ATLANTIC ZONE PROGRAMME

Field Report No. 34

EFFECTS OF FOREST CLEARING AND LAND USE ON SOIL PROPERTIES OF TWO LAND USE SEQUENCES IN COCORI, ATLANTIC ZONE OF COSTA RICA

G. Baltissen

CENTRO AGRONOMICO TROPICAL DE
INVESTIGACION Y ENSEÑANZA - CATIE

AGRICULTURAL UNIVERSITY
WAGENINGEN - AUW

MINISTERIO DE AGRICULTURA Y
GANADERIA DE COSTA RICA - MAG

CONTENT

PREFACE

1. INTRODUCTION 1

2. GEOGRAPHICAL CONTEXT 2

2.1 Location 2
2.2 Inhabitants and recent history of the area 4
2.3 Climate 4
2.4 Geology 5
2.5 Geomorphology 5
2.6 Landuse 6

3. METHODS 7

3.1 Introduction 7
3.2 Description of the deforestation process 7
3.3 Selection of profile sites 7
3.4 Soil profile descriptions 9
3.5 Micromorphological methods 10
3.6 Chemical methods 11
3.7 Physical methods 11

4. DEFORESTATION 12

4.1 Introduction 12
4.2 Deforestation in the Cocori area 13

4.2.1 Deforestation map 13
4.2.2 Methods and reasons for deforestation 13

5. MORPHOLOGICAL OBSERVATIONS 16

5.1 Introduction 16
5.2 Macromorphological (field-) observations 16

5.2.1 Cedral macromorphological observations 16
5.2.2 Sardina macromorphological observations 17

5.3 Micromorphological observations 18

5.3.1 Introduction 18
5.3.2 Cedral micromorphological observations 20
5.3.3 Sardina micromorphological observations 22

6. CHEMICAL AND PHYSICAL SOIL PROPERTIES 24

6.1 Chemical soil properties 24
6.2 Physical soil properties 25

7. DISCUSSION AND CONCLUSIONS 27

7.1 Introduction 27
7.2 Conclusions on soil degradation 27
7.3 Soil taxonomy classification problems 32

8. REFERENCES 33

SUMMARY 34

ACKNOWLEDGEMENTS 35

APPENDIXES

A Field profile descriptions
B Detailed micromorphological descriptions
C Chemical analysis

PREFACE

The work presented in this report was carried out within the context of the Atlantic Zone Programme. This multidisciplinary research programme started in Costa Rica with a diagnostic study of the planning region Huetar Atlantica to identify, amongst other things, important problems that beset agricultural development of the region so as to enable the selection of relevant development oriented research subjects.

The central theme of the Programme is sustained land use. Therefore, a study of the soils and their potential, and of possible effects of land use on soil qualities is an important part of the research.

Until fairly recently most of the Atlantic Zone was still under tropical rainforest. Colonization started in the second half of last century but most of the deforestation took place during the past fifty years. At present primary forest is left only on the slopes of the Turrialba and Irazu volcanoes, and in the northern part of the Zone where the soils are generally less suitable for agriculture. The agricultural frontier in this area nevertheless advances and the forest is rapidly being replaced by grassland and other forms of land use.

The present report deals with a study of the effects of forest clearing and subsequent land use on some physical and chemical soil characteristics. The study was carried out in the subarea Cocori which is considered representative for the agricultural frontier in the northern part of the Atlantic Zone.

The field work was carried out in the period January-March 1987.

The report was presented in partial fulfillment of the requirements for the Masters degree in Soil Science of the Wageningen Agricultural University, the Netherlands.

The work was supervised by Dr. J. Bouma of the Wageningen Agricultural University and by Dr. W.G. Wielemaker of the Programme.

