AGRO-ECOLOGICAL CONDITION OF

THE OXISOL-ULTISOL AREA OF THE AMAZON RIVER SYSTEM

Report of a Survey

from Cerrado to Forest Areas in Brazil

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Report of the Survey Project
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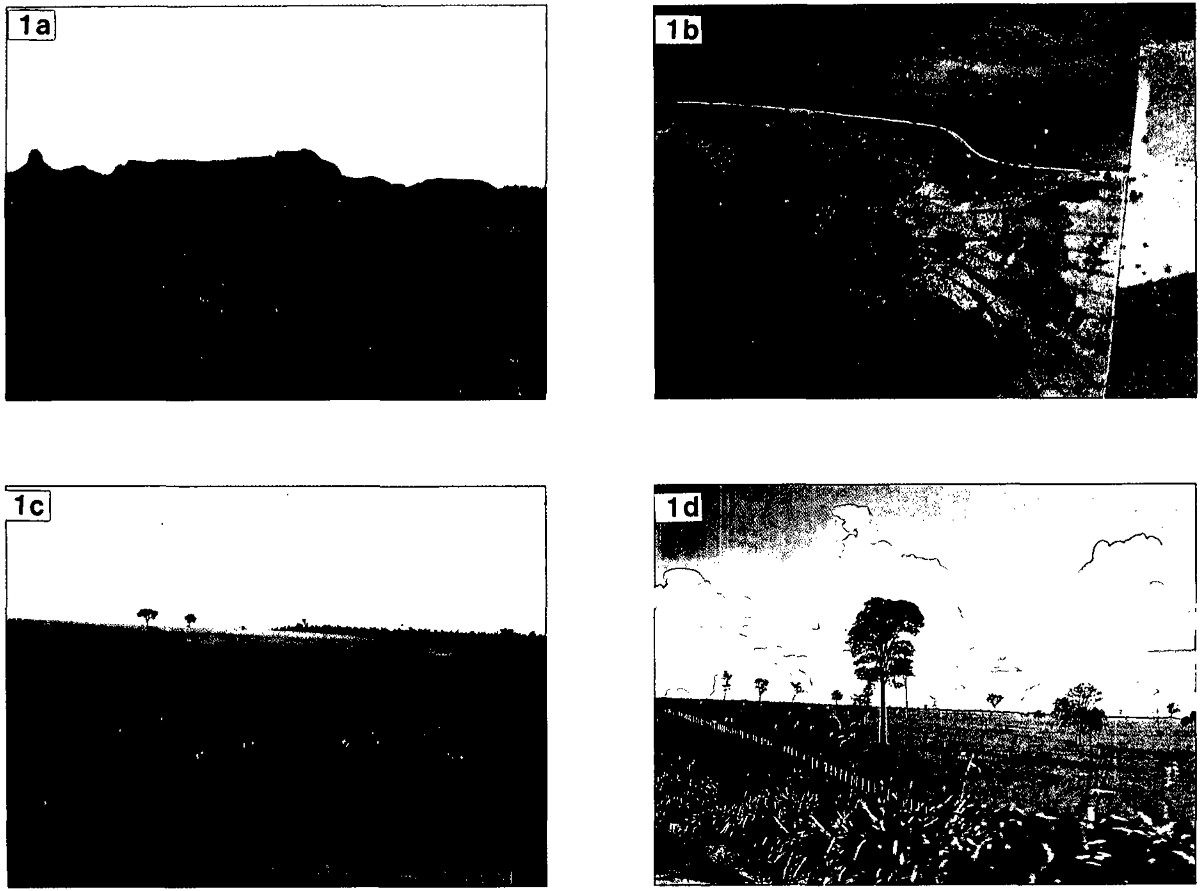

Plate 1. Landscape of Cerrado area in the Brazilian Highland.
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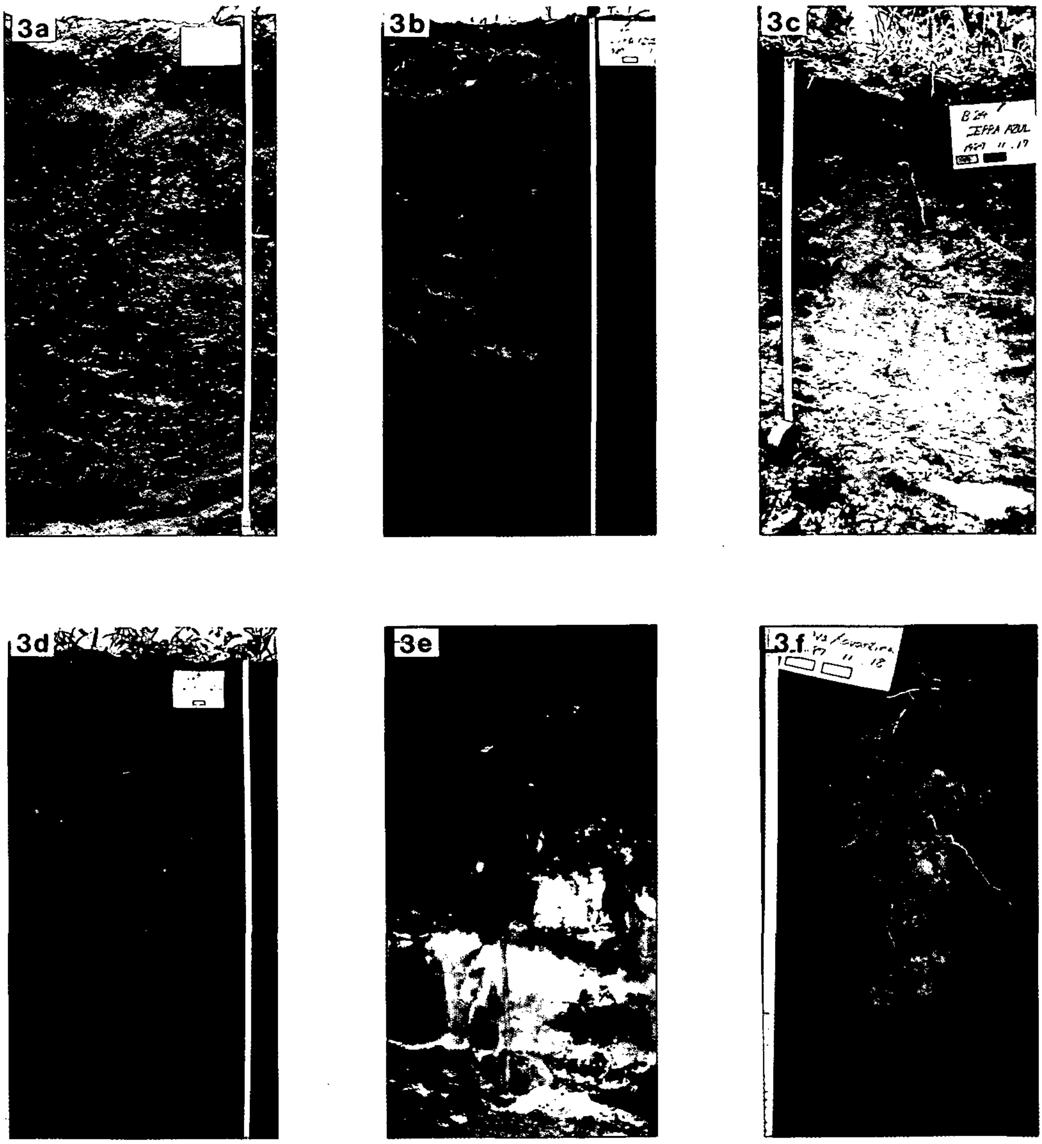

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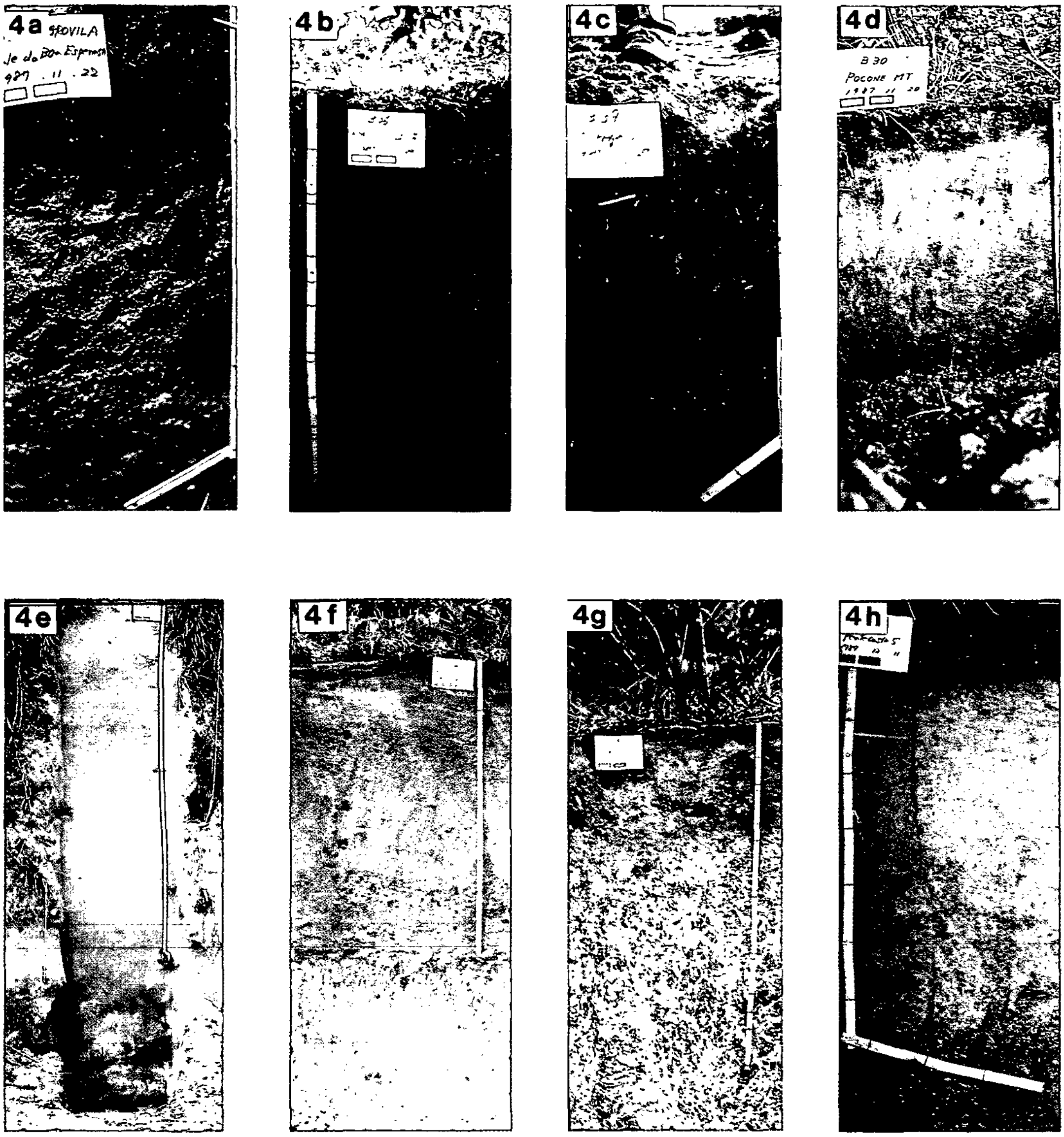

Plate 4. Soil profiles in the Transition Region and Upper Amazon Basin.

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1. INTRODUCTION

1—1. Purpose

The Amazon River System is attracting the attention not only of agricultural scientists but also of environmental scientists, because of its huge potential for producing more food, the fragile nature of its ecosystem, and the suspected influence to global climate when the ecosystem is disturbed. For this reason, this series of surveys was started to grasp the agro-ecological condition of the system where Oxisols and Ultisols are distributed as major soils. The ultimate goal of these surveys is to understand the relationship between ecological condition and agricultural activity in the area for establishing a rational background in order to design optimum farming systems with which a high productivity is sustained and nature preserved under various agro-ecological conditions.

In the preliminary survey (Tanaka *et al.*, 1984), four broad regions were recognized in the Amazon River System : (i) Lower and Central Amazon Basin, (ii) Upper Amazon and Orinoco Basin, (iii) Eastern Ranges and Foothills of the Andes, and (iv) Central Brazilian Highland. In the preceding survey (Tanaka *et al.*, 1986), Llanos (savanna) in the Orinoco Basin of Colombia and forests of Peru in eastern ranges and foothills of the Andes were compared.

In the present survey, the area expanding from Brasília to Cruzeiro do Sul in Brazil was surveyed, which covers the five states of Goiás (GO), Mato Grosso (MT), Mato Grosso do Sul (MS), Rondônia (RO), and Acre (AC). If one goes from east (Central Brazilian Highland) to northwest (Upper Amazon Basin) in the survey area, the altitude decreases, precipitation increases, the duration of the dry season becomes shorter, temperature increases, vegetation changes from Cerrado to forest, and the intensity of human activity decreases, in general. In this area, there are also swampy areas, such as lowlands in Pantanal of Mato Grosso do Sul and in the Rio Araguaia system of Goiás and Mato Grosso. Thus, this survey area provides us with a unique opportunity to analyze the relationship between agro-ecological condition and agricultural activity.

1—2. Composition of Survey Team

Members of the survey team and their responsibilities are listed as follows :

Akira TANAKA: Professor Emeritus, Hokkaido Univ.; Leader, Farming System.
Toshio SAKUMA: Professor of Soil Science, Hokkaido Univ.; Pedology, Soil Physics, and Soil Hydrology.
Nagao OKAGAWA: Lecturer of Soil Science, Kyoto Univ.; Soil Chemical Composition.
Hiroki IMAI: Instructor of Soil Science, Hokkaido Univ.; Soil Chemistry.
Toshiyuki SATO: Instructor of Plant Ecology, Hokkaido Univ.; Plant Ecology.
Junichi YAMAGUCHI: Associate Professor of Plant Nutrition, Hokkaido Univ.; Field Crops.
Konosuke FUJITA: Associate Professor of Pasture Science, Hiroshima Univ.; Pasture.

1—3. Area and Scope

This survey was made along the highways from Brasília to Goiânia, Rondonópolis, Cuiabá, Vilhena, and Porto Velho, and then, stepping-stone-wise to Rio Branco and Cruzeiro do Sul. In addition, side trips were made to Gurupi, Campo Grande, Corumbá, and Sorriso, *etc.*, to reach into the interior.

The survey area (Fig. 1) can be, in a broad sense, divided into the following four Regions:

(1) Brazilian Highland
(2) Pantanal Region (Pantanal lowland and its periphery)
(3) Transition Region (Transition area between (1) and (4))
(4) Upper Amazon Basin

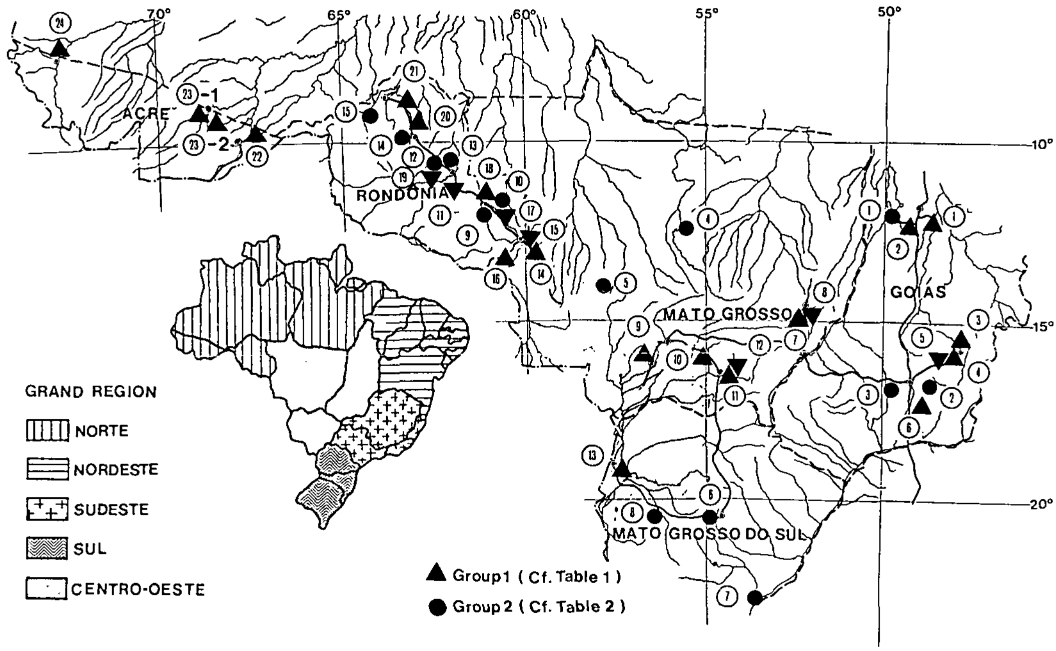


Fig. 1. Survey area and survey sites (Refer to Tables 1 and 2).

It was intended that we travel across the survey area by road as much as possible in order to access the situation of the area closely, but some portions were covered by air because of time limitation.

For making more detailed and efficient observations of soils, vegetation, and crops in the field, the survey was made by dividing the team into two groups. Group 1 consisted of three soil scientists and a plant ecologist (Sakuma, Okagawa, Imai, and Sato), who tried to understand relationships among climate, edaphic condition, and vegetation in various land systems; and Group 2 consisted of crop scientists who were specialized in field crops and pasture (Tanaka, Yamaguchi, and Fujita), and who tried to understand farming systems in each land system. Details of the itineraries of these two groups are given in Appendix 1. The sites where soil and vegetation were inspected by Group 1, and where farms were visited by Group 2, are listed in Tables 1 and 2.

1-4. Acknowledgment

In making arrangements for the survey, Group 1 made contact with Dr. G. Ranzani, EMBRAPA/DPP and with Dr. J. Ribeiro da Silva, EMBRATER, and Group 2 with Dr. É. P. Guimarães, EMBRAPA/CNPAF. They were kind enough to explain the general situation of

Table 1. Brief description of survey sites (Group 1).

Site no.[1)]	Pedon no.	Location	Altitude (m)	Land form
1	-	10 km SE of Cariri (Faz. Ponderosa)	260	Undulating upland (shallow depression)
2	-	20 km W of Formoso do Araguaia (Cooper Java)	190	Lowland
3	B5-B13	EMBRAPA/CPAC	1,200	Undulating upland
4	-	Vargem Bonita	1,100	Shallow valley
5	-	Alexânia (Faz. Ochiai)	1,000	Undulating upland
6	-	Piracanjuba-Cardas Novas	800	Undulating upland
7	B21-B27	50 km SSE of Nova Xavantina (Coper Cana)	550	Undulating upland
8	B28	20 km S of Nova Xavantina	400	River terrace
9	B29-B30	Poconé	170	Inter-terrace lowland
10	B31	50 km NW of Rondonópolis[2)]	300	Rolling hills (foot slope and terraces)
11	B32-B34	Rondonópolis (Faz. Três Irmãos)	280	Pediment, Terrace, Cone, Fan, Valley bottom
12	B35-B38	Rondonópolis (Faz. São Carlos)	450	Undulating upland
13	B39	Corumbá (Agro Villa: Vale Paraíso)	150	Inter-hill lowland, Foot slope
14	B42-B44	70 km SSE from Vilhena (Faz. Italiano)	620	Undulating upland
15	B41	Vilhena (EMBRAPA, Exp. Station)	600	Undulating upland
16	B40	Colorado do Oeste	350	Rolling hills, Inter-hill lowland
17	B45	Marco Rondon	380	Rolling hills (foot slopes)
18	B46	Pimenta Bueno	300	Rolling hills, Terraces
19	B47	Ji-Paraná (Agro Villa: Texeirópolis)	280	Rolling hills, Inter-hill lowland
20	B48	Ariquemes (EMBRAPA, Exp.Station)	150	Rolling hills
21	B49	Porto Velho	80	Terraces
22	B58	Rio Branco (Agro Villa: Humaitá)	160	Terraces, Flood plain
23	B56-B57	Sena Madureira	150	Terraces, Flood plain
24	B50-B55	Cruzeiro do Sul	170	Terraces, Inter-terrace lowland

1) Site no.: Site number in the survey; refer to Fig. 1. 2) Agro Villa: Vale da Boa Esperança.

Table 2. Brief description of survey sites (Group 2).

Site no.[1)]	Location	Altitude (m)	Land form
1	30 km W of Formoso do Araguaia[2)]	190	Lowland
2	Silvânia	900	Undulating upland
3	Palmeiras de Goiás	800	Undulating upland
4	Faz. Progresso	380	Undulating upland
5	Itamarati Norte S.A.	650	Undulating upland
6	Terenos	400	Undulating upland
7	Taquarussu	250	Lowland
8	Faz. Bodoquena	160	Undulating upland and hills, Lowland
9	Pimenta Bueno	300	Rolling hills
10	40 km SE of Espigão d'Oeste	320	Rolling hills, Inter-hill lowland
11	Presidente Medici (Faz. Hermes)	280	Rolling hills, Inter-hill lowland
12	18 km NW of Ouro Preto do Oeste	280	Rolling hills, Inter-hill lowland
13	12 km E of Ouro Preto do Oeste	280	Rolling hills, Inter-hill lowland
14	Ariquemes	150	Rolling hills, Terraces, Lowland
15	40 km SW of Porto Velho	80	Terraces, Flood plain

1) Site no.: Site number in the survey; refer to Fig. 1.
2) Cooperativa Agroindústria Rio Formoso Ltda. (Cooperformoso).

the survey area, to give valuable suggestions, and also to assist in organizing the itineraries by contacting persons who were stationed in the survey area. We express our hearty thanks to them, as it would have been impossible for us to conduct the survey efficiently without their help. During the survey, people from various organizations in the area, listed in Appendix 2, extended assistance by providing information, making transportation available, and accompanying us in the field. We would like to mention their kindnesses with many thanks. We wish to express our thanks also to Dr. Y. Izumiyama and Eng. Y. Horino for their personal friendship making comfortable our stay in Brazil, and to Mr. Robert Kluttz, Lecturer at Hokkaido University, who revised the English.

2. GENERAL CONDITION OF THE SURVEY AREA

2—1. Geographical Position

The survey area extends from the center of Cerrados in the Brazilian Highland to the western end of Amazon forests in the Upper Amazon Basin (Fig. 1).

Population density is higher in the states of Sudeste and Nordeste, but lower than 5 habitant/km^2 in most parts of the present survey area, and less than 2 habitant/km^2 in Norte (including Rondônia and Acre) and Mato Grosso (Fig. 2).

Regional and inter-regional road networks are reasonably well organized in Nordeste, Sudeste, Sul, and southern parts of Centro-Oeste, but are not so in Norte and some parts of Mato Grosso (Fig. 2). Although the highway from Mato Grosso to Rondônia was paved recently, regional roads are often hardly accessible in most parts of Mato Grosso and Rondônia. In Acre, there is no paved main road.

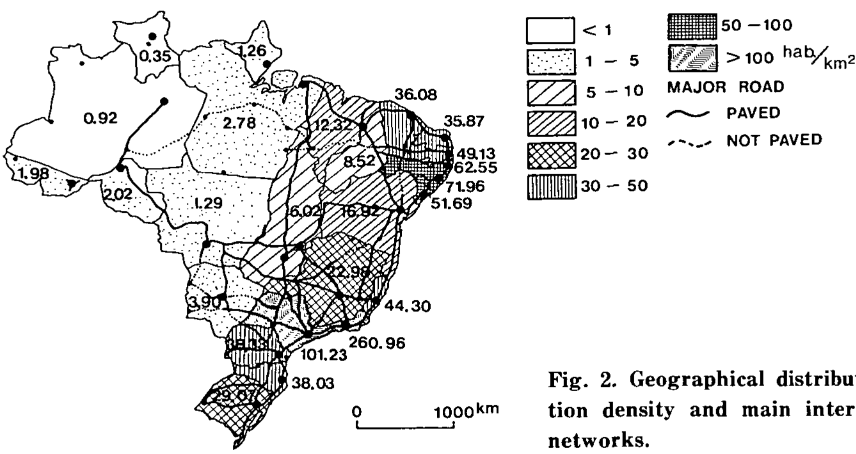


Fig. 2. Geographical distribution of population density and main inter-regional road networks.

In the southern parts of Goiás and Mato Grosso, especially around big cities such as Brasília and Goiânia, markets for farm products are available within short distances, and road systems are well organized for receiving deliveries of agricultural materials such as fertilizers and insecticides, and for shipping out farm products to markets in distant large cities (such as São Paulo), and even abroad. On the other hand, in Rondônia, especially in Acre, it is very difficult to obtain agricultural materials on time, and to sell farm products at a reasonable price because of the poor transportation system.

2—2. Climate and Hydrology

Climate of the Brazilian Highland (Table 3) is characterized by a greater amount of precipitation compared with other savanna areas in the world (Tanaka *et al.*, 1984). Annual precipitation often exceeds 1,500 mm, and total evapotranspiration during the wet season (TWSE) (Cochrane and Jones, 1981) is relatively high (900 to 1,100 mm/year). Duration of the dry season and the total climatic water deficit during this period (CWDD) are the most

Table 3. Climatic data at selected sites in tropical and subtropical South America[1].

Place	Latitude (south)	Longitude (west)	Altitude (m)	Tm (°C)	dT (°C)	P (mm)	Px (mm)	Pn (mm)	Rh (%)	Sd (h)	Ws (m/sec)	Ep (mm)	Nd (month)	CWDD (mm)
Puyo	01 35	77 54	950	21.5	1.5	4,294	453	294	88	985	0.8	1,022	0	0
Tingo Maria	09 08	75 57	665	25.0	0.5	3,072	394	119	79	1,757	1.0	1,258	0	0
Uaupés	00 08	67 05	85	25.4	1.8	2,869	329	160	85	1,998	1.0	2,323	0	0
Alto Tapajós	07 20	57 30	140	24.9	0.6	2,741	416	20	-	1,995	0.6	1,377	4	239
Manaus	03 08	60 01	48	26.9	1.7	1,897	269	38	77	2,127	1.6	1,642	5	326
Santarém	02 25	54 42	20	25.8	1.8	1,975	336	36	84	1,967	1.4	1,488	6	402
Barra do Corda	05 30	45 16	81	25.8	3.2	1,097	214	7	76	2,053	0.8	1,466	8	656
Porto Nacional	10 31	48 43	237	25.6	3.3	1,814	298	<1	-	2,612	0.7	1,466	6	491
Caetité	14 03	42 37	878	21.4	3.8	810	152	9	74	2,453	2.4	1,038	8	370
Formosa	15 32	47 18	912	21.2	4.0	1,595	350	4	-	2,674	2.2	1,004	5	272
Cuiabá	15 35	56 06	171	25.5	4.5	1,378	222	9	-	2,037	1.5	1,443	7	385
Três Lagoas	20 47	51 42	312	23.1	6.3	1,286	202	21	82	2,649	2.0	1,162	7	88
Corumbá	19 00	57 39	138	24.6	5.8	1,120	176	18	-	2,697	1.5	1,362	9	285

1) Data source: Müller (1982). Abbreviations: Tm; Mean temperature. dT; (Tx − Tn), where Tx is mean temperature of warmest month (°C) and Tn is mean temperature of coldest month (°C). P; Annual precipitation. Px; Monthly precipitation (maximum). Pn; Monthly precipitation (minimum). Rh; Mean relative humidity. Sd; Annual duration of sunshine. Ws; Mean wind speed. Ep; Potential evaporation. Nd; Number of dry months (P<Ep). CWDD; Climatic water deficit during the dry season (sum of [Ep−P] for the dry months).

important discriminators of agro-meteorological conditions in the area. The dry season lasts for more than 4 months, and CWDD is within the range of 500 to 750 mm/year in most parts of the Cerrado areas (Tanaka *et al.*, 1984).

Since the temperature regime is mostly isothermic or isohyperthermic in tropical South America, the duration of the crop season is limited principally by the duration of the dry season. The crop season based on the climatic water regime (P>PE, where P is precipitation and PE is potential evapotranspiration) is within the range of 270 to 330 days/year in the Brazilian Highland and is longer than 330 days/year in most parts of the Upper Amazon Basin (Fig. 3).

Water balance in the Amazon Basin as a whole can be summarized as follows (Salati, 1987) : P = 12,000 km^3 (100%), discharge of the Amazon river (D) = 5,500 km^3/year (46%), and evapotranspiration (ET) = 6,500 km^3/year (54%). The high percentage of ET is due to the dense forest. It is forecast by some ecologists that with an increase of deforestation, D

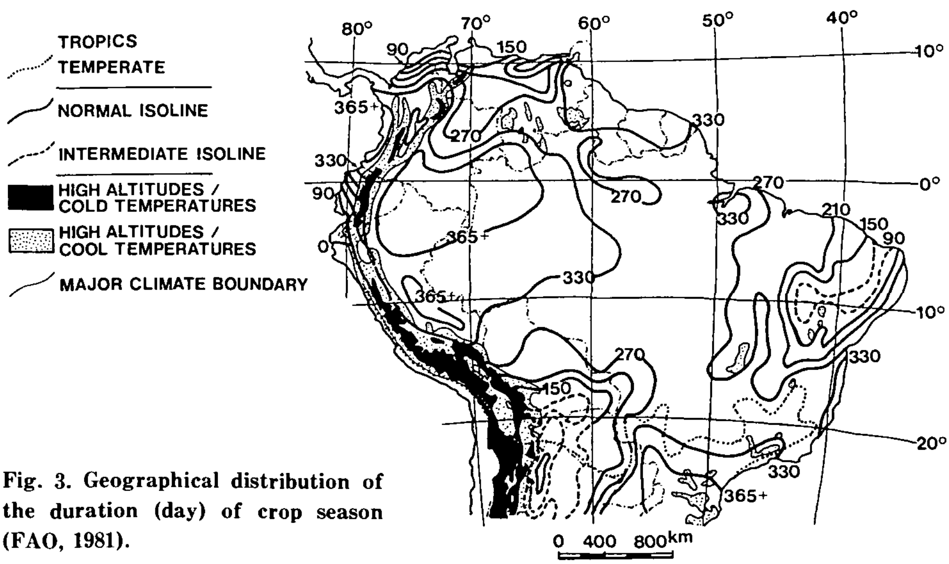


Fig. 3. Geographical distribution of the duration (day) of crop season (FAO, 1981).

increases due to a decrease of ET. It is argued that if the forests are replaced by pasture or field crops, regional or global climatic changes will take place. However, these speculations seem to be rather too simple. Some meteorologists are skeptical. It is necessary to address this subject more precisely from various angles by considering the water conservation capacity of manmade environments.

In most parts of the Brazilian Highland, the annual amount of P exceeds that of PE. There are many big rivers, such as Rio Araguaia, Rio Xingu, Rio Tapajõs, and Rio Paranã, which invade deeply the Highland. Main tributaries of these rivers are perennial streams. Headwaters of these tributaries are trough-shaped depressions without any V-shaped valley. At the bottom of these depressions, generally, there is no perennial stream, but often springs, which are locally called 'Ouro da ãgua'.

In the Pantanal Region, the annual amount of P is slightly less than that of PE, especially in the southwestern part around Corumbã. The river water of Rio Paraguai and its tributaries flows into the Pantanal lowland. The water level above ground in the lowland fluctuates, depending upon the discharge rate of these rivers. During the rainy season, most parts of the ground are flooded (0.5 m in depth), but during the dry season, the ground again emerges.

In the Transition Region and the Upper Amazon Basin, annual PE/P is in the range from 0.4 to 0.8. The high percentage of D in water balance of the Amazon River System is due to a big value of (P−PE) in the western part of the Upper Amazon Basin.

2−3. Geomorphology and Surface Geology

Landscape in the Brazilian Highland is characterized by almost flat, extensive surfaces, which are separated from each other by sharp scarps. Most of these flat uplands (Terra firme) are the remnants of erosion surfaces of the Brazilian shield, and locally called 'Chapada'. The altitude is from 100 to 1,200 m at the erosion surfaces, and is the highest (about 1,330 m) at summits of the mountain ranges around Brasília (Fig. 4).

The lithology of steep scarps around Chapada is variable. There are frequent outcroppings of lateritic ores, Tertiary, Mesozoic, and Plaeozoic rocks, and Precambrian basement complex (MME-SG, 1981−1983; MME-DNPM, 1976−1980). The Tertiary sedimentary rocks are generally lateritic and quartz sandstones, and the older members are often mafic

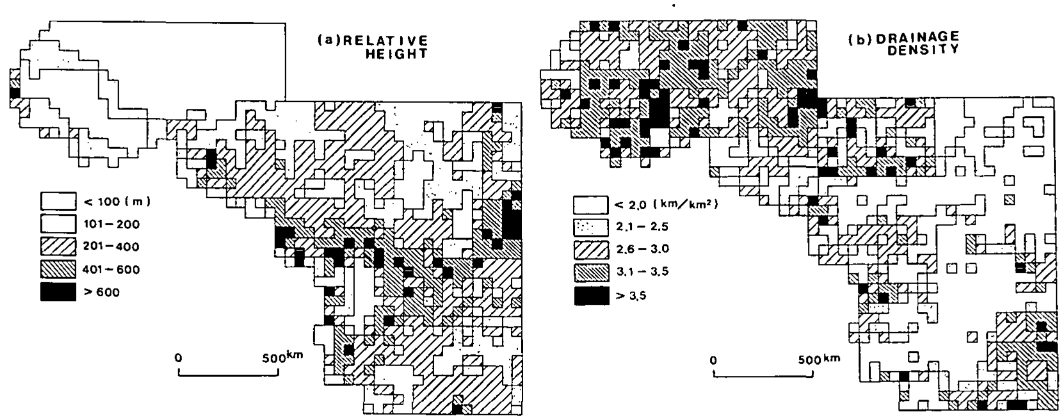


Fig. 4. Geographical distribution of (a) the relative height and (b) the drainage density by each 50 km x 50 km grid in the survey area.

or calcareous. The basement complex is mostly basic metamorphic Precambrian rocks. In the foot slopes, there are gently sloped cones and fans, and these consist of mixed gravelly clays and /or loams, which are relatively high in base content. Surface sediments of the inter-Chapada lowlands, especially in the areas around the watershed in the southern part of Goiás and Mato Grosso, are often rich in bases.

Most parts of the flat plains on Chapada are overlaid with reddish-yellow sandy clays, often accompanied with thin layers rich in hardened plinthite and/or quartzite gravels. Bleached quartz-sand deposits are also found on the surface in patches. The slopes near scarps are often underlaid by the weathering crust of basement complex, especially in the lower highlands.

The Pantanal lowland is encircled by hilly uplands. Because the lower end of the depression is narrowed by the uplands and hills near Corumbá and Bodoquena, the longitudinal slope of the main rivers is very small, *e.g.*, the slope of Rio Paraguai is less than 3 cm/km at the lowest part of the depression (MME-SG, 1982). The landscape of hilly areas surrounding the depression is characterized by remnants of cuestas, such as cuesta scarps, broad valleys, and mesas. The lithology of hilly areas in the Pantanal Region is similar to that in steep scarps and foot slopes of Chapada. Major soil parent materials in the lowland are various alluvial deposits of mixed lithology.

In the Transition Region, rolling hills, terraces, and flood plains are the major elements of landscape. The uplands are generally lower than 400 m. There are rolling hills around Chapada in Rondônia. Generally, these consist of rocky peaks, gentle foot slopes, and inter-hill lowlands. There are many outcroppings of saprolites and fresh rocks of gneiss, schists, and other basic rocks. The deposits in this area are generally young and rich in bases, and their lithology is not simple.

The Upper Amazon Basin is characterized by vast, flat terraces and flood plains at an altitude of 100−150 m. The terraces can be classified into three groups, *i.e.*, high, middle, and low. The high terraces correspond, probably, to the higher terraces at Yurimaguas in Peru. The middle terraces are lacustrine consisting of vast, flat surfaces and low cliffs, and can be divided into two sub-groups by altitude, which correspond to the middle - upper and the lower Inapari formations of Holocene in the upper Rio Acre basin (Campbell and Frailey, 1984). The low terraces are river terraces along flood plains of big rivers. Most of the sediments on terraces and lowlands in the Upper Amazon Basin are clayey mixtures of gray clay, silt, and sand.

The chemical nature of surface sediments on terraces are different, depending upon their origin. Those on the middle and low terraces near Porto Velho and Rio Branco are generally siallitic. On the other hand, those on the high terraces near Cruzeiro do Sul are extremely siliceous. However, basal sediments are generally mafic or calcareous clayey materials, even in the high terraces. Thus, sediments on the lower geomorphic surfaces, including flood plains, are usually clayey and rich in bases.

2−4. Soils

According to EMBRAPA/SNLCS (1981), major soils on the flat plains in Chapadas are generally well-drained Latosols (Latossolo Vermelho-Amarelo Distrófico [Lld], Latossolo Vermelho-Escuro Distrófico [Lvd], Latossolo Amarelo Distrófico [La], *etc.*; Hapl- or Acrustox) and Quartz sands (Areias Quartzosas Distróficas [Q]; Quartzipsamments) (Fig. 5). These soils consist of strongly weathered siliceous materials, infertile in chemical properties,

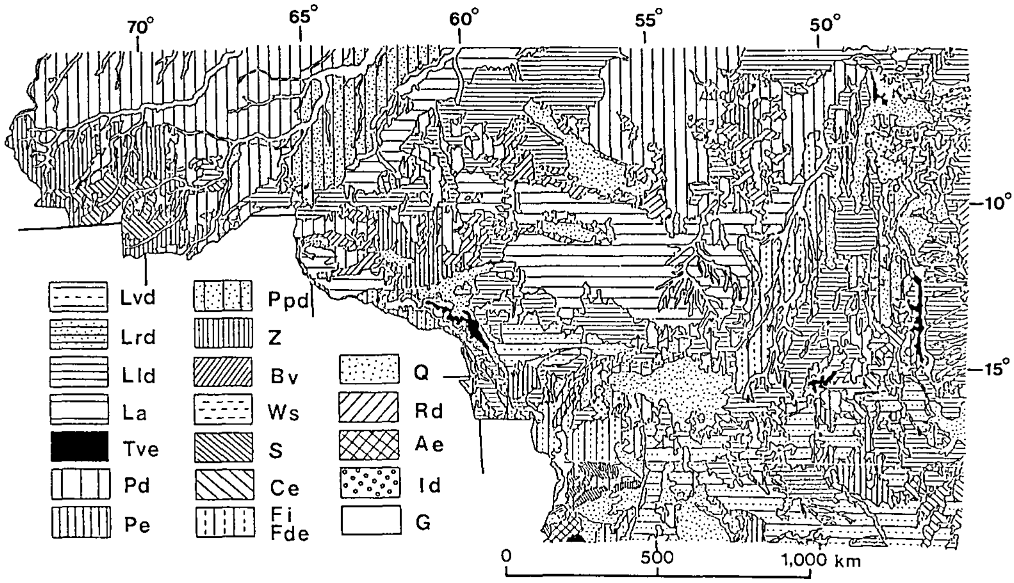


Fig. 5. General soil map of the survey area (EMBRAPA/SNLCS, 1981). Abbreviations: See Table 4.

Table 4. Soils in the survey area and their abbreviations (EMBRAPA/SNLCS, 1981).

Abb.	Soil name	Abb.	Soil name
L	**Latossolos**	**F**	**Lateritas Hidromórficas**
Lvd	Latossolo Vermelho-Escuro Distrófico	Fi	Lateritas Hidromórficas Indiscriminadas
Lrd	Latossolo Roxo Distrófico	Fd	Laterita Hidromórfica Distrófica
Lld	Latossolo Vermelho-Amarelo Distrófico	Fe	Laterita Hidromórfica Eutrófica
La	Latossolo Amarelo Distrófico	Fde	Laterita Hidromórfica Distrófica e Eutrófica
T	**Terras Roxas Estruturadas**	**G**	**Solos Gley**
Tvde	Terra Roxa Estruturada Similar Distrófica e Eutrófica	Gd	Solos Gley Distróficos
Tve	Terra Roxa Estruturada Similar Eutrófica	Gde	Solos Gley Distróficos e Eutróficos
		Q	**Solos Arenoquartzosos Profundos**
		Q	Areias Quartzosas Distroficas
P	**Solos Podzólicos**	**V**	**Vertissolo** (indiscriminados)
Pd	Podzólico Vermelho-Amarelo Distrófico		
Pe	Podzólico Vermelho-Amarelo Eutrófico		
Ppd	Podzólico Plintico Distrófico	**R**	**Solos Litólicos**
		Rd	Solos Litólicos Distróficos
Z	**Podzol**	Re	Solos Litólicos Eutróficos
		Rde	Solos Litólicos Distróficos e Eutróficos
B	**Brunizems**	Rz	Rendzina
Bv	Brunizem Avermelhado		
W	**Planossolos**	**E**	**Regossolos**
Ws	Planossolo Solodico	Ed	Regossolo Distrófico
		Ede	Regossolo Distrófico e Eutrófico
S	**Solonetz-Solodizado**	**A**	**Solos Aluviais**
S	Solonetz-Solodizado (indiscriminados)	Ade	Solos Aluviais Distróficos e Eutróficos
		Ae	Solos Aluviais Eutróficos
C	**Cambissolos**	**I**	**Solos Concrecionários**
Cd	Cambissolo Distrófico	Id	Solos Concrecionários Indivisos Distróficos
Cde	Cambissolo Distrófico e Eutrófico	Ide	Solos Concrecionários Indivisos Distróficos e Eutróficos
Ce	Cambissolo Eutrófico		
Ch	Cambissolo Húmico		

Note:
1) Specification of 'e' and 'd' denotes 'eutrófico (medium to high base saturation)' and 'distrófico (low base saturation)', respectively.
2) [cn] in text and Tables denotes [common to many concretion].

but favorable in physical properties in relation to tilth and development of crop roots. Because of their friable nature, these soils become susceptible to rill and gully erosions, if management is not proper. When heavy machines are used in farming, compaction of subsurface horizons could be a problem.

Soils on the steep slopes around Chapadas and transitional slopes from highlands to lowlands are Cambissolos (Inceptisols), which are characterized by thin gravelly solum. Chemical properties of these soils are variable, depending upon the nature of parent materials. On the contrary, soils of cones and fans on the foot slopes around Chapadas are characterized by their mixed lithology, although they are also classified as Cambissols. Generally, these soils are immature, and high in fertility.

There are vast lowlands in flood plains and valley bottoms along the main stems of big tributaries, *e.g.*, Rio Araguaia, and trough-shaped depressions on Chapadas. These poorly drained lowlands are locally called 'Vãrzea'. These are generally made up of fine textured sediments during Holocene and classified into four types: 'Vãrzea do rio' (wetlands in flood plains and valley bottoms), 'Vãrzea da chuva' (wetlands away from rivers), 'Vãrzea da marẽ' (wetlands in the estuary region), and 'Vãrzea do mar' (wetlands along the ocean coast) (Sombroek, 1966). In the present survey area, the two former types were found. The soils of Vãrzea do rio are poor in drainage and variable in physico-chemical properties, but are generally fertile. In Vãrzea da chuva, fluctuation of the ground water level is due to runoff and/or seepage water from higher places. It is also dependent upon the amount of rainfall, and soils are sandy and siliceous.

In the Pantanal Region, because the annual P is less than PE and the loss of water by deep percolation is small, soils are frequently enriched with bases and soluble salts. Vertissolos [V] (Pelluderts), Solonetz Solodizados [S] (Natraqualfs), and Solos Aluviais Eutrõficos [Ae] (Fluvents) are found in the depression. Although Lvd and Q are the major soils in peripheral uplands, they are frequently associated with eutrophic soils, such as Brunizem Avermelhados [Bv] (Argiustolls) and Podzõlico Vermelho-Amarelo Eutrõfico [Pe] (Haplustalfs and Paleustalfs).

In the Transition Region, the distribution of soils is dependent upon the morphology at stages and the position on a slope: On the ridges, soils are generally very thin and gravelly at the top and on the upper slopes; there are frequent outcroppings of saprolites and/or fresh parent rocks; and on the lower slopes and inter-hill lowlands, soils are characterized by thick dark red solums such as Terra Roxa Estruturada Similar Eutrõfica [Tve] (Tropudalfs) and Distrõfica [Tvd] (Paleudults). Some of these soils are locally called 'Terra Roxa', and are young and fertile, except for those derived from the weathering crust of acidic rocks.

On the terraces and flood plains in the Upper Amazon Basin, the distribution of soils is strongly influenced by the microtopography of the land. In these areas, as the internal drainage is imperfect due to their compact and clayey nature of the basal sediments, Red Yellow Podzolic Soils (Podzõlico Vermelho-Amarelo Distrõfico [Pd]), Pe, and soils with varying hydromorphisms (Lateritas Hydromõrficas Distrõfica [Fd], *etc.*) are developed in complicated patterns.

Major soils in the Brazilian Highland (Lvd, Lld and La; Hapl- and Acrustox) are chemically inert and poor in nutrient elements, but their physical properties are generally favorable. These are deeply drained, well aggregated, and abundant in available water capacity. Siliceous sandy soils in Vãrzea da chuva are very poor in both physical and chemical properties.

Soils on Chapadas in the Pantanal Region (Lvd, Lld, and La) are similar to those in the Brazilian Highland, but immature soils in valley side slopes, terraces, and valley bottoms (Pe; Alfisols and Inceptisols) are variable, depending upon their parent materials. Dark red soils (Pe, locally Bv; Alfisols) on colluvial foot slopes originating from basic parent materials are rich in nutrient elements.

Soils in the Transition Region are also variable in their fertility status. Soils originating from siliceous, acidic rocks (sandstones or granites, Pd, Ultisols, and Inceptisols) are poor in physico-chemical properties, but those from basic rocks of the basement complex (dark red weathered crust, Pe, locally Tve; Alfisols and Inceptisols) are generally rich in nutrient elements and also fairly good in physical properties.

Surface sediments on terraces of the Upper Amazon Basin, especially on the middle and low terraces, are mostly Holocene alluvium. Soils originating from these young sediments are generally rich in nutrient elements, but there are many problems due to immaturity of the soil. For example, poor internal drainage of these clayey soils due to their texture and structure is the most difficult problem in utilizing the land to grow upland crops, and the relatively high exchangeable Al content of these young clayey soils demands a high initial cost in order to improve the soil by liming. Siliceous, sandy soils on high terraces (Pd; mainly Ultisols) are very poor in nutrient elements and also poor in physical properties.

2–5. Vegetation.

