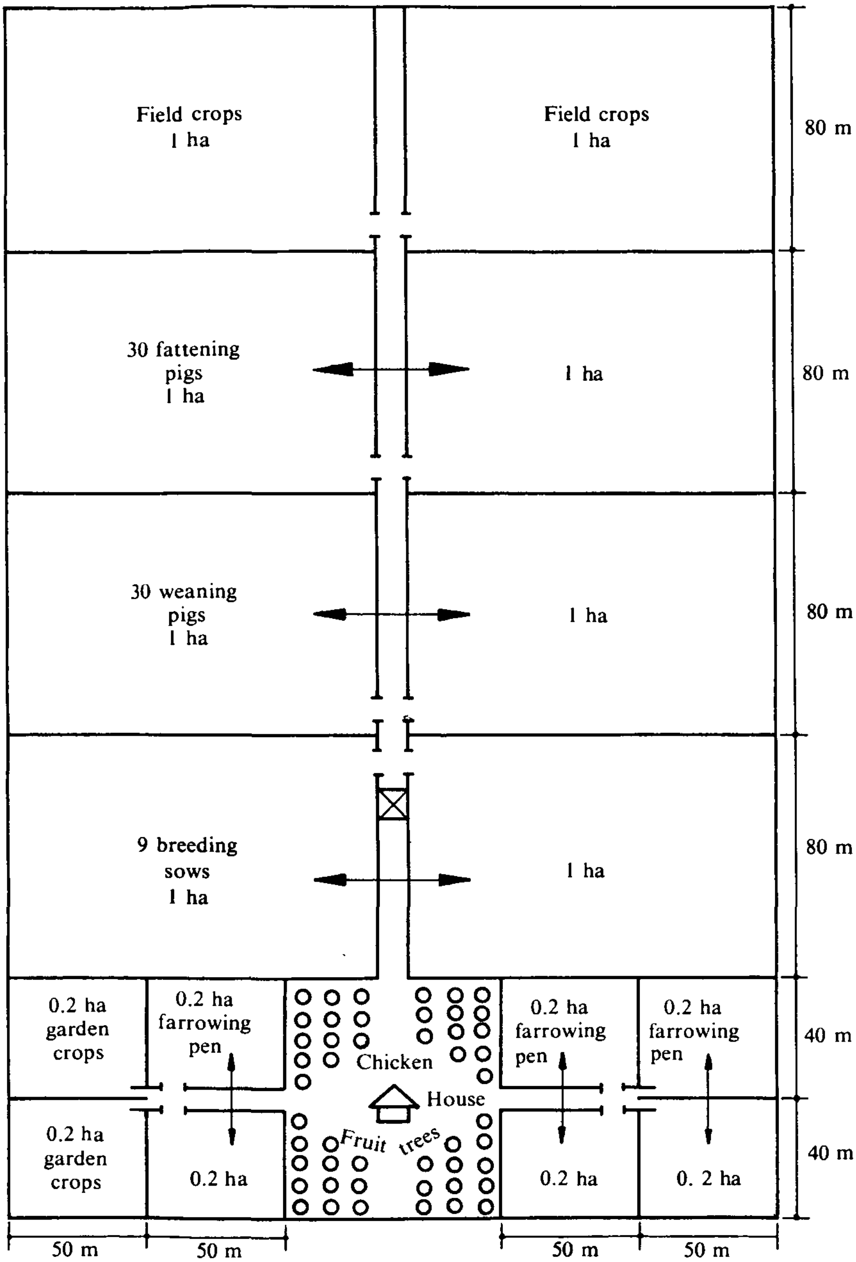

Figure 3. *Integrated foodcrop, swine, chicken and fuelwood production in a 10 hectare family unit.*

Initially, conventional agriculture is practiced on a new plot each year: land clearing and production of short cycle species in conformity with one or another classical multiple cropping system. The perennial species of the future multi-strata system are interplanted during short cycle cropping (Fig. 2). Following a two-year period of short cycle cropping, the mentioned perennial components will have reached a vertically stratified state of development. Four distinct strata are rapidly differentiated and the resultant multi-strata structure and multi-species composition ecologically and biologically approaches a sustained yield forest ecosystem (Dubois, 1977; Holdrige, 1959; Janzen, 1973).