Dr. Jan F. Wienk
Programme Coordinator

1. INTRODUCTION

This report descibes the results of a study for a major thesis on tropical soil science at the Agricultural University of Wageningen. The object of the research is the impact of deforestation and landuse on soil properties. The fieldwork is done from january to march 1987 in the Cocori area, in the Atlantic zone of Costa Rica.
The research is part of a large project of cooperation between CATIE (Centro Agronomico Tropical de Investigation y de Ensenaza), MAG (Ministerio de Agricultura y de Ganaderia), both in Costa Rica and the Agricultural University of Wageningen, the Netherlands. The most important theme of this project is the problem of fast spreading deforestation in the Atlantic zone of which the socio-economic, political and physical aspects are studied (Vleeshouwer and Wielemaker, 1986).
The Cocori area has a hilly landscape, 5 to 200m. above sea level and is strongly influenced by volcanic activity, the climate is very humid. The colonization of the area has only recently started but already large parts of the tropical rainforest have been cleared. Two land use sequences are studied on two different soil types: Cedral (andic humitropept) and Sardina (hydric dystrandept) both with volcanic properties (Soil Survey Staff, 1975). The impact of the landuse types, cacao and pasture, will be compared with the natural situation under tropical rainforest and sites cleared from vegetation.
Allen (1985) pointed out that an analysis to the effects of deforestation and landuse should include data on the physical, biological and chemical properties of the soil, especially those related to soil structure, run off, infiltration and erosion. Here, morphological chemical and physical properties will be described related to soil structure and infiltration, run-off and erosion although increasingly occuring in the area will not be mentioned.
Emphasis is on morphological degradation of soils in the landuse sequences. Compaction is the main cause of structure degradation and causes an increase in bulk density and decrease in porosity that result from pressure exposed on the soil e.g. the treading of animals or the passage of machines (Marshall and Holmes, 1979). Apart from degradation, research is done also on the recovering of soils under secundary vegetation mainly caused by biological activity.
In chapter 2 the geographical context of the area will be described. Chapter 3 deals with the methods that are used in this study. In chapter 4 the deforestation process in Costa Rica and in the Cocori area in particular will be described. Macro- and micromorphological results will be given in chapter 5 and chemical and physical results in chapter 6. In chapter 7 an evaluation and conclusions of the study are presented.

2. Geographical context.

2.1 Location.

The Cocori area is situated in the North-east part of Costa Rica, close to the Nicaraguan border (Fig. 1), in the province of Limon, 25km. North of Cariari (Fig. 2).

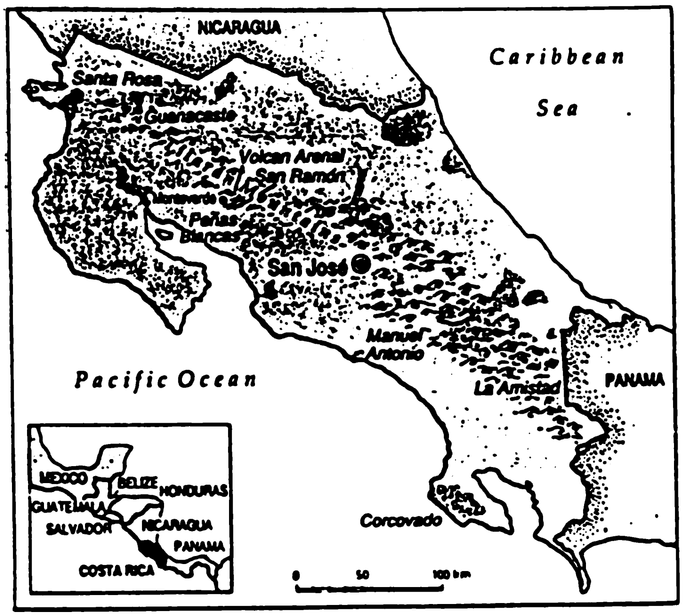

Figure 1. Map of Costa Rica (scale 1:5 000,000).

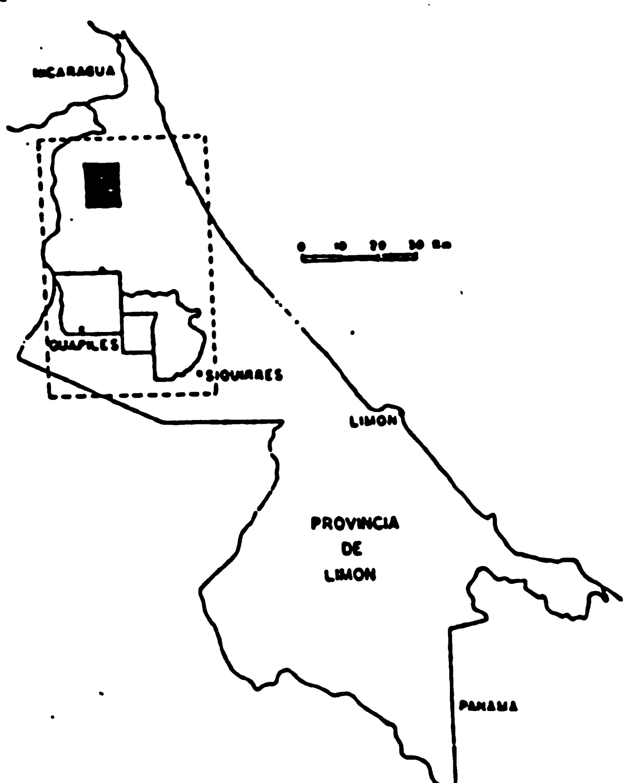

Figure 2. Location of the Cocori area in the Atlantic zone of Costa Rica (scale 1:2 000,000).