By primary division, vegetation regions in Brazil (Fig. 6), which occupy large areas, are the Amazon Forest (35%), Cerrado (20%), the Atlantic Forest (15%), Caatinga (15%), and Pantanal (2%) (Smith, 1962). In the survey made by MME-SG (1983), the following subdivisions were used as the mapping units to compile regional vegetation maps: *i.e.*, 'Cerrado',

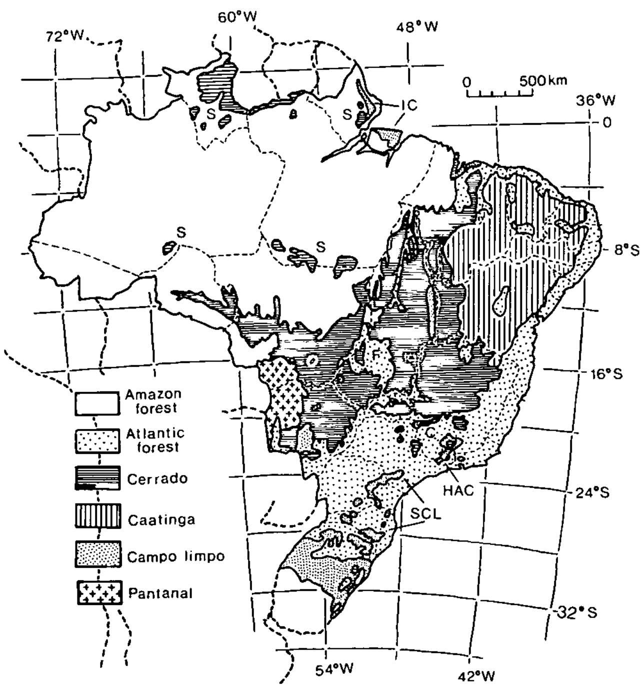


Fig. 6. Main vegetation region in Brazil (Otero, 1971; Eiten, 1982).
IC: Inundated campo. SCL: Southern campo limpo (napeadic campo). F: Upland mesophytic forest. HAC: High altitude campo (alpine fields and campos repestres). S: Amazon savanna.

'Caatinga', 'Floresta ombrófila', 'Floresta estacional', 'Mangue, Restinga e Campos naturais', and 'Contato (Tensão ecológica)'. Further, Eiten (1983) identified 24 subdivisions of vegetation types based mainly on the physiognomy and deciduousness of the vegetation.

These divisions and/or subdivisions are, however, mainly constructed upon the structural types of vegetation. Cochrane *et al.* (1985) pointed out the importance of ecological types in addition to structural types for identifying vegetation. In the present survey area, in fact, vast areas of poorly-drained savanna or forest unique to the lowlands are recognized. Thus, in this report, the following vegetation types were adopted to describe the vegetation at each survey site, principally based on vegetation classification made by Cochrane *et al.* (1984, 1985).

(1) Cerrado (Cer, well-drained savanna): Cerrado occupies a vast area in the Brazilian Highland. This vegetation is composed of species belonging to ancient flora, which had more extensive and continuous distribution in the past (Cole, 1960). The region of this flora is dissected by younger erosion cycles, and has been invaded by younger flora, such as the forest along valleys and Caatinga in eastern Brazil. The 'islands' of Cerrado outside the core Cerrado area give an indication of the extent of Cerrado in the past.

(2) Poorly-drained savanna (Spd, seasonally flooded savanna): In tropical and sub-tropical South America, there are vast areas of poorly drained lowlands covered with grasses, shrubs, and low sparse trees. This vegetation is common in the Pantanal lowland and the Ilha do Bananal depression in the present survey area, and in the lower Piedemonte along the northern bank of Rio Meta in Colombia (Tanaka *et al.*, 1986).

(3) Tropical semi-deciduous seasonal forest (Fds): This type occupies southern parts of Goiás and Mato Grosso, and most parts of Mato Grosso do Sul. It consists of two layers of woody species, generally deciduous (about 15 m in height) and evergreen trees (4—10 m).

(4) Tropical semi-evergreen seasonal forest (Fes): Covers the vast areas of uplands in northern Mato Grosso and major parts of hilly areas in Rondônia and the eastern half of Acre. Maximum height of the woody species is less than 25 m with two layers in general; 20—30% of the upper canopy trees lose their leaves in the dry season ; and most of the lower-layer trees are evergreen.

(5) Tropical rain forest (Ftr): The predominant vegetation on low uplands in the Upper Amazon Basin. This type consists mostly of evergreen trees taller than 30 m with several layers, but generally without shrub layer or undergrowth. The woody layers consist of a large number of species of the Rosaceae, Compositae, and Leguminosae families.

(6) Wetland formations (Wlf): The lower alluvial plains along big rivers ('Várzea do rio') under swampy conditions during most of the year, are covered with swamp and seasonal swamp forests and grassy swamp vegetation (Sombroek, 1966). This vegetation was further subdivided by MME-DNPM (1976—1980) and MME-SG (1981—1983), and presented in Chapter 3.

2—6. Land Utilization

The major agricultural land use system in Brazil has been, traditionally, extensive beef cattle grazing on pasture, especially in the survey area. During the past 25 years, however, there were and still are two major motivating factors to change this situation:

(a) Need for resettlement due to heavy population pressed into the coastal area of Nordeste and into the southern States.

(b) Need to produce more grain (i) to decrease the large amount of import for food and cattle feed, such as wheat, rice, and maize; and also (ii) to increase the export of agricultural products such as soybean.

Based on these needs, the government took various actions, and these resulted in a sharp increase of land area used for grain crops. The increase has been remarkable in Cerrado, where the lands are suitable for grain production, because the landscape is wide and natural vegetation is easy to remove. On the other hand, reclamation activity is yet low in the forest area of Norte, because it is more difficult and expensive to reclaim forests there than in Cerrado, and because infrastructures are still very poor in the area. However, there are certain movements afoot to establish plantations of tree crops, such as coffee, cacao, and rubber, in the area.

Swampy areas are hardly utilized intensively, at least at present. For example, the Pantanal lowland is protected as a nature preserve, although it is seasonally used for grazing cattle without any human input.

In Centro-Oeste, the area of crop fields expanded drastically during the last two decades with a remarkable accompanying increase of the crop field area per farm (Fig. 7). In this area, the strategy of land utilization has been changed radically by the government's policy of developing infrastructures and establishing banking systems to promote mechanized, high input, large-scale grain crop production in Cerrados. Technologies developed by agricultural scientists have played important roles in this drastic change. Although the growth rate of grain production has slowed to some extent during the last 5 years, large development projects are still going on in Chapadas. As there are huge areas of potential arable lands not only in Cerrados but also in Vãrzea, further drastic changes in land utilization may occur, if it is decided to reclaim Vãrzea.

On the other hand, the situation in the Upper Amazon Basin is very different from that in Centro-Oeste. The highway from Cuiabá to Porto Velho was completed in 1984. Rondônia is an active new frontier in Brazil at present. There was gold mining here in the past, lumbering is very active at present, and farmers with only limited capital are coming into the forest area (from which valuable trees have been extracted) by following the trails of lumbermen and trying to establish tree-crop plantations. It may take quite some time, however, to establish efficient infrastructures in the forest area of the Upper Amazon Basin. It is yet very difficult to prognosticate on the future of land utilization in this area.

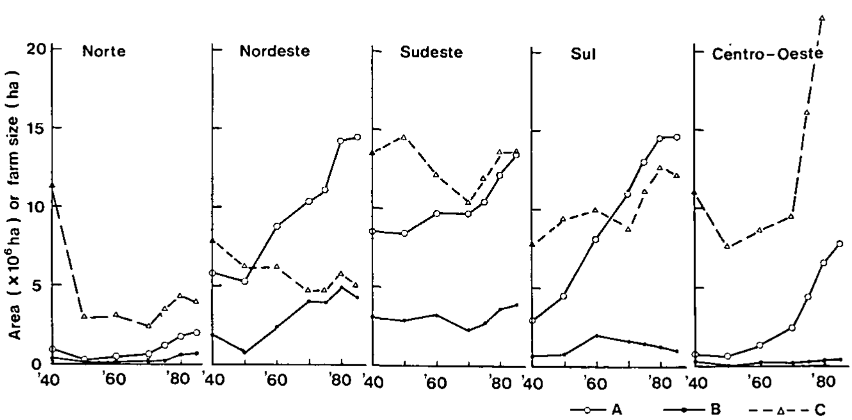


Fig. 7. Change of land utilization for crop production in Brazil.
A: Total cultivated area (annual and tree crops). **B:** Area used for tree crops. **C:** Average area of crop field per farm.

3. DESCRIPTION OF LAND SYSTEMS

3–1. Brazilian Highland

3–1–1. Gurupi System

A representative land system in the northern part of the Brazilian Highland, which includes uplands and a part of the Ilha do Bananal depression (Fig. 8), was surveyed around Gurupi, which spreads out over an almost flat upland at an altitude of about 320 m near the watershed between Rio Tocantins and Rio Araguaia.

Reddish-yellow sandy clays with concretionary layers of reworked iron ore (Belterra clay) and sands overlie directly on saprolites of the Precambrian basement complex. The predominant elements of geomorphic surfaces are residual hills (500–600 m), undulating uplands (200–350 m), low scarps (10–20 m in relative height), and almost flat lowlands (180–190 m).

Shallow dendritic drainage channels develop in broad depressions in the upland areas, and these drainage channels are mostly perennial streams. The drainage channel density is low in uplands and high in these depressions (Fig. 4). In bottom lands of these depressions, soils with varying hydromorphisms exist and the seasonal fluctuation of ground water level seems to be small. The thickness of the overlying unsaturated zone is about 3–5 m in most parts of the upland, but it is often less than 1 m near the scarps facing the Ilha do Bananal depression. In the depression itself, ground water level is high, and is artificially controlled locally to irrigate rice fields. Valleys flowing into the depression are characterized by a relatively wide bottom land with a large pondage capacity.

This land system can be subdivided into several land facets based on pedo-geomorphic conditions and vegetation. Characteristics of these land facets are summarized in Table 5.

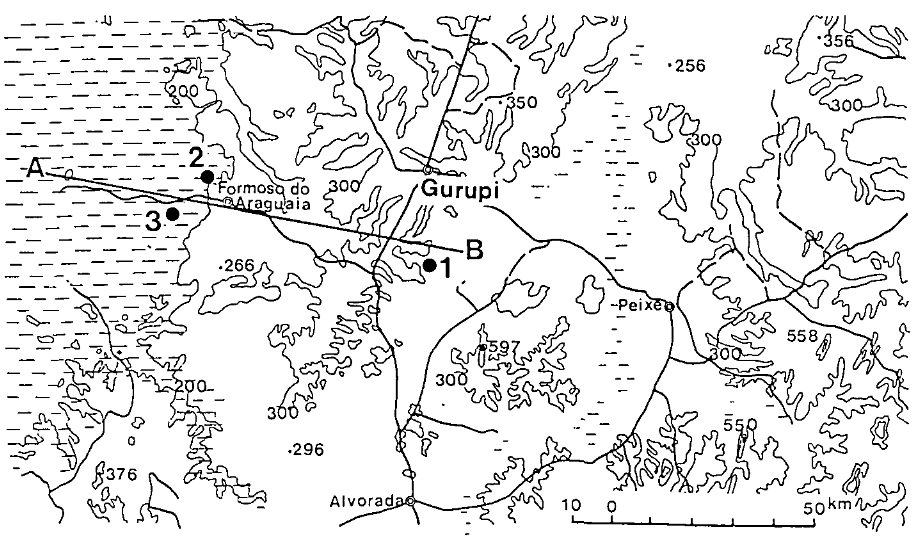


Fig. 8. Map of the survey area in the Gurupi System.
1, 2, and 3: Survey sites.

Table 5. Characteristics of land facets in the Gurupi System (Cariri – Ilha do Bananal depression).

No.	Land facet1)	Soils2)	Drainage3) class	Vegetation4)	Land use
			Upland		
1	Broad Itf	Lld (Lld [cn])	4	Cerradão	Pasture, Grain crops
2	Gentle SSx	Lld [cn]	4(3)	Cerradão	Pasture, Grain crops
3	Gentle SSe and Ats, Valley bottom	Lld [cn], Gd, Ade	1–2	Cerradão, Gallery forest, Várzea do rio	Irrigated rice, Pasture
4	Steep scarp (Faf)	Rd	4	Rock outcrops, Savanna parklands	-
			Ilha do Bananal depression		
5	Flat Afa and Afb	Fd, Gd, Ade	1–3	Poorly-drained savanna, Gallery forest, Alluv.s.decid.s. forest, Várzea do rio	Irrigated rice

1) **Land facets** (includes all subsequent abbreviations): Itf; Interfluve. SSx; Convex seepage slope. SSe; Concave seepage slope. Ccs; Convex creep slope. Faf; Fall face. Tms; Transportational mid-slope. Cfs; Colluvial foot slope. Ats; Alluvial toe slope. Afa; Alluvial flood flat. Afb; Backmarsh and swell. Chb; Channel bed. trough s. valley; trough shaped valley. trough s. valley bottom; trough-shaped valley bottom.
2) **Soils**: See Table 4.
3) **Drainage class**: 1; Poorly drained. 2; Imperfectly drained. 3; Moderately well drained. 4; Well drained. 5; Somewhat excessively drained. 6; Excessively drained.
4) **Vegetation** (includes all subsequent abbreviations): Trop.rain forest; Tropical rain forest. Trop.s.e.s. forest; Tropical semi-evergreen seasonal forest. Trop.s.decid.s. forest; Tropical semi-deciduous seasonal forest. Alluv.s.decid.s. forest; Alluvial semi-deciduous seasonal forest. Alluv.decid.s. forest; Alluvial deciduous seasonal forest.

Interrelations among their various elements along a transect A–B in Fig. 8 are illustrated in Fig. 9.

In the areas around Gurupi and along the main road, there is a considerable area of crop fields planted in sugarcane, maize, soybean, *etc.*, but most uplands are used as improved pasture. There are intentions to develop small irrigated rice fields in shallow depressions. In the Ilha do Bananal depression, a large area of irrigated rice field has been established by a project of the Goiás Government (Plates 12a and 12b).

3–1–2. Brasília System

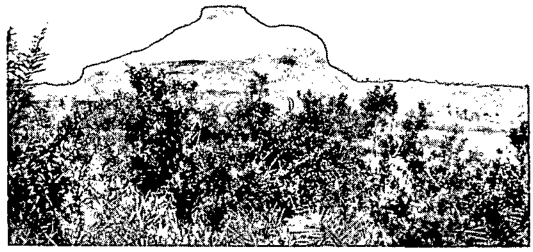
This land system is situated at the highest part of the Brazilian Highland which separates the catchment areas of Rio Amazonas, Rio São Francisco, and Rio Paraná. A detailed survey was made at EMBRAPA/CPAC near the watershed in the previous survey (Tanaka *et al.*, 1984). Complementary surveys were conducted at Vargem Bonita, Núcleo Bandeirante, and Alexânia during this survey (Fig. 10).

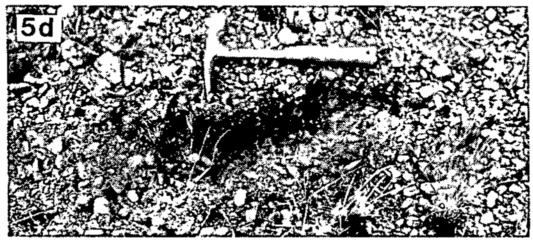
Reddish-yellow sandy clays with concretionary layers of reworked iron ore and bleached quartz sands overlie saprolites of Tertiary sedimentary rocks (lateritic rocks and sandstones). The outcroppings of older members including basement complex are often observed in the valley sides.

The macrotopography of this land system is characterized by large relative height and low drainage density (Fig. 4). The predominant elements of geomorphic surfaces are undulating uplands (>1,000 m), steep scarps (often more than 100 m in relative height), foot slopes (800–1,000 m), and bottom lands with narrow valleys (800–1,000 m). The undulating uplands are

5a

5b





5c

5f

Plate 5. Topography and surface deposits of the Brazilian Highland and the Pantanal Region.
5a. A distant view of the dissected Brazilian Highland (From Faz. Três Irmãos, Rondonópolis System). 5b. A flat-topped residual hill in the Rondonópolis System. 5c. Dissected hills surrounding Chapada in the Serra Azul System. Strip-like micro-reliefs reflect the difference in erosivity of basement rocks. 5d. A gravelly surface deposit on a dissected hill slope; *cf.* Plate 5c. 5e. An example of two-layered clastic deposits on undulating uplands of the Brazilian Highland (near Mutunópolis, Goiás). The top 0.5 m layer is a reddish-yellow sandy clay with many reworked iron ores (hardened plinthite). The second layer is weakly consolidated reddish-yellow sandy clay. 5f. A deep, uniform, friable, bright brown loam deposit in a trough-shaped valley on an undulating upland in the Serra Azul System (near B22).

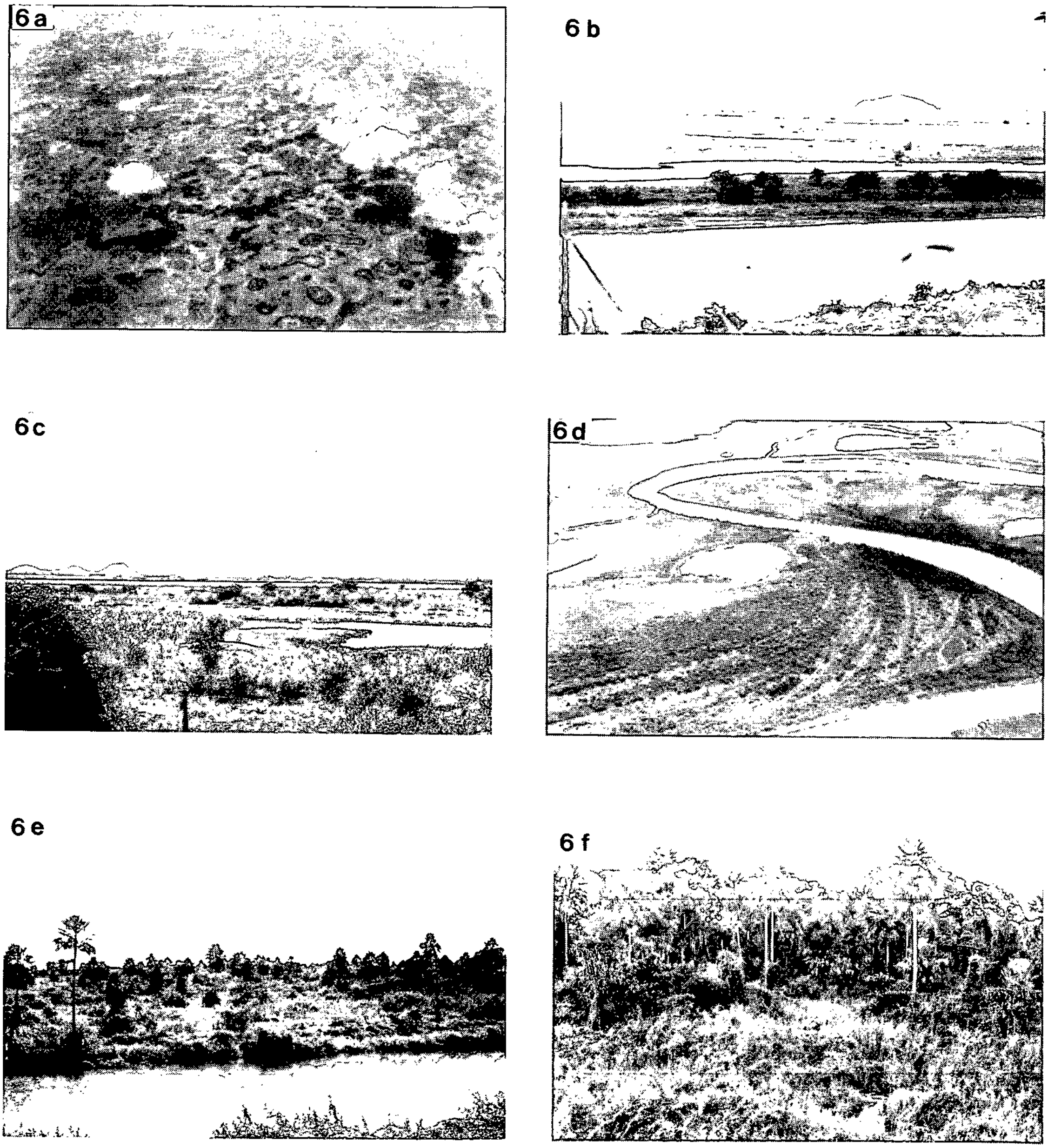


Plate 6. Landscapes of the Pantanal lowland.
6a. An over-view. 6b. Vast flat lowland, residual hill, and meandering river in the Corumbá-Bodoquena System. 6c. A small lagoon with aquatic plants and grasses in the Cuiabá System. 6d. Meandering rivers and lagoons in the southern part (Corumbá-Bodoquena System). 6e. Typical landscape of poorly-drained savanna in the northern part (Cuiabá System). 6f. Grassy swamp vegetation with palms in the southern part (Corumbá-Bodoquena System).

7a

7e

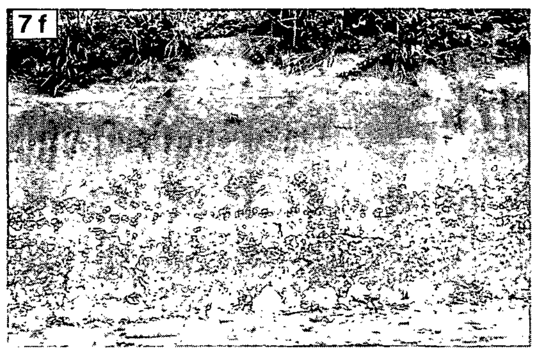


Plate 7. Topography and soil parent materials of the Transition Region and the Upper Amazon Basin.

7a. A steep residual hill with outcroppings of hard rocks at its summit, colluvial slopes, and inter-hill lowlands in the Transition Region (near Ji-Paranã). 7b. Land degradation along a local unpaved road near Colorado do Oeste. 7c. An outcropping of limestone near limestone mine at 40 km SE of Espigão d'Oeste. 7d. An outcropping of Precambrian basement complex (Dark red saprolite with frequent quartzite gravels). 7e. Almost flat terrace plain (middle ?) near Rio Branco in the Upper Amazon Basin. 7f. Clayey terrace deposits with plinthites on the middle terrace at Humaitá near Rio Branco in the Upper Amazon Basin.

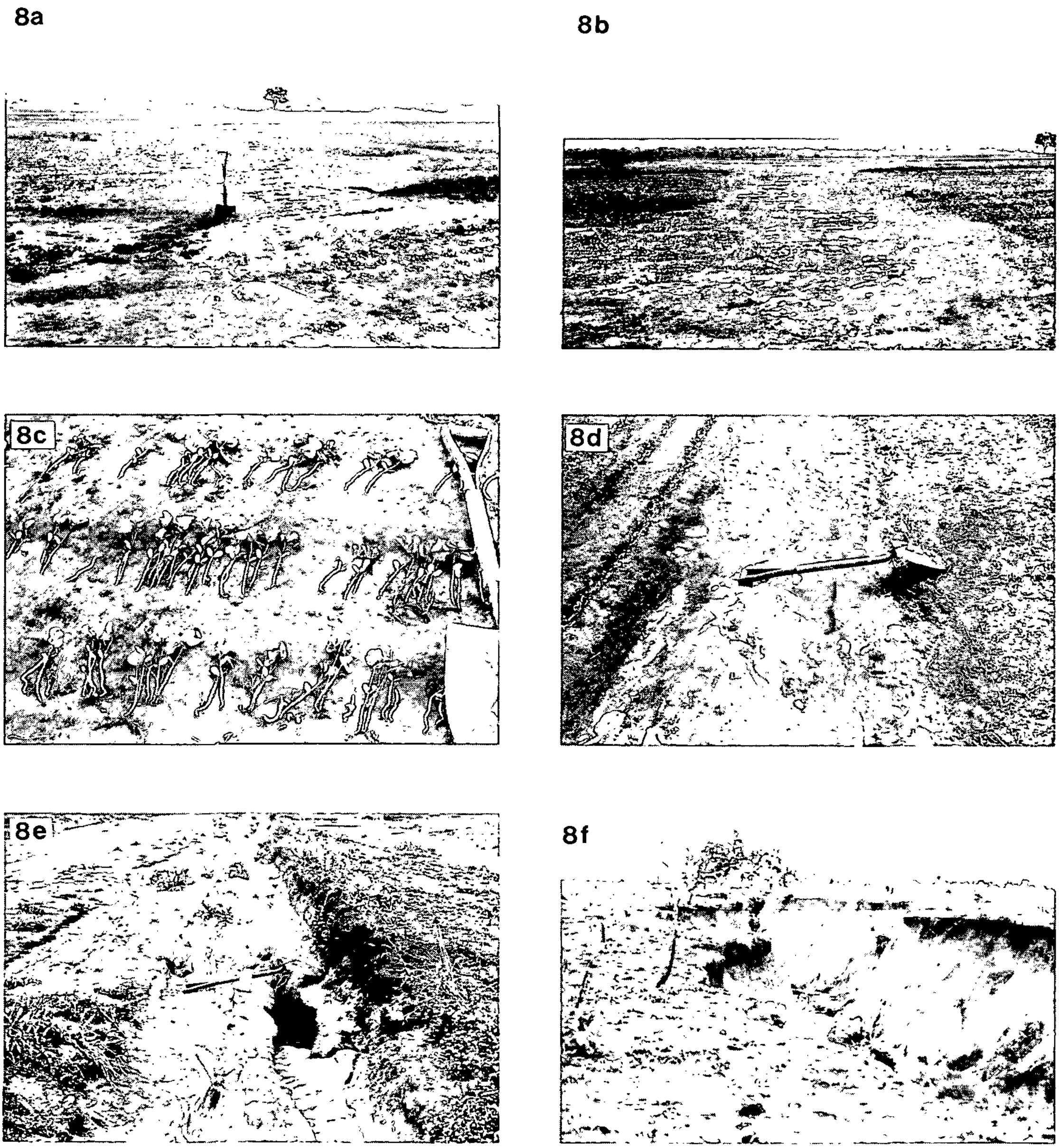


Plate 8. Soil erosion in cultivated crop fields on the Chapada in the Serra Azul System (*cf.* Fig. 41).

8a. Upper reaches of a U-shaped gully (ephemeral gully) near the first terrace waterway broken by the gully. 8b. Middle reaches of the U-shaped gully between the second and third terrace waterways (6 m in width and 15 cm in maximum depth). 8c. Soybean seedlings washed out by overland flows. 8d. Lower reaches of the U-shaped gully along the border of crop field (1.3 m in width and 30 cm in maximum depth). 8e. Lower reaches of the U-shaped gully along the main road (2.5 m in width and 40 cm in maximum depth). The compacted subsurface layer is eroded completely and a shallow gully head cut is formed. 8f. A V-shaped, deep gully formed along the lowest part in the trough-shaped valley.

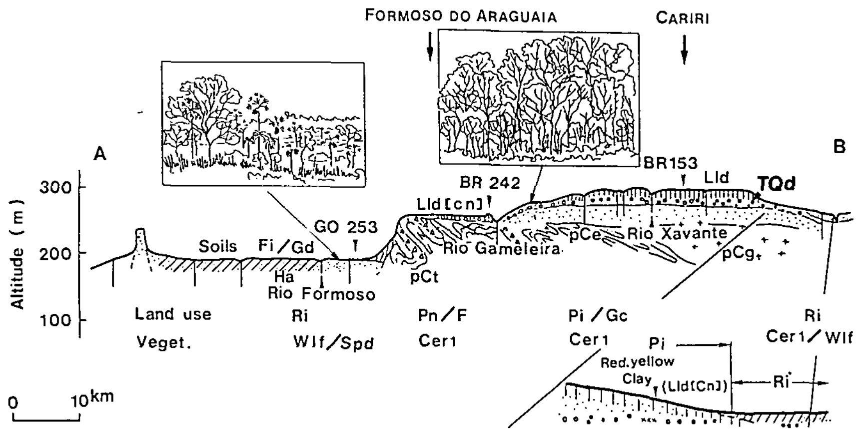


Fig. 9. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Gurupi System (Transect A—B in Fig. 8).

Geology: pCt; Precambrian basement complex, Tocantins group (phyllites, schists, etc.). pCg; ditto, Goiânia Complex (Gneisses, migmatites, etc.). TQd; Tertiary-Quaternary clastic deposits, lateritic sandy clay. Ha; Holocene sand, silt, and clay. Red.yellow; Reddish-yellow (Similar expressions are adopted to other soil colors).

Soils: See Table 4.

Land use (includes all subsequent abbreviations): Ri; Irrigated rice. Gc; Grain crops. Tr; Tree crops. Pn; Native pasture. Pi; Improved pasture. F; Forest (unused).

Veget.(Natural vegetation) (includes all subsequent abbreviations): Cerl; Cerrado. Cer2; Cerradão. Spd; Poorly-drained savanna and gallery forest. Fds; Tropical semi-deciduous seasonal forest. Fes; Tropical semi-evergreen seasonal forest. Wlf; Wetland formation.

BR153, BR242 and GO253: Main road.

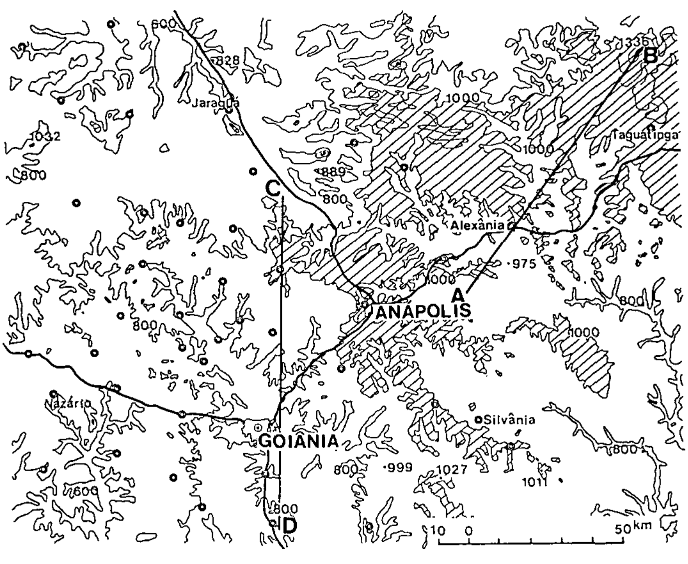


Fig. 10. Map of the survey area in the Brasília and Goiânia Systems.

dissected deeply by dendritic drainage systems, which are mostly perennial streams. Soils with varying hydromorphisms occur in shallow depressions of the uplands (Macedo and Bryant, 1987), showing a high ground water level during the wet season. The thicknesses of aquifer on bed rock and that of the overlying unsaturated zone are about 15—20 m and 5 m, respectively, in most uplands, but ground water level is often less than 1 m at the lower end of the uplands. There are also many springs to be found in shallow depressions and on the lower side slopes and foot slopes of the deeply dissected valleys. The inhabitants obtain water from shallow wells.

This land system can be subdivided into seven land facets (Table 6). Interrelations among these facets along a transect A—B in Fig. 10 are illustrated in Fig. 11a.

Although cattle grazing on pasture is most important in this system, grain crops have become popular, and vegetables and fruit trees are also grown by aggressive farmers, especially in Várzea around Brasília.

Table 6. Characteristics of land facets in the Brasília System (EMBRAPA/CPAC – Alexânia).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Upland		
1	Broad Itf	Lvd, Lld	4-5	Cerrado	Grain crops, Pasture
2	Gentle SSx	Lld, Lvd [cn]	4	Cerrado	Grain crops, Pasture
3	Gentle SSe	Lld [cn], La, Q	3	Cerrado-Cerradão	Pasture, Grain crops
4	Gentle Ats (trough s. valley bottom)	Q, Lld [cn]	2-3		Pasture, Grain crops, Vegetables
5	Steep Tms and Faf	Cd, Ce [cn]		Cerradão	-
			Valley		
6	Gentle Cfs	Lvd	3-4	Cerradão	Pasture, Grain crops
7	Flat Ats, Afa, and Afb	Ade, Ae, Gd	1-2	Cerradão (Gallery forest, Alluv.s.decid.s. forest)	Grain crops, Vegetables

Abbreviations: See Table 4 and footnotes in Table 5.

3—1—3. Goiânia System

This land system is a representative of moderately dissected remnants of the Brazilian Shield. In this system, the areas of (i) Uruana — Itaguaru, (ii) Trindade — Nazário, (iii) Silvânia, (iv) Hidrolândia - Piracanjuba, and (v) Palmeira de Goiás were surveyed (Fig. 10).

Reddish-yellow sandy clays with concretionary layers of reworked iron ore and bleached quartz sands overlie saprolites of Tertiary (lateritic rocks, sandstones, and conglomerates), Mesozoic, Paleozoic, and Precambrian basement complex. Components older than Mesozoic often include calcareous and/or mafic rocks.

The macrotopography of this land system is characterized by large relative height and low drainage density (Fig. 4). The altitude of undulating remnants of erosion surfaces is 700 to 900 m, but their coverage is rather limited. The predominant elements of geomorphic surfaces are undulating or rolling uplands together with frequent rocky peaks (700—900 m), steep scarps (often more than 100 m in the relative height), foot slopes (600—800 m), and valley bottoms (600—800 m). The deeply dissected major tributaries of Rio Paranã are perennial. Thicknesses of aquifer on the bed rock and overlying unsaturated zones are similar to those in the uplands of Brasília. Springs and shallow wells are often found in shallow depressions

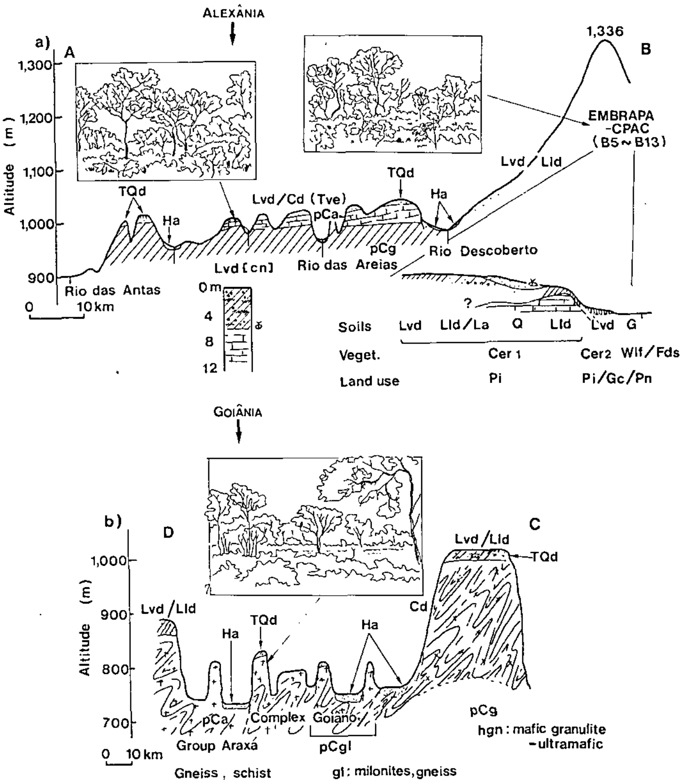


Fig. 11. A schematic illustration of the relationship among topography, soil, and natural vegetation in (a) the Brasília System (Transect A–B in Fig. 10) and (b) the Goiânia System (Transect C–D in Fig. 10).
Geology: pCg; Precambrian basement complex, Goiânia Complex (Gneisses, migmatites, *etc.*). pCa; ditto, Araxá group (Gneisses, schists, *etc.*).
Other abbreviations: See Table 4 and footnotes in Fig. 9.

on the uplands and on lower side slopes of the deeply dissected valleys. In the relatively wide bottom lands of valleys, hydromorphic soils are predominant, reflecting a stable high ground water level.

This land system is comprised of seven land facets (Table 7), whose interrelations along a transect C–D in Fig. 10 are illustrated in Fig. 11b.

Extensive cattle grazing is still now important, but the area of annual crop fields has increased remarkably during recent years.

3–1–4. Serra Azul System

The western reach of the Brazilian Highland is called the Mato Grosso Highland, and is characterized by ridges lying from east to west with undulating or rolling uplands which spread on both sides of the ridges. Dissection is generally stronger on the slopes facing south than on those facing north. Undulating uplands and associated hills, terraces, and lowlands at Serra Azul, where Faz. Coper Cana is located, are illustrated in Fig. 12.

Dark red and/or reddish-yellow sandy clays, and white sands in patches overlie saprolites of Tertiary rock (lateritic rocks, sandstones, and conglomerates) and older sedimentary or metamorphic rock (dark red sandstones, quartzites, phyllites, *etc.*). Hilly areas in the transition from uplands to fluviatile terraces are overlaid with gravelly materials of hardened plinthites, quartzites, and white coarse sands. Surface deposits on the terraces consist of 2–3 layers, *i.e.*, (a) reddish-yellow sand, silt, and clay, locally together with gray white sand, (b) gray clayey deposits with plinthites, and (c) coarse deposits of mixed lithology.

Table 7. Characteristics of land facets in the Goiânia System (Goiânia – Piracanjuba).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Upland		
1	Broad Itf	Lvd, La, Lld [cn]	4-5	Cerrado	Grain crops, Pasture
2	Gentle SSx	Lvd, La, Lld [cn]	4	Cerrado	Grain crops, Pasture
3	Gentle SSe	Lld, Lvd [cn], Q	3	Cerrado-Cerradão	Pasture, Grain crops
4	Gentle Atf (trough s. valley)	Q, La [cn]	2-3	Campo Cerrado, Várzea da chuva	Pasture
5	Steep Tms and Faf (valley side slope)	Cd, Cd [cn]	3-4	Cerradão	-
			Valley		
6	Gentle Cfs	La, Lvd [cn?]	3-4	Cerradão	Grain crops
7	Flat Ats, Afb, Afa	Ade, Ae, Gd	1-2	Cerradão, Alluv.s.decid. s.forest, Várzea do rio	Grain crops, Vegetables

Abbreviations: See Table 4 and footnotes in Table 5.

The macrotopography of this land system is characterized by medium relative height and low drainage density (Fig. 4). The predominant elements of geomorphic surfaces are undulating uplands (500–600 m), steep scarps (more than 100 m in relative height) and hilly transition (300–500 m), almost flat river terraces (300–310 m), and valley bottoms (280–300 m). Most parts of undulating remnants of erosion surfaces are 500–600 m in altitude. A distant view of the uplands, enclosed by high steep scarps and low foothills, illustrates the landscape of 'Chapadão' (Plate 1a).

On the uplands, there are limited numbers of perennial streams, and water can usually be obtained from rivers and shallow wells. This situation is the same in the transition and terrace areas. Judging from the relative height between a river bed and the adjacent upland surfaces, the possible thickness of aquifer is less than 20 m. However, soils of varying hydromorphism in shallow depressions along rivers suggest that there is enough water to keep the soil under anaerobic conditions throughout the year. In the transition and terrace areas, there are many large perennial streams, and water is easily obtained from these rivers and shallow wells.

The main part of this system is a remnant of the erosion surface (Brazilian Shield), that is isolated from the main body by the dissection of big rivers. Fluviatile terraces and valley bottoms are also important land facets of this system (Table 8). The interrelations among elements of these land facets along a transect A–B in Fig. 12 are summarized in Fig. 13.

On the flat uplands in the heart of Chapadão, lands are generally used continuously to grow grain crops under intensive management because soils are relatively fertile Lvd. On the steep scarps and colluvial foot hills, to the contrary, lands are used for extensive pastures or forests because soils are gravelly, shallow, and are frequently found with rock outcroppings. In the periphery of Chapadão, infertile sandy soils originating from siliceous sandstones are often found. These are also left as native pasture or forests. The flat fluviatile terraces were reclaimed quite some time ago and are used by small farms to grow grain crops.

3–1–5. Chapada dos Parecis System

This land system includes three survey sites (Faz. Progresso, Itamarati Norte S.A., and Faz. Italiano). As shown in Fig. 14, the major part of the Chapada dos Parecis proper

Table 8. Characteristics of land facets in the Serra Azul System (Nova Xavantina).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Upland		
1	Broad Itf	Lld, Lvd	4-5	Cerrado	Grain crops, Pasture
2	Gentle SSx	La, Lvd	4	Cerrado	Grain crops, Pasture
3	Gentle SSe	La, Q	3	Cerrado-Cerradão	Pasture, Grain crops
4	Gentle SSe/Ats	Q, La	2-3	Cerrado	Pasture
5	Steep scarps (Faf)	Ed (quartz sandstone)		Cerrado	-
			Transition and Valley		
6	Foot hills (SSx/SSe)	Ed, La [cn]		Cerrado	Pasture
7	Terraces (SSx/SSe)	Lvd, Pd, Q	3	Cerradão	Grain crops, Pasture
8	Flat Afa, Afb	Fd, Ade, Ae	1-2	Cerradão-Alluv.s.decid. s. forest, Várzea do rio	-

Abbreviations: See Table 4 and footnotes in Table 5.

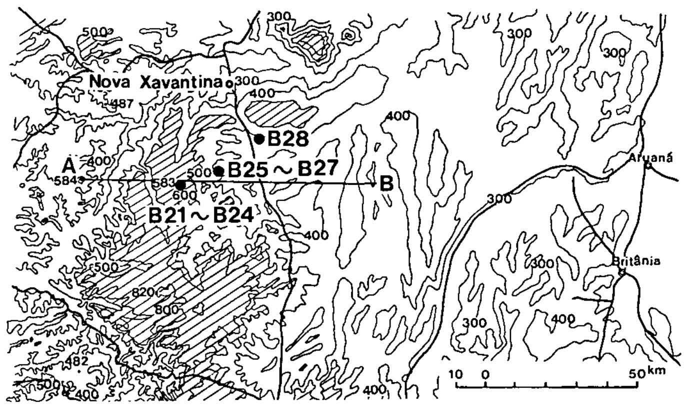


Fig. 12. Map of the survey area in the Serra Azul System.

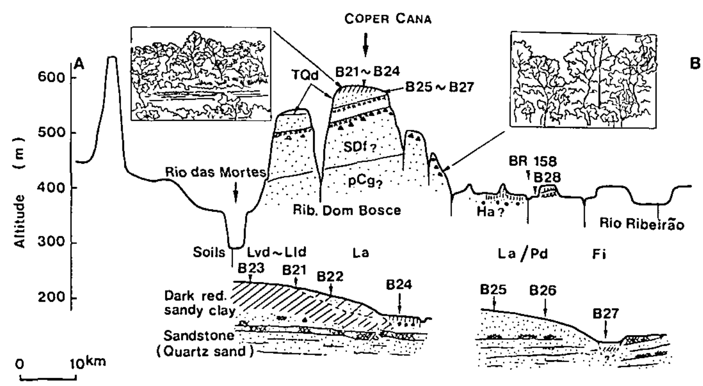


Fig. 13. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Serra Azul System (Transect A–B in Fig. 12).
Geology: pCg; Precambrian basement complex, Goiânia Complex (Gneisses, migmatites, etc.). SDF; Palaeozoic quartz sandstone.
Other abbreviations: See Table 4 and footnotes in Fig. 9.

consists of vast uplands higher than 500 m in altitude. Broad interfluves of the Chapada (700—800 m in altitude) are biased strongly to the south. Therefore, the uplands facing south are more significantly dissected than those facing north. Almost parallel drainage channels of the upper reaches of Rio Juruena invade deeply into the vast uplands facing to the north, and their density is far lower than that of uplands facing south.

The area at the northeastern end of Chapada dos Parecis, where Faz. Progresso is located, is characterized by broad uplands which are dissected by the upper reaches of tributaries of Rio São Manuel (Rio Teles Pires) and Rio Xingu. The macrotopography is characterized by low relative height and medium to high drainage density (Fig. 4). The predominant elements of geomorphic surfaces are undulating uplands (380—450 m), steep scarps, and narrow valley bottoms (350—420 m). The depression along Rio São Manuel is almost flat and enclosed by fault scarps. In this area, reddish-yellow clays, locally together with hardened plinthites and coarser materials, overlie clastic deposits originating from Tertiary-Quaternary lateritic deposits. Surface sediments in the depression along the river are mostly quartz sands underlaid with Cretaceous conglomerates of arkosic matrix. Itamarati Norte S.A. is located near the interfluve of Chapada dos Parecis proper at about 650 m in altitude.

The macrotopography of this area is characterized by medium relative height and low drainage density (Fig. 4). The predominant elements of geomorphic surfaces are vast undulating uplands being slightly inclined toward the north (400—800 m in altitude), steep scarps, and narrow valley bottoms (350—650 m). Dark red heavy clays, found locally together with hardened plinthites, overlie clastic deposits originating from underlying Tertiary-Quaternary lateritic deposits. The surface sediments in the depressions along big tributaries are largely quartz sands underlaid by Cretaceous quartz sand deposits of Utiariti formation. There are some perennial streams dissecting deeply into Chapada, but their upper reaches are often not perennial, especially in higher parts of the Chapada. Most of the hydro-electric stations of this area are situated at sites lower than 500 m in altitude along the main stems of big rivers.

Faz. Italiano is located near the eastern end of Chapada dos Parecis which invades into the catchment of Rio Amazonas as illustrated in Fig. 14. On Chapada, reddish-yellow and/or dark red clays and sandy clays overlie clastic deposits originating from underlying Cretaceous quartz sand deposits. On the upper steep slopes and transitional slopes, there are vast areas covered with sandy soils. On most parts of the transitional rolling hills, dark red basic deposits (underlaid by mafic basement complex) are the predominant soil parent materials. The river terraces along Rio Guaporé are covered with clayey deposits.

The macrotopography of this land system is characterized by medium relative height and low drainage density (Fig. 4). The predominant elements of geomorphic surfaces are undulating uplands being inclined slightly toward the northwest (400—800 m in altitude), steep scarps, undulating erosion surfaces (360—420 m), almost flat river terraces (200—300 m), and broad valley bottoms (350—650 m). Some streams in the broad depressions on the Chapada are perennial, but the upper reaches of small tributaries in the transition from uplands to river terraces are often not perennial, especially in the areas overlaid with coarse sand deposits. At both Faz. Italiano and the experimental station of EMBRAPA at Vilhena, water is obtained from a shallow well. In the upland areas, small ponds are often made to secure drinking water for cattle.

This land system can be subdivided into seven land facets (Table 9). Interrelations among elements of these land facets along a transect A—B in Fig. 14 are illustrated in Fig. 15.

The undulating or almost flat uplands of the Chapada have been, partly, used for extensive cattle grazing, but a vast area is still under natural Cerrados. During the past 10 years, however, development of fields for grain crops has become active. Itamarati Norte S.A. is a typical example of big farms for grain production. Although the rate of change is slower in this area than that in Goiás, the traditional land utilization system, which is biased strongly toward extensive pastures, is being gradually encroached upon by grain crop farms.