A ten-hectare family unit (Fig. 3) is divided into eight lots (1 ha each) which are used following field crops (Table 2) for weaning pigs, fattening pigs and breeding sows. Also, eight lots (0.2 ha each) are formed and used following garden crops (Table 3) for individual farrowing pens. Six strands of barbed wire and closely woven living *Jatropha curcas* (piñón) posts are used as fencing (Payne, 1973). Internal swine parasites are chemically controlled (levamisole) every three months and synchronized with alternate grazing. Also, a 0.4 hectare lot is used for the farm home, chicken house and fruit trees (Table 4).

Table 2. **Major foodcrops in Amazonian Ecuador.**

Local name	Scientific name	Variety
Maíz	*Zea mays*	INIAP VS-2
Yuca	*Manihot esculenta*	Native
Plátano	*Musa acuminata* x *M. balbisiana* AAB	Local
Papa mandi	*Xanthosoma sagittifolium*	Native
Papa china	*Colocasia esculenta*	Local
Papaya	*Carica papaya*	Native

The benefit

A ten-hectare family farm with 1.5 animal units (1 A.U.= 5 adult pigs) per hectare can maintain 12 sows and produce five pigs per sow per year. Estimating each pig at US$75, swine income per year can reach US$4500.

Therefore, swine-fuelwood production has great potential to improve the economic productivity, ecological stability and sociological viability of small farms in the humid tropics east of the Andes.

For technology transfer to the rural masses, small farmer training materials are being prepared for use in local adult education classes, regional radio education courses and practical classes in rural schools.

Table 3. **Minor foodcrops in Amazonian Ecuador.**

Local name	Scientific name	Variety
Mani	*Arachis hypogaea*	Native
Fréjol común	*Phaseolus vulgaris*	Local
Fréjol ratón	*Vigna unguiculata*	Local
Fréjol vainita	*Vigna sesquipedalis*	Local
Habas nativas	*Phaseolus lunatus*	Native
Haba blanca	*Canavalia ensiformis*	Local
Ashipa	*Pachyrrhizus tuberosus*	Native
Piña	*Ananas comosus*	Native
Cocona	*Solanum topiro*	Native
Badea	*Passiflora quadrangularis*	Native
Granadilla	*Passiflora edulis*	Native
Maíz pequeño	*Zea mays*	Local
Camote	*Ipomea batatas*	Native
Papa de soga	*Dioscorea trifida*	Native
Pujín	*Calathea allouia*	Native
Achocha	*Cyclantera pedata*	Native
Tomate criollo	*Lycopersicon esculentum*	Local
Zapallo	*Cucurbita* sp.	Native
Cuchicol	*Amaranthus* sp.	Native
Cebolla criolla	*Allium capa*	Local
Caña de azúcar	*Sacharum* sp.	Local

Table 4. **Fruit trees in Amazonian Ecuador.**

Local name	Scientific name	Variety
Limón mandarina	*Citrus limonia*	Local
Lima	*Citrus limettoides*	Local
Naranja criolla	*Citrus sinensis*	Local
Maní de árbol	*Caryodendron orinocensa*	Native
Guaba ilta	*Inga densiflora*	Native
Arbol de pan	*Artocarpus alfilis*	Local
Cacao blanco	*Theobroma bicolor*	Native
Zapote	*Calocarpum sapote*	Native
Abiyu	*Pouteria caimito*	Native
Anona	*Annona squamosa*	Native
Uvilla	*Pourouma cecropiaefolia*	Native
Guaba común	*Inga edulis*	Native
Guaba machetona	*Inga spectabilis*	Native
Aguacate	*Persea americana*	Native
Guanábana	*Annona muricata*	Native
Chontaduro	*Guilielma gasipaes*	Native
Guayaba	*Psidium guajara*	Native

Integrated Cattle and Timber Production

Cattle production has been one of the major methods for occupying tropical lands, but maintaining the productivity of these lands has been somewhat problematic. One suggested solution is associated forage grasses, forage legumes and timber trees (Bishop, 1978a, b and 1979; Bishop and Muñoz, 1979; Cook and Grimes, 1977; Gregory, 1972; Kennard and Walker, 1973; Kirby, 1976; Knowles *et al.*,1977; Payne, 1976; Peck, 1977; Thomas, 1978).