The area is limited by map coordinates:
Latitude 10 31' - 10 41' N; Longitude 83 40' - 83 46' E. Important rivers are the Colorado River in the North, the Penitencia river in the South and the Sardina river in the West. Since seven years, the accessibility of the area has increased largely due to the construction of two roads, the "Cocori" road in the West and the "Rio Colorado" road in the East (Fig 3.).

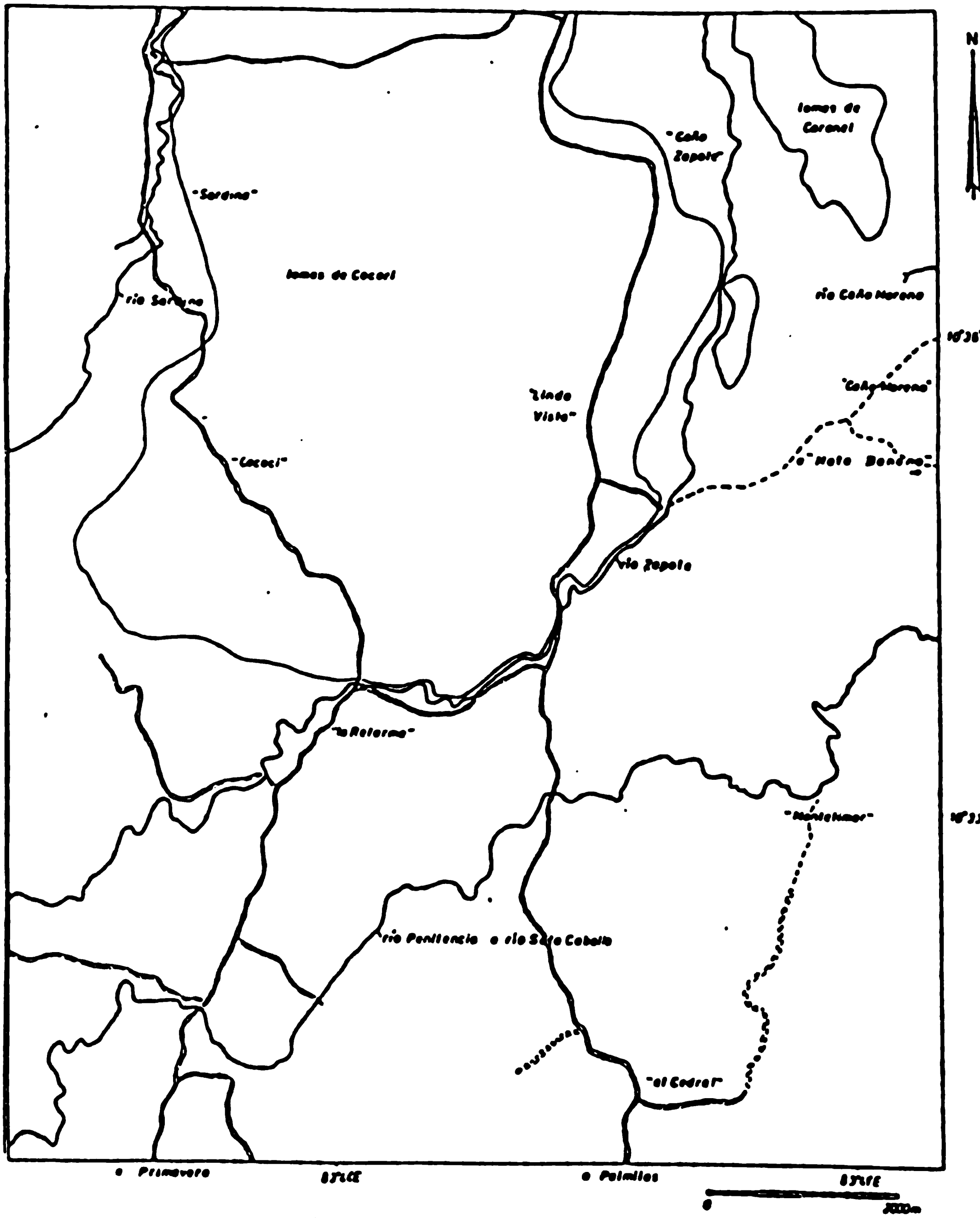

Figure 3. Topographic map of the Cocori area (scale 1:75,000).