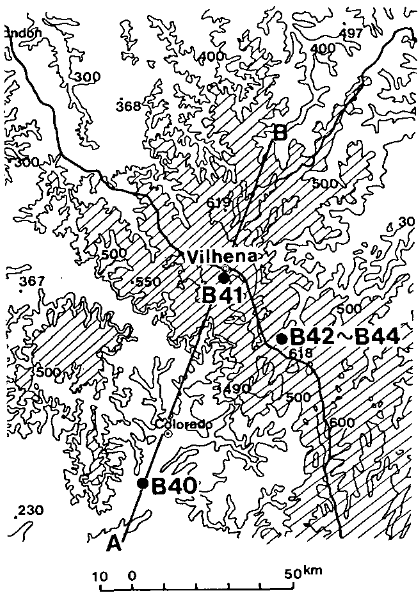


Fig. 14. Map of the survey area in the Chapada dos Parecis System.

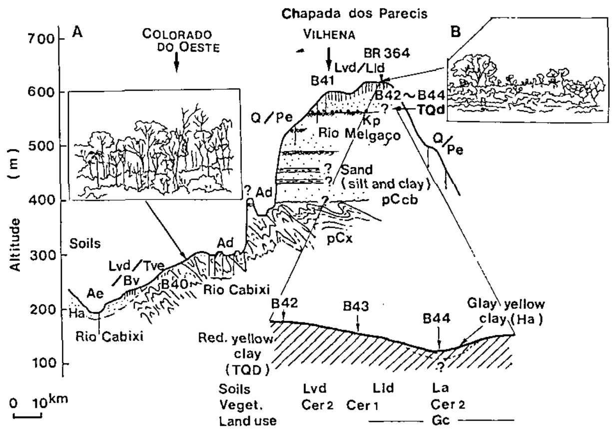


Fig. 15. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Chapada dos Parecis System (Transect A—B in Fig. 14).

Geology: pCx; Precambrian basement complex (Xingu group). pCcb; ditto, fine sandstone. Kp; Cretaceous sandstone. stne. BR364: Main road.

Other abbreviations: See footnotes in Fig. 9.

Table 9. Characteristics of land facets in the Chapada dos Parecis System (Faz. Italiano — Colorado do Oeste).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Upland		
1	Broad Itf	Lvd, Lld, La	4-5	Cerradão-Cerrado	Grain crops, Pasture
2	Gentle SSx	Lvd, Lld	4	Cerradão-Cerrado	Grain crops, Pasture
3	Gentle SSe	La	4	Cerradão-Cerrado	Grain crops, Pasture
4	Gentle SSe/Ats	La, Q (?)	3	Cerradão-Cerrado, Várzea da chuva	Grain crops, Pasture
			Transition and Valley		
5	Steep Tms, Faf	Cd, Q, Tve	3-4	Cerradão/Trop.s.e.s. forest	Pasture
6	Gentle Cfs/SSx/SSe (Foot slope, Terrace)	Tve, Pd (La?)	3	Trop.s.e.s. forest	Grain crops, Cassava [Shifting cultivation]
7	Flat Afa, Afb	Fd, Ade, Ae	1-2	Cerradão-Alluv. decid.s. forest, Várzea do rio	-

Abbreviations: See Table 4 and footnotes in Table 5.

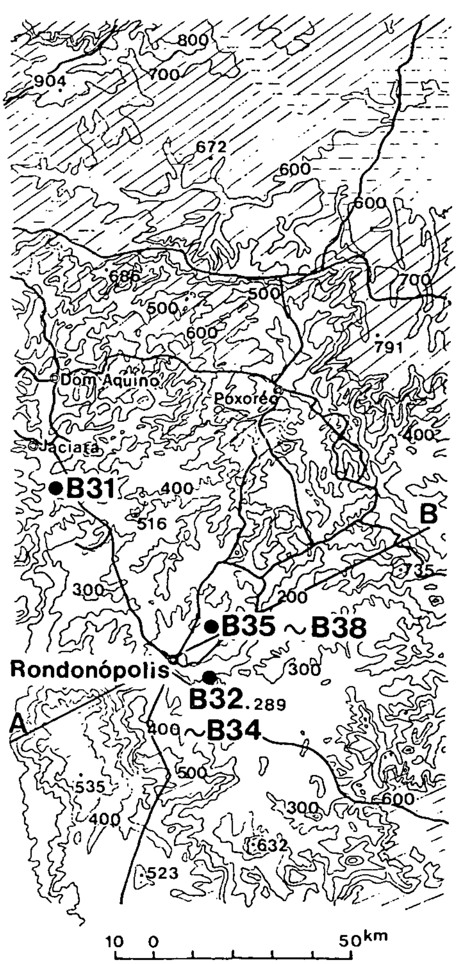
3—2. Pantanal Region

3—2—1. Rondonópolis System

The Pantanal lowland extends from Mato Grosso do Sul in Brazil to Bolivia. The eastern end of the lowland is limited by cuesta scarps often higher than 100 m in relative height. Rondonópolis is located on an upland of the cuesta back-slope facing east. Two survey sites were selected in this area: Faz. Três Irmãos and Faz. São Carlos. The former is situated in a broad valley of cuesta ('Delle') and the latter is on an upland of cuesta back-slope (Fig. 16).

As shown in Fig. 17, the System consists of remnants of undulating upland (erosion surfaces of cuesta back-slopes) and broad valleys formed by consequent streams. On the uplands, dark red and/or reddish-yellow clays overlie clastic deposits of Tertiary-Quaternary lateritic deposits and older sandy sedimentary rocks. The lower foot slopes, river terraces, and flood flats are overlaid with eutrophic clayey deposits.

Macrotopography of this land system is characterized by large relative height and medium



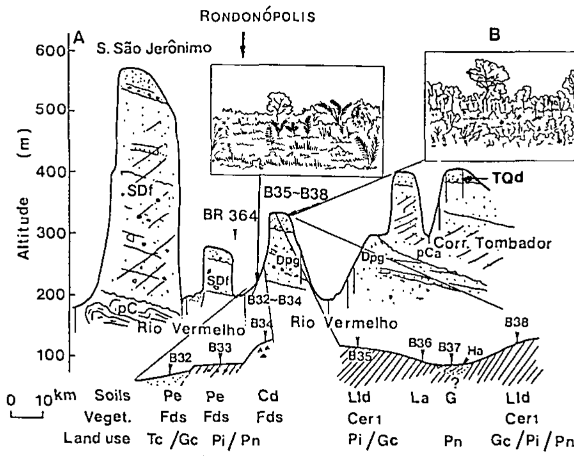


Fig. 17. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Rondonópolis System (Transect A—B in Fig. 16).
Geology: pCa and pC; Precambrian basement complex. SDf; Palaeozoic quartz sandstone. Dpg; Palaeozoic sandstone.
BR364: Main Road. Other abbreviations: See Table 4 and footnotes in Fig. 9.

Fig. 16. Map of the survey area in the Rondonópolis System.

drainage density (Fig. 4). Predominant elements of the geomorphic surfaces are undulating uplands and their remnants (450−600 m), steep cuesta scarps (more than 100 m in relative height), almost flat river terraces (250−350 m), and valley bottoms (200−300 m). The remnants of almost flat back-slopes of the cuesta with altitudes of 500−600 m ('Mesas' or 'Buttes') are the most characteristic topographical elements (Plates 5a and 5b). There are many big perennial streams and springs in the lower colluvial slopes and lowlands. Water can be obtained easily from shallow wells. There are some perennial streams even in the uplands, but water may not be sufficient during the dry season. Small ponds to store drinking water for cattle are frequently seen in the uplands.

The land system can be subdivided into eight land facets (Table 10). Interrelations among elements of these land facets along a transect A−B in Fig. 16 are illustrated in Fig. 17.

In this land system, land utilization varies depending upon the edaphic condition. Although cattle grazing on pastures is important on the uplands, production of grain crops is also active. For example, in Faz. São Carlos with 8,500 ha of land, grain crops such as soybean, upland rice, and maize occupy 50% of the total land area, improved pastures 18%, and the rest is native Cerrado. In lowlands along the broad valleys, including the surrounding colluvial footslopes and terraces, many small farms are located, because the soils are generally fertile and the soil water regime is also favorable for crops. The farming systems practiced by these small farms are generally more complex than those of big farms on Chapadas. Their objective is to use lands of various edaphic conditions most efficiently by combining grain crops, tree crops, and sometimes even irrigated rice on poorly drained lands at the bottom of broad valleys.

Table 10. Characteristics of land facets in the Rondonópolis System (Faz. São Carlos − Faz. Três Irmãos).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Upland		
1	Broad Itf	Lld, Lvd, (La?)	4-5	Cerrado	Grain crops, Pasture
2	Gentle SSx	Lvd, Lld, La	4	Cerrado	Grain crops, Pasture
3	Gentle SSe,	La	4	Cerrado	Pasture, Field crops
4	Gentle SSe/Ats	La, Q	2-3	Cerrado, Várzea da chuva	Grain crops, Pasture
			Transition and Valley		
5	Steep Tms, Faf (Pediment)	Cd, Q, Tve	3-4	Cerradão/Trop.s.decid. s. forest	Pasture
6	Gentle SSx/SSe (Cone, Terrace)	Cd, Ede	3	Trop.s.decid.s. forest	Pasture, Grain crops
7	Gentle Cfs/Ats (Fan)	Pe, Pd, (Tve?)	3	Trop.s.decid.s. forest	Grain crops, Tree crops
8	Flat Afa, Afb (Valley bottom)	Fd, Ade, Ae	1-2	Alluv.s.decid.s. forest, Várzea do rio	Grain crops [irrig. rice]

Abbreviations: See Table 4 and footnotes in Table 5.

3−2−2. Cuiabá System

Cuiabá is situated in a structural depression near the northern end of the Pantanal Region (Fig. 18). The depression is enclosed by steep scarps and mountain ranges except for the south side. The altitude of undulating uplands is 230−250 m at Cuiabá, decreases gently toward the south, and is 150 m at Poconé. The relative height between upland surface and the Pantanal lowland is less than 20 m near the southern end of the upland.

On the uplands, residual clastic deposits of Precambrian rocks (conglomerates and phyllites) are overlaid with reddish-yellow gravelly clay deposits, which are very thin and often completely eroded at the higher parts of the uplands. On the flat lowlands, there are thick eutrophic clayey deposits.

The macrotopography of this land system is characterized by small relative height and high drainage density (Fig. 4). The predominant elements of geomorphic surfaces are rolling uplands (erosion surface, 200−250 m), undulating upland (depositional surface, 120−200 m) and vast lowland (85−100 m). The lower upland surfaces are obliquely joined with the flat lowland surfaces, and topographical discontinuity between the two surfaces is usually obscure. There are many big perennial streams and springs in the uplands and also in the lowlands. Plentiful water can be obtained from shallow wells throughout the area.

This land system can be subdivided into four land facets (Table 11). Interrelations among elements of these land facets along a transect A−B in Fig. 18 are illustrated in Fig. 19.

Most parts of the uplands are covered with natural vegetation, because the edaphic condition is not suitable for cultivation, but lower terrace plains around the Pantanal lowland are used as pastures. In part of the lowlands between terraces, small irrigated rice fields are being developed.

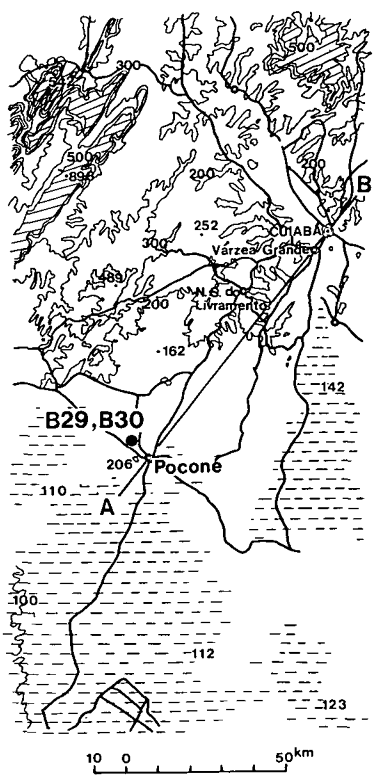


Fig. 18. Map of the survey area in the Cuiabá System.

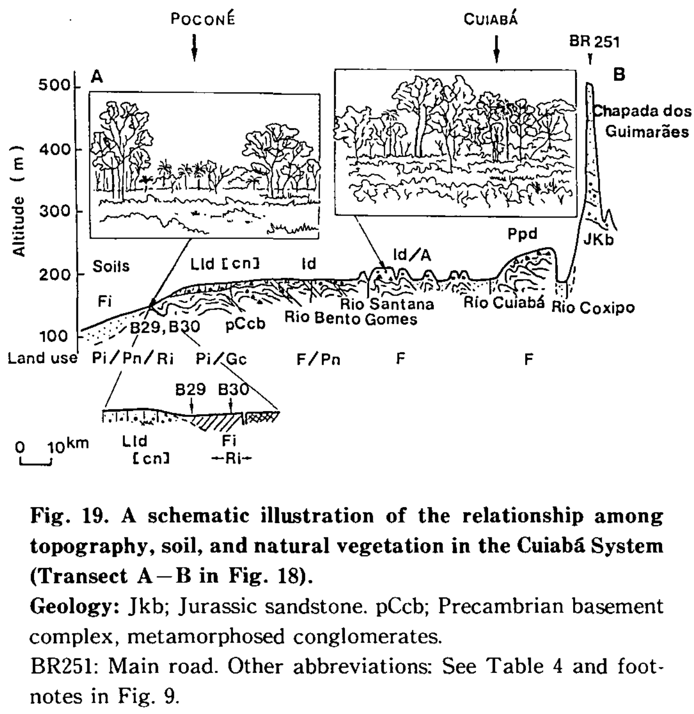


Fig. 19. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Cuiabá System (Transect A−B in Fig. 18).

Geology: Jkb; Jurassic sandstone. pCcb; Precambrian basement complex, metamorphosed conglomerates.

BR251: Main road. Other abbreviations: See Table 4 and footnotes in Fig. 9.

Table 11. Characteristics of land facets in the Cuiabá System (Cuiabá – 60 km south of Poconé).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Upland (erosion surface)		
1	Gentle Itf/SSx/SSe	Id, Rde	4-5	Cerrado (?)	-
			Upland (depositional surface)		
2	Gentle Itf/SSx/SSe (Terrace)	Lld [cn]	4	Trop.s.decid.s. forest	Pasture, Grain crops
			Pantanal lowland		
3	Flat Afa	Fd, Fi, (Fe?)	2	Poorly-drained savanna	Grain crops [irrig. rice], Pasture [seasonal]
4	Flat Afb	Gde, Ae, Fde	1-2	Poorly-drained savanna, Alluv.s.decid.s. forest	Pasture [seasonal]

Abbreviations: See Table 4 and footnotes in Table 5.

3–2–3. Corumbá-Bodoquena System

The following two sites were surveyed: Vale Paraíso near Corumbá, and Faz. Bodoquena (Fig. 20). Corumbá is located on a low upland near the southwestern end of the Pantanal lowland in Brazil, which was uplifted by faulting. Flat-topped hills, which are called 'Morro' or 'Morraria', are a significant element of the landscape in this area. Vale Paraíso stretches along the inter-hill lowlands.

An example of geological profile of these residual hills near Corumbá is illustrated in Fig. 21 (MME-SG, 1982). Basement elements of the hills are mostly Precambrian rocks (jasperoids, conglomerates, granites, and limestones). Quaternary clastic deposits are usually very thin, and limited to a small area. Lower foot slopes, river terraces, and flood flats are overlaid with dark red, eutrophic clayey deposits.

The macrotopography of this land system is characterized by large relative height and medium drainage density (Fig. 4). Predominant elements of geomorphic surfaces are undulating uplands and their remnants (450–600 m), steep cuesta scarps (more than 100 m in relative height), almost flat river terraces (250–350 m), and broad valley bottoms (200–300 m). 'Mesas' or 'Buttes' are also the most characteristic topographical element in this area as in the Rondonópolis System (Plates 6a to 6d). There are many big perennial streams and springs in the lower colluvial slopes and lowlands. Some perennial streams exist even on the uplands, but the amount of water in them is limited during the dry season. Small drinking-water ponds for cattle are frequently seen in the upland.

This land system can be subdivided into five land facets as summarized in Table 12.

The main farming system in this land system is cattle grazing. During the dry season, cattle are grazed on native pasture in the Pantanal lowland, and during the wet season, uplands in the south of Corumbá and in Serra da Bodoquena serve as refuge for cattle. The 'Agro-Villa' project has been launched at certain places (Vale Paraíso, *etc.*) where farmers are assigned to a small farm, and practice cattle grazing as well as production of crops such as vegetables and grains. They have met with success since the soils are fertile in nature.

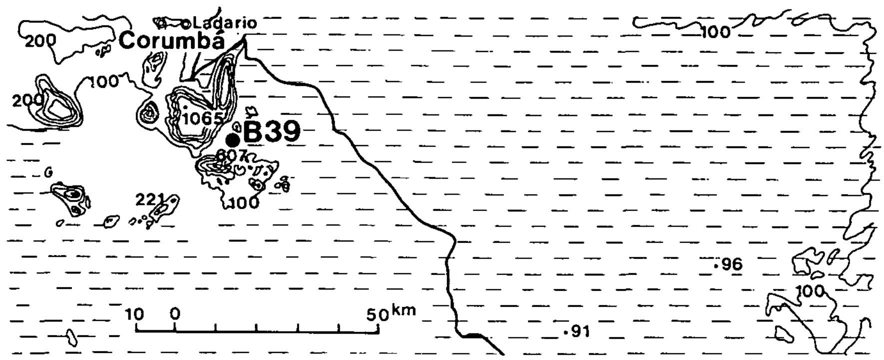


Fig. 20. Map of the survey area in the Corumbá-Bodoquena System.

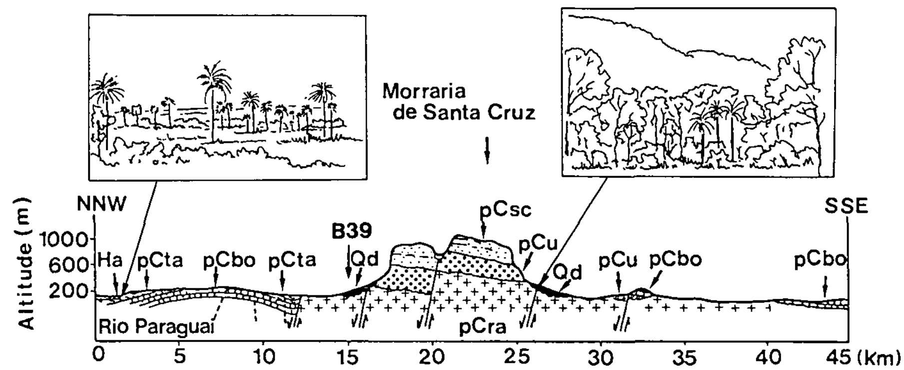


Fig. 21. A schematic illustration of the relationship between surface geology, topography, and natural vegetation in the Corumbá-Bodoquena System (MME-SG, 1982).

Geology: pCta; Precambrian basement complex, limestone. pCbo: ditto, dolomitic limestone. pCsc; ditto, jaspelites. pCu; ditto, conglomerates. Qd; Pleistocene colluvium.

Other abbreviations: See Table 4 and footnotes in Fig. 9.

Table 12. Characteristics of land facets in the Corumbá-Bodoquena System (Corumbá – Bodoquena).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Residual hills		
1	Ridge crest (Itf), Steep Tms/Faf	Rde, Rz		Rock outcrops, Tropical s.decid.s. forest	-
			Transition and Pantanal lowland		
2	Gentle foot slope (Cfs)	Bv, Tve, Rz	3-4	Trop.s.decid.s. forest	Pasture, Tree crops, Grain crops, Vegetables
3	Almost flat SSx/SSe (Terrace)	Bv, Tve	2-4	Trop.s.decid.s. forest	Pasture, Tree crops, Grain crops, Vegetables
4	Flat Afa	Fd, Fe, S, Ade, Q	2	Poorly-drained savanna	Pasture [seasonal]
5	Flat Afb	Gde, Ade, Ws	1-2	Poorly-drained savanna, Alluv.s.decid.s. forest	Pasture [seasonal]

Abbreviations: See Table 4 and footnotes in Table 5.

3-3. Transition Region

The Transition Region is located in the area between the western end of Chapada dos Parecis and the terraces of the Upper Amazon Basin in Rondônia, and is transitional under natural conditions such as climate, geology, vegetation, and social condition. This region consists of (a) hilly areas and (b) small basins with fluviatile terraces, which inter-finger with each other (Fig. 22). However, these are described together for convenience.

Surface geology and soil parent materials of the two land subsystems are very different. A complicated distribution of dark red and/or yellow sand, silt, and clays on the transitional

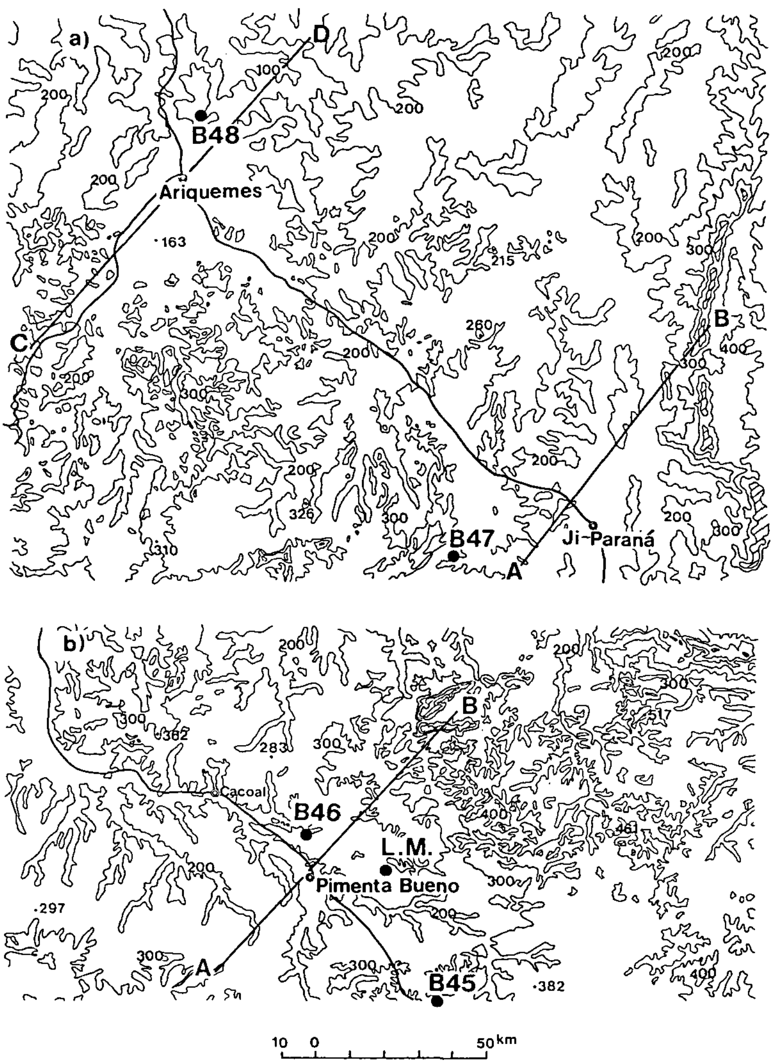


Fig. 22. Map of the survey area in the Transition Region. (a) Ji-Paraná and Ariquemes and (b) Pimenta Bueno.
L.M.: Limestone mine.

slopes indicates frequent outcroppings of various basement rocks. According to the report of RADAMBRAZIL (MME-DNPM, 1978), major basement rocks are Precambrian basement complex of the Xingu group (kizingites, amphibolites, diorites, granodiorites, granites, gneisses, *etc.*) together with frequent intrusions of granites (Rondônia granite, late Precambrian). Basic Cambrian rocks, including para-conglomerates, hornfelses, and limestones, are also important elements in the higher transitional slopes around Pimenta Bueno and Ji-Paraná (Figs. 23 and 24). Overlying soil parent materials vary by reflecting the variation of basement rocks (Figs. 23 and 24). The lower end of the transitional slopes joins with the vast, flat terraces in the Upper Amazon Basin, which are overlaid with clayey sediments.

The macrotopography of this region is characterized by large relative height and high drainage density (Fig. 4). Predominant elements of the geomorphic surfaces are undulating and/or rolling uplands (150–450 m) with steep residual hills, terraces, and valley bottoms (100–300 m). The steep residual hills consist of steep summits, steep side slopes, gentle colluvial slopes, and inter-hill lowlands. At the summits, outcroppings of hard rocks such as gneisses, migmatites, and granites are frequently observed (Plate 7a). Therefore, soils at the summits and upper steep slopes are often very thin. On the contrary, almost flat terrace

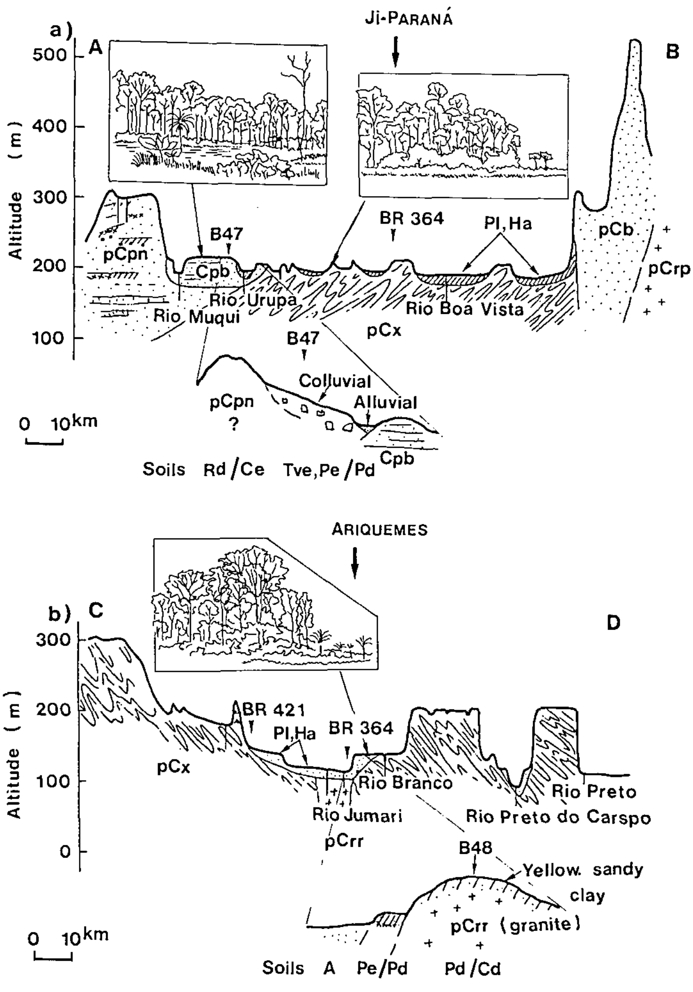


Fig. 23. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Transition Region. (a) Ji-Paraná (Transect A–B in Fig. 22a) and (b) Ariquemes (Transect C–D in Fig. 22a).
Geology: pCx; Precambrian basement complex, Xingu group Kinzigites, amphibolites,diorites, *etc.*). pCrr; ditto, granites, granodiorites, *etc.* pCrp; ditto, granites. pCb; ditto, arkorsic sandstones. pCpn; ditto, sandstones. Cpb; Dark red sandstones. Pl; Pleistocene sand, silt and clay.
BR 364 and BR 421: Main road. Other abbreviations: See Table 4 and footnotes in Fig. 9.

plains and low terrace scarps are the predominant elements on terraces along the flood plain of Rio Madeira, although these areas are dotted with a few residual hills with altitudes of 150 to 250 m. There are many big perennial streams and springs in the lower colluvial slopes and inter-hill lowlands. Water can be obtained easily from shallow wells. In the terrace areas, ground water level is generally high, and perched water accumulating on the clayey subsurface layers can also be used.

This land system can be subdivided into five land facets (Table 13). Interrelations among elements of these along BR 364 are schematically illustrated in Fig. 23a (Transect A—B in Fig. 22a), Fig. 23b (Transect C—D in Fig. 22a), and Fig. 24 (Transect A—B in Fig. 22b).

Because this region is under an early stage of development, lumbering is very active at present. Agriculture is characterized by its mixed nature. Tree crops such as rubber, coffee,

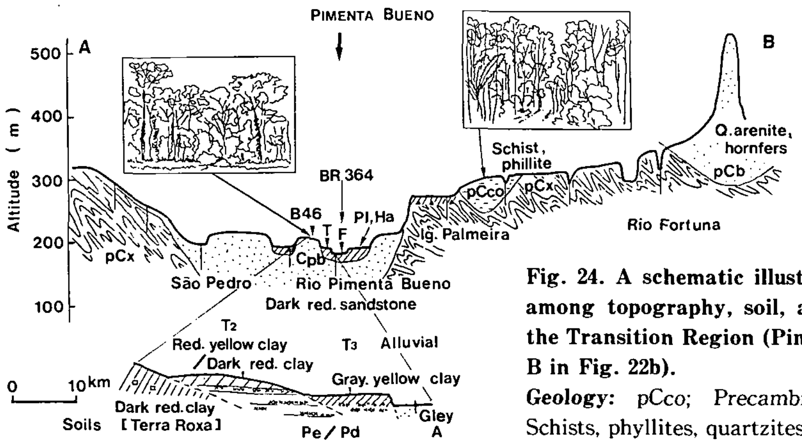


Fig. 24. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Transition Region (Pimenta Bueno, Transect A—B in Fig. 22b).

Geology: pCco; Precambrian basement complex, Schists, phyllites, quartzites *etc.*

Other abbreviations: See Table 4 and footnotes in Figs. 9 and 23.

Table 13. Characteristics of land facets in the Transition Region (Pimenta Bueno — Porto Velho).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
			Residual hills		
1	Ridge crest (Itf), Side slope (SSx/SSe)	Rd		Rock outcrops	-
2	Gentle side slope (Tms)	Pe, Cd, Tvde	4	Trop.s.e.s. forest	Pasture, Tree crops
			Transition and Valley		
3	Gentle foot slope (Cfs)	Pe, Pd, Cd, Q	4	Trop.s.e.s. forest	Pasture, Tree crops, Grain crops, Cassava etc. [Shifting cultivation]
4	Almost flat SSx/SSe (Terrace)	Pe, Pd	2-4	Trop.s.e.s. forest	Pasture, Tree crops Grain crops, Cassava [Shifting cultivation]
5	Valley bottom	Ade, Ae, Gd	1-2	Trop.s.e.s. forest, Várzea do rio,	Pasture

Abbreviations: See Table 4 and footnotes in Table 5.

and cacao, and field crops such as maize, beans, and cassava, are the major crops of small farms on the gentle slopes of relatively good edaphic conditions. Cattle grazing is practiced as well. In areas far from the main paved road, shifting cultivation is practiced. Because there are frequent fertile soils such as 'Terra Roxa' and 'Terra Preta', crops under shifting cultivation produce a reasonably good yield.

3–4. Upper Amazon Basin

This land system includes vast areas of undulating hills, terraces, and lowlands in the southwestern part of the Amazon Basin. The hills and terraces spread over the catchment areas of Rio Madeira and the upper reaches of Rio Acre, Rio Juruá, and Rio Purus in Brazil, and extend into Peru and Bolivia. Three sites were surveyed in Acre (Fig. 25) in addition to the sites in Rondônia.

Surface geology and soil parent materials of the terraces vary with altitude. Deposits on the higher terraces are red and/or yellow sand, silt, and clay, and their composition is variable from place to place. Deposits on the middle and lower terraces, on the contrary, are predominantly clayey silts. These deposits are usually composed of gray-colored indurated materials, and can be separated into two or three members by unconformities. Similar unconsolidated, flat-lying, complex deposits occur widely in the Upper Amazon Basin.

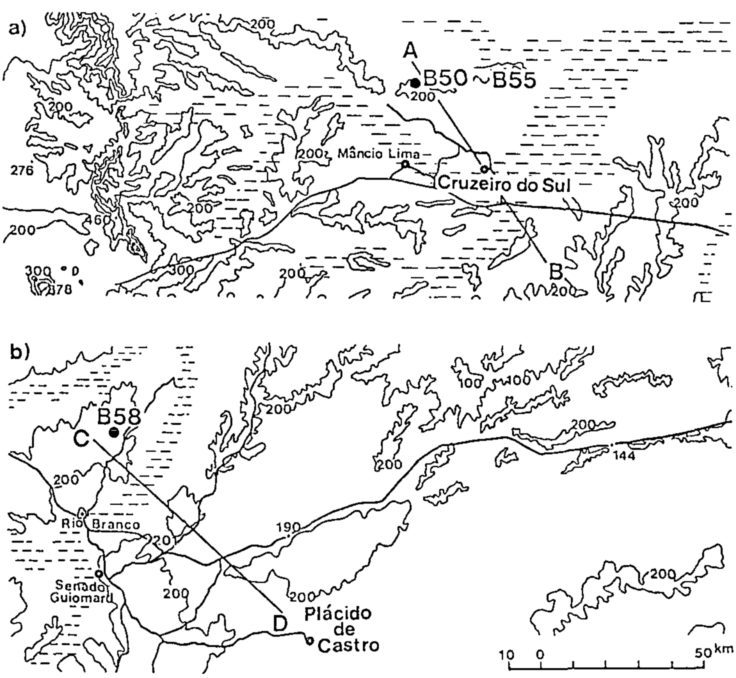


Fig. 25. Map of the survey area in the Upper Amazon Basin. (a) Cruzeiro do Sul and (b) Rio Branco.

The macrotopography of this land system is characterized by low relative height and high drainage density (Fig. 4). The predominant elements of geomorphic surfaces are undulating and/or rolling uplands (relative height: 150–350 m in high terraces), flat terraces (120–150 m in middle and low terraces), and broad valley bottoms (100–120 m). There are many big perennial streams in the lowlands from which water can be obtained easily, and also from shallow wells even at high places.

This land system can be subdivided into six land facets (Table 14). Interrelations among elements of these along transect A–B and C–D in Fig. 25 are illustrated in Fig. 26.

Almost all areas are covered with thick forests and only in the areas near cities/towns (such as Rio Branco and Cruzeiro do Sul) and in a narrow belt along the main road, the lands are used as pastures or for shifting cultivation on a small scale.

Table 14. Characteristics of land facets in the Upper Amazon Basin (Cruzeiro do Sul, Sena Madureira, and Rio Branco).

No.	Land facet	Soils	Drainage class	Vegetation	Land use
				High terrace	
1	Gentle SSx/SSe (Terrace plain)	Pd, Pe	4	Trop.rain forest	Pasture, Tree crops, Grain crops, Cassava [Shifting cultivation]
2	Steep Faf/Tms (Terrace scarp)	Pe, Cd(?)	4	Trop.rain forest	
3	Gentle Tms and Cfs	Pe, Pd, Cd(?)	4	Trop.rain forest	Pasture, Tree crops, Grain crops, Cassava [Shifting cultivation]
				Low terrace	
4	Flat SSx/SSe (Terrace plain)	Pe, Pd, Fd	2-4	Trop.rain forest	Pasture, Tree crops, Grain crops, Cassava [Shifting cultivation]
5	Steep Faf	Pe, Pd		Trop.rain forest	-
				Valley bottom	
6	Flat Afa, Afb	Ade, Ae, Gd	1-2	Trop.rain forest, Alluv.s.decid.s. forest, Várzea do rio	-

Abbreviations: See Table 4 and footnotes in Table 5.

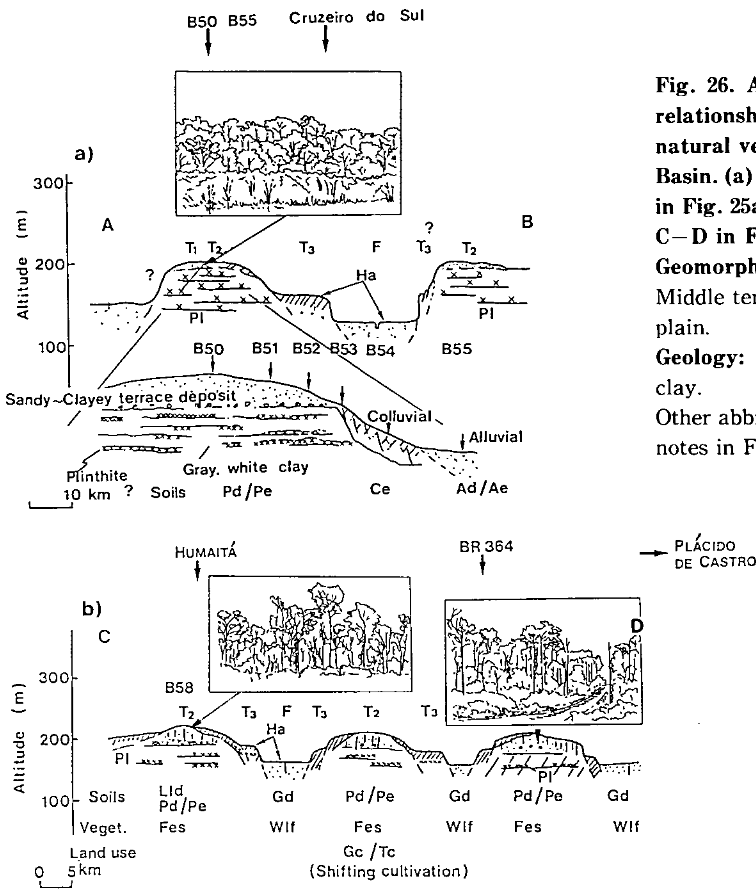


Fig. 26. A schematic illustration of the relationship among topography, soil, and natural vegetation in the Upper Amazon Basin. (a) Cruzeiro do Sul (Transect A–B in Fig. 25a) and (b) Rio Branco (Transect C–D in Fig. 25b).

Geomorphology: T1; High terrace. T2; Middle terrace. T3; Low terrace. F; Flood plain.

Geology: Pl; Pleistocene sand, silt, and clay.

Other abbreviations: See Table 4 and footnotes in Figs. 9 and 24.

4. ENERGY BALANCE AND WATER REGIME

4–1. Energy Balance

Energy balance at earth's surface with vegetation can be written as follows:

$$Rn + lE + H + G + SH + F + Ps = 0 \quad (1)$$

where Rn = net radiation, lE = latent heat flux, H = sensible heat flux, G = ground heat flux, SH = heat storage in vegetation, F = horizontal heat flux, and Ps = energy used in photochemical reactions. In the case of a homogenous surface, F is minor, and even in those with dense vegetation Ps is very small. Although the estimation of G and SH, especially SH, is difficult, the amount of (G + SH) is generally less than 5% of Rn during daytime (Spittlehouse and Black, 1980; Sakuma and Kobayashi, 1987). In the case of tropical forests, however, SH cannot be neglected because of its buffering capacity to a short term variation of the heat balance (Thompson, 1979; Goudriaan, 1979). For a long term mean, however, the influence of SH is not remarkable (Molion, 1987). For these reasons, only the long term balance among major energy items is discussed below.

To estimate the major heat items, the improved Penman method was used in the preliminary report (Tanaka *et al.*, 1984). Since the reflection coefficient (albedo = a) is variable depending upon the color and wetness of a surface, the following three figures are used to estimate Rn in this report: a = 0.18 at wet vegetated surfaces (P>20 mm/month), a = 0.25 at dry vegetated surfaces (1<P<20 mm/month) and a = 0.40 at extremely dry surfaces (P< 1 mm/month). Other basic data for estimating the heat items are obtained from various climatic tables available in literature (Hankock *et al.*, 1979; Müller, 1982; MME-SG, 1981–1983; MME-DNPM, 1976–1980).

Estimated major heat items for selected sites in the Amazon River System are presented in Fig. 27. The seasonal fluctuation of total short wave radiation (Qs) is more significant and the annual Qs is smaller in the forest region of the Amazon River System (Tingo Maria, Manaus, and Santarêm, for example) than in drier areas such as Caetité and Três Lagoas. The dependence of Qs on the duration of sunshine hours (Sd) is illustrated by a very small amount

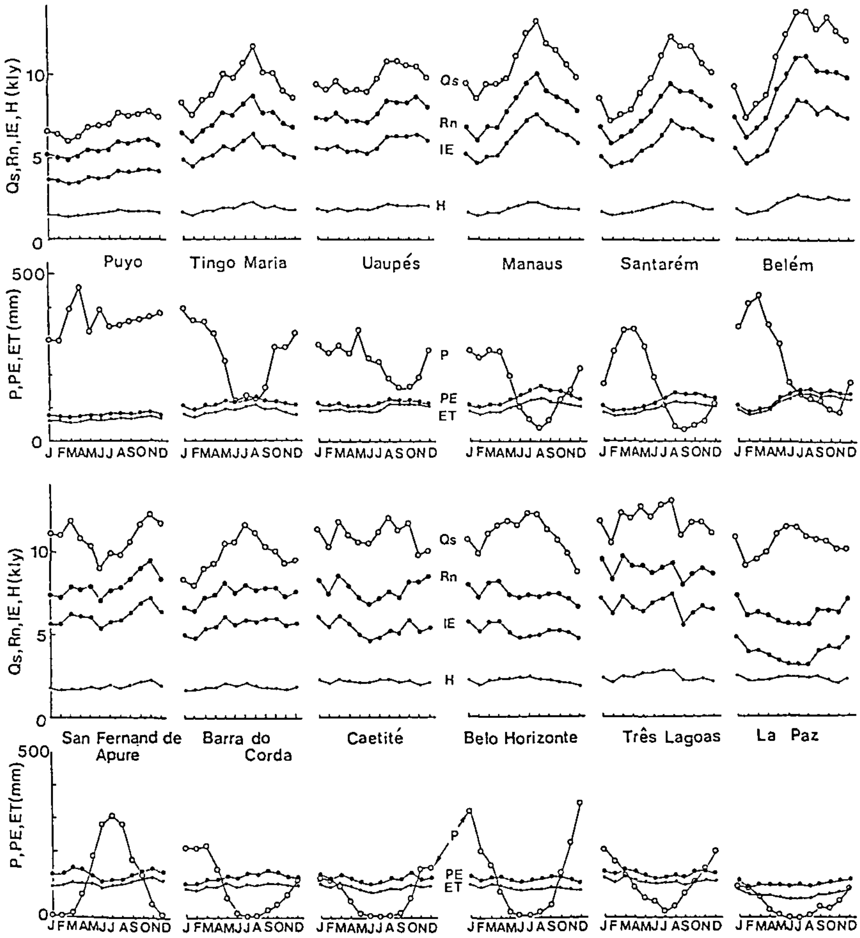


Fig. 27. Seasonal fluctuation of heat balance items and climatic water regime at selected sites in tropical and subtropical South America.

Abbreviations: Qs; Total short wave radiation. Rn; Net radiation. lE; Latent heat flux. H; Sensible heat flux. P; Precipitation. PE; Potential evapotranspiration. ET; Evapotranspiration.

of Qs at Puyo (83 kly/year), where the annual mean of Sd/PSd (PSd = possible duration of sunshine) is about 0.22. In low latitude areas, since the seasonal fluctuation of solar radiation is small, the seasonal fluctuation of Qs is almost parallel to that of Sd/PSd.

The seasonal fluctuation of Rn is almost parallel to that of Qs. Annual Rn in tropical South America is within a range from 65 to 110 kly/year. The relatively large annual Rn at Três Lagoas is attributable to many sunny days a year. On the contrary, the relatively small Rn at Barra do Corda and Caetitê is due to many cloudy days in the wet season and high albedo during the dry season. When albedo is fixed at 0.18, the annual Rn is 100−120 kly/year or more in the Cerrado area, often less than 80 kly/year in the forest region (about 65 kly/year at Puyo, Ecuador, and is likely to be less than 50 kly/year at Yurimaguas, Peru). If it is assumed that the surface is wetter, the Rn in the Cerrado area increases by 30−50% and its seasonal fluctuation becomes smaller. In the case of well-watered surfaces of herbaceous stands in savanna, the albedo is reported to be as small as 0.10 to 0.15 (Frost and Robertson, 1985).

A large part of Rn is consumed as lE (Fig. 27). The share of lE in Rn is generally 70−80%. However, it is often less than 70% in savanna, especially during the dry season, and is frequently larger than 80% in forests under humid conditions.

In savanna, since more Rn is supplied during the dry season, when water is short in the soil, Rn is not utilized efficiently by vegetation. The major reason for limited dry matter production of vegetation in savanna is the seasonal gap between supplies of energy and water.

4−2. Climatic Water Regime

The water balance of a unit volume of soil within a given period should satisfy the following equation,

$$P - E = S + dD + dM + dG \tag{2}$$

where P = precipitation, E = evapotranspiration, S = net surface runoff, dD = increase of surface detention, dM = increase of soil water storage, and dG = net loss of water by deep percolation (= increase of underground storage). P can be obtained from climatic tables and E can be replaced by potential evapotranspiration (PE) or evapotranspiration (ET), which can be estimated by the heat balance analysis. The relation between P and PE or ET may be referred as 'climatic water regime'.

The climatic water regime at representative sites is illustrated in Fig. 27. Tingo Maria and Caetitê are representative of the tropical rain forest region and the semi-desert region (Caatinga) in the Amazon River System, respectively. At Tingo Maria, seasonal fluctuation of P is remarkable, but P is almost equal to PE even in the month with the smallest P. On the contrary, at Caetitê the climatic water deficit is very large, length of the dry season is more than 8 months, water deficit during the dry season exceeds 700 mm, the number of wet months (P>PE) is only two, and climatic water excess during the wet months is very small.

Seasonal fluctuation of the climatic water regime is mainly caused by that of P, because fluctuations of PE or ET are rather small, although these are slightly larger in the forest area, such as Tingo Maria, Manaus, and Santarêm, than in the Cerrado area. As PE fluctuates almost parallel with ET, only PE is used to discuss geographical distribution of the climatic water regime although monthly ET is about 20 mm less than the monthly PE.

Seasonal fluctuation of the monthly climatic water regime by using data P and PE at various sites in the survey area is illustrated in Fig. 28. In the survey area, climatic water deficit in the dry months (CWDD) increases from northwest to southeast. The survey area can be divided into the following four broad regions based on the climatic water regime (Table 15).