Forage legumes and timber trees can fulfill the following functions: (a) significantly increase soil nitrogen by root associations with bacteria and fungi; (b) improve soil fertility through leaf fall; (c) notably improve soil texture and aeration by physical and chemical effects; and (d) substantially increase income from small farm pastures by sale of timber.

In Amazonian Ecuador, studies are being realized to evaluate the forage grass *Brachiaria humidicola* (kikuyo amazónico), the legume *Desmodium ovalifolium* (trébol tropical) and the timber tree *Cordia alliodora* (laurel) in a forestry-pasture system (Fig. 4).

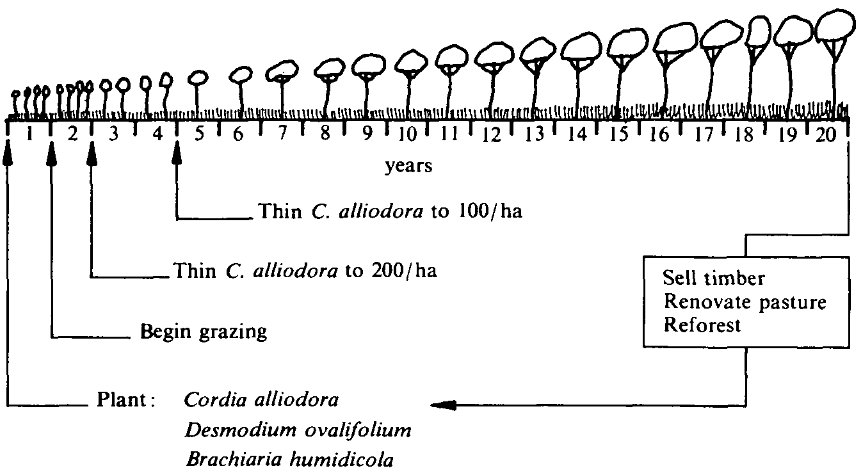

Figure 4. *Integrated cattle and timber production.*

At the beginning of the rainy season the *B. humidicola* and *D. ovalifolium* are established using vegetative material and planting sticks. *C. alliodora* is also transplanted (400/ha) at this time using rootstumps (Fig. 5).

The newly established pastures are not grazed for one year or until timber trees are three meters high. Two years after reforestation, trees are thinned to 200/ha and again after four years leaving 100 high-grade trees per hectare.

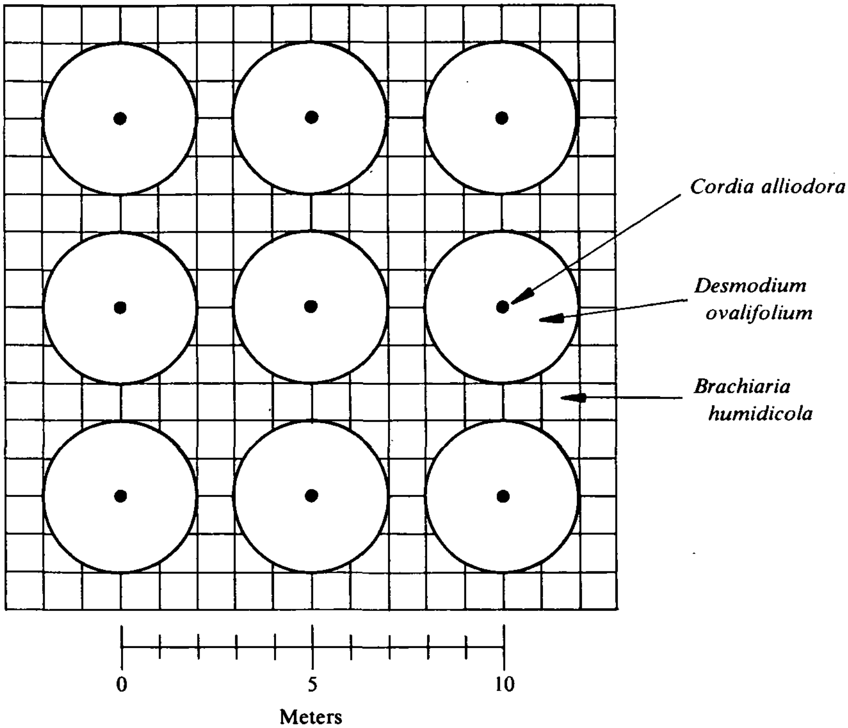

Figure 5. *Planting diagram.*

The benefit

One hectare of pasture maintaining two bovines with 25 percent extraction per year will produce 10 bovines in 20 years. Estimating each adult bovine at US$300, cattle income per hectare in 20 years will be US$3000.

One hundred *C. alliodora* trees per hectare can produce 100 m^3 of timber in 20 years. Estimating each m^3 of *C. alliodora* at US$30, forest income per hectare in 20 years would be US$3000.

Therefore, timber production has great potential to improve the economic productivity, ecological stability and sociological viability of small cattle farms in the humid tropics east of the Andes. It is worth mentioning that both cattle and small stock systems can be combined for a 50 hectare farm, the size often used for module farms in the Amazon (Fig. 6).

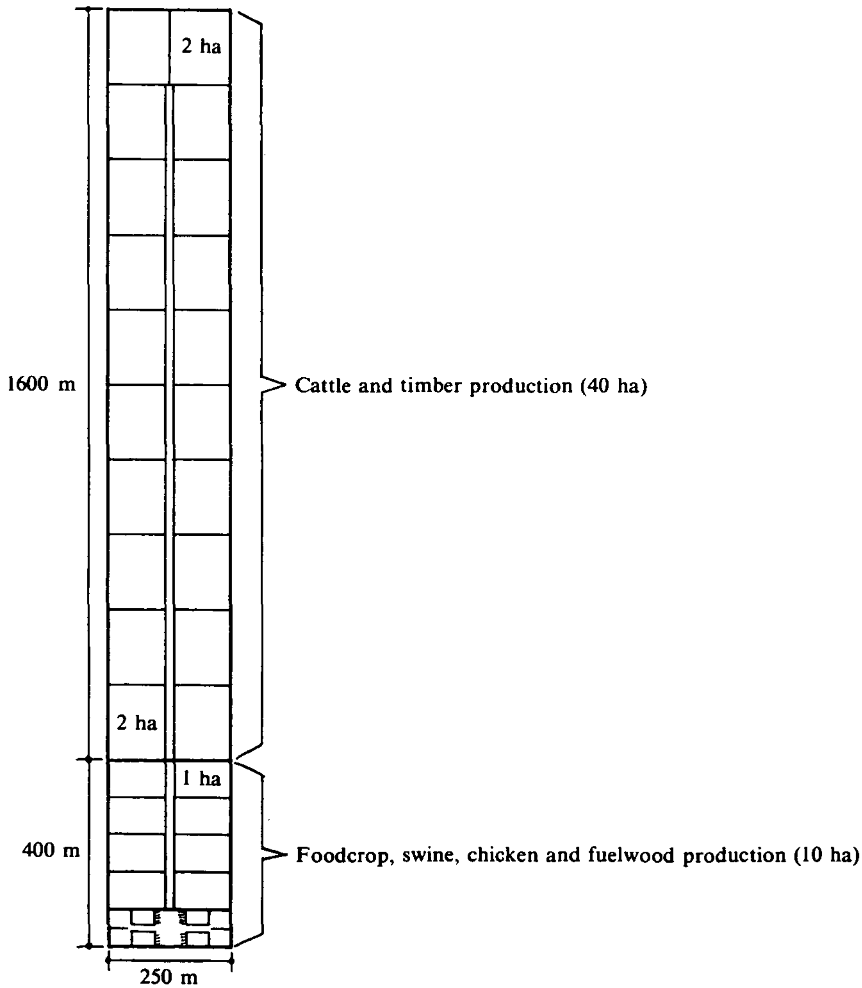

Figure 6. *Mixed production system for 50 hectare farms.*

Technology transfer, as proposed with the swine-chicken-fuelwood system, involves small farmer training material for use in local adult education classes, regional radio education courses and practical classes in rural schools.