1) Brazilian Highland: The number of wet months (P>PE) is usually seven, and climatic

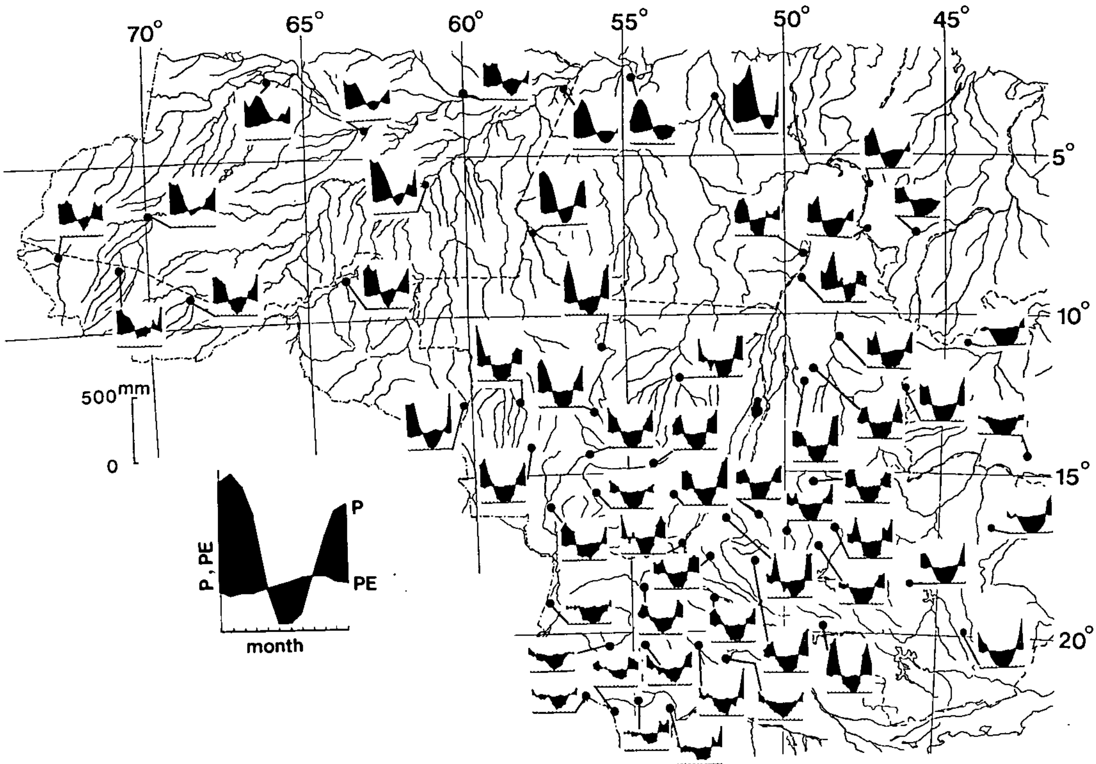


Fig. 28. Geographical distribution of climatic water regime.

water excess during the wet season (CWEW) is 500–1,000 mm. The number of dry months (P<PE) is generally five, but the number of very dry months is usually less than three; climatic water deficit during the dry season is 500–600 mm. Annual P is slightly more than the annual PE at many sites. Annual fluctuation of the monthly water balance is smaller in this region than in the Upper Amazon Basin. At sites on the slopes facing north, water excess during the wet season is greater (700–1,000 mm), and duration of the dry season is shorter than at sites on the opposite side.

2) Pantanal Region: CWDD is less than 450 mm, except for the Cãceres-Corumbá area. CWEW is variable, 70–400 mm. Annual water balance is usually negative, although the difference is only ±15 mm/month, and actual water deficit during the dry season calculated on the basis of ET is about 200 mm or less, which is less than the excess water during the wet season.

3) Transition Region: The climatic water balance is intermediate between the Brazilian Highland and the Upper Amazon Basin. The number of dry months is 4–5, and that of very dry months is less than three. CWDD is 300–500 mm, CWEW is 1,000 mm or more, and annual P apparently exceeds the annual PE.

4) Upper Amazon Basin: The number of dry months is less than three, and there is no very dry month (P<20 mm). CWDD is generally less than 300 mm, and CWEW is more than 900 mm.

Table 15. Annual heat and water balance of four broad Regions in the survey area.

Region	Qs (kly)	Rn (kly)	lE (kly)	PE (mm)	P (mm)	CWDD (mm)	PEW (mm)	DPG (day)
Brazilian Highland	132	92	65	1,498	1,200-2,200	440-635	510-1,150	250-265
Pantanal Region	143	108	78	1,341	1,063-1,560	210-610	70- 620	179-270
Transition Region	123	96	73	1,456	2,100-2,750	280-380	930-1,590	290-320
Upper Amazon Basin	112	87	65	1,475	2,230-2,870	1-210	980-1,510	340-365

Abbreviations: Qs; Total short wave radiation at earth's surface. Rn; Net radiation. lE; Latent heat flux. PE; Potential evapotranspiration. P; Precipitation. CWDD; Climatic water deficit during the dry season. PEW; Precipitation excess during the wet season. DPG; Duration of the period when plants can grow with available soil water.
Qs, Rn, lE and PE were estimated for representative sites. P, CWDD, PEW and DPG were estimated for 75 sites and regional ranges were presented.

4−3. Soil Water Regime

Seasonal fluctuation of the soil water regime at a given site on flat upland can roughly be estimated by combining climatic data and soil water characteristics. Seasonal fluctuation estimate of long term (monthly) water regime of soil with vegetation was based upon the following assumptions: (a) The terms S and dD in equation 2 are negligible, (b) capillary pores of surface soil are saturated with water at the end of the wet season, (c) gravitational water is drained rapidly as dG, (d) the amount of water which is supplied by upward flow from underground storage is far smaller than the amount of PE, and (e) total available water capacity of the rooting zone is 200 mm. Because data on physical parameters of soils in the survey area are not available and water flux due to hydraulic gradients in the soil is not taken into account, the results are only rough estimations. For example, (a) available water capacity (AWC) of soils in the Brazilian Highland with well aggregated, deep solum, *e.g.,* fine textured Latosols (Acrustox and Haplustox), is 150−250 mm/m (Tanaka *et al.,* 1984, 1986) and that of the clayey soils on the Holocene and Pleistocene terraces in the Upper Amazon Basin, mainly reddish-yellow podzolic soils (Pe, Pd, and Ppd, mainly Hapludults), is generally smaller than that of Latosols (100−150 mm/m), and (b) the thickness of the rooting zone is generally deeper in the Latosols than in the podzolic soils (may be 2.5 m and 1.5 m, respectively). If these figures are used, total AWC in the rooting zone is roughly 400 mm and 200 mm for the Brazilian Highland and the Upper Amazon Basin, respectively.

At Gurupi and Diamantino in the Brazilian Highland, the amount of available soil water (AW) decreases rapidly from May to June (Fig. 29), AW becomes zero in late June, and this situation continues for 100−120 days (DAW0, duration of the period AW = 0). The amount of soil water deficit (SWD) during DAW0 is 300−350 mm. Even if total AWC in the rooting zone is assumed to be 400 mm, there is still some available soil water deficit in the dry season, but DAW0 comes to less than 60 days. At many sites in the Brazilian Highland, thickness of the unsaturated zone and that of aquifer are generally more than 5 m and 15−20 m, respectively (Macedo and Bryant, 1987). Thus, if water loss by surface runoff is neglected, water excess during the wet season, 500−1,000 mm, can be stored almost completely in these layers. If all of this water is available to plants, drought is not expected in most parts of the Brazilian Highland. There are frequently perennial springs in the depressions on uplands. The water regime of uplands in this area is not necessarily ‘dry’, and there is a fairly large amount

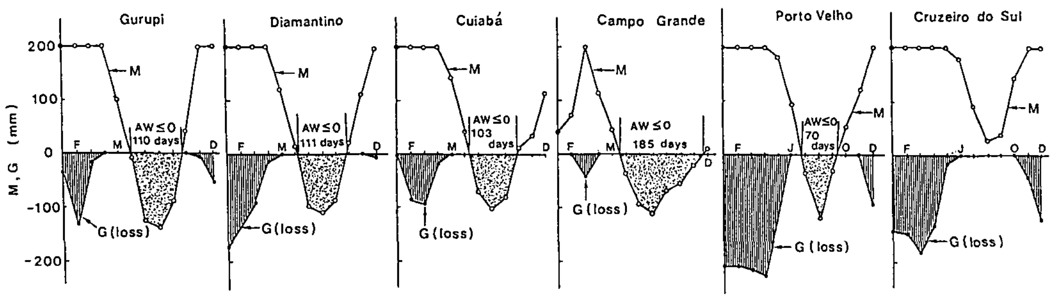


Fig. 29. Water regime of soils at selected sites in the survey area.
Vegetation of sites: Gurupi and Diamantino; Cerrado. Cuiabá and Campo Grande; Tropical semi-deciduous seasonal forest. Porto Velho; Tropical semi-evergreen seasonal forest. Cruzeiro do Sul; Tropical rain forest. Abbreviations: M; Soil moisture storage. G; Loss of water by deep percolation. AW; Available water in soil.

of water that can be utilized for agriculture under natural conditions.

At sites near the area where Caatinga is located, such as Ibipetuba and Caetité, DAW0 becomes more than 150 days. Because the amount of water excess during wet season is small, available soil water becomes zero during the dry season, even if the total AWC of the rooting zone is greater than 400 mm.

At Cuiabá and Campo Grande in the Pantanal Region, since water excess during the wet season is relatively small and there is no very dry month ($P<20$ mm/month), the soil water regime is not necessarily unstable for plants, although DAW0 is fairly long. In the Pantanal lowland, there is usually no water deficit even in the dry season, because of a large amount of water inflow from surrounding uplands.

At Porto Velho in the eastern area of the Upper Amazon Basin, storage of available soil water during the wet season is exhausted during the dry season, and DAW0 is 45−70 days. However, there is no deficit of available soil water if the total AWC of the rooting zone is assumed to be 400 mm.

At Cruzeiro do Sul near the west end of the Upper Amazon Basin, available soil water is not exhausted even in the dry season. Available soil water stored during the wet season is enough to compensate for the CWDD, and the amount of water loss by deep percolation (dG) during the wet season reaches 700−1,000 mm.

Geographical distribution of the duration of the period when plants can grow with available soil water (DPG) is illustrated in Fig. 30. DPG is more than 350 days in tropical rain forests of the Upper Amazon Basin; about 300 days in the surrounding areas of tropical rain forests including Sena Madureira, Porto Velho, Humaitá, Manaus, and Alto Tapajós; 250−260 days in most parts of the Brazilian Highland, including almost all gentle slopes and summits of the Highland which are facing north; and less than 200 days in the valley of Rio São Francisco, east of Serra Geral de Goiás, except for southern parts of the watershed and the Pantanal Region. In the hilly areas, extending south of the highest mountain ranges, *i.e.,* Serra dos Pirineus - Serra do Caiapó, the variation of DPG is rather considerable (220−350 days) depending upon the topography of sites.

The value of DPG in Fig. 30 at a given place is generally shorter than the corresponding value in Fig. 3. This is because the DPG is based on available soil water by assuming that total AWC of the rooting zone is 200 mm. In the Brazilian Highland, DPG can be 320 days if total AWC is assumed to be 400 mm instead of 200 mm. Moreover, the value of the duration of

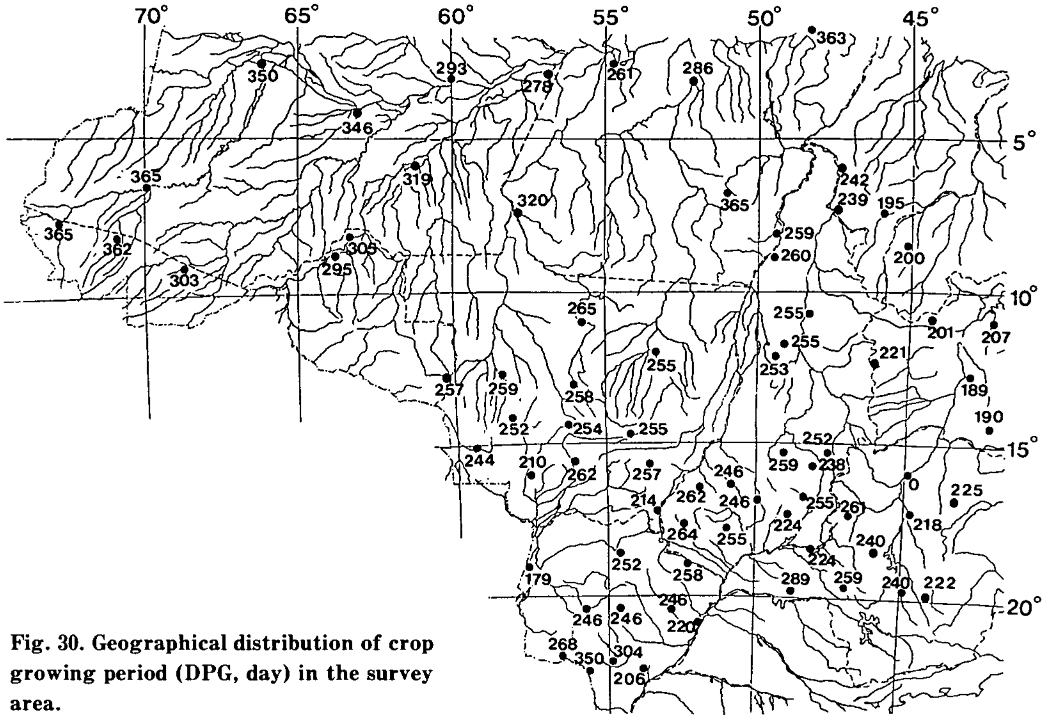


Fig. 30. Geographical distribution of crop growing period (DPG, day) in the survey area.

plant growth in Fig. 3 may be somewhat too long, if (1) water loss by surface runoff and (2) soil factors which limit the expansion of root systems (existences of gravelly layers or compacted subsurface layers, a high degree of Al saturation of the soil, *etc.*), are taken into consideration.

In this context, the status and depth of gravelly layers of hardened plinthites bear important significance. In the highest plains of the Brasília and Goiânia Systems, soils with a thick gravelly layer at relatively shallow depth are often found. Most of them are not cultivated, most probably, due to poor water-holding capacity of the soil and retarded root growth.

Compaction of subsurface soil is also a serious problem in arable lands in this area. Under natural conditions, soils on uplands in the Brazilian Highland are usually porous and high in infiltration capacity, but the soils are very susceptible to compaction under management with heavy machines, especially at the top of subsurface layers.

Field measurements of the infiltration capacity of soils were made by using a double ring infiltrometer method on fine and medium textured cultivated Lvd (Acrustox) and La (Haplustox) in the Serra Azul System. The water intake rate of cultivated top soils is high enough to absorb all water even under very heavy rains, but that of compacted subsurface soils is very low (Fig. 31). In a fine textured soil, the final rate of the compacted subsurface layer is as low as less than 10 mm/hour, because subsurface soils consist predominantly of unstable macro-aggregates, which are susceptible to deterioration. When the aggregates are broken down and the coarse pores collapse by mechanical compression, the water intake rate is reduced remarkably, water loss by the surface runoff increases, and soil erosion takes place.

During the survey, there was a heavy rain of about 60 mm/hour at Serra Azul, and a remarkable amount of water was lost to surface runoff. There are similar heavy rains frequently at the beginning and end of the rainy season in this region. Because heavy rains result in surface sealing and serious reduction of infiltration capacity in surface soils in

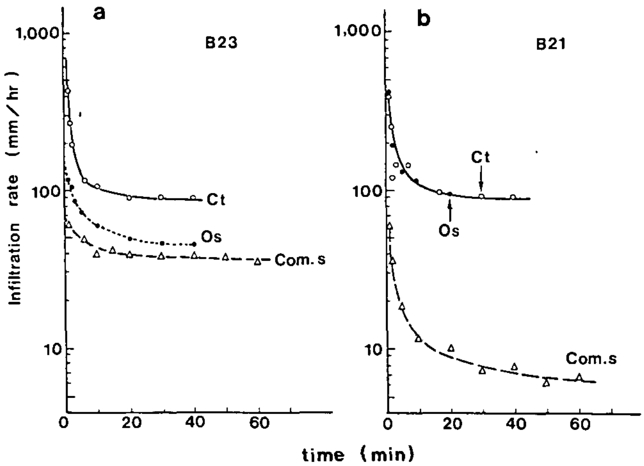


Fig. 31. Infiltration capacity of cultivated soils (B23 and B21) in the Serra Azul System.
Abbreviations: Ct; Cultivated top soil. Os; Original subsurface soil. Com.s; Compacted subsurface soil.

addition to the compaction of subsurface soils, water loss by surface runoff is much greater in arable lands than in lands under natural conditions.

Soil compaction may also cause a decrease of the rooting zone of crops. In Latosols in the Highland, bulk density does not increase significantly by mechanical compaction, but the infiltration rate decreases and hardness increases seriously at the top of B horizon, just under the plowed layer. For example, the soil compaction index (soil hardness index by Yamanaka's method) exceeded 30 mm (extremely compact) in cultivated Lvd (Acrustox) at São Gotardo, Minas Gerais (Tanaka *et al.*, 1984). Generally, the thickness of Ap horizons in intensively cultivated fields is usually about 25 cm, and the AWC of this horizon is only 50 mm. This amount may not be enough to compensate for the water deficit during a dry spell in the rainy season ('Veranico'). Therefore, if the roots of a crop do not penetrate into deeper layers, the crop will suffer from water stress during veranico, or during the transitional period from wet to dry seasons.

There are large areas occupied by Quartzipsamments (Areias Quartzosas, Q) on uplands of the Brazilian Highland. These soils are characterized by deep solum predominated by coarse quartz sand. As the infiltration capacity of these soils is very great, the loss of water by surface runoff is negligible. AWC of these soils is, however, very small, and crops suffer frequently from drought. Soils with such characteristics are also used locally as crop fields, but water management is very difficult, especially in areas of interfluve and upper convex seepage slopes.

Soils in the Pantanal Region are variable, but Lvd, Lrd, and Q are the major constituents on the uplands. Although data on the characteristics of soils related to water are not available, the situation may be similar to that in the Brazilian Highland. Because CWDD is generally less than 400 mm, and there is no very dry month, the water deficit of soil in this area may not be so serious as in the Brazilian Highland.

In the Upper Amazon Basin, fine textured soils on the terraces, *e.g.*, Pd, Pe, and Ppd (mainly Hapl- or Paleudults), are usually low in AWC, because their subsurface layers are often heavy clay or compact silty clay with frequent plinthites. In these soils, the rooting zone is limited to very shallow layers due to poor internal drainage, and because of this, total AWC of the rooting zone is generally less than 200 mm/m. However, since the amount of CWDD is small, severe drought is not expected even during the dry season.

5. PEDO-GEOMORPHIC PROCESSES AND NATURE OF SOILS

5–1. Geomorphological Events and Soil Parent Materials

In the equatorial regions, the direct influence of paleo-environment in the glacial age was not identified in the past, but during the last 10 years many evidences of its influence have been presented (Fig. 32). In this area, climate after the later periods of the last glacial age changed drastically, and this change strongly influenced the present status. Temperature and humidity dropped, and the extent of the tropical rain forest decreased during the last glacial age (21,000–13,000 years B.P.) (Absy and Van der Hammen, 1976; Van der Hammen *et al.,* 1981; Dickinson and Virji, 1987). After the drier period, most parts of the world's tropics became wetter than during the glacial age and the present (Street-Perrott and Harrison, 1984). In northern South America, evidences of the wetter climate from about 11,000 to 5,000 years B.P. together with one or more short dry periods are presented (Bradbury *et al.,* 1981; Campbell and Frailey, 1984). Under such humid conditions during the early Holocene, massive seasonal floodings occurred and a thick blanket of sediments was deposited widely over the southwestern part of the Upper Amazon Basin (Campbell and Frailey, 1984). Over the last 5,000 years, climate in tropical South America turned somewhat drier as indicated by lower water levels of lakes in the Andean ranges (Van der Hammen, 1982). However, pollen analysis in seasonal lakes of the flooded river plains suggests that savanna did not expand into the Upper Amazon Basin (Absy, 1982).

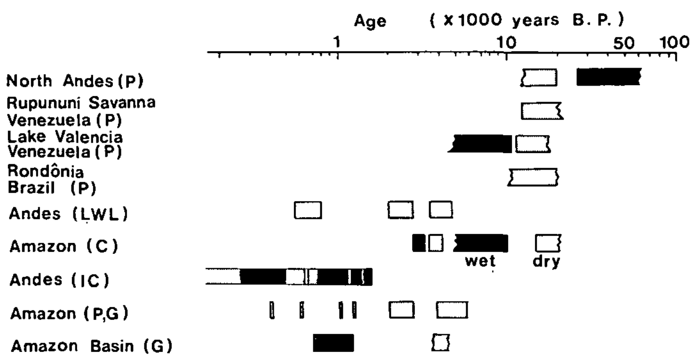


Fig. 32. Paleo-environmental evidences in the Amazon River System.
Letters in parentheses: P; Pollen record. LWL; Paleo-hydrological record (Lake water level). C; Paleo-climatic data (simulation). IC; Ice core record. G; Geological, geomorphological, and pedological records.

In the Brazilian Highland influences of historical change in the climate described above are also noticed. There are frequent patches of sand, gravelly layers of reworked iron ore, fossil stream channels, river terraces, *etc.,* on uplands and valley side slopes. These suggest that climatic change from the latter period of the last glacial age to the present had strong influence upon the distribution of soil parent materials, and also upon soil genesis in the area. The influences are illustrated, for example, by the relationship between topography and soils in the Rondonópolis System (Fig. 33).

Among the four pedons on a Chapada, B35 and B38 are well drained, but B37 is poorly drained. Pedon B37 is located at the bottom of a depression on undulating uplands, 'Várzea da chuva', and is coarser in texture ('Várzea arena'), higher in silica/alumina ratio, and also higher in CEC of clay fraction than the clayey soils at well drained positions (B35 and B38).

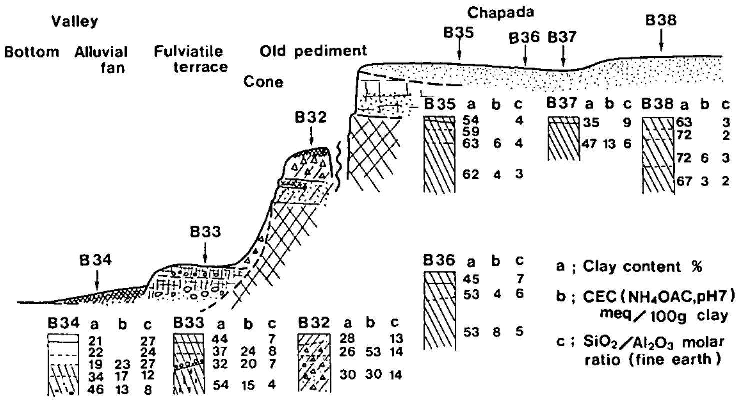


Fig. 33. A schematic illustration of the relationship between topography and soil properties in the Rondonópolis System.

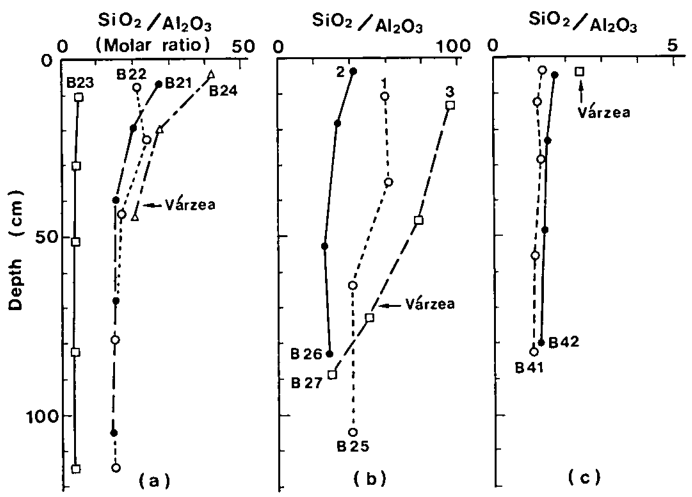


Fig. 34. Profiles of the silica/alumina ratio on the members of upland toposequence in the Brazilian Highland.
(a) Serra Azul System (dark reddish-yellow clay), (b) ditto (yellow sand), and (c) Chapada dos Parecis System (reddish-yellow clay).

Properties of soil on the concave seepage slope (B36) are intermediate between these two extremes. This situation suggests that soil materials were redistributed within a slope, finer components were washed away from the soils at lower positions, and these became coarser and more siliceous than those at higher positions. Similar relationships were confirmed in other soils on the uplands (Fig. 34). The silica/alumina ratio is very different among soils depending upon the parent materials. However, among members of a given toposequence, the soils at Vãrzea are apparently higher in silica/alumina ratio than those at interfluves and upper convex seepage slopes, especially those in upper horizons.

Another characteristic of soils in the Rondonópolis System (Fig. 33) is a wide lithological difference in parent materials among soils on side slopes. In a given pedon (B33), there is a distinct discontinuity between the third and fourth horizons identified by the existence of a gravelly layer, and by changes of the silica/alumina ratio and clay activity. Parent materials of B33 on the terrace are apparently different from those of B34 on the pediment, but those of B34 and B32 are similar, although chemical properties of surface horizons are somewhat different. These situations suggest that environmental conditions during sedimentation were unstable, and there were frequent denudations and redistributions of soil materials in varying degrees by flooding, mass wasting, and sheet washing.

In the Transition Region, the relationship between macrotopography and soil characteristics is also noticed. However, these relationships are often disturbed by surface geology because there are various parent rocks upon which the topography is closely dependent.

In the Upper and Central Amazon Basin, a broad Plio-Pleistocene plateau, Amazon Planalto, is recognized. The terrace-like broad plateau consists of almost flat surfaces at 20−40 m above the local river water level, and is covered with a thick clayey sediment (Belterra clay).

At pedon B49 near Porto Velho the terrace plain (Planalto) is comprised of flat surface at about 40 m above river level. Surface sediments can be divided into two stratigraphic units by an unconformity (Fig. 35a). The upper unit is uniform clayey sediment with a thickness of only 0.8 m. The lower unit is more than 5 m in thickness, and can be subdivided into 2−3 layers by their degree of consolidation and the nature of plinthites. The morphology of the lower unit is similar to that of Belterra clay described by Sombroek (1966).

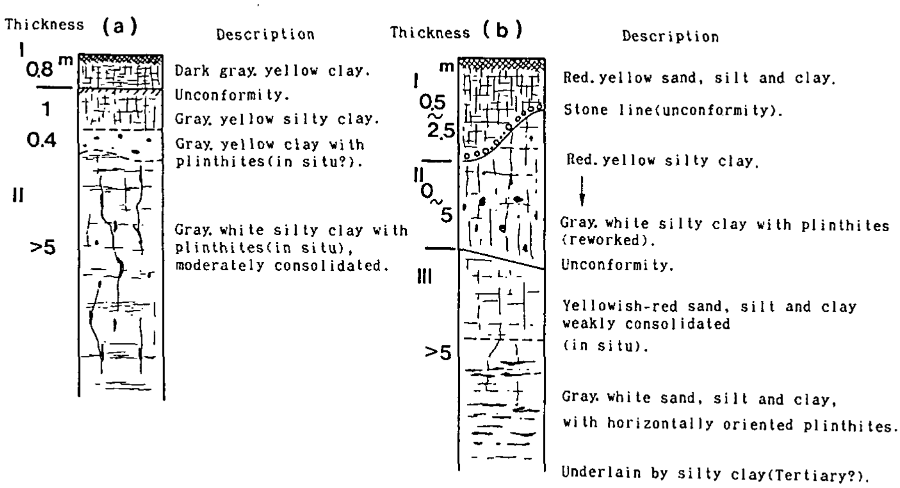


Fig. 35. Morphology of clayey surface sediments on the terraces in the Upper Amazon Basin. (a) B49 and (b) Humaitá, near Rio Branco.

At a site near Rio Branco similar unconsolidated sediments were found (Fig. 35b). At this site, at least four stratigraphic units are recognized by distinct unconformities. The fourth member is not described in the figure, but is moderately consolidated silty clay, and seems to be comparable to unit II of B49. The third member is composed of clayey sediment, its thickness is more than 5 m, the color changes gradually from reddish-yellow at top layers to grayish-white at bottom layers, and there are frequent soft plinthites which are horizontally oriented and seem to have been formed *in situ.* The upper two members are composed of reddish-yellow clayey materials and grayish-white silty clay with plinthites. Their thickness is different from site to site, especially in the second member which is often missing on the summits of undulating uplands. These facts show that the upper two members are rather young and deposited under relatively unstable environment.

Recently, Campbell and Frailey (1984) reported on the morphology and age of unconsolidated sediments in the Upper Amazon Basin. According to their findings, sediments with about 30 m in thickness along the upper reaches of Rio Acre in Peru and Bolivia are referred to as Inapari formation (ONERN, 1977). These sediments can be subdivided into three distinct categories: The lowest (3−7 m in thickness) is resting directly upon Huayquerian (late Miocene) with an estimated age of 5,500−10,000 years B.P. by radio carbon dating, and the upper two (lower and upper with thicknesses of 10 m and 15−20 m, respectively) are composed of moderately indurated clayey silts or sandy silts. Similar unconsolidated, flat-lying, complex deposits have been reported widely in the Upper Amazon Basin, and these are considered to be Pliocene-Quaternary (MME-DNPM, 1976, 1977). The information presented by Campbell and Frailey (1984) suggests that the present drainage system of the Upper Amazon Basin is very young, and therefore the soil parent materials also.

5−2. Chronology of Pedological Processes and Nature of Soils

(1) Brazilian Highland and Pantanal Region

Soil materials are generally very old, strongly weathered, and almost uniform. However, the soils themselves are not necessarily old due to disturbance caused by climatic changes during the glacial and post glacial ages. The almost level broad plains ('Chapadas') were originally formed by the peneplanation during Tertiary. These consist of a series of gentle slopes with a convex cross section and shallow trough-shaped valleys, which were formed by weak denudation due to sheet wash throughout the period. There are many shallow depressions without any V-shaped valley. The differentiation between (1) interfluves and convex seepage slopes and (2) concave seepage slopes proceeded slowly throughout Pleistocene and Holocene.

Fine textured reddish-yellow Latosols (Lvd, and La; mainly Haplustox and Acrustox) occupy the convex seepage slopes on Chapadas, and relatively coarse siliceous Latosols are formed on concave seepage slopes of shallow depressions in Chapadas and the peripheral lowlands. Such a spatial pattern of soils on the surface have been formed through long-lasting pedo-geomorphic processes. However, the partial modification of soil patterns on the surface (formation of sand patches, washing out the gravelly layers of iron ore, *etc.*) took place during Pleistocene to Holocene.

Pedons B22 and B23 in the Serra Azul System are representative of clayey and siliceous, sandy Latosols, respectively. Deeply drained, thick, reddish-brown, clayey B horizons are the most characteristic feature of B23 (Fig. 36). Although the clay content of these horizons is higher than 50% (Table 16), the texture examined on the field is clay loam throughout the profile because of their well developed, stable micro-aggregates. On the contrary, B22 is characterized by bright brown, loamy B horizons. These are also well drained and very friable, but the stability of micro-aggregates is less than that in the clayey B horizons of B23. Since B22 is located near the bottom of a shallow depression, its moisture condition is favorable for plant growth, but is very susceptible to gully erosion. This is due to the high erosivity of subsurface horizons to the scouring of channel flows (*cf.* section 5−4). Pedon B24 is representative of the pedons on lower alluvial flood flats (Afb) with A/C horizon sequence. A few reddish-brown mottles appear even in the top horizon.

Matured Latosols in the heart of Chapadas (Lvd; U/Itf, SSx, or SSe) are characterized by B horizon with a low silica/alumina ratio, medium pH, small absolute value of dpH (pH(KCl) − pH(H_2O)), small CEC, low exchangeable bases and Al, and low clay activity (CEC of less than 10 meq per 100g clay). These physico-chemical characteristics are common in Latosols in both the Brazilian Highland and the Pantanal Region.

Physico-chemical characteristics of soils on the concave seepage slope and alluvial toe slope of the Chapadas (B22 and B24) are influenced by the siliceous parent material (*cf.* Table 16). The B and C horizons of these pedons are siliceous, acidic, and high in Al saturation and clay activity. Judging from the similarity in element composition between B22 and B25, it is apparent that the parent material of B22 is inherited mostly from the weathered crust of

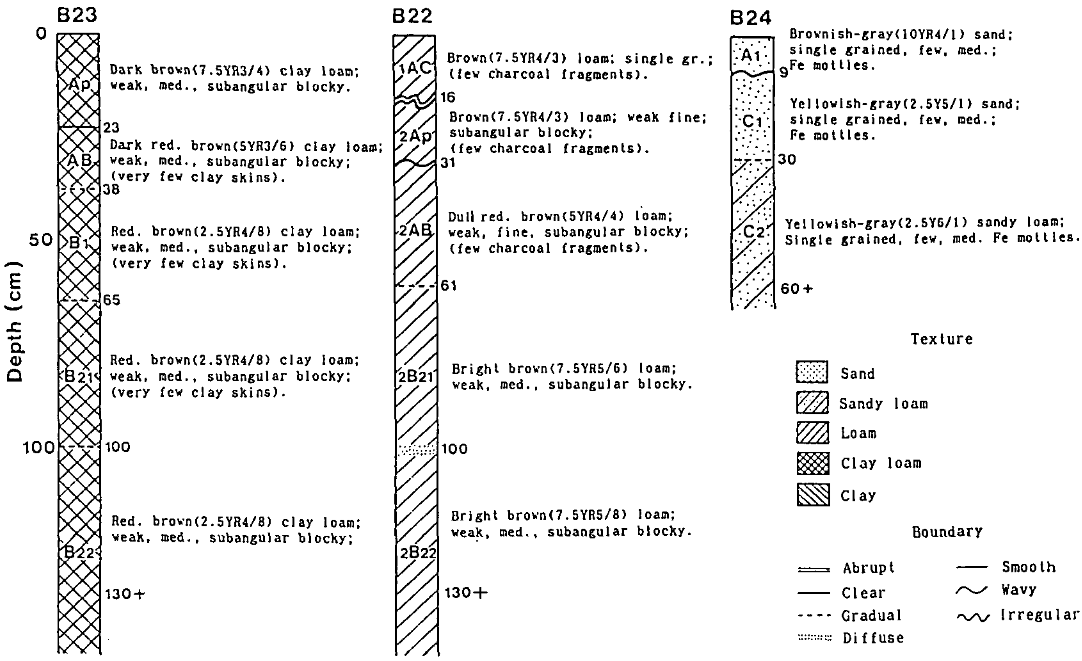


Fig. 36. Brief profile description on the members of a toposequence in the Serra Azul System (B23, B22, and B24).

Table 16. Physico-chemical properties of members of a toposequence (B23, B22, and B24) and related pedons in the Brazilian Highland (Serra Azul System).

Pedon no.	Land facet[1)]	Horizon	Sand (%)	Clay (%)	Element composition (%)[2)] SiO_2	Al_2O_3	Fe_2O_3	TiO_2	B.E.[3)]	P_2O_5	pH H_2O	KCl	CEC (meq/100g)	ECEC (meq/100g)	Ex. cation (meq/100g) Ca	Mg	K	H	Al	PAC[4)]	Br2-P[5)] (P_2O_5 mg/100g)
B23	U/SSx	Ap	56.4	42.6	64.4	25.7	7.6	2.0	0.2	0.08	5.3	4.3	6.9	6.0	5.1	0.4	0.1	0.1	0.2	740	4.6
		AB	48.9	57.3	62.6	26.8	8.2	2.2	0.1	0.05	4.8	4.2	4.0	0.8	0.2	0.1	0.1	0.2	0.2	600	0.4
		B_1	39.7	53.9	58.9	30.2	8.5	2.3	0.1	0.05	4.6	4.6	2.9	0.5	0.1	0.1	0.0	0.1	0.0	650	0.1
		B_{21}	41.5	54.2	57.3	31.3	8.9	2.4	0.1	0.04	4.8	5.0	5.7	0.2	0.1	0.1	0.0	0.0	0.0	610	0.1
		B_{22}	44.0	41.5	57.3	31.0	9.1	2.5	0.1	0.04	5.0	5.5	1.3	0.3	0.1	0.1	0.0	0.0	0.0	630	0.0
B22	U/SSe	2Ap	80.6	19.4	90.9	6.5	1.6	0.9	0.1	0.03	5.0	4.1	3.1	1.1	0.1	0.0	0.1	0.3	0.5	250	2.8
		$2B_{22}$	74.5	25.5	85.9	9.9	2.9	1.2	0.1	0.03	5.3	5.0	1.0	0.2	0.0	0.0	0.0	0.0	0.0	330	0.2
B25	U/SSx	A_1	92.1	6.7	95.8	2.7	0.7	0.6	0.1	0.05	4.5	4.0	1.7	0.8	0.1	0.0	0.1	0.4	0.2	130	0.9
		AB	93.7	6.3	95.7	2.7	0.7	0.7	0.1	0.02	4.8	4.1	1.2	0.7	0.0	0.0	0.1	0.4	0.1	150	0.5
		BC	87.3	11.0	94.2	3.9	0.8	1.0	0.1	0.02	5.1	4.2	0.4	0.5	0.0	0.0	0.1	0.2	0.1	190	0.3
B24	U/Afb	A_1	88.6	9.1	95.3	3.9	0.0	0.7	0.1	0.02	5.0	4.1	1.5	0.7	0.1	0.0	0.1	0.2	0.4	150	1.3
		C_2	80.6	17.2	91.2	7.5	0.0	1.1	0.1	0.02	5.2	4.1	1.2	0.7	0.1	0.0	0.1	0.4	0.1	190	0.7
B28	T2/SSx	Ap	74.2	25.1	88.5	7.9	2.5	0.5	0.7	0.04	5.2	4.0	6.4	2.7	1.3	0.7	0.3	0.3	0.2	280	2.5
		B_1	61.7	24.3	82.0	13.2	3.1	0.8	0.8	0.04	4.9	3.7	4.6	2.5	0.2	0.4	0.1	0.4	1.4	320	0.4
		B_{22}	49.4	47.9	77.5	16.5	3.9	0.9	1.0	0.04	5.0	3.7	5.2	2.6	0.1	0.2	0.2	0.3	1.9	390	0.1

1) U; Upland. T2; Middle terrace. Others; See footnotes in Table 5. 2) Total analysis by X-ray fluorescence spectrometry.
3) B.E.; Basic elements ($CaO+MgO+K_2O$). 4) PAC; Phosphorus absorption coefficient. 5) Br2-P; Available P (Bray 2 extraction).

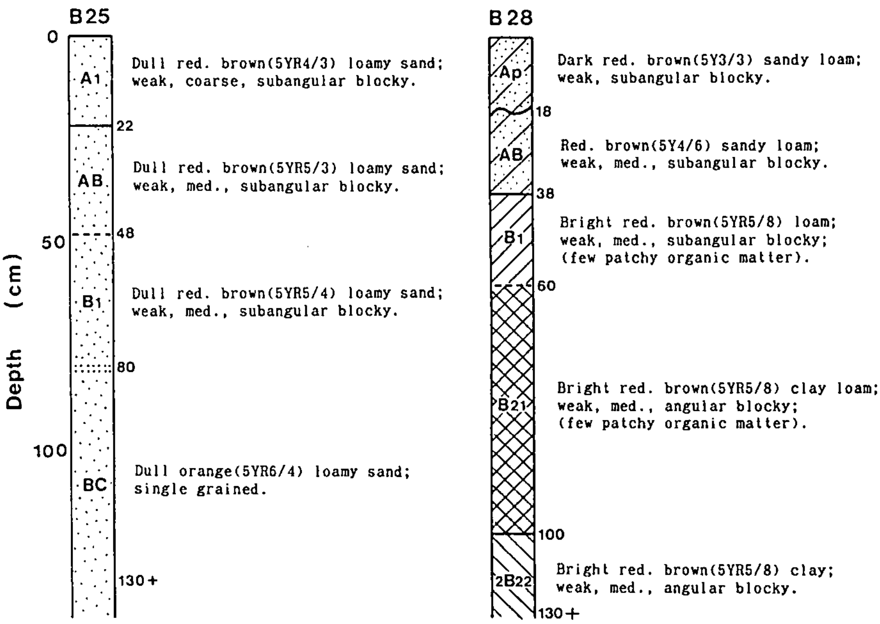


Fig. 37. Brief profile description on the members of a toposequence in the Serra Azul System (B25 and B28).

quartz sandstone.

Pedon B25 is a representative of young soils derived from Tertiary quartz sandstone (Fig. 37). It is extremely siliceous, sandy, and small in CEC, ECEC, and exchangeable bases throughout the profile. Similar soils are found frequently on the convex slopes of peripheral areas of Chapada, where the loss of weathered materials due to erosion is significant.

Pedon B28 is representative of Lld on fluviatile terrace along the flood plain of Rio Araguaia. The profile is deeply weathered, but lithological discontinuities within the profile are recognized by the two clear, smooth boundaries at depths of 38 cm and 100 cm. Physico-chemical properties of this pedon change discontinuously with depth. The deeper clayey horizons are characterized by high clay activity and also by high exchangeable Al content.

On valley side slopes and bottoms of the main stem of drainage systems in the Brazilian Highland and the Pantanal Region, talus cones, low fluviatile terraces, and fans were formed during Pleistocene and Holocene. Soil parent materials and soils found on these slopes were largely formed during the period after the last glacial age. Physico-chemical properties of soils on fluviatile terraces and valley bottoms in these regions can be summarized as follows: (i) Soils are variable, reflecting complicated distribution of young soil materials; (ii) pH is slightly acidic to neutral but the absolute value of dpH is generally larger than 1; (iii) CEC and base saturation are high and clay activity is also high; and (iv) exchangeable Al is low except for some alluvial soils around Poconé.

Pedon B39 (Tables 17 and 18) is representative of eutrophic soils on a colluvial toe slope in the area near Corumbá in the Pantanal Region. The profile is shallow and genetic horizons are poorly defined. The very dark reddish-brown, clayey BC and C horizons with a few dark red pebbles are the most characteristic feature of this pedon. These are siallitic, rich in basic metals and phosphorus, high in pH and base saturation, and also very high in available phosphorus (Bray 2-P).

Table 17. Brief description on a representative eutrophic soil in the Pantanal Region (B39. Land facet: Middle terrace, Colluvial foot slope).

Horizon	Depth (cm)	Description
Ap	0-22	Brownish black (5YR2/2) clay loam; weak, fine, subangular blocky structure; fraible; clear, smooth boundary.
AB	22-39	Very dark reddish-brown (5YR2/3) clay loam; weak, fine, subangular blocky structure; fraiable; clear, smooth boundary.
BC	39-55	Very dark reddish-brown (5YR2/4) light clay; very weak, fine, subangular blocky structure; firm; few (<1%) pebbles; clear, smooth boundary
C	55-70+	Dark reddish-brown (5YR3/3) light clay; firm-very firm

Table 18. Physico-chemical properties of a representative eutrophic soil in the Pantanal Region (B39. Land facet: Middle terrace, Colluvial foot slope).

Horizon	Sand	Clay	Element composition (%)[1]						pH		CEC	ECEC	Ex. cation (meq/100g)						PAC[3]	Br2-P[4]
	(%)	(%)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	B.E.[2]	P_2O_5	H_2O	KCl	(meq/100g)		Ca	Mg	K	Na	H	Al		(P_2O_5 mg /100g)
Ap	67.7	24.3	74.9	13.4	5.4	0.6	5.5	0.10	7.1	6.8	16.6	15.5	11.5	3.6	1.0	0.4	0.1	0.0	540	48.6
AB	71.9	20.2	77.5	11.1	5.7	0.6	4.8	0.14	7.3	6.1	10.0	9.9	6.7	2.3	0.6	0.2	0.0	0.0	360	14.6
BC	65.5	29.9	73.2	13.2	8.2	0.6	4.6	0.10	6.5	4.6	14.0	12.8	7.3	4.2	0.3	0.9	0.1	0.0	530	1.6
C_1	73.1	23.7	75.7	12.4	6.4	0.5	4.8	0.09	6.7	4.8	12.3	12.0	6.9	3.8	0.2	1.0	0.1	0.0	530	2.1

1) Total analysis by X-ray fluorescence spectrometry. 2) B.E.; Basic elements ($CaO+MgO+K_2O$). 3) PAC; Phosphorus absorption coefficient. 4) Br2-P; Available P (Bray 2 extraction).

(2) Transition Region

According to the small scale soil map by EMBRAPA/SNLCS (1981), major soils in the Transition Region are Pd or Pe, but the genetic horizons which characterize these soils are not fully developed (Fig. 38).

Soils of hills and inter-hill lowlands are generally very young and their physico-chemical properties vary with their parent material (Table 19). Except for sandstones, saprolites and parent rocks sampled are basic or ultra-basic, and some of them, *e.g.*, saprolite 6 (Colorado do Oeste) and saprolite 11 (Ouro Preto, near B47), are low in SiO_2 content. The SiO_2 content of fresh migmatite from a hilly area near Ji-Paranã is slightly higher than 52%, which is the critical level dividing neutral and basic rocks. The content of basic metal elements is diverse, reflecting the diversity of rocks and weathering processes.

Pedon B47 is representative of eutrophic soils originating from mafic parent material. It is characterized by the dark reddish-brown B horizon which is low in the silica/sesquioxide ratio, large in ECEC, high in basic element content, pH, and base saturation (Table 20). On the contrary, soils originating from acidic parent materials (*e.g.*, B48) are characterized by clayey yellowish-brown A_3 and B horizon, which are generally siliceous and acidic. Although the clay activity is relatively high, CEC is not high because clay content is low, and the exchange sites are occupied mostly by acidic cations.

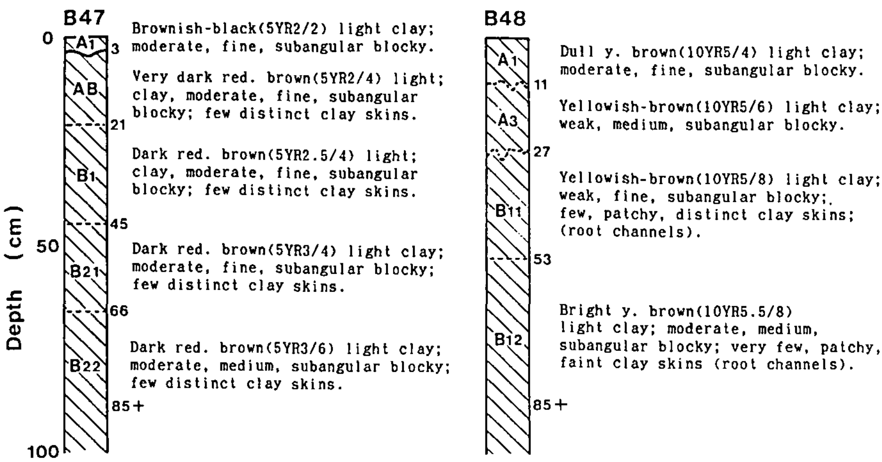


Fig. 38. Brief description on representative soils derived from basic (B47) and acidic (B48) materials in the Transition Region.

Table 19. Element composition of selected saprolites and parent rocks in the survey area.