Acknowledgements

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Conclusions and Recommendations

Present Status

Based on the presentations and discussions at the Conference, the following conclusions were reached concerning the present status of agricultural and land use research in the Amazon region. Since only selected research components were reviewed at the Conference the list is incomplete and provides only an initial assessment.

1. Not all of the countries which have territory in the Amazon Basin have given the development of this region the same priority in their national programs. However, all nations consider it essential that research be intensified to provide some technical knowledge necessary for the rational use of the humid tropics. Rational land use involves the development of agronomically, economically and ecologically sound production systems plus the infrastructure necessary to provide inputs and markets for the products.

2. Research results obtained in the Amazon provide a good base for developing a more coherent and integrated strategy of further research. Examples of such results include: (a) a better understanding of the natural ecosystems and their potential to provide food, fiber, fuel and forest products; (b) the recuperation of degraded pastures and the potential of low-input legume-based pastures; (c) the quantitative assessment of the land resource base; (d) evidence of low-input sustained permanent crop and forestry systems in some soil types; (e) the feasibility of the continuous production of annual crops in

acid infertile soils with inputs; and (f) extremely innovative integrated agroforestry systems.

3. Current research efforts are insufficient compared to the needs, both in the amount and depth of the work, as well as the concentration in a few locations.

4. The vast majority of research focuses on single disciplines such as ecology, soils, pastures, annual, perennial and forestry crops. There is an urgent need for multidisciplinary programs that integrate these components in order to understand the reasons that underlie the success or failure of various practices and to develop practical solutions where necessary.

5. Communicating research results among the different Amazon countries is difficult. Improved communication within the region is badly needed for technology transfer and modification.

6. Technology must be developed **in situ**, and must consider both biological and socioeconomic constraints.

Appropriate technology in Amazonia means low-input technology, due to infrastructure and energy constraints. It is possible to develop improved methods for present farming systems that would significantly increase productivity. Examples include: (a) introduction of new or underutilized species or cultivars that are tolerant to diseases, soil acidity, low nutrient levels, high aluminum concentrations, temporary drought stress, and other constraints common to the Amazon; and (b) selection of farming practices and production intensities appropriate to the fertility of soils and availability of inputs.

There are major divisions of the Amazon, both natural and socioeconomic. The two main biological divisions, the rain forests and the semi-evergreen seasonal forests, are different enough to justify research efforts in both zones. Substantial differences also exist between areas with large populations and active migration, and those with low demographic pressures. The greatest challenges occur in areas that have already been settled and seriously altered, and in areas where development pressures are greatest.

7. Useful experience has been gained and successful technologies developed by indigenous populations, but most agricultural activities in the Amazon are practiced without the benefit of soil research information. If this trend is not reversed, large areas of forests will continue to be cleared and poorly utilized. Appropriate agricultural technology can ensure that each hectare cleared remains productive.

Future Research Needs

The Conference participants identified the following research needs as those of most importance. This list is preliminary and incomplete since it is based primarily on the presentations made at the Conference and could not include all relevant research.

1. Develop quantitative information on basic ecological processes such as nutrient cycling in natural and agricultural ecosystems.

2. Inventory and characterize the biotic resources of the Amazon Basin.

3. Further study of farming or forestry methods practiced by indigenous people and new settlers in order to learn from their experience and to provide baseline data.

4. Collect germplasm of plants of both known and potential value for the Amazon. This could include explorations in other tropical forested areas of the world.

5. Expand and strengthen land resource inventories (including climate, vegetation, topography, soils) at a large map scale to serve as a guide for land use decisions in areas where development will take place.

6. Interpret the main physical constraints (climatic, edaphic, etc.) in quantitative terms, including critical levels and tolerance

ranges for the most important plant species and existing production systems.

7. Carry out research on animal nutrition and diseases limiting rates of reproduction and growth.

8. Estimate the tolerance parameters of the ecosystems (i.e., what percent of an area can be put into agriculture without significantly changing the energy or hydrologic balance).

9. Develop methods for determining which land facets are suitable for agriculture like intensive crop production, pastures, forestry, permanent crops, etc., and which areas should be left untouched. It has been suggested that várzeas are most appropriate for annual crops and terra firme for perennial crops and pastures for livestock raising, but solid scientific evidence is still lacking.

10. Study alternative systems of land clearing that minimize soil disturbance and erosion hazards and that facilitate the rapid establishment of a plant canopy.

11. Monitor soil and biomass changes with time, after natural systems are converted to farming systems. This would include monitoring the effect of management practices such as periodic burning, mulching and pest and disease control.

12. Introduce new species or varieties tolerant to serious diseases, soil acidity, limited nutrients and other constraints common to the Amazon. This applies to food crops, pastures, livestock, permanent crops, forestry and agroforestry cultivars at various input levels.

13. Compare introduced with native species at various input levels.

14. Study integrated land use systems having a wide variety of food, cash and fuel crops and livestock.

15. Evaluate the impact of different land use systems on the socioeconomic conditions of local populations.

16. Assess individual and social costs and benefits with different development strategies.

17. Assess infrastructure needs for input and marketing systems.

18. Identify regions that should be preserved for native people, national forests, parks, wildlife and gene pool reserves.

Recommendations for an Amazon Research Network

The representatives of national institutions and international agencies at the conference, after reviewing present national policies and state of knowledge reports, recommended that an Amazon Research Network be established. This would be a region-wide, nonpolitical, cooperative effort to develop sustainable and productive land use systems for the humid tropics of South America through the expansion and strengthening of research on: ecology and the use of native flora and fauna, soils and nutrient management, hydrology and climate, permanent crops, agroforestry, forestry, annual crops, pastures, animal and veterinary science, and socioeconomic factors. The objectives of such a Network would be to:

1. Protect the natural resource base and maintain its inherent productivity;

2. increase food, fiber, and renewable energy production;

3. regenerate degraded ecosystems;

4. use effectively the limited available energy resources;

5. maintain a majority of the humid tropics in their natural state.

The Network would address these objectives by facilitating development of relevant research, training, and information dissemination activities throughout the Amazon region. Its functions would be to:

1. Provide mechanisms for improved communications and rapid exchange of research results.

2. Identify research needs and priorities and if necessary bring them to the attention of appropriate research institutions and funding agencies.

3. Foster cooperative and complementary research activities, which take advantage of institutional strengths, minimize duplication and enable multidisciplinary teams to address complex problems.

4. Assist in strengthening research stations, throughout the Amazon basin, including all major ecological subdivisions such as the tropical rain forest and the seasonal forest regions.

5. Hold periodic Network meetings as one means for developing cooperative work plans, evaluating results and transferring information.

In order to implement these recommendations, an interim Steering Committee was formed. The Committee's function would be to develop a framework and guidelines for the Amazon Research Network and to initiate its activities. The members of the Steering Committee follow:

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Acronyms

CATIE (Costa Rica)	Centro Agronómico Tropical de Investigación y Enseñanza
CEPLAC (Brazil)	Comissão Executiva do Plano da Lavoura Cacaueira
CICOLAC (Colombia)	Compañía Colombiana de Alimentos Lácteos S.A.
CIMMYT (México)	Centro Internacional de Mejoramiento de Maíz y Trigo
CNPMF (Brazil)	Centro Nacional de Pesquisas de Mandioca e Fruticultura
CNPSe (Brazil)	Centro Nacional de Pesquisa de Seringueira
CODESUR (Venezuela)	Comisión para el Desarrollo del Sur
CONIF (Colombia)	Corporación Nacional de Investigación y Fomento Forestal
CORPAC (Peru)	Corporación Peruana de Aeropuertos Comerciales
CPAC (Brazil)	Centro de Pesquisa Agropecuária dos Cerrados
CPATU (Brazil)	Centro de Pesquisa Agropecuária do Trópico Umido
CREA (Ecuador)	Centro de Reconversión Económica del Austro