Survey site no.1)	Sample name	Geology2)	Element composition (%)3)								
			SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	MnO_2	K_2O	P_2O_5
1	Saprolite 3	pC, Phillite	47.7	26.8	13.4	1.40	0.02	1.90	0.04	8.80	0.02
7	Sandstone	T/M, Quartz sand	97.8	1.8	0.0	0.16	0.02	0.03	0.00	0.11	0.01
10	Saprolite 9	T, Sandstone	78.3	12.5	4.7	0.20	0.38	0.66	0.13	3.03	0.04
16	Saprolite 5	pC, Gneiss?	64.2	20.5	9.8	0.73	2.91	1.17	0.15	0.38	0.06
16	Saprolite 6	?	51.0	20.9	18.4	1.91	0.03	2.14	0.13	5.40	0.05
18	Fresh limestone4)	C	19.6	3.6	1.3	0.19	42.8	30.6	0.49	1.33	0.10
18	Saprolite 10	C (dark red/gray)	62.1	22.4	7.7	0.92	0.13	3.38	0.14	3.16	0.15
19	Fresh migmatite	pC (basic)	52.7	14.2	11.7	1.05	11.5	7.55	0.19	1.02	0.12
19	Saprolite 11	pC? (dark red)	44.2	26.0	26.4	2.56	0.22	0.26	0.19	0.01	0.20

1) Refer to Table 1 and Fig. 1. 2) pC; Precambrian. C; Cambrian. M; Mesozoic. T; Tertiary. 3) Total analysis by X-ray fluorescence spectrometry. 4) At Espigão d'Oeste, Rondônia.

Table 20. Physico-chemical properties of soils originating from basic (B47) and acidic (B48) materials in the Transition Region.

Pedon no.	Land facet1)	Horizon	Sand (%)	Clay (%)	Element composition (%)2)						pH		CEC	ECEC	Ex. Cation (meq/100g)					PAC4)	Br2-P5)
					SiO_2	Al_2O_3	Fe_2O_3	TiO_2	B.E.3)	P_2O_5	H_2O	KCl	(meq/100g)		Ca	Mg	K	H	Al	(P_2O_5 mg /100g)	
B47	H/Cfs	A_1	64.1	28.6	78.5	7.9	8.9	2.3	2.1	0.14	6.7	6.1	17.9	13.7	10.8	2.5	0.3	0.0	0.0	660	3.0
		AB	62.8	28.7	73.9	9.7	11.8	2.5	1.9	0.11	7.0	5.5	5.6	4.1	3.5	0.4	0.2	0.0	0.0	360	0.3
		B_1	59.6	33.1	76.3	9.1	10.2	2.3	1.9	0.08	6.9	5.4	4.9	3.6	3.1	0.3	0.2	0.0	0.0	380	0.1
		B_{21}	47.8	48.3	68.7	14.3	12.7	2.2	2.0	0.08	6.9	5.6	5.5	4.0	3.4	0.3	0.3	0.0	0.0	470	0.1
		B_{22}	43.9	50.2	67.9	14.8	13.3	2.0	1.8	0.08	6.9	5.7	6.0	3.8	3.1	0.4	0.3	0.0	0.0	460	0.1
B48	H/SSx	A_1	54.1	42.9	84.0	12.0	2.9	0.9	0.2	0.03	4.7	3.7	7.2	1.9	0.2	0.1	0.2	0.7	0.7	370	2.2
		A_3	48.8	48.2	81.8	14.4	2.7	0.8	0.2	0.02	4.3	3.7	4.8	1.9	0.1	0.0	0.1	0.6	1.0	380	0.9
		B_1	39.5	58.0	77.7	17.6	3.7	0.8	0.2	0.02	4.6	3.8	4.1	1.7	0.1	0.1	0.1	0.6	0.9	360	0.8
		B_2	34.9	64.1	74.3	20.4	4.0	1.0	0.2	0.02	4.3	3.8	3.9	1.9	0.1	0.0	0.1	0.4	1.2	360	0.3

1) H; Hills. Others; See footnotes in Table 5. 2) Total analysis by X-ray fluorescence spectrometry. 3) B.E.; Basic elements ($CaO+MgO+K_2O$). 4) PAC; Phosphorus absorption coefficient. 5) Br2-P; Available P (Bray 2 extraction).

(3) Upper Amazon Basin

Soil materials of terraces and lowlands in this region are young and mixed. There is a broad Plio-Pleistocene Planalto with Belterra clay. After deposition of the clay, the region subsided, and surface sediments were deeply weathered and partly eroded under the drier and more-seasonal-rainfall climate from Pleistocene to early Holocene. During Holocene, there were massive floods, and the terraces were overlaid locally with thick alluvial silty clay sediments. These sediments were then eroded out rapidly because they were susceptible to erosion, and older reddish-yellow clays with plinthites were exposed at some sites even on the terraces. A heavy suspended sediment load of Rio Madeira (*cf.* 5−3) suggests that severe denudation and redeposition are still going on in lowland areas.

Soils in this region are predominantly young Pd on terraces of Pleistocene and Holocene. A sandy Pd on a high terrace near Cruzeiro do Sul (B50) is characterized by light colored AE and deep, bright brown B horizons (Fig. 39). The soil is extremely siliceous and acidic throughout the profile. The degree of Al saturation in the AE and AB horizons exceeds 70%, but the absolute amount of exchangeable Al is less than about 1 meq/100g throughout the profile because of small ECEC (Table 21). Soils on the middle and low terraces are, generally, finer and more silty than those on the high terrace. However, their textural profile is variable from place to place, suggesting an unstable sedimentation process. For example, in B58, which is representative of low terrace soils near Rio Branco, clay content increases from 37% in A_1 to 54% in $2C_1$ and the silt/clay ratio from 0.72 in A_1 to 0.49 in $2C_1$. The B horizon of this pedon is low in pH and dpH, and high in exchangeable Al. Pedon B49, which is a representative soil on the middle terrace, is similar in texture with B58, but is similar with B50 in physico-chemical properties. For example, the silt/clay ratio is lower than 0.1, ECEC is less than 2.5 meq/100g, and the exchangeable Al is less than 1.5 meq/100g throughout the profile. Although these properties are similar to those of mature soils, the pedon may not be old judging from its geomorphic position. The wide variation in physico-

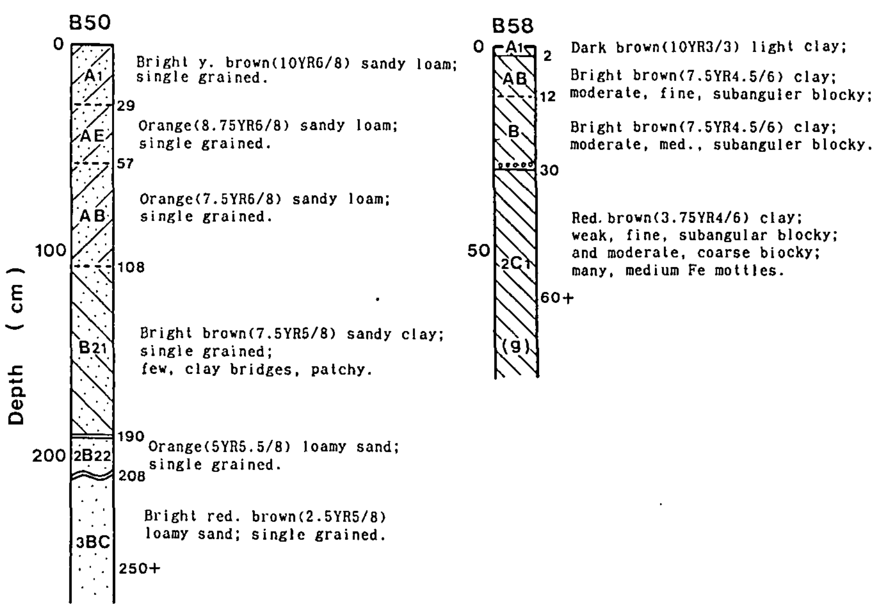


Fig. 39. Brief description of profiles of a sandy soil (High terrace, B50) and a clayey soil (Low terrace, B58).

chemical properties of soils on the terraces may be attributable to the difference in terrace deposits.

Table 21. Physico-chemical properties of soils on high (T1), middle (T2), and low (T3) terraces in the Upper Amazon Basin.

Pedon no.	Land facet[1]	Hori-zon	Sand (%)	Clay (%)	Element composition (%)[2] SiO_2	Al_2O_3	Fe_2O_3	TiO_2	B.E.[3]	P_2O_5	pH H_2O	pH KCl	CEC (meq/100g)	ECEC (meq/100g)	Ex. Cation (meq/100g) Ca	Mg	K	H	Al	PAC[4]	Br2-P[5] (P_2O_5 mg/100g)
B50	T1/SSx	A_1	78.2	17.0	93.1	4.7	1.5	0.5	0.2	0.02	4.6	4.0	2.4	1.6	0.0	0.0	0.0	0.4	1.1	310	0.4
		AE	77.9	20.6	91.8	5.8	1.6	0.6	0.2	0.02	4.8	4.1	2.4	1.6	0.0	0.0	0.0	0.3	1.1	310	0.3
		AB	81.1	18.9	90.1	7.0	2.0	0.6	0.2	0.02	4.8	4.1	2.0	1.6	0.0	0.0	0.0	0.3	1.1	310	0.2
		B_{21}	74.4	25.6	93.4	4.5	1.5	0.5	0.1	0.02	5.0	4.1	1.6	1.2	0.1	0.0	0.0	0.3	0.8	160	0.1
		B_{22}	86.9	12.6	95.9	3.0	0.6	0.3	0.1	0.02	5.2	4.2	1.4	0.7	0.1	0.0	0.0	0.3	0.3	130	0.1
		BC	85.7	14.3	96.9	2.1	0.6	0.2	0.2	0.02	5.4	4.2	1.7	0.8	0.0	0.0	0.0	0.3	0.4	120	0.2
B49	T2/SSx	Ap	39.0	57.9	70.0	24.0	2.7	3.1	0.2	0.05	4.7	3.9	5.4	2.4	0.1	0.2	0.2	0.6	1.4	530	1.2
		C_1	37.2	59.3	69.4	24.5	2.7	3.1	0.2	0.05	4.7	3.9	4.3	2.0	0.1	0.0	0.1	0.5	1.3	440	0.5
		C_2	34.2	59.2	68.4	25.6	2.7	3.1	0.1	0.05	5.2	4.0	4.1	2.0	0.0	0.0	0.1	0.4	1.5	550	0.4
		2AB	34.5	63.1	67.5	26.4	2.8	3.1	0.1	0.05	5.0	4.0	6.5	1.9	0.0	0.0	0.0	0.4	1.4	650	0.3
		2C	33.3	64.8	69.3	24.4	2.9	3.2	0.2	0.05	5.2	4.0	4.7	1.7	0.1	0.0	0.1	0.4	1.1	540	0.3
B58	T3/SSe	A_1	37.6	36.2	79.2	9.3	8.4	1.4	1.6	0.15	4.9	3.9	15.5	7.6	4.9	1.6	0.3	0.4	0.3	500	7.1
		AB	33.9	40.6	71.8	11.4	13.9	1.4	1.4	0.13	4.7	3.6	10.0	6.4	0.7	0.3	0.2	0.5	4.7	560	2.4
		B	30.0	46.4	69.1	13.0	14.6	1.4	1.6	0.16	4.7	3.6	10.3	6.6	0.2	0.1	0.1	0.3	5.9	630	0.5
		$2C_1$	19.1	54.3	61.4	18.9	15.9	1.3	2.3	0.14	4.8	3.7	13.7	9.0	0.1	0.2	0.1	0.4	8.2	830	0.1

1) See footnotes in Table 5. 2) Total analysis by X-ray fluorescence spectrometry. 3) B.E.: Basic elements ($CaO+MgO+K_2O$).
4) PAC; Phosphorus absorption coefficient. 5) Br2-P: Available P by Bray 2 extraction.

5−3. Nature of Terrestrial Water

Big rivers which flow out from the Brazilian Highland are mostly 'black water rivers' (Tanaka *et al.,* 1984). Since the suspended solid load of these rivers is extremely low, their contribution to the suspended sediment yield of the Amazon is small in comparison to that of white water rivers flowing out from the Andean range through lowlands of the Upper Amazon Basin.

Suspended sediment discharge of the Amazon River at Obidos, about 700 km downstream from Manaus, is estimated to be 3−3.5 million t/day, and for the most part attributable to the two main white water rivers, *i.e.,* Rio Solimões and Rio Madeira; the contribution of a typical black water river, such as Rio Negro, is almost negligible (Meade *et al.,* 1985). Because of this, the watershed of a black water river in the Brazilian Highland can be considered as a closed system, at least from the viewpoint of suspended solids. This view is supported by the microtopography of flood plains along these rivers. There is no differentiation of natural levees ('Várzea alta') or point bars (elevated flood plain, 'Restinga') and backmarshes ('Várzea baixa') in the flood plains of black water rivers. In flood plains along the main stems of large white water rivers, a typical microtopography characterized by natural levee, point bars, and backmarshes develops.

Water samples from the Brazilian Highland, where aquifer is composed of strongly weathered materials, are generally very low in concentrations of alkali and alkali-earth metal ions, sulfate, and silica (Table 22). On the other hand, water samples from the Pantanal and the Transition Regions (where aquifers are predominantly composed of various fresh rocks and young deposits) are high in concentrations of the above-mentioned components. These data clearly demonstrate that the composition of natural water reflects the geological and pedological characteristics of aquifer.

The NO_3-N concentration of water samples is, generally, unexpectedly high. It is higher than 0.5 ppm in many samples, and exceeds 1 ppm in a sample from Corumbá, which is considered to be the critical level as favorable irrigation water to lowland rice in Japan. Richey and Ribeiro (1987) studied the NO_3-N discharge from main tributaries of the Amazon River System, and reported that (i) at Vargem Grande in the Andean range, NO_3-N concentration was 0.1−0.4 ppm, and its flux was 1.8−4.0 kgN $ha^{-1}y^{-1}$, (ii) in the white water rivers, such as Rio Madeira and Rio Purus, the concentration was lower than 0.2 ppm and its flux was 0.9−2.6 kgN $ha^{-1}y^{-1}$, and (iii) in the black water rivers, such as Rio Jutaî and Rio Negro, concentration fluctuated depending on the rate of water discharge, but the NO_3-N flux was very slow (less than 0.9 kgN $ha^{-1}y^{-1}$) regardless of the water discharge rate. From this information along with the data presented in Table 22, it can be said that (i) NO_3-N concentration of ground water and river water at upper reaches is higher than that at the main stems, indicating that a considerable amount of NO_3-N is consumed between upper and lower reaches of a tributary, and (ii) the data obtained at Vargem Grande are not great enough to represent adequately the situation of headwaters in the Amazon River system.

Table 22. Chemical nature of terrestrial water in the survey area.

Land system	Geology[1)]	Water sample		Element content (ppm)							
		Source[2)]	No.[3)]	K	Na	Ca	Mg	NO_3-N	SO_4-S	P	Si
Gurupi	Oxic clay	R	1	1.1	1.0	2.5	0.6	0.2	0.0	0.01	2.9
Serra Azul	Oxic clay/Alluvium	R	3	0.6	0.3	0.8	0.1	0.5	0.0	0.01	3.7
Cuiabá	B.comp./Alluvium	R	3	2.7	1.5	2.4	0.5	0.8	0.0	0.0	8.4
Corumbá	B.comp.	R	2	2.3	8.4	6.8	1.9	1.1	0.4	0.02	8.1
Rondônia											
Colorado do Oeste	Calcareous clay	R	2	3.0	3.0	14.5	4.8	0.3	3.1	0.02	13.7
	Calcareous clay	W	1	1.5	0.8	8.2	0.4	0.4	0.0	-	5.3
Vilhena	Oxic clay	R	1	0.4	0.4	0.9	0.1	0.8	1.9	0.0	3.5
Cacoal - Ji-Parana	Calcareous clay/B.comp.	R	3	4.4	2.3	9.6	3.5	0.6	2.6	0.02	11.1
		W	3	3.3	4.4	13.7	4.0	0.6	0.5	0.03	15.2
Ji-Paraná - P.Velho	Mixed clay/Alluvium	R	2	3.3	1.5	5.4	1.6	0.7	5.8	0.01	8.0
	W.crust., granite	SS	1	1.8	0.8	0.8	0.1	0.3	2.7	0.0	3.6
	Calcareous clay	W	1	2.9	0.9	1.6	0.1	0.4	0.8	0.0	8.0
	W.crust., granite	W	1	1.0	0.9	0.7	0.1	0.2	4.6	0.01	2.9
	Mixed clay	W	1	0.6	1.0	2.7	0.1	0.2	0.6	0.01	1.2
Acre	Oxic sand/clay	SS	1	0.5	0.2	0.8	0.1	0.6	2.3	0.0	1.2
	Mixed clay	R	2	1.9	1.5	10.5	1.3	0.5	2.3	0.0	6.3

1) Predominant materials of aquifer: B.comp.; Basement complex. W.crust.; Weathered crust.
2) Sample source: R; River. SS; Local small stream. W; Well. 3) Number of water samples.

5−4. Soil Erosion

Two soil profiles of Vârzea da chuva in trough-shaped depressions on Chapada are illustrated in Fig. 40. Pedon B27 is topped by a sandy horizon (1A/C) which has been deposited by a recent event occurring probably during the last 10 years. The buried 2Ab and 2ACb horizons also seem to be young, but not younger than several hundred years judging from their thickness, and iron (= 0.0%) and humus content. This situation suggests that soil erosion is taking place in the cultivated area on Itf, SSx, and SSe of Chapada. Similar pedons topped with very recent sediments (*e.g.*, B22 and B37) are often found in cultivated areas on Chapadas.

Pedon B44 has also clayey layers brought on by a recent redeposition at the top. Although the genesis of these layers is not known, they are susceptible to compaction, because coarse aggregates have been destroyed and changed into fine fragments during the redeposition. The very firm subsurface horizons are extremely poor in drainage, but are resistant to the scouring by channel flows.

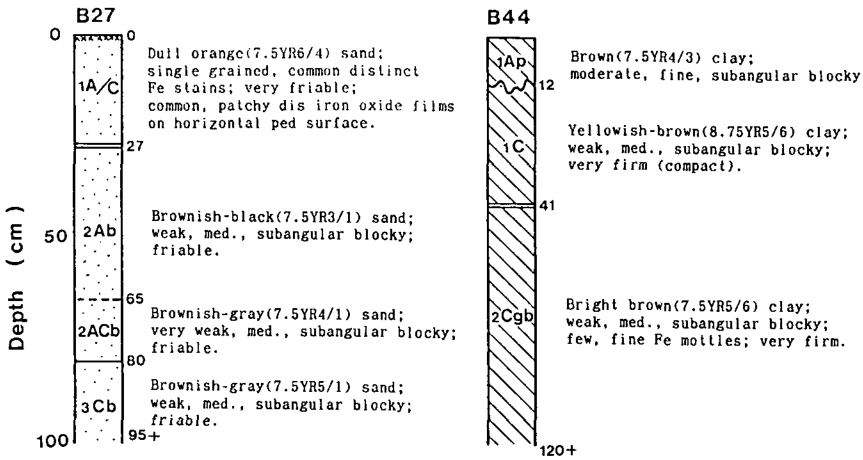


Fig. 40. Buried soils at the bottom of a shallow depression in Chapada (B27 and B44. Land facet; Upland, Alluvial toe slope).

Figure 41 illustrates gulleys observed in the Serra Azul System which were formed by heavy rain mentioned in section 4−3. The development process of these gullies is speculated as follows: (i) The surface storage of excess water is accumulated, and small overland flows (rills) occur on bare, gentle slopes (Itf and SSx) where the clayey soils with low infiltration capacity are predominant; (ii) these flows come into a narrow area along roads and pour into a field; (iii) overland flows in the field wash out topsoil loosened by recent cultivation, and shallow U-shaped waterways, the 'ephemeral gully' (Foster and Meyer, 1972) (less than 20 cm in depth and about 10 m in maximum width), develop; (iv) soil materials transported along the ephemeral gully fill up the terrace waterway in the field and the terrace ridge is broken, gradually breaking down the parallel terrace system from top to bottom; (v) overland flows along the terrace waterways are concentrated again into a narrow area along the border of the field and flow out into the road; (vi) because the compacted clayey subsurface layer in the area along the border and road is resistant to scouring by gullies, a shallow U-shaped

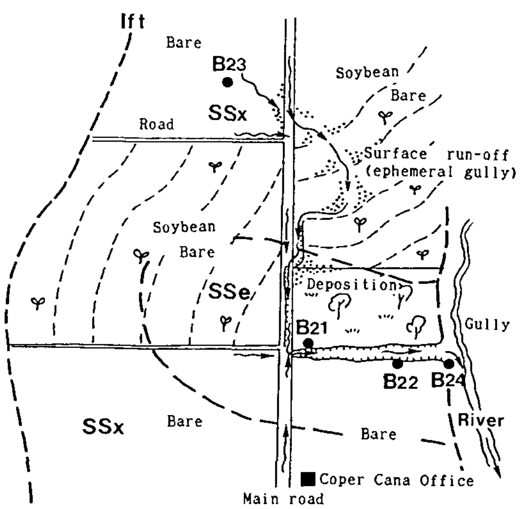


Fig. 41. Illustration of the gullies observed in the Serra Azul System.

waterway (less than 40 cm in depth and 2.5 m in maximum width) is formed along the border between field and road; (vii) excess water discharged from fields is transported rapidly through this waterway, concentrated into a valley head, and flows down along the trough-shaped valley; and (viii) because soils in the trough-shaped valley are sandy and their subsurface layers susceptible to scouring by the channel flow, gully head-cuts are formed along the bottom of the valley and their bases are scoured rapidly, and the V-shaped, deep gully develops to a size of 5—7 m in depth, 10—20 m in width at the land surface, about 150 m in length. The height of the head-wall at its starting point by the road attains to about 3.5 m.

It is apparent that severe soil erosion is caused when the layout of farm roads, crop fields, and terrace waterways are not properly made. As mentioned in section 4—3, there are frequent heavy rains in the Cerrado area even during the dry season. These heavy rains cause a great amount of surface runoff and severe soil erosion. Although soil conservation practices such as broad-based terracing and contour strip cropping are introduced reasonably well, the protection of soils from erosion is still a very big problem.

Multi-layered soils in Vãrzeas suggest that dense vegetation in these depressions is playing an important role in soil conservation and in the environment of Chapadas. It is necessary to establish an appropriate land utilization system with which high productivity is sustained continuously by preventing destruction of the system itself.

Soil erosion is the main cause of water pollution and sedimentation in the lower river reaches. For information concerning this problem, water dispersible clay content (WDC) and flocculation ratio (FR) averaged by parent materials and soils are presented in Table 23.

Lateritic materials (Latosols; Haplustox and Acrustox) on Chapadas in the Brazilian Highland and the Pantanal Region are variable in both WDC and FR, but on the average, these are characterized as meta-stable (medium WDC and medium FR) in surface horizons

Table 23. Water dispersible clay content and flocculation ratio of soil materials.

Parent material	Soils	Top soil[1)]			Subsurface soil[2)]		
		n	WDC	FR[3)]	n	WDC	FR[3)]
Brazilian Highland and Pantanal Region							
Lateritic clay and sand	Lvd, Lld, La	17	11.6	65.0	26	7.5	87.3
Dark red clayey (basic)	Pd, Pe, Tve, B	8	7.4	72.7	8	11.3	62.0
Quartz sandstone	Q, Pd, C	4	4.0	58.0	4	6.1	56.8
Alluvium (upland, sandy)	A, Fd	4	1.7	93.5	3	4.8	71.9
Alluvium (clayey, gley)	Gd	3	0.0	100	5	0.0	100
Transition Region and Upper Amazon Basin							
Dark red clayey (basic)	Pe, Pd	6	5.7	78.3	9	11.5	71.6
Yellow clayey (acidic)	Pd	2	25.9	43.3	3	16.7	71.3
Clayey terrace deposits	Pd	5	10.7	72.9	8	16.5	59.6
Sandy deposits	Pd	5	6.5	71.2	6	2.8	95.0

1) Top soil: A, Ap, Ab, AB and AC. 2) Subsurface soil: B, BC and C.
3) n; Number of samples. WDC; Water dispersible clay (%).
FR; Flocculation ratio = ([(Clay - WDC) / Clay], %).

and stable (low WDC and high FR) in subsurface horizons. Lower FR values were seen in B23 and B42, but on the contrary, in B35, B36, and B38, especially in their subsurface horizons, these were mostly higher than 90%. Sandy materials originating from quartz sandstone are low in FR, but the WDC values are also low because of their low total clay content. Alluvial sandy deposits in Vãrzea da chuva are low in WDC. The strongly reduced, clayey sediments in the Pantanal lowland (B29 and B30) show very low WDC, though their total clay content is fairly high. Yellow clayey materials originating from acidic parent rocks and clayey terrace deposits in the Transition Region and Upper Amazon Basin are unstable (high in WDC and low in FR). Especially in their subsurface horizons, the average value of WDC exceeds 15% and that of FR is lower than 60%. Sandy deposits in these regions are stable in terms of WDC and FR. Dark red, young, clayey deposits originating from basic materials are intermediate in both WDC and FR throughout the survey area.

The low suspended sediment load of clear water rivers in the Brazilian Highland is partly due to the high stability of micro-aggregates in the region's soils. The high suspended sediment load of the Rio Madeira system, on the contrary, (*cf.* section 5−3) can be attributed to such an unstable nature of surface deposits on hills and terraces in its watershed.

6. VEGETATION

6−1. Vegetation Types

In Table 24, the survey sites (pedon number) and tree-shape estimation sites in the three broad vegetation regions (Fig. 6) are shown along with vegetation types as well as some climatic data. These sites are also indicated on the vegetation map (Fig. 42).

As explained in section 2−5, we had opportunities to glance at the six vegetation types and their transitions in the survey area. Based on information obtained from literature (Eiten,

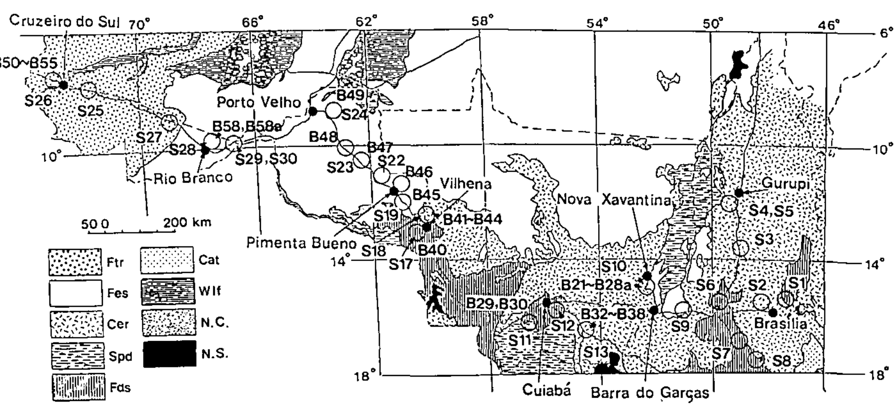


Fig. 42. Vegetation map (Cochrane *et al.*, 1985) and survey sites.
Vegetation type: Ftr; Tropical rain forest. Fes; Tropical semi-evergreen seasonal forest. Cer; Cerrado. Spd; Poorly-drained savanna. Fds; Tropical semi-deciduous seasonal forest. Cat; Caatinga. Wlf; Wetland formation. N.C.; Nonclassified. N.S.; Not surveyed. Open circle: Observation sites. S: Tree-shape estimation sites.

1982; Cochrane *et al.*, 1985) and through the survey, characteristics of these vegetation types are briefly described below: Their schematic sketches are shown in Fig. 43.

Table 24. Survey and tree-shape estimation sites in broad vegetation regions[1] and brief meteorological data.

State	Vegetation type[2]	Pedon no.	Tree-shape est. site[3]	Land system[4]	Temp. (°C)	Precipitation (mm)	DPG[5] (day)	Habitat[6]
				Amazon forest				
Acre	Ftr	B50-B55	s25-s26	(Upper Amazon Basin)	22-24	2,000-2,250	365	N, S
	Ftr	B56-B57	s27	ditto	24-26	2,000-2,250	303	A, S
	Fes	B58, B58a	s28-s30	ditto	24-26	2,000-2,250	303	A, S
Rondônia	Fes	B47-B49a	s22-s24	ditto	24-26	2,250-2,500	295	N, S
	Fes	B46	s21	ditto	24-26	2,250-2,500	257	N
	Tvg(Fds-Cer)	B40	s17	(Transition Region)	22-24	1,750-2,000	>257	P
				Cerrado				
Rondônia	Cer	B41-B44	s18	Chap. Parecis	22-24	2,000-2,250	257	P, S
	Tvg(Cer-Fds)	B45	s19, s20	ditto	22-24	2,000-2,250	>257	S
Mato Grosso	Tvg(Cer-Spd)	B29, B30	s11	Cuiabá	24-26	1,250-1,500	<209	C
	Tvg(Cer-Fds)	B31-B38	s13	Rondonópolis	22-24	1,500-1,750	262	N, P, C
	Tvg(Cer-Spd)	-	s12, s14	ditto	22-24	1,250-1,500	262	S, N
	Cer	B28, B28a	-	Serra Azul	22-24	1,750-2,000	257	P, S
	Cer	B21-B23	-	ditto	22-24	1,500-1,750	<262	C, P, S
	Cer	B24-B27	s10	ditto	22-24	1,500-1,750	<262	N
Goiás	Cer	-	s9	Goiânia	22-24	1,500-1,750	262	N, S
	Tvg(Cer-Fds)	-	s7, s8	ditto	22-24	1,750-2,000	234	C, S
	Cer	-	s4, s5	Gurupi	24-26	1,750-2,000	255	P, C
Brasília, DF	Cer	-	s3, s6	Brasília	22-24	1,500-1,750	<259	P, N, S
	Cer	-	s2	ditto	20-22	1,500-1,750	228	N
	Cer	-	s1	ditto	18-20	1,500-1,750	<228	N, S
				Pantanal				
Mato Grosso do Sul	Spd	B39	s16	Corumbá-Bod.	24-26	1,000-1,250	179	N, C, S
	Tvg(Cer-Spd)	-	s15	ditto	24-26	1,250-1,500	246	N, S

1) Broad vegetation regions; refer to Fig. 6. 2) Refer to section 6-1. 3) Tree-shape estimation site number; refer to Fig. 42. 4) Upper Amazon Basin and Transition Region are not land systems. Chap. Parecis; Chapada dos Parecis. Bod; Bodoquena. 5) Number of days when crop can grow with the available water in the soil. 6) N; Natural. S; Semi-natural. A; Abandoned. C; Crop field. P; Pasture.

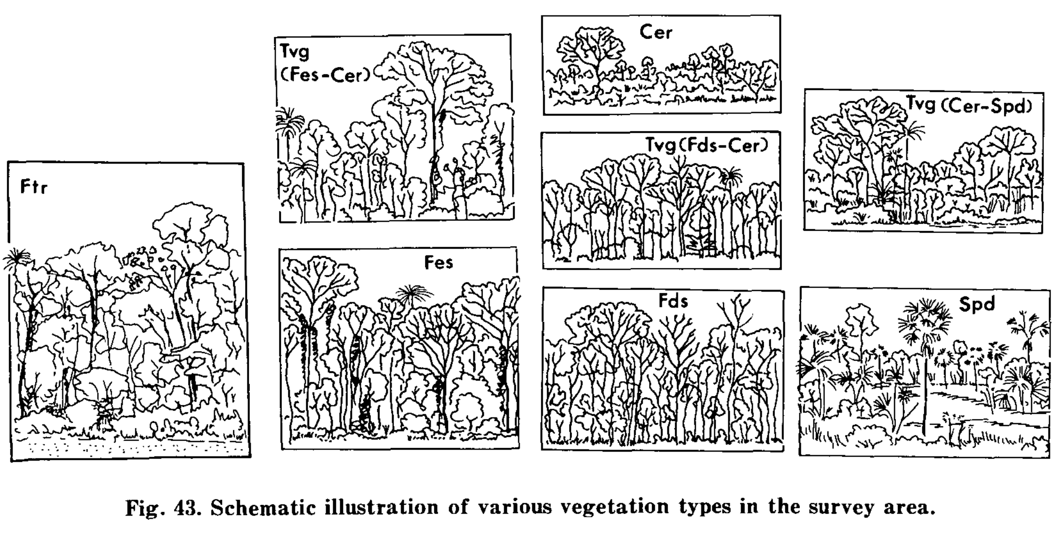


Fig. 43. Schematic illustration of various vegetation types in the survey area.

9a

9b

9c

9d

9e

9f

Plate 9. Vegetation in Cerrado and poorly-drained savanna.

9a. Cerrado in hilly area at Nova Xavantina. 9b. Cerrado at the highest part of the Mato Grosso Highland. 9c. Invasion of the tree species on abandoned pasture in Cerrado. 9d. Gallery forest near B24 in the Serra Azul System. 9e and 9f. Aquatic plants in the Pantanal lowland.

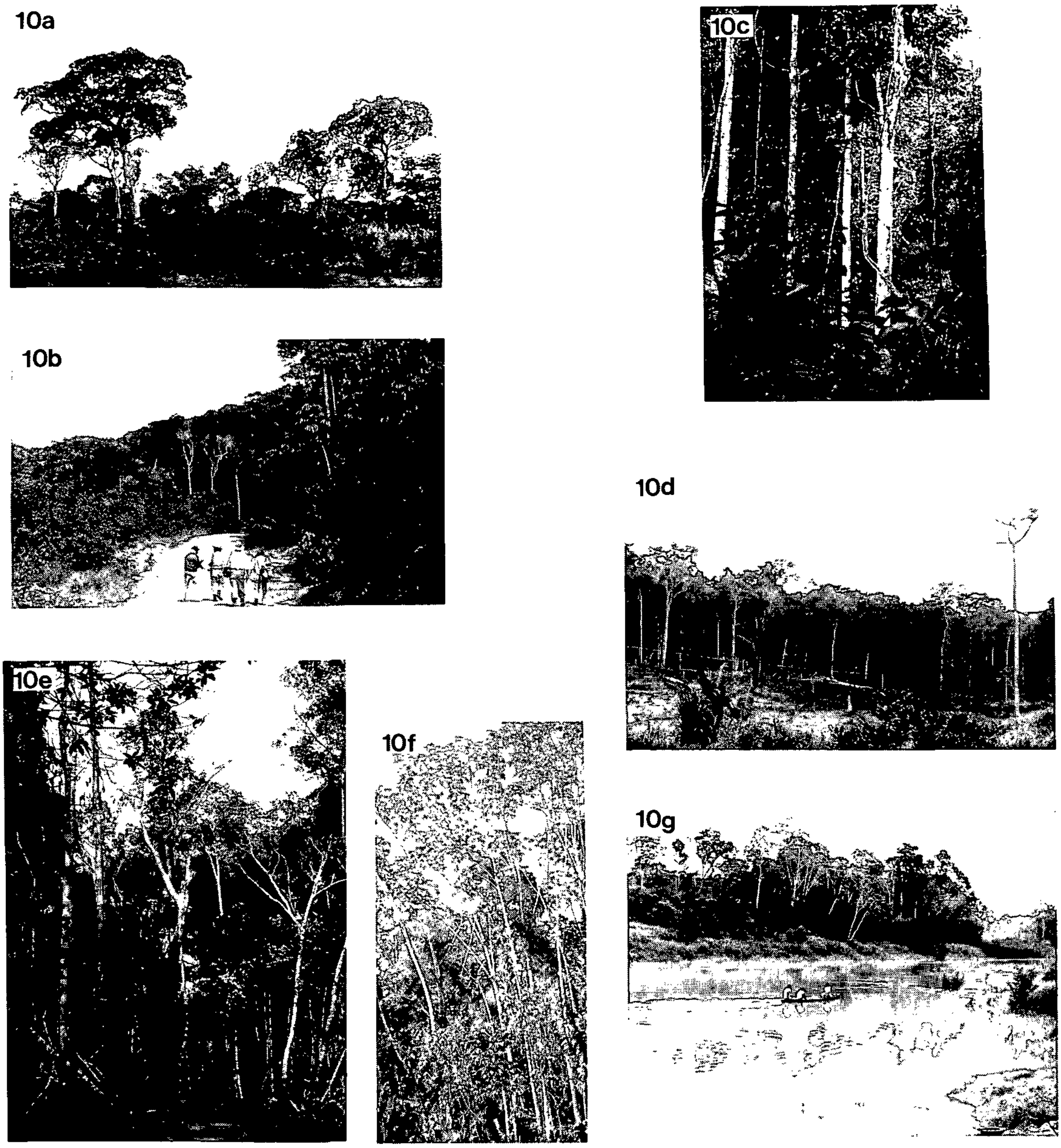


Plate 10. Transition vegetation and semi-evergreen seasonal forest.
10a. Transition vegetation from Cerrado to tropical semi-evergreen seasonal forest. 10b and 10c. Tropical semi-evergreen seasonal forest at Ariquemes. 10d. Tropical semi-evergreen seasonal forest near Rio Branco. 10e. Secondary forest developing on a sandy soil near Marco Rondon. 10f. Pioneer trees of *Cecropia* near Porto Velho. 10g. Tropical semi-evergreen forest on a river bank.

6−1−1. Cerrado (Cer: Well-drained savanna).

Cerrado occurs on uplands in the Brazilian Highland. It is a tropical, intermediate-rainfall vegetation, and is physiognomically and ecologically related to the moist, summer-rainfall dystrophic savannas and woodlands of other continents, such as the southern African 'Miombo' and related woodlands, and the *Eucalyptus* woodlands in northern Australia.

The density of woody plants is lower at places where soils are shallow, extremely low in plant nutrients, high in exchangeable Al saturation, or are seasonally saturated with moisture (Eiten, 1978) (Plate 9a). Cerrados are subdivided into the following structural types and sub-types by Tothill (1984):

1) Cerrado
   a) Campo limpo (savanna grassland): With some shrubs within herbaceous canopy.
   b) Campo sujo (tree/shrub savanna): With trees or shrubs, less than 2% cover.
   c) Campo cerrado (wooded savanna): With trees, 2−15% cover.
   d) Cerrado (savanna woodland): With trees, 15−50% (average 20−30%) cover.
2) Cerradão (woodland or open forest): Screophyllous woodland, more than 50% cover.
3) Sabana parqueada (savanna parkland): Savanna dotted with tree groves.

The woody layer is characterized by short tree species frequently with twisted trunks such as *Bowdichia virgilioides, Byrsonima crassiflora,* and *Curatella americana*; and the herbaceous layer is characterized by species such as *Leptocoryphium lanatum, Trachypogon plumosum, Andropogon* sp., *Axonopus* sp., *Bulbostylis* sp., *Paspalum* sp., and *Rynchospora* sp.(Tothill, 1984). The herbaceous stratum plays an important role in annual production and regrowth of vegetation, although the woody stratum is the obvious feature of the vertical component (Plate 9b).

Beside poorly-drained wetlands in depressions on upland, graminoids, lycopods, and palm trees dominate. The tree height gradually increases and tree shape becomes normal from the upper to lower positions on slopes. Gallery forest along rivers consists of trees taller than 20 m.

Following are noted the physiognomic impressions from the Cerrado area in the Brasília System: The uplands are covered with woodland consisting of 5−10 m trees with corky, twisted trunks; dominant trees are *Connarus* sp., *Davilla elliptica, Qualea gradiflora, Q. multiflora, Q. parviflora, Byrsonima verbascifolia,* and *B. coccolobifolia,* in addition to the species mentioned above. Humid undulating foot slopes are covered with grasses. In the area along streams, there are gallery forests consisting of more than 10 m tall palms and semi-deciduous trees.

6−1−2. Poorly-drained savanna (Spd).

This type is a vegetation developed under conditions of seasonal waterlogging, where, in turn, water shortage often occurs for some periods during the year. Plant species composition varies from place to place depending upon drainage conditions. Coverage by evergreen and deciduous trees is limited; common species are *Syagrus comosa, Casearia* sp., and *Byrsonima* sp.

The Pantanal lowland is an example of Spd, which is characterized by a seasonal change in the water level on the ground; land surface above water is reduced to about 10% of the whole area by end of the rainy season. The vegetation is diverse in a narrow area (Plates 9e and 9f). Five vegetation sub-types are known in the Pantanal lowland: (a) *Typha* marshes in ponds or swamps; (b) grass-sedge marshes with broad-leaved, 0.3−2 m tall herbs; (c) medium tall grass marshes with scattered palm trees of *Mauritia vinifera*; (d) herb marshes or swamps with a dense layer of *Polygonum, Xyris,* and *Araceae* in thin stemmed shrubs with variable densities; and (e) vegetation on the foot slopes of hills which are not always flooded every year (Eiten, 1982). When the survey team visited Poconé and Corumbá during an early period of the rainy season, three types of vegetation were noted; *i.e.,* aquatic plants at pond side, grasses with palms on slightly higher ground, and forests on the foot slopes of hills. In the nature preservation area, many kinds of birds and animals are to be found. The Pantanal lowland is known as an ideal island on the earth, a natural habitat created especially for animals.

Ilha do Bananal depression in the Gurupi System is another example of Spd, which is surrounded by uplands covered with Cerrado vegetation. The gallery forest consisting of trees less than 15 m in height develops along streams. Various grasses and herb marshes appear in dotted patches, depending upon the water level.

6–1–3. Tropical semi-deciduous seasonal forest (Fds)

Trees in this type grow as tall as 20–25 m in height, and have a shape similar to that of Tropical rain forest (Ftr) and Tropical semi-evergreen seasonal forest (Fes). Tall deciduous trees, however, sometimes occur together with tall evergreen trees along streams.

During this survey a margin of Fds was observed near Colorado do Oeste. Large trees of 30 m in height and 100 cm in diameter at breast-height (DBH) appeared in isolated cases on steep slopes of small valleys, where sometimes liana plants hung on them. Dead trunks of 36 m height and 150 cm DBH stood in crop fields and pasture on the undulating terrace plains. This situation demonstrates that these plots were established by clearing Fds. Common trees are *Byrsonima* sp., *Caesalpinia echinata, Hymenaea* sp., *Caryocar coriaceum,* and tall palms (*Orbignya*).

6–1–4. Tropical semi-evergreen seasonal forest (Fes)

This type is characterized by the predominance of tall trees with two layers. Dominant trees may reach a height of more than 25 m in fertile soils; less than 20% foliage in the upper canopy lose their leaves in the dry season. Many species in the upper layer are facultatively deciduous. A high proportion of the lower-layer trees and herbaceous plants are evergreen. This vegetation type differs also from the tropical rain forest (Ftr) by the fact that fewer trees are buttressed. In the early dry season, many species produce flowers, especially the lower-layer trees which tend to be small-leaved (Cochrane *et al.,* 1985).

The Transition Region in Rondônia and eastern Acre is categorized by this vegetation type. In the natural condition, 3–5 layers of trees and undergrowth are found and total coverage exceeds 150%.

At Felix Fleury near Espigão d'Oeste, large trees (25–30 m and sometimes 35 m in height) are crowded on calcareous rocks in Fes. Liana plants and epiphytes grow on trunks. Fern flora consist of five species of *Adiantum* spp., *Selaginella* sp., and *Thelypteris* spp.

From Ariquemes to Porto Velho in Rondônia (Plates 10b and 10c), there was a secondary succession of *Cecropia ficifolia* (Plate 10f) on cleared lands near the road; this is a typical process of forest recovery on cleared lands in Fes. It was almost a pure stand and the tree height was uniform at each site; it varied, however, 5–10 m at different sites, depending upon the duration after clearing the land. This species reaches 10 m in height within 4–5 years on lands cleared by the slash-and-burn method (Uhl and Jardan, 1984).

6—1—5 Tropical rain forest (Ftr)

Tropical rain forest spreads over the Upper Amazon Basin including western Acre. This vegetation is characterized by the predominance of broad-leaved evergreen trees, casting their leaves and growing new ones continuously and simultaneously. Large trees may develop plank buttresses, although these are more common in areas with impeded drainage (Cochrane *et al*, 1985). Highest trees are taller than 30 m and consist of 4—7 layers of trees and undergrowth; liana plants hang on the trunks and branches of big trees. Total coverage of layers is above 200%, but the coverage of the forest floor is poor. Takeuchi (1961—62) described the structure of the North Amazon forest as consisting of three tree strata, undergrowth, lianas, and epiphytes.

If one looks at this scene from the air, the canopy surface is completely covered by dense, dark green foliage. The upper layers (I—III) of tall trees, which are distributed in variable sizes, are closely touching each other, but not overlapping. Flying over the area near Cruzeiro do Sul, it was observed that 30—35 m trees stood one by one on the top of crowded canopies, and there were more than three species of large (taller than 30 m), blooming trees at 100—300 m intervals but never clustered, and along small streams palm trees dominated on a line. Microtopography is undulating with 200—400 m intervals, resembling a tile board.

6—1—6. Wetland formations (Wlf)

This type is the major vegetation in Vãrzea do rio, where water is at excess levels for most of the year under swampy conditions, and can be comparable to 'Esteros' by Tothill (1984). The lower alluvial plains which are intermittently inundated have swamp and seasonal swamp forests ('Mata de vãrzea'). These forests have fewer species than those on uplands ('Mata de terra firme'). The diversity of forest vegitation depends mainly upon the length and frequency of flooding and the quality of flood waters. The swamps which are permanently inundated have forest ('Igapõ forest'), but are rather poor in tree species. Characteristic species are *Virola* sp. and *Symphonia globurifera.* Palms, such as *Euterpe oleracea* and *Iriartia exorrhiza,* are common and sometimes make up the entire vegetation. In the lowest spots of flood plains, treeless grasslands ('Campo de vãrzea do rio') occur with floating grasses (Sombroek, 1966).

6—1—7. Transition vegetation (Tvg)

In addition to the six vegetation types mentioned above, there are (i) patchy mixtures of two or more vegetation types in climatic transition areas, such as the southeastern part of Rondônia (Fig. 42), occuring generally on a large scale, (ii) a succession of vegetation due to changes in drainage conditions within short distances, such as along slopes (examples described in section 6-3), and (iii) vegetation under the regeneration process after disturbances, as shown in section 6-4. In this report, all of these are denoted as 'Transition vegetation'.

6—2. Numerical Description of Forest Structure and Tree Shape

6—2—1. Structure of forests

Data on the following four parameters were collected to express the characteristics of vegetation; *i.e.*, maximum tree height (H), number of layers (NL), total coverage (TC), and floristic richness (NS). The definitions of these parameters are illustrated in Fig. 44. The number of layers is identified even in shrubs and grassland.