CRIA (Peru)	Centro Regional de Investigación Agraria
CVG (Venezuela)	Corporación Venezolana de Guayana
EMATER (Brazil)	Empresas Estaduais de Assistência Técnica e Extensão Rural
EMBRAPA (Brazil)	Empresa Brasileira de Pesquisa Agropecuária
IBDF (Brazil)	Instituto Brasileiro de Desenvolvimento Florestal
IBGE (Brazil)	Instituto Brasileiro de Geografia e Estatísticas
IBRD (U.S.)	International Bank for Reconstruction and Development
IBTA (Bolivia)	Instituto Boliviano de Tecnología Agropecuaria
ICA (Colombia)	Instituto Colombiano Agropecuario
ICRAF (Kenya)	International Council for Research on Agroforestry
IERAC (Ecuador)	Instituto Ecuatoriano de Reforma Agraria y Colonización
IGAC (Colombia)	Instituto Geográfico Agustín Codazzi
IHRO (Ivory Coast)	Institut de Recherches pour les Huiles et Oleagineux
IITA (Nigeria)	International Institute for Tropical Agriculture
INATA (Brazil)	Instituto Agronômico de Tome-Açu
INATAM (Brazil)	Instituto Experimental Agrícola Tropical Amazônico
INCRA (Brazil)	Instituto Nacional de Colonização e Reforma Agraria

INCRAE (Ecuador)	Instituto de Colonización de la Región Amazónica Ecuatoriana
INCORA (Colombia)	Instituto Colombiano de la Reforma Agraria
INDERENA (Colombia)	Instituto de Desarrollo de los Recursos Naturales Renovables
INIA (Peru)	Instituto Nacional de Investigación Agraria
INIAP (Ecuador)	Instituto Nacional de Investigación Agropecuaria
INP (Perú)	Instituto Nacional de Planificación
INPA (Brazil)	Instituto Nacional de Pesquisas da Amazônia
INPE (Brazil)	Instituto Nacional de Pesquisas Espaciais
INTSOY (U.S.)	International Soybean Program
IRRI (Philippines)	International Rice Research Institute
IVIC (Venezuela)	Instituto Venezolano de Investigaciones Científicas
MARNR (Venezuela)	Ministerio de Recursos Naturales Renovables
MOP (Venezuela)	Ministerio de Obras Públicas
NAS (U.S.)	National Academy of Sciences
NCSU (U.S.)	North Carolina State University
ONERN (Peru)	Oficina Nacional de Evaluación de Recursos Naturales
ORDELORETO (Peru)	Organismo Regional de Desarrollo de Loreto
ORDES (Peru)	Organismos Regionales de Desarrollo
PIN (Brazil)	Programa de Integração Nacional

POLAMAZÔNIA (Brazil)	Programa de Pólos Agropecuários e Agrominerais de Amazônia
PREDESUR (Ecuador)	Sub-Comisión Ecuatoriana para Desarrollo del Sur del Ecuador
PROBOR (Brazil)	Programa de Incentivo a Produção e a Beneficiamento de Borracha Vegetal
PRODEPEF (Brazil)	Programa de Desenvolvimento e Pesquisa Florestal
PROTERRA (Brazil)	Programa de Redistribução da Terra
SENA (Colombia)	Servicio Nacional de Aprendizaje
SPVEA (Brazil)	Superintendência do Plano de Valorização Econômica da Amazônia
SUDAM (Brazil)	Superintendência de Desenvolvimento da Amazônia
UEPAEs (Brazil)	Unidades de Execução de Pesquisa de Âmbito Estadual

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