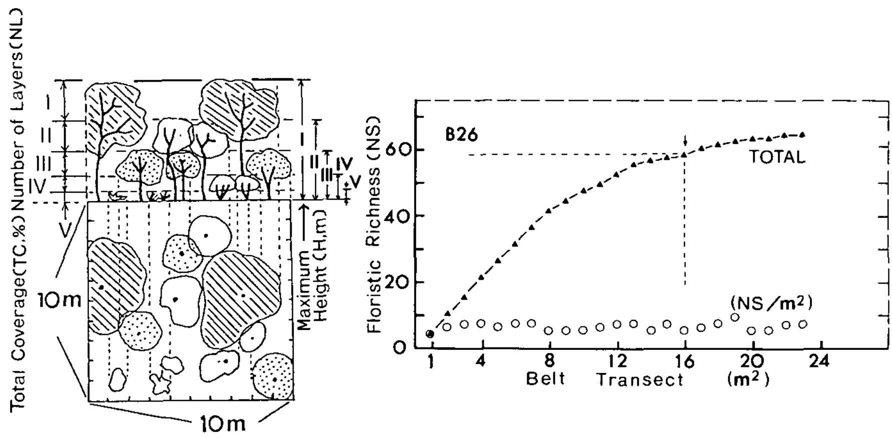


Fig. 44. Schematic illustration of tree-shape parameters to express vegetation characteristics (Right figure is an example at B26).

Maximum height (H, m): Height of the tallest plant in 10 m x 10 m quadrat.

Number of layers (NL): Number of foliage clusters. Number was counted from the top height of vegetation.

Total coverage (TC, %): Sum of coverages in each layer.

Floristic richness (NS): Number of species in a belt transect of 1 m x 16 m. Open circles indicate the number of species observed in each 1 m x 1 m quadrat.

Figure 45 illustrates the characteristics of natural and semi-natural vegetation at selected survey sites as expressed by the four parameters; semi-natural vegetation denotes a partially disturbed natural vegetation or abandoned fields or pasture (longer than 10 years). In this figure, each parameter is expressed in relative values to the respective maximum value (maximum tree height = 35 m, number of layers = 7, total coverage = 320%, and floristic richness = 118). It may not be adequate to compare vegetation types only with these parameters, because data are limited. However, the following tendencies are noted: Maximum tree height is shorter, the number of layers fewer, total coverage less, and floristic richness is higher in the Cerrado than in the forest area (Ftr, Fes, and Fds).

There are statistically significant positive correlations among maximum tree height, the number of layers, and total coverage, whereas floristic richness is not correlated with any other parameter (Table 25). There are, generally, more than four layers in any vegetation. Among the natural and semi-natural types, the vegetation types which had more than four layers were selected, and the coverage and height of each layer were compared with the others (Table 26). The mean height of layers I and II was 12 and 6 m in Cer, 27 and 14 m in Fes, and 20 and 11 m in Ftr, respectively. The mean coverage of each layer ranged from 15 to 29% in Cer, from 30 to 53% in Fes, and from 14 to 44% in Ftr. The mean total coverage was 116%, 184%, and 146% in Cer, Fes, and Ftr, respectively. The maximum tree height and total coverage in Ftr seemed physiognomically to be greater than those in Fes, and much greater than those in Cer; the height and coverage in Ftr were smaller, however, than those in Fes, perhaps because the survey sites in Ftr were limited.

Significantly positive correlations were found among the heights of each layer: When the

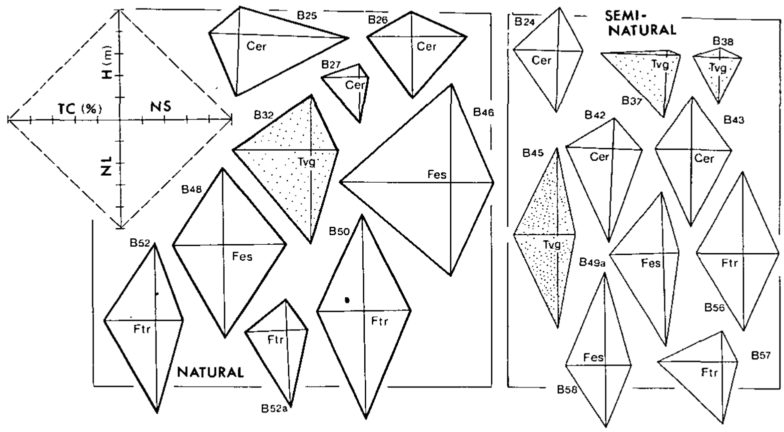


Fig. 45. Illustration of the structure of natural and semi-natural vegetation among various vegetation types. Number on symbols: Refer to observation sites in Fig. 42.

Table 25. Correlation coefficient among vegetation characteristics.

Vegetation character	Species richness	Number of layers	Total coverage(%)
Maximum tree height (m)	0.329	0.806**	0.426*
Species richness	-	0.385	0.120
Number of layers	-	-	0.537*

* and **: Significant at p<0.01 and p<0.001, respectively.
Number of samples is 34, selected from pedon number B21–B58a.

upper layers are tall, the lower layers are also tall (Table 27). There is no statistically significant correlation in the coverage among each layer, indicating that there is not any correspondence between foliage development at higher positions and those underneath.

6–2–2. Estimation of human impact on vegetation characteristics

In this survey were studied not only natural vegetation, but also vegetation under human impact at varying intensities, such as pasture and crop fields with intensive or poor management, and secondary vegetation on farmlands abandoned recently or not so recently. Usually, the vegetation of crop fields or improved pasture is simpler than natural and semi-natural vegetation. To express the intensity of human impact on the characteristics of vegetation, the following two parameters are introduced.

(a) Complexity: $(NL \times NS)^{1/2}$, where NL represents the number of layers and NS the floristic richness (number of species). This parameter is introduced to estimate quantitatively the vegetation complexity, since the number of layers and the number of species represent an important component of vegetation structure and flora, respectively. In a bean field free from weeds, for example, the value of vegetation complexity is 1, because NL = 1 and NS = 1. In a case of natural vegetation consisting of four layers and a floristic richness of 49, however, the complexity is 14. The semi-natural vegetation can be almost represented by a value of 5–10.

Table 26. Tree height and coverage of four layers (I, II, III, and IV) at selected sites[1] in three vegetation types[2].

	Tree height (m)				Coverage (%)				
	I	II	III	IV	I	II	III	IV	Total
				Cerrado (Cer)					
Maximum	17	8	4	2	50	29	90	60	135
Minimum	8	4	1.0	0.5	10	2	10	10	85
Mean	12	6	2	0.9	27	15	27	29	116
CV (%)	29	23	53	67	56	60	114	60	16
				Tropical semi-evergreen seasonal forest (Fes)					
Maximum	32	19	10	7	80	90	50	40	320
Minimum	20	6	2	0.3	30	15	10	10	115
Mean	27	14	7	3	53	46	30	33	184
CV (%)	17	35	45	80	37	61	47	40	43
				Tropical rain forest (Ftr)					
Maximum	31	15	10	5	25	50	60	90	185
Minimum	10	6	0.5	0.3	10	10	10	5	125
Mean	20	11	6	2.5	14	30	44	32	146
CV (%)	43	37	62	72	42	60	42	97	14

1) Sites in which vegetation had more than four layers, including natural and semi-natural vegetation. 2) Pedon numbers included were B24a, B25, B26, B42 and B43 in **Cer**, B46, B48, B49a and B58 in **Fes**, B50, B52, B52a, B56 and B57 in **Ftr**.

Table 27. Correlation coefficient of tree height and coverage among layers (I, II, III, and IV) in various vegetation types.

Layer	Tree height (m)			Coverage (%)		
	I	II	III	I	II	III
II	0.928**	-	-	0.347	-	-
III	0.823**	0.907**	-	-0.371	0.022	-
IV	0.681*	0.769*	0.920**	-0.044	-0.426	0.062

* and **: Signifant at $p<0.01$ and 0.001, respectively.
Number of vegetation is 18, selected from pedon number B21-B58a having more than four layers.

(b) Intensity: $(H \times TC)^{1/2}$, where H is maximum height (m) and TC is total coverage (%). This parameter is introduced to express the intensity of a vegetation, since these two parameters are considered to be rational for evaluating the volume of vegetation.

It should be noted here that because this survey was made at an early period of the rainy season, the foliage of crops was generally very sparse, and a well managed crop field almost bare ground. Thus, the data on crop fields do not represent the situation pertaining when crops are fully grown.

There is a loose positive correlation between two parameters (Fig. 46): A large value of intensity associates with a large value of complexity. Regressions of complexity with intensity seem to be somewhat different, however, between vegetation in the Cerrado (Cer, and Tvg(Cer-)) area and that in the forest (Fes, Ftr, and Tvg(Fes-)) area. With a given value of intensity, the complexity is found greater in the Cerrado than in the forest areas.

Generally speaking, complexity is in the order of natural > semi-natural > pasture > crop field vegetations, and intensity is in the order of natural forest > semi-natural forest > natural and semi-natural Cerrado > pasture > crop fields.

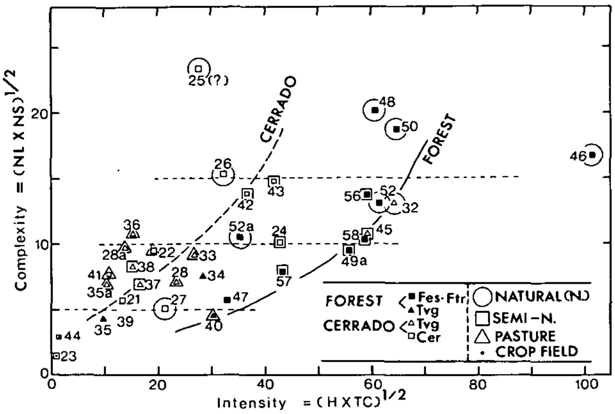


Fig. 46. Relationship between intensity and complexity under various levels of human impact upon various vegetation types.

By looking only at vegetation in the forest (Fes, Ftr, and Tvg(Fes-)) area, it may be speculated that (a) vegetation in crop fields and pasture is low in both intensity and complexity, (b) when these are abandoned, vegetation in the plot increases quickly in intensity, but slowly in complexity, and (c) when vegetation reaches a certain intensity, the intensity does not increase beyond that level, but complexity continues to increase. A similar tendency appears to exist in the Cerrado area, although when a plot under intensive human impact is abandoned, the rate of increase in intensity is slower, but that in complexity is faster in the Cerrado than in the forest areas.

At a given complexity, the maximum tree height and the number of layers are greater in the forest than in the Cerrado areas (Fig. 47).

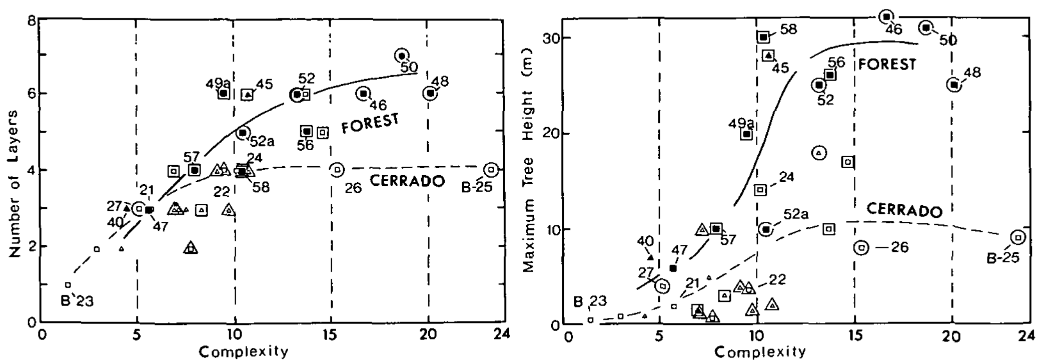


Fig. 47. Number of layers, maximum tree height, and total coverage in relation to the complexity in various vegetation types. Symbols: Refer to Fig. 46.

6−2−3. Tree shape

By using photographs of various vegetation types taken at each tree-shape estimation site, data of the following parameters were collected for individual trees of layer I in the vegetation: (a) FD/H, ratio of the foliage depth (FD) to the maximum tree height (H); (b) FW/H, ratio of the foliage width (FW) to H; (c) FD/FW; and (d) SL/H, ratio of the main stem length (SL) to H.

The mean values of these parameters are smaller in trees of Ftr and Fes than those of Cer, and trees in Tvg show intermediate values as shown in Fig. 48.

Relationships among these parameters are summarized in Table 28. There were significant negative correlations between FW/H and FD/FW for all vegetation. This means that a tree having larger foliage width in comparison to its height has smaller foliage depth in comparison to its width. Trees in Fes showed significant correlations among all parameters except between SL/H and FD/FW.

Figure 49 summarizes the information obtained by using these parameters. The trees in Cer are only less than one third the height of those in Fes and Ftr; they have fewer main branches, but the density of branches on the main trunk is higher, and the trunks are twisted. The relative amount of tree foliage in Cer is larger in comparison to tree height, while that in Fes and Ftr is smaller on a straight, tall trunk.

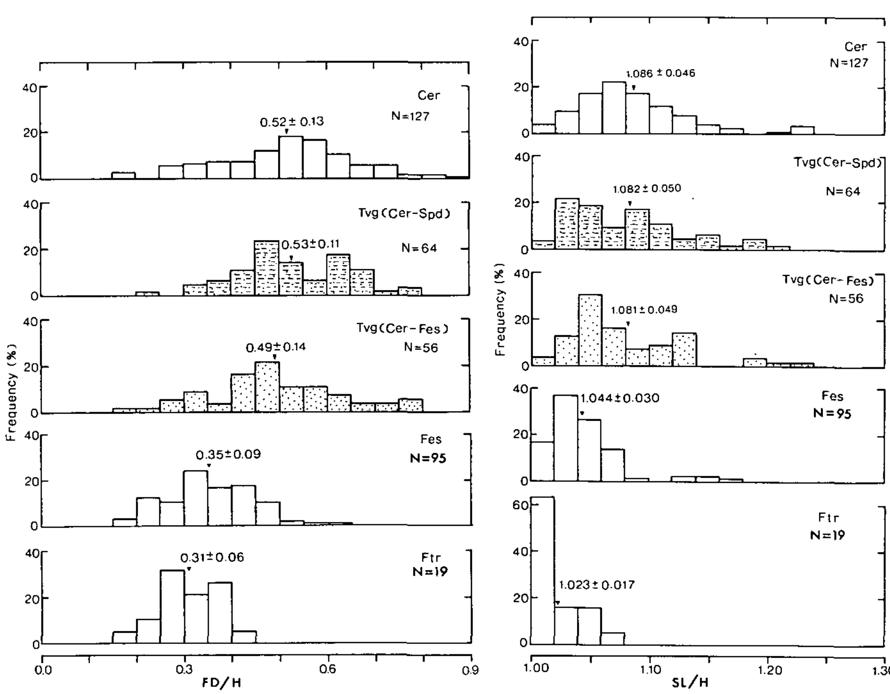


Fig. 48. Tree-number frequency distribution of the foliage depth/tree height (FD/H) and the main stem length/tree height (SL/H) in various vegetation types.

Table 28. Correlation coefficient[1] among tree-shape parameters in various vegetation types.

Tree-shape parameter	Vegetation type					
	Cer	Tvg (Cer-Spd)	Tvg (Cer-Fes)	Tvg (Fes-)	Fes	Ftr
SL/H-FW/H	0.165	0.362*	0.403*	0.205	0.388**	0.201
SL/H-FD/H	-0.024	0.463**	0.250	0.614*	0.211	-0.176
SL/H-FD/FW	-0.168	0.013	-0.214	-0.286	-0.221	-0.338
FW/H-FD/H	0.425**	0.275	0.592**	0.547*	0.597**	0.589
FW/H-FD/FW	-0.521**	-0.640**	-0.609**	-0.541*	-0.541**	-0.662*
FD/H-FD/FW	0.426**	0.429**	0.188	0.356	0.277*	0.179
No. of trees	127	64	56	22	95	19

1)* and **: Significant at p<0.01 and p<0.001, respectively.
2) SL/H; ratio of the main stem length (SL) to the maximum tree height (H). FW/H; ratio of the foliage width (FW) to H. FD/H; ratio of the foliage depth (FD) to H. FD/FW; ratio of FD to FW. FW/H; ratio of FW to H.

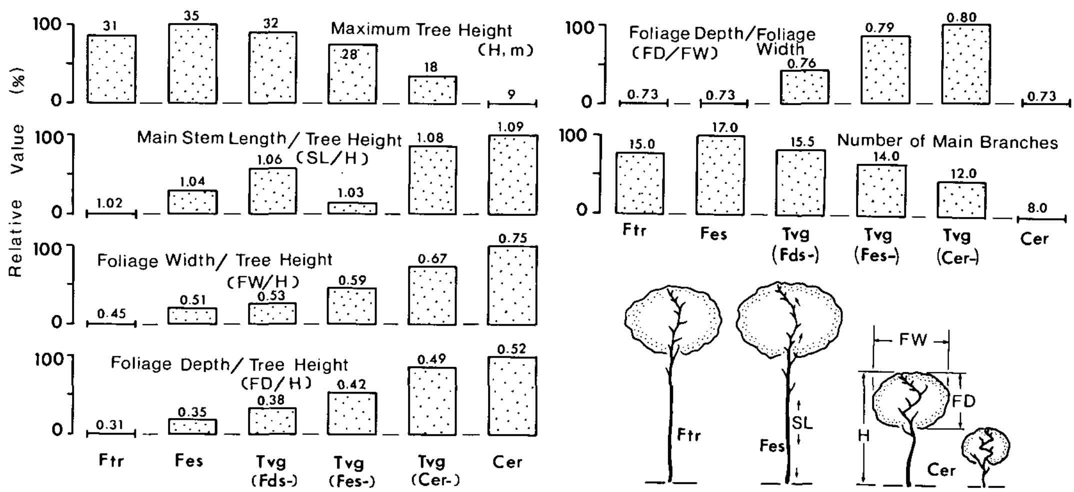


Fig. 49. Schematic illustration of representative tree-shapes in various vegetation types.

In Table 29, correlation coefficients between the tree-shape parameters and the meteorological data are shown. The result indicates that among trees found in an environment with smaller precipitation and a shorter DPG (a longer dry season), the trunk is more twisted and the foliage is wider and thicker in comparison to tree height. Based on the data presented above and on general observations during the survey, the following statements can be made: Trees in Cer are short, with twisted trunks and large foliage width relative to their tree height. These tree-shape characteristics are related to relatively low temperature, limited precipitation, and a long dry period. Climatic conditions make the density of trees low and growth slow; this situation can be one of the reasons for the relatively larger foliage width in Cer. Conversely, trees in Fes and Ftr are tall, with straight trunks and small foliage width

Table 29. Correlation coefficient[1] between tree-shape parameters and meteorological data.

	Tree-shape parameter[2]			
	SL/H	FW/H	FD/H	FD/FW
Temp.[3]	-0.521*	-0.633**	-0.350	0.332
Precip.[4]	-0.674**	-0.507*	-0.663**	-0.216
DPG[5]	-0.483*	-0.436	-0.536*	-0.156

1) * and **: Significant at p<0.01 and p<0.001, respectively. Number of samples: 31 (s1-s30 and a site between s9-s10). 2) See footnotes in Table 27. 3) Temp.: Annual mean air temperature (°C). 4) Precip.: Annual precipitation (mm). 5) DPG: Number of days when plant can grow with the available water in soil.

relative to their height. These characteristics are related to high temperature and abundant precipitation. Such climatic conditions make the density of trees great and growth fast, and competition among trees may result in the above-mentioned tree-shape characteristics.

6–3. Vegetation Types in Relation to Climatic and Edaphic Conditions

Six vegetation types and Transition vegetations are found in the survey area. Regional distribution of these types coincides well with that of climatic parameters. Vegetation type changes from Cer to Fds, and then to Fes and Ftr following, for example, a decrease in the number of dry months per year and in the climatic water deficit during dry months (CWDD, see Table 15), and with an increase in duration of the period when plants can grow with available soil water (DPG; see Fig. 30).

In tropical South America, savannas exist in areas with more humid conditions (annual precipitation of more than 1,000 mm) than do those on other continents. The reason for this phenomenon has been discussed by many authors. Sarmiento (1983) proposed the following: (a) Climatic conditions, especially their seasonal fluctuation, favor savanna over forest; (b) the infertile nature of the soil favors savanna; (c) the presence of strong seasonal graminoids contributes to recurrent fires which control the regeneration of woody species; (d) if the environment condition in savanna is marginal for forest, the unstable equilibrium favors the predominance of herbaceous species through fire and grazing; and (e) the nutrient cycle in the area can, in time, favor savanna.

The climatic condition of the Amazon Basin has changed drastically during the last 20,000 years. During the drier period of the last glacial age (ca. 18,000 years B.P.), net water supply during the period from June to August in the ice age was estimated to be 2–5 mm/day less than that at present (Sarnthein, 1978). This drier climate resulted in an expansion of savanna and the development of sand deserts in the lower Orinoco Basin and on slopes around the tropic of Capricorn. Many publications reported that the change from dry to humid climate took place rapidly within a few hundred years. During the warm and humid period around 6,000 years B.P., the expanded savanna of the Amazon lowland gradually degenerated, and various types of forest vegetation expanded beyond their current ranges. During the last 5,000 years, the climate has been becoming drier, and forests on well-drained upland are being exposed to unfavorable conditions.

Fire is a very important factor in establishing savanna. Sanford *et al.* (1985) sampled many charcoal pieces from tropical rain forests of the Venezuelan Amazon, and estimated that the age of these charcoals ranged from a few hundred to 6,000 years. This shows that forests in the area have encountered repeated burning caused either by wildfires or by the slash-and-burn agriculture of various ages (Dickinson and Virji, 1987). Wildfires during dry periods of the last 5,000 years was one of the important causes of forest degradation in the Amazon, especially in the Brazilian Highland, although human activity also was another cause.

In Cerrado, there are many kinds of corky woods and plants with deep roots and/or rhizomes. After a vegetation is burned during the dry season, new leaves flash from remaining stems and rhizomes during the rainy season and new stems spring from the rhizomes. Because of such characteristics, many plants survive for long periods in a dwarf and twisted structure even under conditions of frequent fires.

Another factor which controls the distribution of vegetation type is the edaphic condition. Drainage is the most dominant edaphic factor. Pantanal vegetation occurs on seasonally flooded, poorly-drained lowlands, and there is unique vegetation even in small Vărzeas.

Chemical properties of the soil may also control vegetation type. As mentioned previously, the development of Cerrado is suspected to be associated with high exchangeable Al saturation and low plant nutrient status in soil. In respect of this issue, the survey team was puzzled on observing the following: There was quick-growing secondary forest on a very poor soil (B45, weakly podzolized sandy soil). The forest was estimated to be less than 25 years old judged by its floristic richness and display of branches, but was as tall as 30 m and comprised 2−3 layers (Plate 10e). How is it possible for a poor soil like this to support such quick forest growth ?

Table 30 shows both total and available amounts of various plant nutrients in each horizon of B45. By assuming that forest dry matter is 300−400 t/ha (Santos, 1986), for example, with 0.5% K, the amount of K contained in the forest is estimated at 150−200 g/m², which is about half the amount of total K in the soil at a 1 m depth. If this amount is absorbed at a constant rate during a 25-year period, the rate of K absorption by the forest is 8−9 g $m^{-2}y^{-1}$, which is only slightly less than the total amount of exchangeable K in the soil (9 g/m²). These data indicate that K, which recycles within the soil-plant system, plays an important role in forest growth as indicated by the higher available K content in the topmost soil layer. Owing to the soil-plant recycling system, the nutrient status of a forest is maintained at a reasonable level

Table 30. Amount of various nutrient elements and cation exchange capacity (CEC) in the top 1 m layer of a weakly podzolized sandy soil (Quartzipsamments ?) at B45.

Depth (cm)	Horizon	Element content2) Ca	Mg	K	P	Ex. cation3) Ca	Mg	K	Na	Bray 2 - P	CEC3)
		(g/m²)				(meq/m²)				(mg P_2O_5 /m²)	(meq /m²)
0- 4	A	4.3	0.5	15.3	2.9	1.1	0.7	0.6	2.4	1.6	1.6
4- 25	AE	21.0	15.1	85.5	13.1	1.1	0.6	1.9	1.1	1.7	2.1
25- 38	B_{11}	8.6	0.4	47.5	8.8	0.8	0.3	0.9	0.7	0.9	1.7
38- 67	B_{12}	2.6	16.2	106	20.0	1.7	0.6	2.0	1.5	1.2	3.5
67-100	B_3C	2.9	9.2	123	20.1	3.6	0.7	3.6	1.7	3.3	2.6
0-100		39	41	378	65	8	3	9	7	9	12

1) By assuming the volume weight of soil is 1 g/cm³. 2) Total analysis by X-ray fluorescence spectrometry. 3) Extracted with 1 M NH_4OAc (pH = 7.0).

even on poor soil. Thus, it may be uncommon that the nutrient status of a soil becomes the controlling factor of vegetation type under natural conditions. It should be mentioned, however, that adverse soil characteristics such as low soil pH associated with high exchangeable Al saturation, can be a factor which controls the vegetation type in some cases, such as in Cerrado (Eiten, 1978).

As discussed previously, various vegetation types develop in relation to climate, drainage, and nutrient status, *etc.* The southeastern part of Rondônia provides unique opportunity to look into the changes of vegetation type caused by various factors, since there are found various vegetation types in scattered patches and the area is climatically on the border between the areas of Cer, Fes, and Fds.

If one goes from Vilhena to Colorado do Oeste by car, it is possible to see a rapid change of vegetation type from Cer to Tvg, and then to Fds (Fig. 50). As the climatic condition does not change much along the road, it is suspected that the change is due to the edaphic condition and to the intensity of human activity. Cerrado around Vilhena seems to be derived from Fds, because this Cer is lower in floristic richness than that in the Brazilian Highland, and Fds at Colorado do Oeste seems to be a natural forest as it is constituted of large trees, taller than 30 m and 80 cm in DBH.

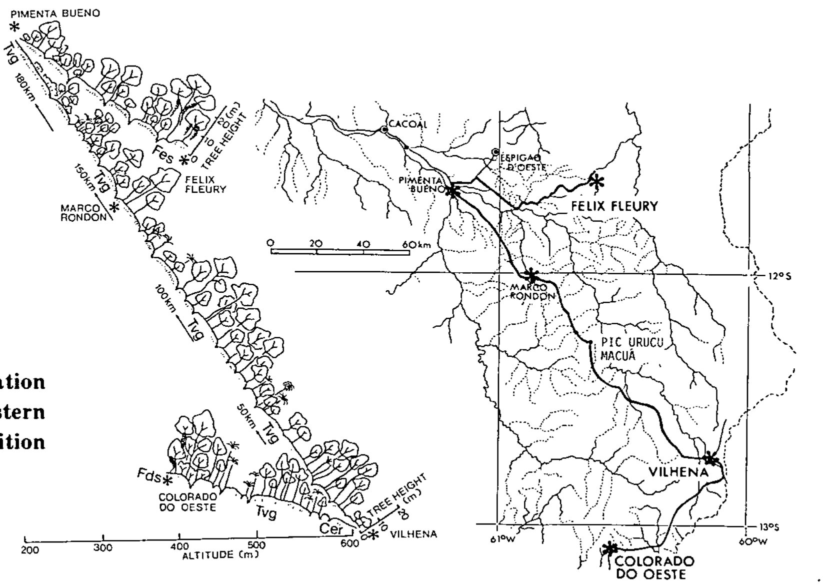


Fig. 50. Outline of vegetation changes in the southeastern part of Rondônia (Transition vegetation).

Felix Fleury is more humid (P = 2,250 mm/year) than Vilhena (P = 1,750 mm/year), and vegetation type in the area is Fes. Vegetation changes along the road from Vilhena to Felix Fleury via Pimenta Bueno are very complicated, however: There are some crop fields, pasture, and plantations of rubber trees, cacao, *etc.*, in patches; there are various types of Tvg(Fes-Cer) in patches depending upon microtopography and the degree of human impact; beside swamps and ponds, some kinds of palms occur in patches in forests of 10–15 m tall evergreen trees; in crop fields on steep slopes, large trees, components of the previous natural vegetation (Fes), remain.

From these observations, it can be said that in the Transition Region, there were Fes, Fds, and Cer, depending upon climatic and drainage conditions. Because of an increase of human activity, the areas of Tvg(Fes-Cer) and Cer have increased.

Sequential changes of natural vegetation along slopes were observed frequently in areas of various vegetation types. Examples of such changes follow:

(a) A slope with natural vegetation at Nova Xavantina in the Cerrado area (Fig. 51): Floristic richness is extraordinarily high at the top of the slope (B25), where the soil is well drained, and it is very low at the bottom of the slope, where the land is flooded during the wet season and becomes dry in the dry season (B27). Tree height decreases from top to bottom of the slope. The dominant trees at the top are *Erythroxylum tortuosum* and *Curatella americana*. Herbaceous species are dicots on the dry lands, and graminoids and two lycopods on wet lands. There are some palms at the bottom of a trough-shaped valley. The sequential change described above seems to be controlled mainly by the soil moisture regime.

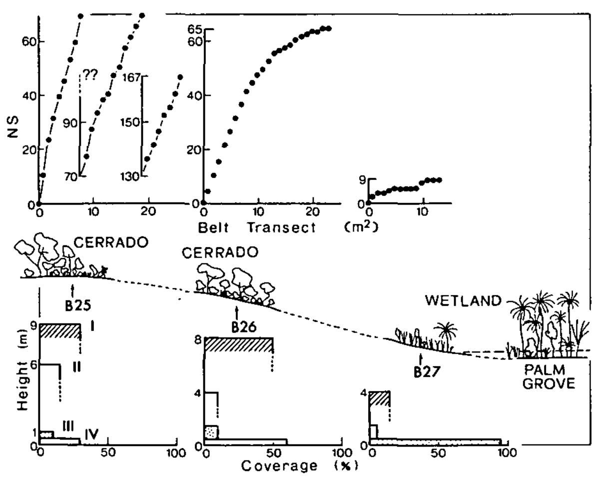


Fig. 51. Vegetation change in relation to drainage condition at Nova Xavantina in the Cerrado area.

(b) A slope with natural vegetation at Cruzeiro do Sul in the Tropical rain forest area (Fig. 52): Within the toposequence from the top of undulating high-terrace plain to pond, the height of evergreen trees ranges from 20–25 m to 5 m. This drastic change in tree height seems to be associated with the depth of surface soil. Maximum tree height on the slope has two modes (e-g and i-k in Fig. 52), and trees on the side slope (h) are shorter, because top soil on the slope has been washed away. Broad-leaved trees in the pond are dying, suggesting that the pond was created recently.

6–4. Vegetation in Relation to Land Use

Following are examples of the land use situations at various toposequence positions within a farm:

(a) A farm in the Cerrado area at Nova Xavantina (Fig. 53): Flat land at the top of a slope ('Chapada') was used for grain crop fields; the middle–low positions were used for pasture, and the pasture was utilized more intensively at the middle than at the lower positions in toposequence; and there was a gallery forest on terrace along a stream (B24a). Crop fields were free of trees, and thus, floristic richness was very low. On pasture land, trees were more frequent and taller, and the floristic richness was much greater at lower than at higher positions due, probably, to less disturbance by cattle and to better moisture condition of the soil at the lower position in toposequence.

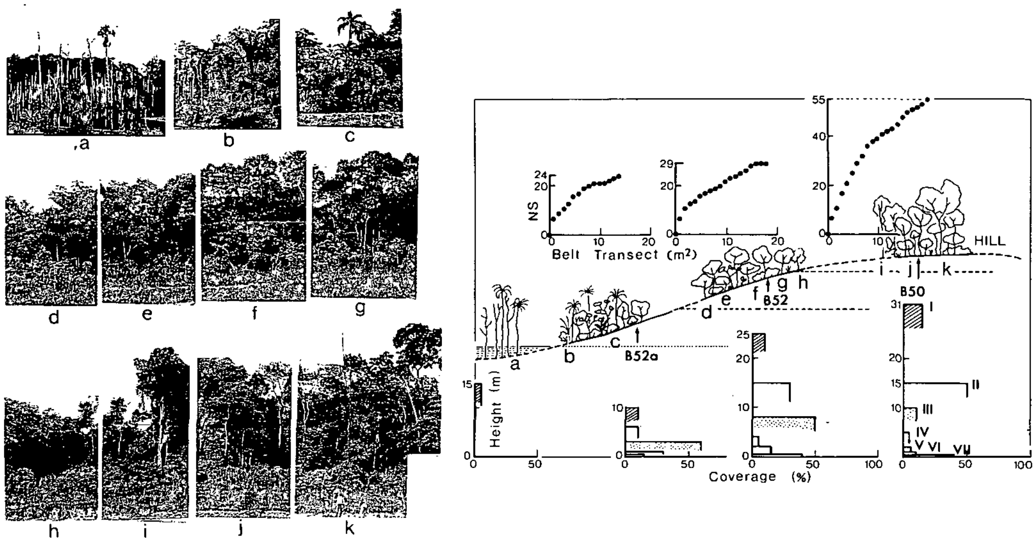


Fig. 52. Vegetation change in relation to microtopography at Cruzeiro do Sul in the Tropical rain forest area (s26).

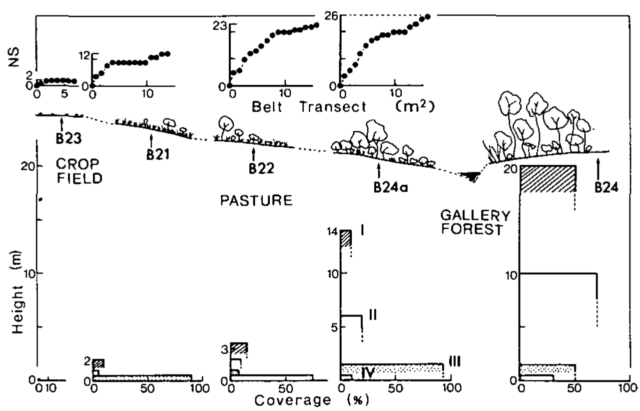


Fig. 53. Location of crop field and pasture along a slope at Nova Xavantina in the Cerrado area.

(b) Faz. São Carlos at Rondonópolis in the Cerrado area (Fig. 54a): A slope was used for improved pasture. The pasture was intensively managed by regular mowing; the intensity of management was less, however, at the bottom of the slope, because the land was wet and flooded in the rainy season. At a higher position on the slope (B35), *Brachiaria* species dominated under intensive management; at lower positions (B35a and B36) many kinds of trees were invading; and beside a swamp, Graminoideae and Lycopodiaceae dominated instead of shrubs (B37). The total coverage was similar among the various sites; but the floristic richness was apparently greater and the number of layers greater also at the edge of the pasture, where invading natural plants escaped mowing.

(c) Faz. Três Irmãos in the Transition vegetation area at Rondonópolis (Fig. 54b): On an old pediment at the top of a slope (B32), where the soil contains much coarse gravel, a forest of Tvg(Cer-Fds) remains, having a maximum tree height of 20 m and four layers. In a marsh along a stream at the bottom of the slope (s13), on the other hand, there is a mixed forest consisting of palm trees and semi-evergreen seasonal, broad-leaved trees. Lands on terrace at higher positions along the slope (B33) are used for pasture or crop fields; those on an alluvial fan at lower positions (B34) for coffee and rubber trees; and on the marsh at bottom there are sporadic irrigated rice fields.

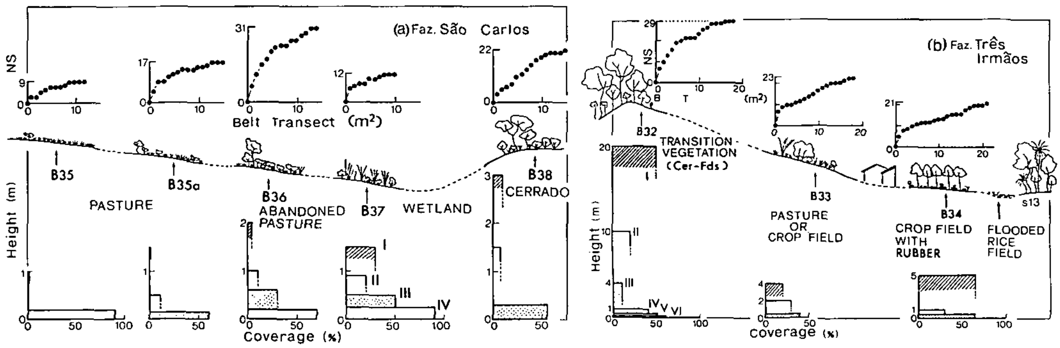


Fig. 54. Vegetation change in relation to land use associated with topography on two farms at Rondonópolis in the Transition vegetation.

(d) Faz. Italiano in the Cerrado area at Vilhena (Fig. 55): There are Cerradão at the top of a slope (B42), Cerrado at the middle position (B43), and crop fields on the almost flat land at the bottom of a trough-shaped valley (B44). A short distance from the crop fields, there is a forest of Transition vegetation, which is dominated by trees taller than 20 m with a total coverage of 150%, but with poor undergrowth. Judging from the situation observed, it was speculated that the lands between B42 and B44 were used for native pasture in the past. Several years ago the farmers discontinued cattle grazing and cleared the lands between B43 and B44. Crop fields have been developed so far only on B44. Because of this land use history, there is a Cerradão at B42 and a Cerrado at B43. It is suspected that the original vegetation on all sites (B42, B43, and B44) was Cerradão or Transition vegetation. Such a change from Cerradão at an upper position to Cerrado at a lower position in toposequence has been described by Silberbauer-Gottsberger and Eiten (1987).

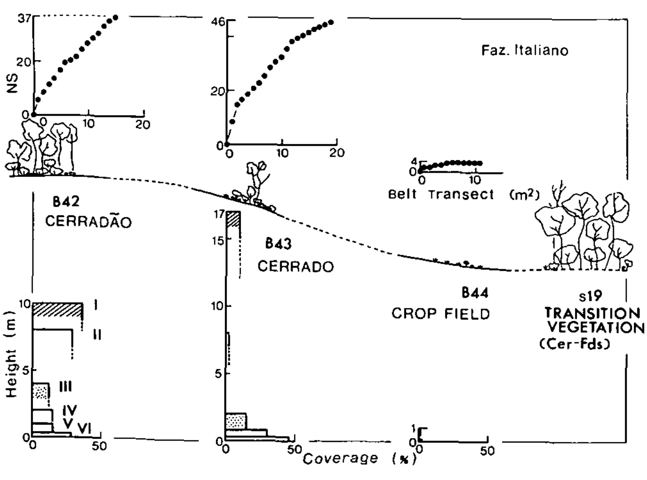


Fig. 55. Vegetation change from Cerradão to Cerrado in relation to land use at Faz. Italiano near Vilhena in the Cerrado area.

These examples demonstrate that (i) lands are used in various ways, such as for field crops, pasture, and tree crops, depending upon the characteristics of the lands, and that (ii) the floristic richness of utilized land increases from the invasion of natural flora caused by a decrease in the intensity of management, and also by an extension of duration under low management condition.

Some observations on revegetation after disturbances to natural vegetation have been conducted in recent years (Uhl, 1987; Uhl *et al.*, 1988; Hayashi, 1988). They concluded that reforestation after land clearing was very slow in Caatinga; and was also slow even in Amazon forests, when clearing was made on a large scale with heavy equipment.

In forest areas, the recovery of vegetation is much faster when a land is cleared by the slash-and-burn method rather than by the use of huge machines (Uhl *et al.*, 1982). In slash-and-burn shifting agriculture, the problem is to protect crop fields from quick invasion of natural flora. When a plot cleared by the slash-and-burn method is abandoned secondary forest establishes itself within a few months, because (1) the topsoil is not disturbed, (2) the stumps, roots, and rhizomes of plants from the previous forest are kept alive on/in the ground, since clearing is done in a crude manner, and (3) seeds of the natural flora are supplied from adjacent forests, since the size of cleared plots is generally small. In Amazon forests, trees grow 10−20 m in height during a 5-year period on land cleared by the slash-and-burn method (Uhl *et al.*, 1982). On the other hand, when clearing is done by big machines on a large scale, the speed of reforestation is very slow, because topsoil is disturbed completely, roots and rhizomes are destroyed, the supply of seeds from neighboring forest is less, and thus, it is hard for seeds to germinate and for young plants to anchor in the ground. Soil surface is also frequently disturbed by water runoff and soil erosion.

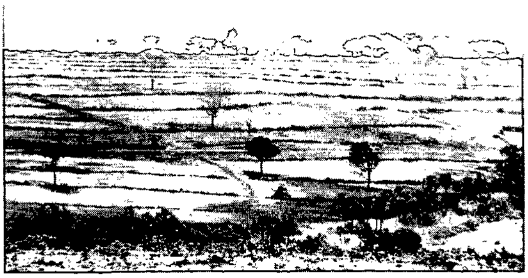
In the Cerrado area, the regrowth of vegetation after fire seems to be rather fast, since plants in this vegetation type have characteristics that enable them to tolerate fire, drought, *etc.* It was observed that the trunks of trees in Cerrado which were burned during the dry season grew more than 1 m within a month after the start of the rainy season. However, on a plot which was completely burned, the recovery of vegetation by seedings may be limited even for rapid-growing drought-tolerant species, because of severe water deficit and very high temperature of the surface soil during the long dry season. Since the albedo of a burnt surface is as low as 0.05−0.10 due to its black color (Frost and Robertson, 1985), the soil temperature, especially at the top few cm, becomes extremely high.

In the Cerrado area, natural savanna can be used as native pasture for grazing cattle, although the carrying capacity is very low; establishing improved pasture is, however, necessary to increase this capacity. On the other hand, establishment of improved pasture for pasture-cattle farming in the forest area is indispensable because useful native grass species are limited in dense forests. To maintain high productivity of improved pastures, weed control should be more intensive in the forest area than in the Cerrado area, because infestation by natural flora is more aggressive. Management of soil fertility should be, however, more intensive in the Cerrado area than in the forest area, because soil fertility is lower.

To establish crop fields on a large scale is far more expensive in the forest area than in the Cerrado area, because the biomass is much greater and the stumps and branches of large trees are more difficult to remove. It is also more difficult to maintain weed-free crop fields in forest areas than in the Cerrado area.

Tree crops such as rubber, coffee, cacao, and oil palm do better in forest areas than in the Cerrado area, because of favorable climatic conditions.

11a



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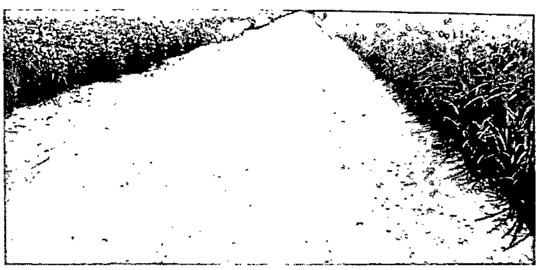

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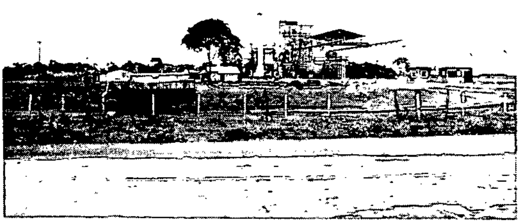

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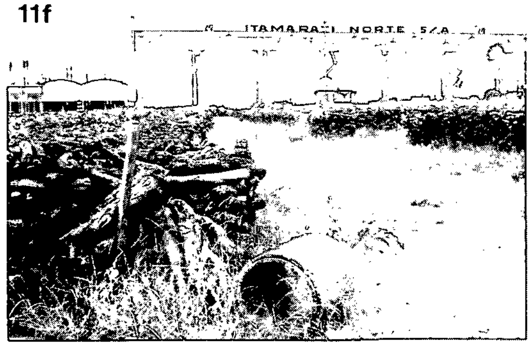
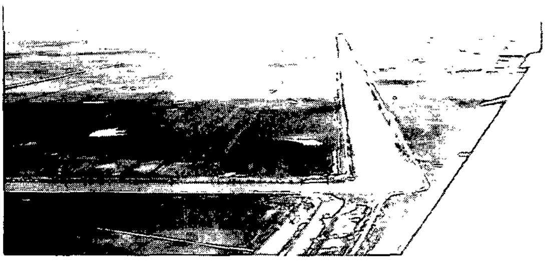


Plate 11. Field crop systems in the Cerrado area.

11a. Reclamation of the undulating upland. Removed stumps are lined up approximately on the contour. 11b. A large-scale mechanized field of soybean at Faz. Progresso in Mato Grosso (MT). 11c. ditto, of rice and soybean at Itamarati Norte S.A., MT. 11d. Intensively managed crop fields with a center pivot system in the Goiânia System. 11e. An alcohol plant near Alvorada, Goiás. 11f. Cerrado woods for fuel and grain silos in background at Itamarati Norte S.A., MT.

12a



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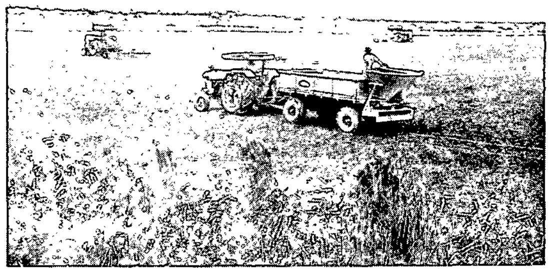

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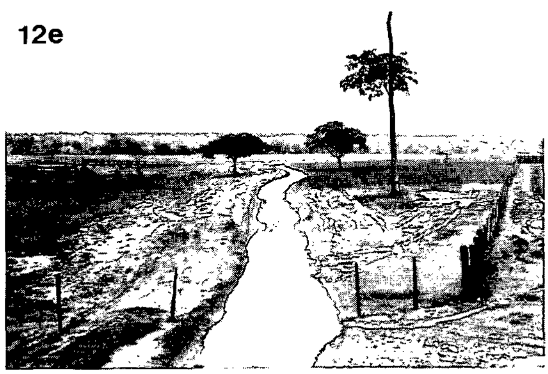


Plate 12. Irrigated rice cultivation in Vârzea.

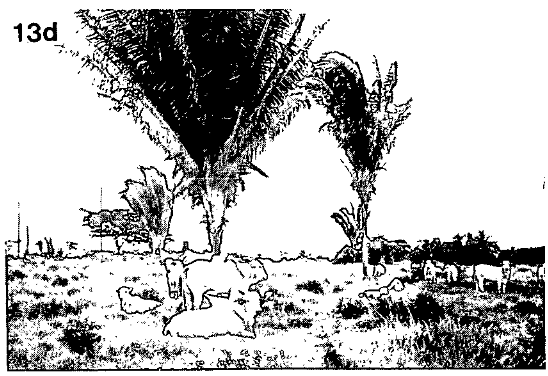
12a and 12b. Main irrigation canal and irrigated rice fields, and mechanized management at Cooperformoso in the Rio Araguaia lowland, respectively. 12c and 12d. Vârzea rice near Taquarussu along Rio Ivinhema in Mato Grosso do Sul and at Palmeiras in Goiâs, respectively. 12e. An irrigation channel for small irrigated rice fields near Cariri in the Gurupi System.

13a

13b

13c

13d



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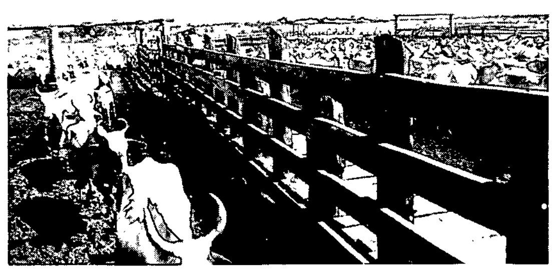

Plate 13. Pasture-beef cattle system.

13a and 13b. Cattle grazing on native and improved pasture in Cerrado. 13c and 13d. ditto in the forest area. 13e. Pasture plowed for renovation at Ouro Preto do Oeste. 13f. Cattle gathered from the Pantanal lowland at the beginning of floods at Faz. Bodoquena, Mato Grosso do Sul.

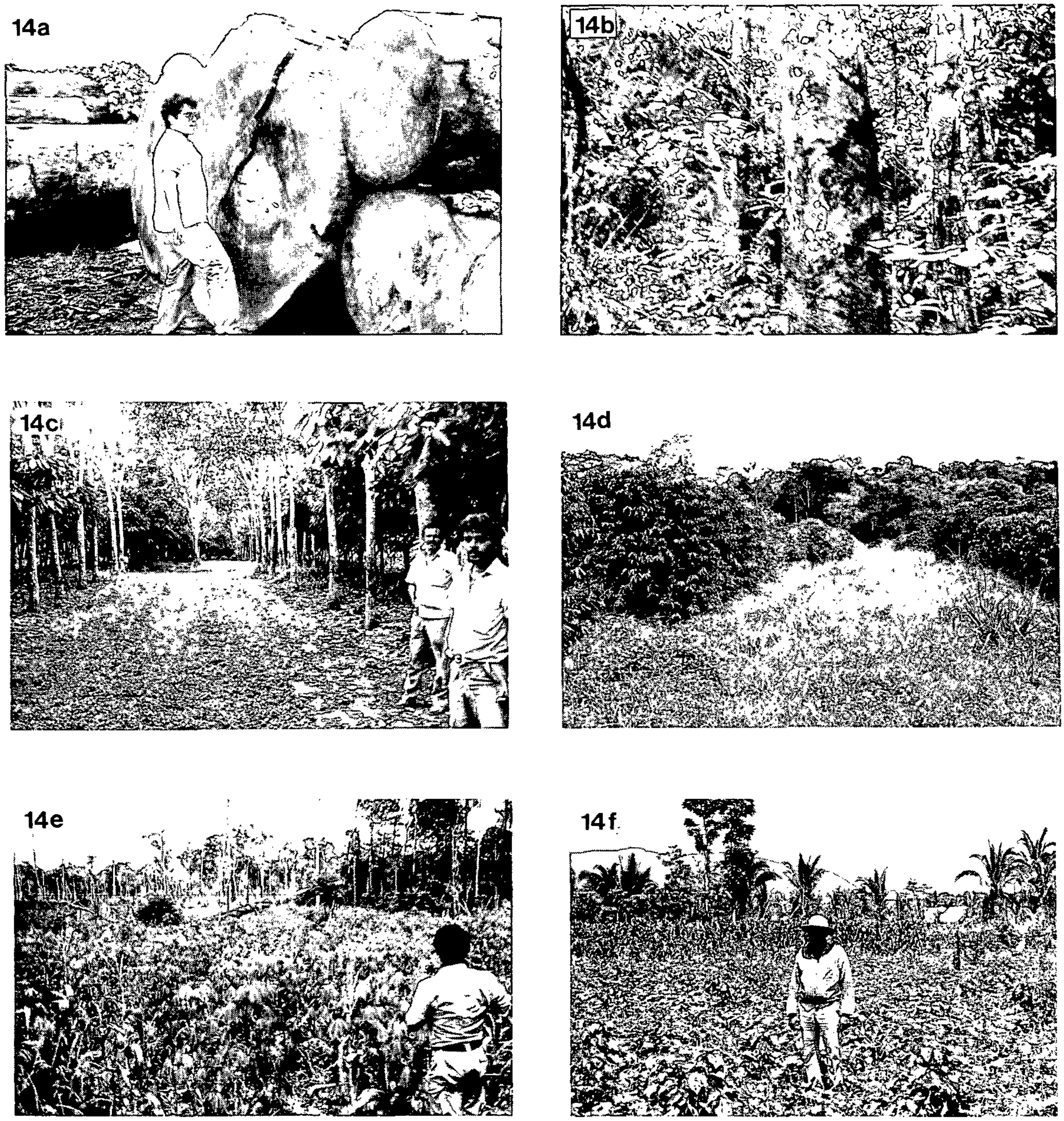

Plate 14. Land utilization in the Transition Region and the Upper Amazon Basin.
14a. Lumbering in the forest area. 14b and 14c. Natural and planted rubber trees in Rondônia, respectively. 14d. Coffee plantation at Ouro Preto do Oeste. 14e. Mixed cropping of maize and cassava in slash-and-burn shifting agriculture. 14f. Vegetable cultivation at a small farm in an Agro-Villa (Vale da Boa Esperança) in the Rondonópolis System. Similar Agro-Villa projects are going on in hilly areas of the Pantanal and in the Transition Region.

Forests in the survey area (Rondônia, for example) are being cleared very rapidly. Destruction of forests in the Amazon area is a world-wide concern at present. It is speculated that (a) the Amazon forest plays an important role in regulating global equilibrium of O_2 and CO_2 concentrations in the atmosphere through its huge capacity to photosynthesize, and (b) if the destruction of the forest continues, the supply of O_2 to living creatures decreases, and global temperature will increase due to the greenhouse effect caused by an increase of CO_2 concentration in the atmosphere. However, information available at present is not great enough to identify whether these speculations are correct or not. For example, there is no evidence that photosynthetic activity in the natural Amazon forest is higher than that of a tree crop plantation or a crop population under good management. Nevertheless, it is not desirable to destroy forests unnecessarily.

At present, there are government regulations to protect vegetation in Brazil. For example, (a) a certain percentage of farmland must be kept under natural vegetation or planted forests, (b) gallery forests along rivers should not be destroyed, and (c) any management enforced on the Pantanal lowland is prohibited, although cattle grazing on the native vegetation is permitted. There is no question about protecting nature if men can afford to feed themselves otherwise. In Brazil, population density is yet very low in comparison to that of other countries, such as the Asian. Moreover, some agricultural lands are not necessarily used to maximum efficiency. The need to protect valuable vegetation by rational methods is urgent in order to avoid unnecessary waste and destruction. By obtaining consistently high production of animals and crops from utilized lands, this can be done.

One question remains for a team member who has special interest in pteridophytes (Sato): Why is the pteridophyte flora so poor in the survey area ? There was no fern species at 35 sites out of the 40 surveyed in the Cerrado area. The number of species encountered during this survey was about 1,000 in seed plants, but only 20 in pteridophytes. Tryon and Conant (1975) recorded 279 species of pteridophytes in the Amazon Basin. Whereas this number was almost one third of those found in Japan, this country comprises only one tenth the total area of the Amazon Basin.

7. FARMING SYSTEMS

7—1. Farm Size and Land Price

7—1—1. Farm size

The mean size of farms in Brazil is 64 ha (Table 31). By region, it is smaller in Nordeste and Sul, larger in Norte, and very large in Centro-Oeste depending upon conditions of natural environment and the developmental history in each region. The mean size by state in the survey area is in the order of Mato Grosso do Sul > Mato Grosso > Goiâs > Acre > Rondônia. It is as large as 570 ha in Mato Grosso do Sul, and is 75 ha in Rondônia.

Variation of farm size is very large also within each state. There are many farms with less than 10 ha, but some farms comprise more than 10,000 ha. This situation indicates the diversity of farming systems in the area. Large farms are operated with many employees and seasonal labor, and farmers of small farms work at large farms as seasonal laborers. There are differences in the distribution of farm size among states in the survey area: In Mato Grosso do Sul and Mato Grosso, more than 80% of the farmland encompasses farms larger than 1,000 ha, and more than 30% of farms larger than 10,000 ha, although there are many farms smaller than 10 ha. In Goiâs, on the other hand, 42% of the farmland is owned by farms within the range of 100—1,000 ha, and farms larger than 10,000 ha and smaller than 10 ha are fewer here than in other states. This means that the farm size is smaller but more uniform in Goiâs than in Mato Grosso do Sul and Mato Grosso. In Rondônia, farms within the range of 10—1,000 ha occupy about 70% of the total number of farms and the total land area. Farm size is generally smaller in Rondônia than in Centro-Oeste. The situation in Acre is somewhat different from that in other states, for the distribution of farm size appears to be bimodal: There are many farms with 10—1,000 ha, but the proportion of the acreage belonging to large farms with more than 10,000 ha is also considerable.

Table 31. Farm size by region and state in the survey area (1985).

Region or State	Percentage of farm number with various sizes (ha) in total farm number					Percentage of farm area occupied by farms with various sizes (ha) in total farm area					Mean farm size (ha)
	<10	10 to 100	100 to 1,000	1,000 to 10,000	10,000<	<10	10 to 100	100 to 1,000	1,000 to 10,000	10,000<	
Brazil	53	37	9	0.8	0.04	2.7	18	35	29	15	64
Norte	33	50	16	0.8	0.06	1.4	21	30	21	27	90
Nordeste	71	24	5.1	0.4	0.01	5.4	23	39	23	8.9	33
Sudeste	36	50	13	0.8	0.02	2.2	23	47	23	4.8	74
Sul	42	52	5.4	0.5	0.005	5	34	36	22	3.4	41
Centro-Oeste	23	40	31	6.2	0.4	0.3	4.5	26	43	27	370
Goiás	16	42	36	5.1	0.1	0.3	7.3	42	43	7.8	265
Mato Grosso do Sul	27	34	26	10	0.8	0.2	2.2	17	49	31	567
Mato Grosso	33	38	22	6.3	0.8	0.3	2.9	13	37	46	487
Rondônia	28	52	19	0.5	0.04	1.6	33	36	16	14	75
Acre	8.3	51	40	0.8	0.07	0.2	16	43	10	31	168

Data source: IBGE (1987).

In the survey area, there were various development projects which were organized or promoted by the government or cooperatives. During the 1970's, for example, INCRA requisitioned a vast area of unused Cerrados and allocated these lands for development. The development area was then divided into lots of a certain size, and these were assigned to individual immigrants. The size of each lot was an optimum size to be managed by family labor plus some seasonal labor with reasonable machinery in some cases; but other immigrants received only a minimum-size plot of land for survival by farming with minimum equipment.

For development projects in Cerrado, lands were cleared and converted into crop fields by the project authority; these lands were then divided into lots and assigned to immigrants mostly from the southern states who possessed experience in farming and also funds to pay for land and equipment. Lot size was 400—600 ha in the early 1980's, but is generally 300—400 ha at present. The fund required for immigrants is considerable, but they can be quite successful if their management is reasonable.

In the Rio Formoso Project of the Goiâs Government, 5,200 ha of rice fields with irrigation and drainage facilities was established in 1979 in a Vârzea of Rio Formoso near Gurupi, and the fields (average size about 150 ha) were assigned to 34 farmers.

In Rondônia were various development projects. Immigrants to this area were mostly from Nordeste, and had fewer funds than those in Cerrados. Lands with native vegetation were divided into lots and assigned to each immigrant. The size of a lot was generally 100 ha at the early stage (about 1975), although some immigrants obtained a larger lot (250–260 ha). It required 5 to 7 man-days to open one hectare of forest by ax, but less than 3 man-days by chain-saw. Many immigrants opened forests only with axes, since they did not have funds to acquire chain-saws. Gradually, the lot size became smaller due to scarcity of lands, and it is sometimes only 25 ha at present. Many farmers in this area are not rich; they can survive with the food produced on their own farm, but cash income is generally very small.

7–1–2. Land price

The land price around Goiânia is about US$2,400/ha (Table 32). It is higher than that of other places in the state because a farmer with 100 ha of land can be successful by growing vegetables and keeping dairy cows. The land price of Cerrados in Formoso do Araguaia is only one twentieth of that around Goiânia; on the other hand, a farmer has to have at least 1,000 ha to maintain his farm due to the high transportation cost of farm products. At Silvânia, which is not very far from Goiânia, there are very cheap lands because these can be utilized only as native pasture due to poor fertility of the soil. In Terenos county near Campo Grande in Mato Grosso do Sul, a wide variation in land price was mentioned, depending upon the nature of soil; good lands demand a high price (US$2,000/ha), but the price of lands with poor soils is less than one tenth that of those with good soils.

In Rondônia (at Presidente Medici, for example) there are Cerrado as well as forests ('Mata'). Because soils are better, the land price is much higher in the forest area than in the Cerrado. The land price of Cerrado in Rondônia, however, is almost one fourth that near Goiânia. With a given fund an immigrant can acquire much more land in Rondônia than in Goiás, but the farm size is generally larger in Goiás, because farmers there have more funds.

Table 32. Land price at various locations in the survey area (rough information collected during the survey).

State	Location	Specification	US$/ha1)
Goiás	Around Goiânia	-	2,400
	Near (North) Goiânia	-	1,200
	Silvânia	Poor soil	300
	Jataí	-	700
	Formoso	-	120
Mato Grosso	Terenos	Good soil	2,000
	Terenos	Poor sandy soil	200
Rondônia	Presidente Medici	Cerrado	90-180
	Presidente Medici	Forest	600

1) At US$1.00 = Cz$77.00 [Official rate on January 15, 1988]

7–2. Situation of Land Utilization

7–2–1. Statistics on land utilization

Farmland : In Brazil, farmers can be classified into four categories based on the nature of the right to manage farmland: (a) Farmers who manage land with their own legal ownership, (b) those who manage fixed land, borrowing continuously (tenant), (c) those who manage land, borrowing for a few years and then moving from place to place ('parceiro'), and (d) those who manage certain land for a considerable period without any settled legal right. Lands with some kinds of farming rights are referred to here as farmland.

Farmlands occupy only 45% of the total area of Brazil (Table 33). The percentage is very low (13%) in Norte, especially in Amazonas (4%), where development activities are yet very low. As there are lands used for houses, factories, roads, *etc.*, the percentage of farmlands cannot be 100%. Thus, high values in Sudeste and Sul (above 80%) indicate that there is no no-man's territory in these regions; whereas, no-man's territories are plentiful in Norte, and remain, to some extent, in Centro-Oeste. In the survey area, the percentage of farmlands occurs in the following order: Mato Grosso do Sul (89%) > Goiás (74%) > Mato Grosso (43%) > Acre (39%) > Rondônia (25%).

Table 33. Situation on land utilization from various regions in Brazil (1985)[1].

	Total land acreage (1,000 km²)	Farmland (% against total land)	Utilized land (% against farmland)	Pasture[2]	Crop field	Improved[2] pasture (% against pasture)	Perennial crop field (% against crop field)
				(% against utilized farmland)			
Brazil	8,451	45	60	77	23	38	19
Norte	3,551	13	16	72	28	53	33
Nordeste	1,540	60	52	70	30	29	29
Sudeste	919	80	80	77	23	41	28
Sul	562	87	73	59	41	27	6
Centro-Oeste	1,879	62	63	90	10	42	4

1) Data source: IBGE (1987), except the figures of pastures.
2) Data source: Mattos et al. (1986) [Data in 1980].

Utilized farmland : Of farmland area, 40% is not utilized in Brazil. It was mentioned during the survey that government regulation stipulates that (a) 20% of the farm area of any farm, (b) lands within 100 m distance from a river, and (c) lands with a slope greater than 45° must be kept under natural vegetation or forests. Thus, it is understandable that the percentage of utilized lands is not 100% even in the most intensively used area. Nevertheless, the percentage is very low in Norte, indicating that a sizable land area owned by farmers is not fully utilized. The percentage in Centro-Oeste is 63%. This means that if a person has land, he is using most of that land for some purpose.

Lands used for pasture : Of all utilized farmland area, 77% is under pasture in Brazil. The percentage is higher in Centro-Oeste, indicating that pastures are very dominant in this region.

Pastures can be divided into native pasture and improved (planted) pasture. Improved pasture occupies 38% of the total pasture area in Brazil. This percentage is higher in Norte.

Crop fields : Crop fields occupy 23% of the utilized farmland area in Brazil. This figure indicates that crop fields occupy only less than one third of the pasture area. As the percentage of pasture is very large, crop fields occupy only 10% of the whole in Centro-Oeste.

Of crop fields, 19% is used for perennial crops and 81% for annual crops in Brazil. The percentage for perennial crops is high in Norte (33%), indicating that these crops are important there. It is, however, very low in Centro-Oeste (4%), indicating that annual crops are far more dominant. The percentage of perennial crops in Goiás, Mato Grosso, Rondônia, and Acre are 3, 6, 42, and 24%, respectively. Perennial crops are important in Rondônia.

7−2−2. Situation of land utilization in the survey area

Information collected during the survey on land areas under various conditions in selected counties or farms is given in Table 34. The method of collecting data was not systematic: Some data were on a county in which various types of farms were included, and others were on farms of extremely different sizes. Moreover, the number of cases studied was very limited. Thus, it may not be rational to discuss further these data; nevertheless, some comments are made below.

Table 34. Situation on land utilization in selected counties or farms in the survey area.

County or Farm	Total acreage (1,000 ha)	Native vegetation or secondary forest (% against total acreage)	Pasture		Crop	
			Native	Improved	Perennial	Annual
			(% against utilized acreage)			
Palmeiras county, GO	209	20	85		-	15
Silvânia county, GO	429	25 (Cerrado 21, Forest 4)	57	31	-	12
Terenos county, MS	400	40 (Nat.veg. 20, Forest 20)	41	38	-	21
Faz. Bodoquena, MS	350	26	66	32	-	2
Faz. Progresso, MT	3	47 (Including unused pasture)	-	-	-	100
Itamarati Norte S.A., MT	100	40	-	10	-	90
Farmer A, RO (Ouro Preto do Oeste)	0.26	8	-	41	54	5
Farmer B, RO (Ouro Preto do Oeste)	0.10	10	-	55	28	17
Faz. Presidente Hermes, RO (Presidente Medici)	15	95	-	100	-	-
Farmer C, RO (Near Porto Velho)	0.016	63	-	-	-	100

Nat.veg.: Native vegetation.

Palmeiras county and Silvânia county in Goiás, which are not very far from Goiânia, were surveyed. Generally speaking, soils are better in the former than in the latter. These are rather old settlements; for example, the development of Palmeiras started about 100 years ago. In Palmeiras, virgin lands including forests occupy 20% of the area. Of the utilized farmland acreage, 85% is for pasture and 15% for annual crops. In Silvânia, there are 2,115 farms with an average size of 205 ha. Cerrado plus forests occupy 25% of the total area. Of the utilized land, 88% is used for pasture (of which 57% is native pasture and 31% improved pasture) and 12% for annual crops. These figures demonstrate that in the areas not very far from Goiânia, 20−25% of the farmland is kept under natural vegetation (Cerrado) or forest (sometimes planted) by government regulation. Of utilized farmland, 10−15% is used for annual crops and the rest for pastures, of which more than half is native pasture.

In Terenos county nearby Campo Grande in Mato Grosso do Sul, there are about 700 farms with an average size of about 500 ha. The situation here is similar to that of the counties near Goiânia described above, although the acreage under forest and for annual crops is larger in Terenos. In this county, the poultry industry is active.

Faz. Bodoquena is an example of huge beef-cattle farms in the Pantanal Region. It started operation about 70 years ago with 350,000 ha. Utilized lands occupy 74% of the total acreage, of which 66% is in the Pantanal lowland, 32% is used as improved pasture on hills with good soils, and 2% is under field crops managed by a parceiro to establish new improved pasture from hilly forests.

Faz. Progresso is located in a Cerrado area far north of Cuiabá, and is an example of successful grain production farms on Cerrado in Mato Grosso. The owner acquired 3,000 ha of land including some forests and intended to establish improved pasture by planting *Brachiaria decumbens* in the early 1970's. Later, however, he decided to become a grain farmer and started to grow rice (upland rice in this report unless otherwise mentioned) by converting the pasture to crop fields in 1976, more emphasis being given to soybean from 1978. At present, 47% of his land is under native vegetation or abandoned pastures, and 100% of the utilized land is used for grain crops. Neighboring cattle sometimes graze on his old pasture.

Itamarati Norte S.A. is an another type of Cerrado grain production farm in Mato Grosso. It is managed by a company with large capital. The company began to operate in 1975 in a remote area with 100,000 ha of land on Chapada dos Parecis. They constructed a road to reach the highway, houses for workers, and facilities for processing the harvested grains, *etc.*, and the farm is equipped with all necessary heavy machines. At present, 40% of the total area is kept under natural vegetation for environmental protection; and of the utilized land, more than 90% is used for grain production. The rest is given to pastures for dairy cows for the purpose of efficiently utilizing wastes from the farm, such as rice bran and broken grains.

In Rondônia, farmers are classified into three categories: 'Fazendeiro' (more than 500 ha), 'lote' (50—100 ha), and 'ribeirinho' (small subsistence farmer living along rivers). In this area, people were previously living only along rivers because there was almost no road. Immigrants started to settle in about 25 years ago; development projects became active about 15 years ago, and were accelerated after completion of the highway from Cuiabá to Porto Velho in 1984.

Farmer A and Farmer B are lotes, who were immigrants under the government resettlement projects. Since Farmer A settled earlier (in 1975) and had more funds than Farmer B, he was assigned to a larger lot (260 ha) than Farmer B (100 ha). In both cases, only somewhat less than 10% of their land is under natural forest and the rest is used for improved pasture, perennial crops, and annual crops. Between these two farms, there is a clear difference in the farming systems based on preference and skill: Farmer A gives more emphasis to tree crops and pasture, and in contrast, Farmer B to pasture and annual crops.

Faz. Presidente Hermes is an example of fazendeiros. The owner, who lives in a city, acquired 15,000 ha of land with virgin forest some 50 years ago. He was able to get a considerable income by extracting valuable trees from the forest, and then the land was kept idle for a long period. As the highway was completed in 1984, he decided to establish a cattle farm on his land in 1985, began improved pasture by clearing the forest, and 5% of the land (800 ha) has, so far, been developed. In future it may become a large cattle farm. On the pasture, he keeps 2,000 head of calves, and sells 500 head every year by rearing calves from 150 to 225 kg live weight.

Farmer C is an example of ribeirinhos. He is borrowing 16 ha of land from a land owner without any specific obligation, and practices shifting agriculture by the slash-and-burn method. Of this land, more than 60% is kept under forest (mostly secondary forest), and the rest is being used for crops. These types of farmers are not few in the area. The landowner is getting nothing from ribeirinhos, but it is a way to protect his land ownership, and to make clearing the land easier when he decides to do so.

7–2–3. Utilization of Vãrzea

In the survey area there are various types of wetlands. Swamps in (a) depressions of the Brazilian Highland (Vãrzea da chuva), (b) overflow plains of large rivers, such as at Formoso do Araguaia (Vãrzea do rio), and (c) the vast lowland of the Pantanal. The land is flat and covered with characteristic vegetation mixed with some palms, such as *Mauritia flexuosa.* Although the wetlands are very different in size, these can be made into crop fields by providing drainage. On such fields, lowland rice is the most suitable crop, because the soil is moisture saturated or flooded during the rainy season, and more water is available even during dry spells than fields on uplands. Irrigated rice fields can also be made in these lands more easily than in ordinary lands because of the availability of water and because of topography.

In Brazil, rice growing conditions are classified into 'irrigado' (irrigated), 'Vãrzea' (swamp), and 'sequeiro' (upland). Of the total area given to rice in Brazil, 17%, 6%, and 77% are under irrigated, swamp, and upland conditions, respectively (Table 35). In the largest rice producing state, Rio Grande do Sul, irrigated rice occupies 95% of the total rice area, and the yield is more than 4 t/ha on average; whereas, in the states of Centro-Oeste and Rondônia almost all rice is produced under upland conditions, and the average yield by state is lower than 1.5 t/ha. Generally speaking, yield is high in irrigated rice, intermediate in Vãrzea rice, and low in upland rice. Although huge areas of Vãrzea exist in Brazil, they are hardly utilized at present.

Table 35. Percentage of acreage under various rice growing conditions in major rice producing states[1].

State	Production (1,000 ton)	Acreage (1,000 ha)	Yield[2] (t/ha)	Acreage under various rice growing conditions (% against total rice acreage)		
				Irrigated	Várzea	Upland
Goiás	1,356	1,070	1.27	3	1	96
Minas Gerais	952	588	1.62	9	26	65
Mato Grosso	799	594	1.35	0	0	100
Mato Grosso do Sul	276	220	1.25	9	8	83
Rondônia	279	159	1.76	0	0	100
São Paulo	543	313	1.74	7	0	93
Santa Catarina	451	140	3.21	54	0	46
Rio Grande do Sul	2,988	727	4.11	95	0	5
Piauí	380	250	1.52	5	0	95
Maranhão	1,292	937	1.38	-	1	99
Brazil	10,404	5,591	1.86	17	6	77

1) Data source: Teixeira (1987a). 2) In paddy.

During the survey, visits were made to observe two development programs of Vãrzea. One is an example of small programs. In Palmeiras county, there are small Vãrzeas in depressions on the highland, and their total area is 1,400 ha. It was decided to develop these Vãrzeas one by one in 1982, and by the 1987/88 season about 700 ha had been developed. The method of development is very simple: Natural vegetation was removed and drainage channels and contour-line dikes were constructed, all manually. At present, water level in fields can be controlled reasonably well during the rainy season, and thus two crops of rice (or, rice and field beans) can be grown annually. The yield of rice per crop is 4.5 t/ha on average and the maximum yield so far obtained is 10 t/ha.

Another is an example of large programs. There are 2.5 million ha of Vãrzeas, which can be developed, along the Rio Araguaia system in Goiãs and Mato Grosso. Cooperformoso is a cooperative, which manages 5,200 ha of irrigated rice fields. A Vãrzea area was developed along Rio Formoso, a branch of Rio Araguaia, by the Rio Formoso Project of the Goiãs Government. In March 1979, they started to reclaim the area, which was very flat (20 cm/km inclination) and with Vãrzea vegetation; constructed a large water reservoir and roads; cleared the land and divided it into plots (about 1,000 m × 250 m) by making roads and drainage and irrigation channels for each plot; assigned these plots to farmers; and by November of the same year, farmers had sown lowland rice in the plots. At present, Cooperformoso consists of 35 member farms (average size 150 ha) and possesses a full set of grain processing and storage facilities. Crops are managed by individual farmers, but water management and processing, storing, and marketing of products are done by the cooperative. The average yield of rice is about 5 t/ha. Rice is doing well, although there are some problems such as zinc and sulfur deficiencies and iron toxicity. In some years, it is not possible to plant rice in all fields because of a water shortage. In such years, about one sixth of the plots are given to soybeans. After Cooperformoso, Cooperjaba, and Coopergram were established, and 34,000 ha of Vãrzeas in this area are going to be converted to irrigated rice fields by these cooperatives.

These examples demonstrate a huge potential production of rice by developing Vãrzea. It should be mentioned here that fields for irrigated rice, which are properly terraced and enclosed by ridges, serve as water reservoirs and protect lands from soil erosion.

7−3. Types of Farming Systems

A farmer operates his farm by using a specific farming system, and Fig. 56 illustrates the major farming systems in the survey area.

7−3−1. Cerrado area

a. Native pasture-beef cattle system : Traditionally, extensive beef cattle grazing on native pastures with minimum input was and still is the dominant system in the area. The only management on native pasture is to put fire on dried pasture by the end of the dry season.

b. Improved pasture-beef cattle system : More recently, beef production in Cerrado has been intensified by establishing improved pastures. During the process, Cerrado or native pastures are cleared, upland rice is grown for 1−3 years with lime and phosphorus application, and then, improved grasses are sown. As the soil fertility is increased by fertilizer application to rice, grasses introduced and established after rice grow better. To maintain productivity of the improved pasture, it is necessary to renovate the pasture every 5−7 years by growing rice. By assuming that an improved pasture is renewed every 6 years, with two rice crops in each pasture renovation period, rice occupies one fourth of the farm. Thus,

```
                            <<<  Cerrado  Area  >>>
a. Native Pasture - Beef Cattle System
     Cerrado --x--> Native Pasture ------------->
b. Improved Pasture - Beef Cattle System
        Cerrado
          or        --+--> Rice (1-3 y) ---> Improved pasture (5-7 y) --+--> [Repeat]
     Native pasture
c. Grain Crop System
        Cerrado
          or        --+--> Rice (1-2 y) --x--> Soybean (7-8 y) ---> Maize (1 y) --+--> [Repeat]
     Native pasture
                            <<<  Forest  Area  >>>
d. Shifting Cultivation System
                    Rice, Maize or Beans (2 y)
     Forest --+-->              +              ---> Secondary forest (Several y) --+--> [Repeat]
                         Cassava (3 y)
e. Tree Crop System
                         Grain crops (2-3 y)
     Forest --+-->              +                   --+--> [Repeat]
                    Caffee, Cacao or Rubber (app.30 y)
f. Improved Pasture - Cattle System
     Forest --+--> Rice (1-3 y) ---> Improved pasture (6-8 y) --+--> [Repeat]
```

--+--> ..... --+--> : Repeated cycle.   y : year

Fig. 56. Major farming systems in the survey area.

upland rice is an important component in the improved pasture-beef cattle system. In a sense then, this system is a rotation between pasture and rice.

Rice, associated with improved pasture, is frequently grown by parceiros. When the owner of a beef cattle farm decides to establish an improved pasture from virgin land or to renovate his old pasture, he lends the land to a parceiro. The parceiro moves in with his equipment and grows rice by applying fertilizers for a few years; then he returns the land to the owner and moves away. Contract between landowner and parceiro differs from case to case. For a parceiro in Palmeiras county, the contract was as follows: 45 ha of old pasture was lent to the parceiro; he plowed the pasture land, applied fertilizers, and grew rice for three years; when rice was sown in the 3rd year, improved grasses also were sown; after harvesting the rice, he returned the land, on which improved pasture had now been established. The parceiro paid nothing to the landowner, but the owner got a new improved pasture. In the case of a parceiro who was operating at Faz. Bodoquena, he borrowed 5,000 ha of land, which was newly cleared from forests and plowed by the owner. Then he moved into the area with heavy equipment, grew rice (1,500 ha), soybeans (3,000 ha), and maize (500 ha) with fertilizer application for 5 years, after which he returned the land to the owner and moved out of the area. For use of the land he paid 20% of his products at each harvest to the landowner. In these cases, the overall farming system is a combination of the improved pasture-beef cattle system and the grain crop system operated by the landowner in association with a parceiro.

c. Grain crop system: Although the Cerrado area is poor in chemical properties of the soil, it is suitable for mechanized, high-input crop production, because the topography is suitable for establishing large plots for efficient operation with heavy machines. After the establishment of Brasília in 1960, the situation of roads and markets improved, development was accelerated by various government projects, and grain production became an important industry in this area.

Chapadão is typical of the topography suitable for large-scale mechanized crop production. On the Chapadãos in Mato Grosso do Sul, development by government policy has become active since the early 1970's. At the beginning, Cerrado vegetation was removed and coffee plantations established. But coffee plants suffered seriously from frosts in 1975 and again to some extent in 1978. By 1980, the emphasis was shifted to rice by the POLOCENTRO (Programa de Desenvolvimento dos Cerrados, 1975—1980), and then, soybeans came into the area in 1981. Soybean has become the most important crop in this area, because it is most suitable for large-scale mechanized farming and the market price is favorable. The standard size of such farms is 3,000—5,000 ha.

Yields of rice and soybean decrease when these are successively grown in a field. Thus, some farmers practice rotation systems. For example, in Faz. Progresso the rice - maize - soybean - soybean - rice system is used. This means that the crop fields are assigned to soybean, rice, and maize in a ratio of 2 : 1 : 1 by area. In Itamarati Norte S.A., the ratio is 2 : 1 : 0.5.

It is possible to combine the pasture-cattle system and the grain crop system into a single farming system, but it would appear that there is a tendency for the landowner to choose only one of them. The pasture-beef cattle system is a low input, long term business, whereas the grain crop system is a high input, short term business. Both systems can be big business if the farm is sufficiently large. If not large, however, the grain crop system is more profitable, although the work is harder. At present, government policy is to promote the grain crop system by providing loans for land development and soil management to crop farmers, but not to cattle farmers.

Farmers with limited land area near cities combine the raising of dairy cows, pigs, and poultry with horticulture, *etc.* into their farming systems to get maximum benefit, and so doing they can be successful.

7—3—2. Forest area

d. Shifting cultivation system : The regenerating power of vegetation in the forest area is much higher than that in the Cerrado area. Even if a forest is cleared by the slash-and-burn method and the plot is given to crops for a few years, a secondary forest regenerates very quickly when the plot is abandoned, and if the plot is not large, it is quickly engulfed by forest.

In shifting cultivation, forest and crop field are rotated at several-year intervals. The system followed by a ribeirinho near Porto Velho was as follows: After clearing a forest plot, rice, maize, and field beans are sown generally in mixture for the first year, and cassava is also planted with wider spacing in the same plot. When grain crops are harvested, cassava is left in the plot. In the second year, grain crops are sown and harvested again, but cassava is allowed to grow continuously. In the third year, as the plot is already covered with a canopy of cassava, no other crop is planted anew, and cassava is eventually harvested. The plot is then left for secondary forest to come in, and the secondary forest is allowed to grow 3—4 years until the plot is cleared again for cropping.

A ribeirinho along Rio Machado also practiced shifting cultivation. In addition to crop production, he manages a pasture on Várzea, on which he temporarily fosters a few calves from a nearby cattle farm for a fee. Some ribeirinhos in this area are earning cash by tapping natural rubber trees, and also live by hunting and fishing.

e. Tree crop system : This system is common in the forest area. After clearing a plot of forest by the slash-and-burn method, seedlings of coffee, cacao, rubber, or citrus trees are planted; rice, maize, field beans, or cassava are also planted in the same plot for a few years until the seedlings of tree crops grow large; and then, the plot is given over totally to the tree crops. It takes 4—6 years after planting to start harvesting coffee or cacao, and a few more years to start tapping rubber trees. More labor is needed to tap rubber trees than to harvest coffee. Neither fertilizers nor any large equipment are used to manage tree crops. The greatest investment in the tree crop system is the cost of seedlings,-which is quite high.

f. Improved pasture-cattle system : This system in the forest area is almost identical with that in the Cerrado area. There are, however, some differences between them, which will be described later.

Since the farm size assigned to immigrants in this area is generally small, their farming is mostly for subsistence. Even if a farmer intends to become a tree crop farmer, it takes quite a long time after planting to start harvesting the products of trees. Hence, it is necessary to combine two or three cropping systems. For example, a farmer at Ariquemes settled on 100 ha land 12 years ago; only 50 ha has so far been developed; out of the developed land, about 40% is under improved pasture on which 40 dairy cows are kept; the remaining 60% of the land is used for coffee, cacao, and rubber trees; and various field crops for home consumption are planted between the small trees. The farmer mentioned that a large proportion of his income at present was from the cheese he produced at home.

Besides these small farms, there is a limited number of large farms. They are engaged in the improved pasture-beef cattle system, but not in the grain crop or tree crop systems.

In Pimenta Bueno, there are Cerrados as well as forests. Following is a summarized comparison of the farm situation between these two ecosystems: In the Cerrado area, farm size is generally 500—1,000 ha; the improved pasture-beef cattle system is practiced, and some rice, maize, cassava, and pineapple, *etc*., are grown only for home consumption. On the other hand, farm size in the forest area is much smaller (50—100 ha), and grain crop, tree crop, and improved pasture-cattle systems are practiced.

7—4. Components of Farming Systems and Soil Fertility Management

7—4—1. Pasture-cattle systems

The pasture-cattle system comprises pasture and cattle. In the survey area, the proportion of cattle for beef, dairy, and beef-and-dairy is 84%, 6%, and 10%, respectively (1975). Beef cattle farming is far more dominant than dairy cow farming. Common breeds of beef cattle in this area are Nelore, Gir, and Guzera, which are subraces of Zebu. In the areas near Brasília and Goiânia, *etc*., dairy cows are raised on improved pastures, sometimes even with help from the protein bank. Some farms of medium size in Rondônia, in which the tree crop system is an important component, keep dairy cows such as Girolândia (Gir × Holândia), mostly for their own consumption.

Outline of beef cattle management is as follows (Fig. 57): By having 100 head of cows and 3—4 head of bulls on a farm, 70 head of calves are bred annually; from these calves, 35 head of bull calves are raised on the farm itself or in other farms for 36—40 months, and then sold to the market; 35 head of heifers are kept on the farm and start to mate 30 months after birth; and 35 head of old cows are sold out annually. The fattening of raised cattle is carried out by using the protein bank consisting of leguminous pastures (such as *Cajanus cajan, Calapogonium mucunoides,* and *Pueralia phaseoloides*), and soybean curd as protein supplement.

Native pasture is dominant in the Cerrado area. It is mostly comprised of *Andropogon, Trachypogon, Cymbopogon, Heteropogon, Aristida, Digitaria, Axonopus, etc.* Its carrying capacity is only 0.1—0.2 A.U. (A.U.: animal unit. 1 A.U. = 300 kg live weight) $ha^{-1}y^{-1}$, because

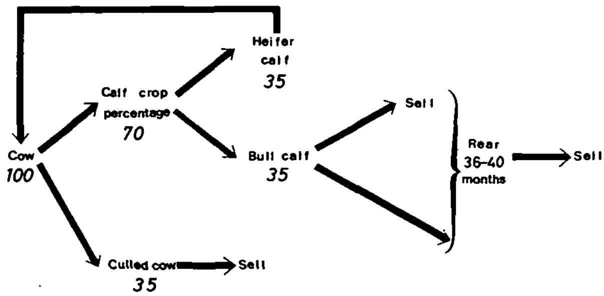

Fig. 57. A schema for balance of feeding, calf crop percentage, and marketing of beef cattle in the southern part of Goiás.
Figures indicate head number.

foliage productivity, palatability, and digestibility are very low during the dry season, although these are reasonably high during the first few months of the rainy season, when young shoots are emerging from the stubble which is burnt off at the end of every previous dry season.

For improved pasture, grasses such as *Panicum maximum* were introduced some time ago, but now these have been replaced by *Brachiaria decumbens* and *B. humidicola.* By the introduction of *Brachiaria* spp., the carrying capacity is increased to 0.5 – 1.0 A.U.$ha^{-1}y^{-1}$ due, mostly, to tolerances of low soil fertility and to water stress of these species, and also to the residual effect of fertilizers applied to rice crops before the land was used for pasture. Cattle suffer rather frequently, however, from deficiency of mineral elements, such as phosphorus, calcium, sulfur, and copper, even with the improved pasture. These minerals are therefore supplemented. This means that although the energy supply of pastures to cattle is improved by introducing improved grasses, mineral deficiency is sometimes, rather, promoted. Thus, to maintain high productivity in cattle breeding, attention should be given to meeting the physiological needs of the animals by providing not only energy, but also minerals and proteins. Fertilizer application, weed control, adequate stocking rate, *etc.*, are prerequisite to maintaining a stable and high productivity of cattle on pastures.

In Cerrado, the productivity of pasture in the dry season is less than one fifth of that in the rainy season. Due to insufficiency of feed, particularly protein, cattle lose live weight during the dry season. Therefore, the introduction of leguminous species, such as *Calapogonium mucunoides, Centrosema* sp., and *Stylosanthes* sp., into pastures is recommended, or else the establishment of a protein bank using *Leucaena leucocephala, Cajanus cajan,* and *Stylosanthes* sp., *etc.* These are, however, hardly practiced by farmers at present. Improving the productivity of pastures in the dry season is a key to fostering the carrying capacity of pastures in Cerrado.

In the forest area, after clearing trees, native pasture does not spring up spontaneously, because grass species are scarce under forest conditions. Thus, it is necessary to introduce grass species such as *Panicum maximum, Brachiaria* spp., and *Andropogon gayanus.* The mixing of leguminous species such as *Pueralia phaseoloides* with these grasses is recommended. The method of establishing an improved pasture in this area is as follows: Small trees and bushes in a forest are cut down, but large trees are kept standing because they are hard to cut; plant materials on the ground are dried for some period by sunshine, and then burned; even after burning, large trees are still standing although these are dead or surviving, and the trunks and stumps remain in the ground because they are difficult to uproot or burn completely. Grasses are then sown on the ragged land. Thus, it takes quite some years for a new pasture to become uniform and without obstacles. Because of this, it is extremely expensive to establish annual crop fields which can be operated by heavy equipment in the forest area.

The carrying capacity of improved pastures is 0.5–1.0 and 1.5–3.0 $A.U.ha^{-1}y^{-1}$ in the Cerrado area and in the forest area, respectively (Table 36). The higher carrying capacity in the forest area is due to greater feed production owing to a shorter dry season and better soil fertility. The situation may, however, change to some extent in future, since fertilizers are used in the Cerrado area, but not in the forest. It is said that beef cattle farms of adequate size in the forest area are richer than those in the Cerrado because of the higher carrying capacity of pastures. In the Cerrado area, for beef cattle farms of medium size, fertilizer application is indispensable in maintaining the farm profitably.

Table 36. Comparison of pastures in Cerrado and forest areas.

Area	Type of pasture	Carrying capacity ($A.U.ha^{-1}y^{-1}$)	Dominant pasture species	Management		
				Renovation interval (year)	Fertilizer in renovation	Weeding
Cerrado	Native	0.1-0.2	Hyparrhenia spp. Panicum spp. Andropogon spp.	-	None	Burning
	Improved	0.5-1.0[1)]	Brachiaria spp.	5-7	Yes	Burning or Renovation
Forest	Native	-	-	-	-	-
	Improved	1.5-3.0[2)]	Panicum maximum Brachiaria spp. Andropogon gayanus	7-8	None	Burning or Renovation

1) Ratio in the dry season to in the rainy season = 10-20%
2) ditto = 50%

Weed control is important in pasture management. Weeds are more aggressive in the forest area than in the Cerrado. Major weeds are *Vernonia* sp. and *Digitaria* sp. on fertile soil, and *Imperata brasiliensis* on less fertile soils. Weeding can be done by herbicide application, by burning during the dry season, or by disking the land. Herbicides are not generally used, however, because they are too expensive.

Faz. Bodoquena is an example of huge pasture-beef cattle farms in the Pantanal Region. Management of the farm is very different from that in the Cerrado or forest areas. The farm has 250,000 ha of pasture (70% natural savanna in the Pantanal lowland and 30% improved pasture on upland) and keeps 70,000 head of Nelore. During the season when there is no flood water in the lowland (August to January) all cattle except for bull calves are grazed there, and during the season when there is flood water in the lowland the cattle are transferred to improved pastures on upland. The stocking rate in the lowland is 0.2 A.U./ha in natural vegetation and that in improved pasture on upland is 0.5 and 1.0 A.U/ha during the dry and rainy seasons, respectively. Thus, the carrying capacity of overall pasture lands on this farm is about 0.3 $A.U.ha^{-1}y^{-1}$. Productivity is reasonably high, because natural vegetation in the lowland is reasonably abundant during the dry season due to favorable moisture and fertility conditions of the soil. There is, however, occasional danger of losing cattle by unexpected deep floods in the lowland. The reason why bull calves are kept on upland during the dry season is to avoid a decrease of daily weight gain due to too active wandering over a large area of lowland.

7—4—2. Crop systems

Crops : The ranking of areas planted in various major crops in Brazil is soybean ≒ maize > rice ≒ field beans > sugarcane > coffee ≒ cotton ≒ cassava > banana (Fig. 58). The area planted in wheat is 3.9 million ha (FAO, 1986), but it is omitted in Fig. 58, because detailed data were not available. Price of grains are in the order of field beans > rice = soybean > maize (Table 37).

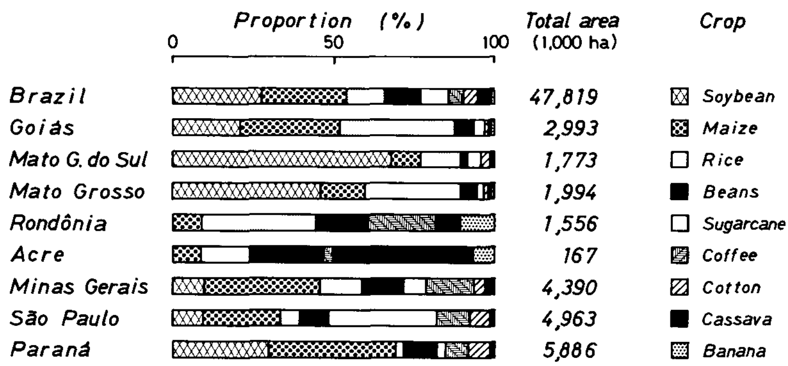

Fig. 58. Proportion of area assigned to major crops in selected states in Brazil (IBGE, 1983; Teixeira, 1987b). Data on Rondônia and Acre are from 1980 and those on other states are from 1985/1986.

Table 37. Price of grains in Brazil (US$/t)[1].

Crop		Government price	Market price
Rice[2]	Upland	154	235
	Irrigated	180	235
Maize		119	135
Soybean		139	225
Field beans		390	587

1) Data collected at Campo Grande in January, 1988 at exchange rate of US$1.00 = Cr$77.00.
2) In paddy [polished rice / paddy = 0.75]

In Centro-Oeste, where Cerrado dominates, three field crops, *i.e.*, soybean, rice, and maize, occupy about 90% of the area of crop fields. There are, however, considerable differences in the proportion of these crops among the states. In Goiás, the proportion of soybean is less because farm size is smaller. In Mato Grosso do Sul, soybean occupies 68% of the crop field area due to an enormous farm size generally. The situation in Mato Grosso is intermediate between these two states, probably because of a larger proportion of rice due to its earlier stage of field development. Some farmers grow field beans. As field beans do well only on fertile soils in cooler climate, they are grown at selected sites in the dry season, frequently with irrigation. In Cerrado, intentions are to establish coffee plantations, but the area planted in coffee is negligible at present. Cotton, cassava, and banana are also grown to some extent. Soybean and rice are grown on large farms, and field beans and cassava on small farms (Fig. 59).

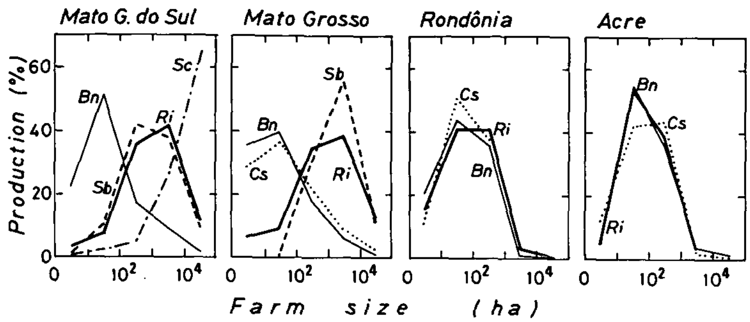

Fig. 59. Percentage of crop production in different farm sizes (1980).
Figures are based on the total production in each state (IBGE, 1983).

In Rondônia and Acre, as field crops are mostly for subsistence, various crops are grown, such as rice, field beans, maize, and cassava, but there is no clear difference of importance among them. These crops are often mix-cropped in a field; *i.e.*, the percentage of monoculture in the total harvested area is 30–60% in rice and maize, and 50–80% in field beans and cassava (IBGE,1983). Major tree crops in this area are coffee, rubber, cacao, and citrus.

Varieties : In soybean, IAC varieties were common in the Cerrado area (Table 38). They are, however, being replaced by new varieties. For example, in Rondonópolis county, among soybean varieties used by farmers in 1987–88, 40% was Cristalina, 20% was IAC 5, IAC 7, or IAC 8, and 20% was Engopa or Doko. Major varieties used at Itamarati Norte S.A. were Doko and Cristalina. These varieties are adapted to high soil fertility, and produce stable high yields in the Cerrado area with high inputs, owing to relatively long duration (45–55 days from emergence to flowering, and 110–140 days to maturity), even in low latitude areas (Kiihl *et al.*, 1985). They are also well adapted to mechanized planting and harvesting (relatively tall stature). Duration of seed viability and tolerance to *Cercospora sojina* are another important varietal trait in soybean.

Table 38. Varieties of grain crops grown in the survey area.

Soybean		Upland rice		Irrigated rice		Maize
IAC 5		IAC 25	[S]	CICA 8	[M]	C-111
IAC 7		IAC 47	[M]	CICA 9		AG-401
IAC 8	[S]	IAC 164	[S]	Metica 1	[M]	AG-40401
BR 10		Cuiabana	[M]	BR-IRGA 409	[S]	XL-685
BR 11		Rio Paranaíba	[M]			Contimax
Doko	[M]	Araguaia	[S]			
Engopa		Guarani	[S]			
Tropical		Central América	[M]			
Cristalina	[M]	Gabassou	[M]			
		Guaporé	[M]			

[S] Short duration : 105-115 days in rice and soybean and 110-115 days in maize.
[M] Medium duration : 125-135 days in rice and soybean and 140-145 days in maize.

In rice, IAC varieties are also dominant for upland rice throughout the survey area. There is no distinct difference in varieties between the Cerrado and forest areas. Among IAC varieties, IAC 25 and IAC 47 seem to be more widely grown: For example, these two varieties occupied 30−40% of the total in Rondônia. Several varieties were, however, recently released by EMBRAPA/ CNPAF. Many of them are crosses between IAC varieties and upland varieties in West Africa. These new varieties, such as Cuiabana, are rapidly adopted by farmers, especially by large-scale farmers in the Cerrado area. Blast resistance and drought tolerance are the important varietal trait for upland rice.

For Vârzea rice or irrigated rice, CICA 8, CICA 9, and Metica 1, which were released by CIAT-ICA in Colombia, are popular. At Cooperformoso, it was mentioned that they were able to obtain about 5 t/ha of paddy by introducing these varieties, because they can be used in the rainy season as well as in the off-season. However, CICA 8 is not sufficiently resistant to blast, and Metica 1 to *Helminthosporium* under these conditions.

In maize, hybrid varieties are extensively used by large-scale farmers in the Cerrado area. For example, at Itamarati Norte S.A. AG-40401 (Agroceres Co.) was most widely used, followed by XL-685 (Braskalb Co.) and C-111 (Cargill Co.). At Faz. Progresso, Cargill varieties, such as C-111, C-317, C-525, and C-115, were grown. No information on maize varieties was given in the forest region. Small-scale farmers are, however, most probably using only local open-pollinated materials.

Yields : The average yields of soybean and maize in Centro-Oeste are higher than those in the whole of Brazil, indicating that the region is suitable for these crops (Table 39). Rice yield in this region, on the other hand, is lower because of a higher yield in the southern states, where irrigated rice is common. Of the total production in Brazil, Centro-Oeste produces more than one third of the national soybeans due to its large area as well as to its high yield, and one fourth of its rice due to a large area given to rice cultivation.

Table 39. Average yield of various crops in Brazil and Centro-Oeste (1986/87).

Crop	Yield (t/ha)		b/a	Centro-Oeste/Brazil (%)	
	Brazil [a]	Centro-Oeste [b]		Area	Production
Soybean	1.84	2.05	1.11	31	34
Maize	1.98	2.56	1.29	12	16
Rice	1.73	1.32	0.76	36	28
Field beans	0.40	0.46	1.15	5	6

Data source: Teixeira (1987b).

The Jataí - Santa Helena - Quirinópolis triangle in Goiás is called the 6−4−3 farm area, which means the yields of maize, rice, and soybean in this area are 6, 4, and 3 t/ha, respectively. These figures may not be without some exaggeration, but give indication of the situation. The standard farm size in this area is 2,000 ha, and one soybean field is generally more than 100 ha. It is a typical large-scale, mechanized, productive, grain crop farming area.

Average yields of various crops on farms visited during the survey (Table 40) were slightly higher than the averages in Centro-Oeste. There are tendencies toward higher yields in Mato Grosso, especially in Rondônia. Maximum yields obtained by farmers, which were mentioned during the survey, are 3.5 t/ha in soybean, 2.5 t/ha in upland rice, 10 t/ha in Várzea rice, and 6 t/ha in maize.

Table 40. Average yield of various crops on farms visited during the survey (t/ha).

State	Soybean	Rice	Maize
Goiás	2.3	1.4	-
Mato Grosso do Sul	2.2	1.5	2.9
Mato Grosso	2.5	1.8	4.0
Rondônia	-	2.5	4.1

Crop rotation : When a crop is planted in a given field successively, the yield often tends to decrease from one season to the next. This tendency is most prominent for rice in the Cerrado area. For example, an experiment conducted in Goiás demonstrated that the yield of rice was 2.07, 1.02, and 0.40 t/ha in the 1st, 2nd, and 3rd year, respectively.

The reason for this decline is not very clear, yet. The yield decline is not so acute in soybean as in rice: The yield of 2 t/ha in the 1st year may become 1 t/ha after four crops of soybean. The major reason for this decline is the increase of weeds and soil compaction from continuous soybean growing. However, some farmers grow soybeans for seven or even ten consecutive years in the same field without serious yield decline, probably because weeds are not so aggressive in the field.

In maize, the yield decline from continuous cropping is negligible. Maize is not generally grown continuously, however, because it is less profitable. The major reason for the inclusion of maize in a crop rotation system is that weeding of soybean fields is very expensive, and weeds in a field are efficiently depressed by growing maize due to its dense leaf canopy during growth, and also it provides a thick cover of dried stovers on the ground during the dry season after harvesting. Maize also makes the depth of rhizosphere greater.

For of these reasons, the most common rotation system for grain crops in the Cerrado area is rice (1—3 years after reclamation), soybean (several years), maize (1 year), soybean (several years), and so on.

Land development and field preparation : As lands in the Cerrado area are flat, they are naturally suited for the operation of heavy machines. It is not difficult to remove trees, since these are not too dense and large. By pulling a strong chain across a plot with two heavy tractors at both ends, all trees are uprooted. These trees are used to make charcoal or sometimes as fuel to operate facilities for processing harvested grains. After removing trees, fire is set during the dry season to remove remaining bushes and weeds. Then, 16 or 24 inch disc-harrowing is done. This operation is very efficient, because the plots are flat and large, and the soil is friable. For example, a large tractor (350 HP) is able to prepare a 100 ha field per day. Disc-harrowing is also commonly adopted to renovate old pastures or to prepare crop fields for planting the next crop. By means of this operation, plant materials left on newly opened Cerrado land, remaining grasses in old pastures, or residues of previous crops are incorporated into the soil. By start of the rainy season, fields may be disc-harrowed again, and the land is ready for sowing crops.

Plowing is not common because it is inefficient and causes soil compaction. Sometimes, disc-plowing (25—30 cm depth) is practiced every 3—4 years to make the effective soil layer deeper, especially for maize.

It is indispensable that crop fields be protected from soil erosion as it could become a serious problem in the Cerrado area. In almost all fields, counter line ridges (more than 60 cm in height) are established at certain distances to prevent water runoff across the slope, depending upon the degree of slope and size of field. At the end of each ridge in the lower corner of fields, where water trapped by the ridge flows out, a water reservoir (5 m × 5 m at the top and 2 m in depth, or larger) is located to prevent water flow by making a stream along the corner. Generally, these ridges and reservoirs are constructed following the instruction of experts, and repaired every 5–6 years.

There is danger of these ridges breaking down during heavy rains. In the past, disc-plowing to about 10 cm depth was the common practice in field preparation. With this practice, however, a plow-pan was developed that made the amount of runoff water greater. Nowadays, it is recommended that the residues of previous crops be cut and mixed with soil by chisel plowing (30–40 cm depth) to facilitate water percolation into the soil. As large gullies develop frequently along roads, the proper layout for farm areas as well as individual farms is very important.

In forests, land development is much more difficult than in Cerrado. As described previously, after clearing forests by the slash-and-burn method, there remain too many obstacles for large machines to operate, and crops can only be planted by hand. Thus, the area is suitable for small-scale farmers. As crop fields are small and surrounded by forests, soil erosion is not necessarily a serious problem, at least at present.

Cropping season : In the Cerrado area, because of the prominent dry season, only one crop is grown per field per year, although there are some cases where more than one crop is grown. Sowing of summer rainy-season crops, such as soybean, rice, and maize, begins as soon as rains start in August–September and is at its peak in November in the Cerrado area, but the start and peak are one month ahead in Rondônia due to the earlier arrival of rains (Fig. 60). Harvesting of these crops in the Cerrado area starts in February and is at its peak in March and April, when rains stop. The peak is February in Rondônia. Field beans are a dry season crop; they are sown by the end of the rainy season (March to April) and harvested in June–July. Growth duration is very short. There is no clear growing season for Cassava.

As illustrated in Fig. 60, the peak of sowing in November and also that of harvesting in April are very prominent in soybean. At Faz. Progresso, it was mentioned that soybean

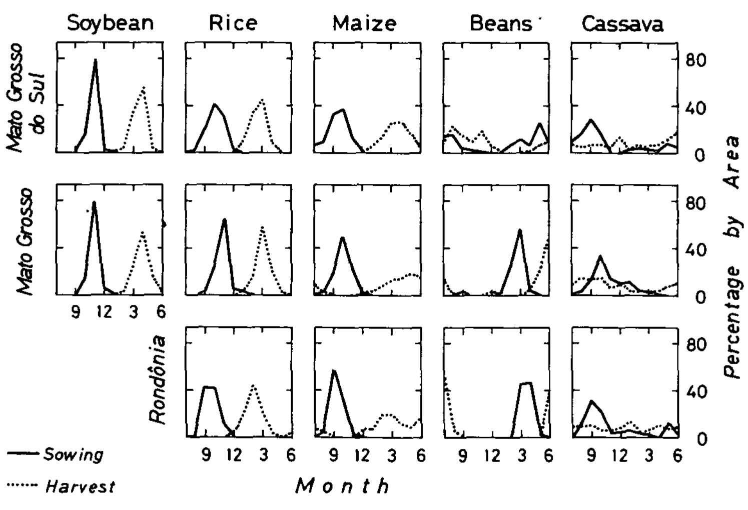

Fig. 60. Growth season of annual crops in various states (IBGE, 1983).

should be sown during the 50-day period from October 20 to December 10. Sowing dates for maize or rice are more flexible. According to information collected in Mato Grosso, maize is sown at any time between early September to January; rice is sown from August (shortly before rain starts) to December, but November sowing is not suitable, since flowering takes place during the peak rain period and plants suffer from severe blast. Since (a) the sowing and harvesting periods of soybean, rice, and maize almost coincide, (b) the planting coverage is very large, and (c) because rains are erratic and farmers therefore very busy at sowing and harvesting; hence, a considerable number of laborers must be hired for these operations.

If water is available, more than one crop can be grown per year. For example, in the fields on a Vãrzea in Palmeiras two crops of rice are grown, or one of rice and one of field beans (Oct./Nov.—April/May and again June/July—Oct.). On some large farms, there are various-sized installations of the pivot irrigation facility (54, 96, or 118 ha in coverage), by means of which rainy season crops can be irrigated during 'Veranico'. In addition, in the dry season field beans and wheat are produced, as well as soybean and rice for seeds, which demand high market prices.

Workers and equipment : On large farms, permanent employees are hired, in addition to seasonal workers, and heavy equipment is used. It was said that a farm with 4,500 ha of land at Terenos hired 15 permanent employees and 50 seasonal workers for 2 months, and had one 350 HP tractor, fifteen 100 HP tractors, and three combines. It was also said that in Chapadão an average farm of 3,000 ha hired 15—30 permanent employees and 100 seasonal workers for 2 months. At Itamarati Norte S.A., there were 50,000 ha of crop fields, 800 permanent employees, 1,600—2,000 temporary workers for 6 months, forty 200 HP tractors, eighty 100 HP tractors, fifty 65 HP tractors, ninety-five combines, and three small airplanes. On this farm, however, there were activities other than farming itself, such as processing of harvested grains and construction of houses and roads.

These figures give an idea that to manage 1,000 ha of grain crop farmland, it is necessary to hire 3—10 permanent employees and 10—30 seasonal laborers for 2 months, and to have about 400 HP of tractor-power and 1—2 combines. There seems to be no clear difference in these figures between farms with a few thousand ha and those with several ten-thousands.

7—4—3. Management of soil fertility

Since, among grain crops, rice is most tolerant to adverse soil conditions such as low pH, high exchangeable Al, and low available phosphorus, it is grown as a pioneer crop in the process of land development in Cerrado. Even with rice, it is indispensable that certain amounts of lime and phosphorus fertilizers be applied for getting a reasonable yield in the Cerrado area. After growing rice by applying these materials for a few seasons, the soil condition becomes amenable to growing improved pastures, soybean, maize, *etc.* Annual application of chemical fertilizers to provide plant nutrients to each crop, however, is also indispensable for getting high yields. Thus, soil fertility management is divided into (a) amelioration of soils to initiate farming, and (b) plant nutrient management to obtain a high yield from each crop.

The average amount of fertilizer ingredients used per unit field area in Brazil is 87 kg/ha of $N + P_2O_5 + K_2O$ (Table 41), which is intermediate between the advanced and advancing countries in the world. There are, however, wide differences in this amount among regions. In Norte the amount is very small, 10 kg/ha. In Rondônia, it was said that no chemical fertilizer is used, because soil fertility is reasonably high and farmers cannot afford to use fertilizers because they are too expensive. In contrast, the amount is rather large, 92 kg/ha,

Table 41. Amount of fertilizer ingredients applied to crops in various regions in Brazil (kg/ha).

Region	N	P_2O_5	K_2O	Total
Brazil	20.7	35.3	30.6	86.6
Norte	2.4	3.7	3.5	9.6
Nordeste	11.8	11.4	13.6	36.8
Sudeste	40.2	50.7	50.2	141.2
Sul	19.2	39.0	31.1	89.3
Centro-Oeste	13.4	46.8	32.0	92.2

Figures denote the total amount of ingredients (N + P_2O_5 + K_2O) used in Brazil,1987 (ANDA, 1987) divided by the total area planted with annual crops in 1985 (IBGE, 1987).

in Centro-Oeste. In the Cerrado area, farmers apply considerable amounts of fertilizers for growing field crops since soils are poor and they can afford to use them because bank loans are available.

The ratio of N : P_2O_5 : K_2O in fertilizers used was 1 : 3.0 : 1.6 in the 1950's, and 1 : 1.7 : 1.3 in 1983–85 (Fig. 61). In Centro-Oeste, the ratio is 1 : 3.5 : 2.4 at present (Table 41). Reasons for the high ratio of P_2O_5 in this area are the low phosphorus status of the soil and the high proportion of soybean among crops.

Of the total amount of fertilizers consumed in Brazil, 85% of N and 93% of P_2O_5 are produced in the country, but only 3% of K_2O (Table 42). Consumption is increasing very rapidly (Fig. 61), and the industry is catching up to meet the increased demand.

Among fertilizers produced in Brazil, urea comprises 60% of N, ammonium phosphate 13%

Table 42. Total amount of fertilizer ingredients used and produced in Brazil and their percentages in each compound produced (1987)[1].

Ingredient	Amount of fertilizer ingredients (1,000 t)		Compound	Percentage of ingredient of each compound[2]
	Used	Produced[3]		
N	880	748 (85)	Urea	60
			Ammonium phosphate (mono- and di-)	13
			Ammonium nitrate	9
			Compound fertilizers	9
			Calcium nitrate	5
			Ammonium sulfate	5
P_2O_5	1,504	1,399 (93)	Superphosphate (single and double)	57
			Ammonium phosphate (mono- and di-)	28
			Compound fertilizers	11
			Fused Ca-Mg phosphate	2
			Partially acidified rock phosphate	2
K_2O	1,302	39 (3)	Potassium chloride	100

1) Data source: ANDA (1988). 2) On the basis of the total amount of respective ingredients produced in the country. 3) Figures in parentheses are percentage of the amount of fertilizer ingredient production in the country to that used.

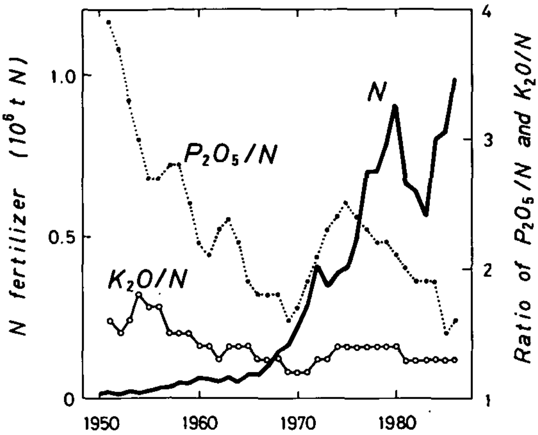

Fig. 61. Consumption of nitrogenous fertilizers (N) and ratios of P_2O_5 and K_2O to N consumption in Brazil from 1950/1951 to 1986 (ANDA, 1987).

of N and 28% of P_2O_5, and superphosphate 57% of P_2O_5. Farmers use these fertilizers in various forms: Only 22% is used as single fertilizers, and the remaining 78% as combined fertilizers, of which bulk blended fertilizers comprise 54% (Table 43). As farm size is large, bulk blended fertilizers are most common.

Table 43. Form of fertilizers used in Brazil.

Form		Amount (1,000 t)	(%)
Single fertilizer		2,137	22
Compound fertilizer	Granular	1,837	19
	Powder	479	5
	Bulk blended	5,192	54
Total		9,645	100

Data source: ANDA (1987).

All crops are not necessarily always applied with chemical fertilizers. For example, in the case of pastures, only 15% of the area receives fertilizers. This percentage is high in soybean (92%), wheat (95%), sugarcane (90%), and tomato (90%), while it is low in cassava (25%) (ANDA, 1987). Because of the large areas planted and high percentage of fertilizer used, the three major crops, *i.e.*, soybean, rice, and maize, make up for 40% of the total fertilizer used in 1986.

Common methods of using limestone are as follows: In Itamarati Norte S.A., 5–7 t/ha of limestone, preferably dolomitic limestone, is applied in split doses during 2–3 rice crops on a newly opened field from Cerrado in order to raise the soil pH from 4.8–5.0 to 6.0, and the exchangeable (Ca + Mg) from 0.5 to 3.0 meq/100g soil. In Faz. Progresso, a plot of pasture was made into crop field by applying 2 t/ha of limestone, and rice was planted during the first year; the next year 3 t/ha of limestone was applied again and soybean was planted; during the following 2–3 years soybean was planted continuously without limestone application; then, limestone was applied, and soybean was planted again. A standard amount of limestone application to continuous crop fields at Rondonópolis county is 3 t/ha of dolomitic limestone every 5 years plus 1 t/ha every 2–3 years.

The price of limestone set by the government is US$56/t. One ton is equivalent to 0.35–0.5 t of grain by government price. Thus, limestone application is profitable.

Recommendations for the amount of fertilizers to be applied to field crops in the Cerrado area are given in Table 44. During this survey, information on the amount of fertilizer application was collected in six cases. The averages of these data are given in Table 45. These tables indicate that the practices by farmers are within the range of recommendation. Generally speaking, the largest amount of fertilizers is given to maize and a small amount to rice. The amount of N applied to soybean is negligible. In rice it is rather small (less than the recommended amount), because rice is frequently planted in newly-opened fields, where the natural supply of N is likely to be greater than that in the established fields, and rice becomes more susceptible to blast with a large amount of N application. Farmers practice split application of N in rice and maize as recommended. The top dressing is made by airplane on big farms. Application of zinc to upland rice and the use of rhizobia to soybean are common among farmers as recommended.

Table 44. Recommendation of fertilizer application to major crops in the Cerrado area[1].

Crop	N (kg/ha)		P_2O_5 (kg/ha)			K_2O (kg/ha)		
	Basal	Top-dressing	Avail. P[2] in the soil[3] Low	Med.	High	Exch. K[2] in the soil[4] Low	Med.	High
Upland rice[5]	15	30	80	40	0-20	60	30	0-15
Maize	30	60	90	60	30	60	30	0-15
Bean	10	30	80	40	0-10	45	30	0-15
Soybean[6]	0-20	-	90	60	0-40	40	30	0-10

1) Data source: Malavolta and Kliemann (1985).
2) Extracted with double acids (0.05N HCl + 0.025N H_2SO_4).
3) Avail. P: Available P level; Low = Lower than 6 ppm, Med.(medium) = 6 to 10 ppm, and High = Higher than 10 ppm.
Note: S should be applied at the rate of 1/5 or larger amount of P_2O_5 applied in all cases.
4) Avail. K: Available K level; Low = Lower than 60 ppm, Med.(medium) = 61 to 100 ppm, and High = Higher than 100 ppm.
5) Together with 1-2 kg Zn/ha.
6) Seeds should be inoculated, and Co, Mo, and Zn should be applied whenever necessary.

Table 45. Average of total amount of N, P_2O_5, and K_2O applied to various crops in the Cerrado area (kg/ha).

Crop	N	P_2O_5	K_2O
Rice	19	52	33
Soybean	2	70	51
Maize	53	81	57

Figures are estimated with the information collected during the survey.

Examples of farmers' practices of fertilizer application in the Cerrado area are as follows:

Soybean:

(a) 300 kg/ha of 0/2−20−10 (compound fertilizers with composition of 0−2% N, 20% P_2O_5 and 10% K_2O) [Palmeiras, Goiás]

(b) 200 kg/ha of 0/4−14−8, plus 1 t/ha of single superphosphate [Chapadão, Mato Grosso do Sul]

(c) 300 kg/ha of 0−20/25−20/25 [Faz. Progresso, Mato Grosso]

Rice and Maize:

(a) 200 kg/ha of 4−30−10/15; plus 5 kg/ha of $ZnSO_4$ in rice and 20 kgN/ha of urea or ammonium sulfate as top-dressing in maize [Palmeiras, Goiás]

(b) 300 kg/ha of 5−20/25−20; plus 100 and 200 kg/ha of ammonium sulfate as top-dressing in rice and maize, respectively; 40 kg/ha of FTE every 2 years [Faz. Progresso, Mato Grosso]

Farmers generally use combined fertilizers for basal application, and urea or ammonium sulfate for top-dressing.

The prices of 0−20−10 and 5−20−20 are estimated to be US$190 and 290/t, respectively. Thus, 300 kg of 0−20−10 is equivalent to 0.42 ton of soybean, and 200 kg of 5−20−20 to 0.37 ton of rice or 0.49 ton of maize at the government price. These figures suggest that application of chemical fertilizers to these crops is economically profitable.

It was noticed during the survey that the amount of N applied to crops is rather low in relation to yield in the Cerrado area. This may suggest that the N-supplying power of soil in the Cerrado area is reasonably high. At Itamarati Norte S.A., for example, 130 kgN/ha was applied to maize and 6 t/ha of grain yield obtained. By assuming the harvesting index to be 0.5, N content in the stover and grain 0.5 and 1.5%, respectively, and the absorption percentage of applied fertilizer-N 50%, the amount of N absorbed by the crop from soil is estimated to be 55 kgN/ha. It is reported that the yield of maize in this area is often as high as 3 t/ha without fertilizer-N application (CAC-CC, 1985−87; Malavolta and Kliemann, 1985; Goedert, 1986). If this is the case, it is estimated that 60 kgN/ha is absorbed by maize from the soil. It would be interesting to know where such a large amount of N is derived.

8. SUMMARY AND COMMENTS

1. This survey was made in an area extending from Brasília to Cruzeiro do Sul, in which vegetation changed from Cerrado to tropical rain forest; the Pantanal area also was included. The survey areas are broadly divided into four Regions, and Table 46 gives an outline of the climate, land form, soil, vegetation, and farming system in each Region.

2. Characteristics of these Regions are described below:

(a) Brazilian Highland: There is a considerably long dry season, but duration of the crop season, in which crops can grow with moisture in the soil based upon the seasonal fluctuation of available soil water, is more than 250 days per year (Table 15 and Fig. 30). The major land surface consists of huge, undulating uplands (Chapada) accompanied by depressions (Várzea da chuva). Major soils are well-drained, fine-textured Haplustox and Acrustox (Lvd and Lld) on the uplands, and Haplustox (La) and Quartzipsamments (Q) in the depressions. The chemical nature of these soils is very poor, and they are susceptible to soil erosion, but are easy to cultivate. Cerrado (Well-drained savanna) vegetation dominates. This vegetation is

Table 46. Brief description of four Regions in the survey area.

Character	Brazilian Highland	Pantanal Region	Transition Region	Upper Amazon Basin
Climatic condition1)				
Qs (kly)	132	143	123	112
Rn (kly)	92	108	96	87
PE (mm)	1,500	1,300	2,000	1,500
P (mm)	1,200 - 2,200	1,100 - 1,600	2,100 - 2,800	2,200 - 2,800
CWDD (mm)	440 - 640	210 - 610	280 - 380	0 - 210
CWEW (mm)	510 - 1,150	70 - 620	930 - 1,590	980 - 1,510
DPG (day)	250 - 265	180 - 270	290 - 320	340 - 365
Land surface	Flat upland (well drained, Chapada) surrounded by steep scarps	Lowland encircled by hilly upland	Rolling hills, Terrace, Flood plain	Flat terrain in flood plain
Soils2)	Lld, Lvd, La, Q (old and poor)	V, S, Ae Upland : Lvd, Lrd, Q	Pd, Pe [Tve, Tvd] (young and fertile)	Pd, Pe, Ppd, Fd
Vegetation type3)	Cer, Spd Tvg(Cer-Fes)	Spd, Cer, Fds	Fes, Tvg(Fes-Cer)	Ftr, Wlf
Farming system4)	Nat.Past., Imp.Past., Grain (large scale)	Nat.Past., Grain etc. (small scale)	Tree, Field crops (small scale), Imp.Past.(small and large scale), Shift. agric.	Shift. agric., Imp.Past.

1) **Climatic condition:** All data are per year basis. Qs; Total short wave radiation. Rn; Net radiation. PE; Potential evapotranspiration. P; Precipitation. CWDD; Climatic water deficit during dry months. CWEW; Climatic water excess during wet months. DPG; Duration of the period when plants can grow with available soil water.
2) **Soils:** See Table 4.
3) **Vegetation type:** Cer; Cerrado (Well-drained savanna). Spd; Poorly-drained savanna. Ftr; Tropical rain forest. Fes; Tropical semi-evergreen seasonal forest. Fds; Tropical semi-decidous seasonal forest. Wlf; Wetland formation. Tvg; Transition vegetation.
4) **Farming system:** Imp.Past.; Improved pasture with cattle. Nat.Past.; Natural pasture with cattle. Grain; Soybean, rice, and maize. Tree; Rubber, cacao, and coffee. Field crops; Maize, bean, rice, and cassava. Shift. agric.; Slash-and-burn shifting agriculture.

high in floristic richness, but contains only scattered, short trees with twisted trunks.

Because of the nature of vegetation and topography on the uplands, it is easy to clear the land and establish large farms. The pasture-beef cattle system and the grain crop system are common. Native pasture occupies more than half of the total pasture area. On improved pasture, upland rice plays an important function in renovating them. Since about two crops of rice are planted with fertilizer application where improved pasture is renovated at about six-year intervals, rice occupies about one quarter of the area of beef-cattle farms with improved pasture. The grain crop system on large farms (mostly larger than several thousands ha) has become popular since about 1980. In this system, soybean, rice, and maize are grown with high input (such as the use of soil amelioration materials and a high rate of chemical fertilizers), and with heavy equipment. Due to adequate management supported by scientific information and banking systems, the yield of these crops is reasonably high. Soil erosion seems not to be so serious at present, but proper precaution should be taken continuously to prevent erosion, especially in the layout of farm roads and terrace waterways. Most of the depressions are kept under natural vegetation, but some flooded rice fields are established in them.

(b) Pantanal Region: Climate in the southern part is drier than that in the Brazilian Highland. The crop season is 270 days in the north and 180 days in the south. The major land surfaces are the vast lowland (the Pantanal), which is seasonally flooded every year, and enclosed with the steep scarps of undulating uplands and rolling hills to the south. Major soils are Tropaquents, Quartzipsamments, Natraqualfs, *etc*., associated locally with Pelluderts in the lowland; and Acrustox, Argiustolls, and Paleustalfs, *etc*., on the surrounding uplands. The vegetation types are Poorly-drained savanna (Spd) in the lowland, and Well-drained savanna (Cer), Tropical semi-deciduous seasonal forest (Fds), and Transition vegetation from forest to Cerrado or to artificial vegetation (Tvg) in the surrounding uplands. A unique farming system, which is practiced by huge farms, is cattle grazing on natural vegetation in the lowland during the dry season and on improved pasture in highlands during the wet season—typical extensive farming. Small farms practice farming systems with various crops, not only common grain crops, but also tree crops, vegetables, and irrigated rice as well. The Pantanal lowland is rich in wild animals, and is given over to the preservation of nature.

(c) Transition Region: The climate is intermediate between the Brazilian Highland and the Upper Amazon Basin. The crop season ranges from 290 to 320 days. The area is comprised of hilly areas and inter-hill lowlands. The soils are variable: Those on the hills are thin and gravelly, and those on the lowlands are Tropudalfs and Paleudults, which are frequently fertile depending upon the parent materials. The kinds of vegetation also vary, while dominant types are Tropical semi-evergreen seasonal forest (Fes) and Transition vegetation between Fes and Cerrado (Tvg(Fes-Cer)). Areas of Cerrado and Transition vegetation are increasing from the increase of human impact. After the highway from Cuiabá to Porto Velho was constructed in 1984, the Region became a new frontier, and lumbering very active. Since valuable trees are only few in a forest, many large trees remain even after valuable ones have been removed by lumbermen. Thus, it is very hard to clear forest for farmland.

Farmers who settled in the forest area were assigned to relatively small lots, spent much time creating farmland, and at present practice various cropping systems, such as the tree crop system (rubber, coffee, cacao, *etc*.) combined with various field crops (rice, maize, field beans, cassava, *etc*.), mostly for home consumption, except for tree crops and rice. Sometimes they practice the improved pasture-cattle system for themselves. Annual crops generally do reasonably well even with very low input (no fertilizer used), ostensibly due to high soil fertility. Weed control is a hard task because of aggressive infestation. As most farms are rather new, their success in future is not yet predictable. A limited number of large farms practice the improved pasture-beef cattle system. Ribeirinhos, who settled either some time ago or only recently in the area, practice the slash-and-burn shifting cultivation system, and also make fishing, hunting, and tapping of natural rubber trees their livelihood.

(d) Upper Amazon Basin: The climate is humid, and crops can be grown almost throughout the year. The major geomorphic surfaces are rolling uplands, flat terraces, and broad valley bottoms. The soils are Paleudults with varying hydromorphism, and some of them are imperfect in internal drainage. Vegetation in this Region is Tropical rain forest (Ftr) and Wetland formation (Wlf). Farming activities are yet few, because there is no major road, although there are some pastures and plots of shifting cultivation.

3. Following are the selected points to which the survey team has paid special attention:

(a) A huge, productive grain production area has been developed within a decade in the Cerrado area, where soils are extremely poor in chemical fertility, and rather susceptible to erosion if management is not proper. This is a unique example for demonstrating what can be done with high inputs of investment and technology, and it is important to follow closely the development of the area in future.

(b) Within a one-year period, an irrigated rice area of considerable size (Cooperformoso) was established in the vast swampy area (Vãrzea do rio) along the Rio Araguaia by reasonable investment, and irrigated rice fields are being well managed at present. This demonstrates the potential of irrigated rice production on Vãrzea, which covers 2.5 million ha of reclaimable area only along the Rio Araguaia in Goiãs and Mato Grosso.

(c) The Pantanal lowland, a huge swampy area (14.5 million ha in Brazil) is protected for nature preservation, although cattle are grazed without any human input. While nature preservation is important, the area would be one of the centers of rice production if it were located in monsoon Asia, where the population pressure is high and lowland rice is the most common crop.

(d) In the forest area, large and beautiful forests are being converted to farmland, and established farmlands are not necessarily being utilized efficiently. It is a pity to see the destruction of forests without reasonable benefit to human beings.

4. With limited observation and information obtained during the survey and from literature, our team proposes the following broad strategy for further study:

(a) Food and feed production should be increased, while minimizing the reclamation of virgin lands by (i) promoting the reallocation of abandoned or non-utilized farmlands, (ii) increasing the productivity of extensively utilized lands, such as native pasture, and (iii) reclaiming virgin land, which can be converted into productive farmland with minimum investment and without giving adverse effect to the environment, such as, for example, Vãrzea.

(b) In reclaiming virgin land for farmland, the balance between cost (not only the amount of investment, but also the loss of nature and adverse effects upon the environment, *etc.*) and benefit (increase of production, beneficial effects upon the environment, *etc.*) should in the long run be critically analyzed not only from the viewpoint of individual farmers, but also from national and global perspectives.

(c) Areas which must be protected from reclamation should be clearly identified from various points of view. For example: (i) Typical areas of various vegetation types and the habitats of wild animals should be identified and preserved as natural parks for the preservation of nature, (ii) strategic areas for flood and erosion control should be identified and protected, and (iii) adequate areas for recreation should be selected and developed.

(d) The urgent need is to collect reliable data for comparing the photosynthetic ability, water conservation capacity, balance sheet of plant nutrients, *etc.* in various natural vegetation settings and farmlands under different managements. Such data will certainly provide us the necessary information with which to enable (i) the prediction of global influence caused by large-scale modification of natural vegetation and (ii) the establishment of an optimum land utilization system.

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Appendix 1. Itinerary (November, 1987 to February, 1988)

Group 1 (Sakuma, Okagawa, Imai, and Sato)

Nov. 1 Flew from Tokyo.
2 Arrived at Brasília.
3-4 Visited EMBRAPA/CPAC and reviewed research works.
5 Prepared for the survey trip.
6 Visited EMBRAPA/DPP and EMBRATER.
7 Visited Nikkey farmers in Vargem Bonita and Núcleo Bandeirante.
8 Visited Faz. Ochiai at Alexânia.
9-10 Arranged the survey trip.
11 Drove from Brasília to Gurupi via Anápolis.
12 Visited paddy rice projects at Faz. Ponderosa and Cooper Java, Rio Formoso.
13 Drove from Gurupi to Goiânia via Porangatu and Ceres.
14 Drove to Caldas Novas via Piracanjuba and came back to Goiânia.
15 Drove to Barra do Garças via Nazário and Arenápolis.
16 Visited EMATER at Barra do Garças. Drove to Nova Xavantina.
17 Surveyed four soils (B21—B24) and vegetation types at Coper Cana.
18 Surveyed four soils (B25—B28) and vegetation types Returned to Barra do Garças.
19 Drove to Cuiabá via Primavera.
20 Visited EMATER and EMPA at Cuiabá. Drove to Poconé and surveyed two soils (B29 and B30) and vegetation types.
21 Visited the National Park near Porto Jofre.
22 Visited Agro Vila, Vale da Boa Esperança near Palmeiras, and sampled one soil profile (B31) and vegetation. Drove to Rondonópolis via Jaciara.
23 Surveyed three soils (B32—B34) and vegetation types at Faz. Três Irmãos.
24 Surveyed four soils (B35—B38) and vegetation types at Faz. São Carlos.
25 Drove from Rondonópolis to Campo Grande via Coxin. Visited EMBRAPA/CNPGC.
26 Moved to Corumbá, Pantanal by train.
27 Visited EMPAER at Corumbá and surveyed one soil profile (B39) and vegetation at Vale Paraíso.
28 Flew from Corumbá to Campo Grande.
29 Flew to Porto Velho.
30 Visited EMBRAPA at Porto Velho. Arranged the survey trip.
Dec. 1 Drove to Vilhena.
2 Visited EMBRAPA at Vilhena. Drove to Colorado do Oeste and surveyed one soil profile (B40) and vegetation.
3 Surveyed one soil profile (B41) and vegetation at Vilhena and three soils (B42—B44) at Faz. Italiano near Comodoro.
4 Drove from Vilhena to Cacoal via Pimenta Bueno. Surveyed one soil profile (B45) and vegetation.
5 Surveyed one soil profile (B46) and vegetation at Pimenta Bueno. Visited limestone mine at 40 km SE of Espigão d'Oeste.
6 Drove from Cacoal to Ji-Paraná. Surveyed one soil profile (B47) at Teixeirópolis.
7 Visited EMBRAPA at Ouro Preto do Oeste and EMBRAPA at Ariquemes. Surveyed one soil profile (B48) and vegetation at Ariquemes. Moved to Porto Velho.
8 Surveyed one soil profile (B49) and vegetation at Itapuã do Oeste.
9 Flew from Porto Velho to Rio Branco.

10 Visited EMBRAPA/UEPAE and EMATER/Acre at Rio Branco. Flew to Cruzeiro do Sul.
11 Surveyed six soils (B50–B55) and vegetation types.
12 Flew from Cruzeiro do Sul to Sena Madureira. Surveyed two soils (B56–B57) and vegetations.
13 Flew to Rio Branco. Surveyed one soil profile (B58) and vegetation at Humaitá.
14 Drove to Plácido de Castro and returned to Rio Branco.
15 Flew to Brasília.
16 Collected maps of the survey area at Fundação Instituto Brasileiro de Geografia e Estatistica (IBGE).
17 Visited EMBRAPA/CNPH, EMBRATER and EMBRAPA/DPP. Sato visited Dr. Eiten, Brasília University.
18 Sakuma, Okagawa and Imai visited Ministério da Agricultura.
19 Prepared soil samples.
20 Flew from Brasília to São Paulo.
21 Visited IAC and collected information on soils of São Paulo State. Visited Faz. Monte d'Este.
22 Visited CAC-CC.
23 Flew from São Paulo to Rio de Janeiro.
24-25 Flew to Tokyo via Los Angeles.

Group 2 (Tanaka, Yamaguchi and Fujita)

Jan. 5 Flew from Tokyo via Los Angeles.
6 Arrived at São Paulo and flew to Goiânia.
7-8 Visited EMBRAPA/CNPAF and reviewed the program.
9 Arranged the survey trip.
10 Surveyed the Cerrado ecology from Goiânia to São Luis de Montes Belos (130 km WNW of Goiânia).
11 Surveyed farmers' and experimental fields at Palmeiras (80 km WSW of Goiânia).
12 Visited the local EMATER office and surveyed farmers' fields at Silvânia (76 km east of Goiânia).
13 Flew from Goiânia to Rio Formoso and surveyed the irrigated rice project.
14 Flew back to Goiânia.
15 Flew to Campo Grande via Cuiabá and Corumbá. Visited the local EMPAER office and surveyed a farmer's field at Terenos (30 km west of Campo Grande).
16 Surveyed a newly opened 'Várzea' rice field at Taquarussu (along Rio Ivinhema, 100 km ESE of Dourados).
17 Visited the EMPAER head office at Campo Grande.
18 Surveyed Pantanal and upland crop field at Faz. Bodoquena (45 km SW of Miranda).
19 Drove from Campo Grande to Rondonópolis. On the way, visited the local EMPAER office at Pedro Gomes.
20 Visited the local EMATER office at Rondonópolis. Drove to Lucas de Rio Verde via Cuiabá.
21 Surveyed the production and experimental field at Faz. Progresso (50 km south of Sorriso). Visited a farm in the Piuva Colonization Project. Drove to Diamantino.
22 Drove to Itamarati Norte S. A. via Alto Paraguai and Arenápolis. Surveyed the production field.
23 Drove from Itamarati Norte S. A. to Tangará da Serra and visited the EMPA local experimental station. Drove to Cuiabá via Barra do Bugres.
24 Flew to Porto Velho.
25 Visited the EMBRAPA/UEPAE head office. Drove to Ouro Preto do Oeste. On the way, visited the EMBRAPA local experimental station and surveyed a farm at Ariquemes.
26 Visited the EMBRAPA local experiment station at Ouro Preto do Oeste. Surveyed farmers' fields at 18 km NW and 12 km E of Ouro Preto do Oeste. Drove to Ji-Paraná.

27 Drove to Presidente Medici. Visited the EMBRAPA local experiment station and surveyed a farmer's field. Visited Faz. Hermes and made a boat trip in Rio Machado (Surveyed a 'Ribeirinho' farm at Muqui).
28 Drove to Pimenta Bueno and visited the local office of EMATER. Surveyed farmers' fields in Cerrado and Cerradão vegetation. Visited the limestone mine at 40 km SE of Espigão d'Oeste.
29 Drove from Ji-Paraná to Porto Velho. Visited a farmer's field at 40 km SW of Porto Velho along Rio Madreira.
30 Flew from Porto Velho to Brasília via Rio Branco and Cuiabá.
31 Visited the Botanical Garden, DF and farms (banana and coffee plantation) at Formosa.
Feb. 1 Visited EMBRAPA/CNPH and EMBRAPA/CPAC.
2 Flew from Brasília to São Paulo. Visited ANDA.
3 Visited CAC-CC.
3-5 Flew from São Paulo to Tokyo.

Note: See Appendix 2 for organization abbreviations.

Appendix 2. Institutions and Persons Assisting the Survey

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)/DPP, Brasília, Distrito Federal (DF)
Dr. Guido Ranzani, Soil Scientist

EMBRAPA/Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Brasília, DF
Dr. Euclides Kornelius, Associate Director (Research)
Dr. Youichi Izumiyama, JICA Expert

EMBRAPA/Centro Nacional de Pesquisa de Hortaliças (CNPH), Brasília, DF
Dr. Antonio Carlos Guedes, Chairman
Eng. Yoshihiko Horino, Vegetable Crop Researcher

Empresa Brasileira de Assistência Técnica e Extensão Rural (EMBRATER), Brasília, DF
Eng. Jairo Ribeiro da Silva, National Cassava Manager

Universidade de Brasília, Brasília DF
Dr. George Eiten, Professor

EMBRAPA/Centro Nacional de Pesquisa de Arroz e Feijão (CNPAF), Goiânia, Goiás (GO)
Dr. Luis Fernando Stone, Associate Director (Research)
Dr. Élcio Perpétuo Guimarães, Rice Breeder

Empresa de Assistência Técnica e Extensão Rural (EMATER), Goiânia, GO
Eng. Jailton de Almeida Diniz

Gurupi office of Empresa de Assitência Técnica e Extensão Rural Estado (EMATER) de GO
Eng. Ângelo Neto Nacimento Cruz, Director

Cooperativa Agroindustrial Rio Formoso Ltda. (Cooperformoso), Gurupi, GO
Eng. João Carlos Farencena, Agronomist

Empresa de Pesquisa, Assistência Técnica e Extensão Rural do Mato Grosso do Sul (EMPAER), Campo Grande, Mato Grosso do Sul (MS)
Eng. Reinald Bazoni, Rice Researcher

Fazenda Bodoquena S. A., Miranda, MS
Eng. Pedro Vilella Olinto, Assistant to Director

Empresa de Pesquisa Agropecuária do Estado de Mato Grosso, S.A. (EMPA/MT), Cuiabá, Mato Grosso (MT)
Eng. Nelson Vital Monteiro de Arruda, Director of Technician
Eng. Luiz Gonzaga de Barros, Rice Breeder

Cooperativa Agropecuária Mista Canarana (Coper Cana), Nova Xavantina, MT
Eng. Carlos Alberto Narafon, Agronomist

Cuiabá office of EMATER, MT
Eng. Sebastian Silva, Director

Barra do Garças office of EMATER, MT
Eng. Zélio do Costa Ribero, Director
Eng. Leonel Alves Pereira, Agronomist

Nova Xavantina office of EMATER, MT
Mr. Aldo Dunck, Extension Specialist

Fazenda Três Irmãos, Rondonópolis, MT
Mr. Satoshi Umekawa, Owner

Fazenda Progresso, Sorriso, MT
Mr. Munefumi Matsubara, Owner

Fazenda Itamarati Norte S.A., Diamantino, MT
Eng. Tochio Hirooka, Agronomist

EMBRAPA/Unidade de Extensão de Pesquisa de Âmbito Estadual (UEPAE), Porto Velho, Rondônia (RO)
Dr. Moacir José Sales Medrado, Director
Eng. Diógenes Pedrosa de Azevedo, Rice Reseacher
Eng. Newton de Lucena Costa, Forage/Pasture Researcher
Eng. Francisco Leônidas, Agronomist

Porto Velho office of EMATER, RO
Eng. Rubens Sousa Jacarandá, Agronomist

EMBRAPA/UEPAE, Rio Branco, Acre (AC)
Eng. Francisco Rildo Cartaxo Nobre, Soil Researcher
Eng. Tâmara Cláudia de Araújo Gomes, Soil Researcher

EMATER/Acre, Rio Branco, AC
Eng. Renido Moura da Cunha, Director General
Eng. Raimundo Barros Lima, Director of Technician

Cruzeiro do Sul office of EMATER, AC
Eng. José Maria de Lima, Agronomist
Eng. José Jesus Santos Lima, Agronomist

Ministério da Agricultura, AC
Eng. Carlos Alberto B. Reis, Federal Delegate

Instituto Agronômico de Campinas (IAC), Campinas, São Paulo (SP)
Dr. Hiroshi Nagai, Agronomist

Associação Brasileira para Pesquisa da Potassa e do Fosfato (POTAFOS), Piracicaba, Campinas, SP
Eng. Agr. T. Yamada, Director

Associação Nacional para Difusão de Adubos e Corretivos Agrícolas (ANDA), São Paulo, SP
Mr. Carlos Alberto Pereira da Silva, Director

Cooperativa Agrícola de Cotia, Cooperativa Central (CAC-CC), São Paulo, SP
Mr. Toru Matsumae, General Director
Eng. Hideki Amenomori, Production Assistant