2.2 Inhabitants and recent history of the area.

Untill 1970 there was not much agricultural activity in the area, along the rivers bananas were cultivated and there was some timbertrading. Selective clearing of forest took place near the rivers controlled by the "Atlantic Trade Company" together with the Cubans, the Atlantic port of Tortuguero was important at that time. After the Cuban revolution the trading diminished fast and in 1962 it stopped (Wielemaker, 1988).
From 1970 onward the area became more densily populated and agricultural activities were more serious. In other parts of Costa Rica (eg. Guanacaste) most of the rainforest had already been cut and extensive cattle-breeding didn't give much opportunities for work (Gudmundson, 1983), so colonization of soils in the very humid part of the country (the Atlantic zone) increased. Apart from Costarican settlers many people from Nicaragua came to the area in the last few years.
Because the prices of land and timber went up, landownership and timber trade continue to be the most important economic activities in the area. But without government action most of the forest will have disappeared in the near future

2.3 Climate.

The climate is characterized by high temperatures and precipitation throughout the year. The mean annual rainfall is 3000 to 6000 mm (Nuhn, 1978). There is not a meteorological station in the area and therefore the data of the meteorological station in Guapiles (40km to the South) and in Tortuguero (20km East) are used.

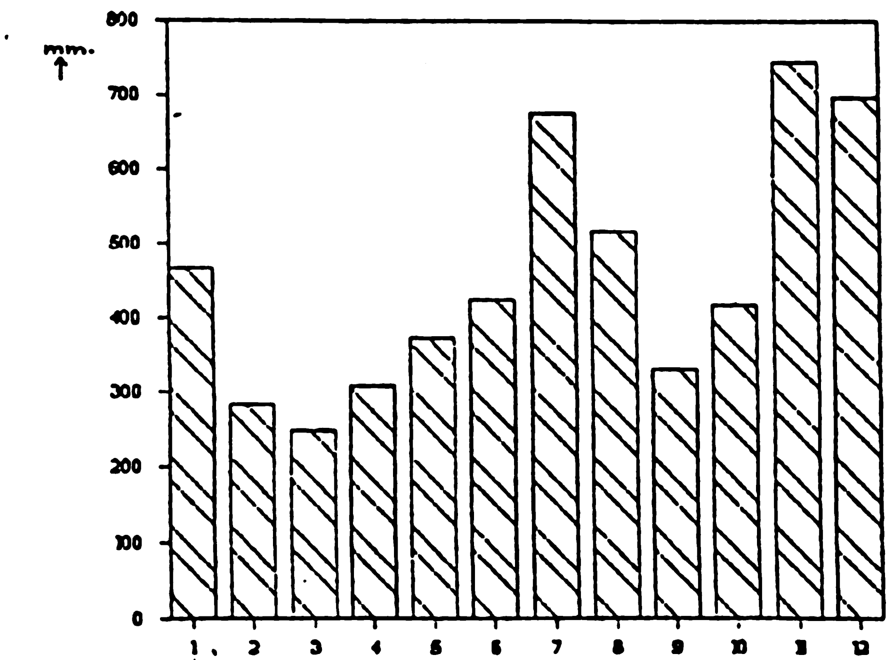

Figure 4. Mean monthly rainfall at Tortuguero.

At Guapiles the mean annual precipitation is 4500mm (average of 18 years) and at Tortuguero (Fig. 4) it is even higher: 5500mm (average of 8 years). February, march and april are relatively dry months.
The mean annual temperature is 26 C and the relative humidity is very high, normally more than 90%.
Based on the system of Koppen the climate may be classified as an Af or tropical rainforest climate (Koppen and Geiger, 1954).
For classifying the soils in the area, the climatic data are of importance: the soil moisture regime is perudic and the soil temperature regime is isohyperthermic (Soil Survey Staff, 1975).

2.4 Geology

The Atlantic zone of Costa Rica is the transition between the central mountain range (Cordillera Central) and the coastal area. The Cordillera Central is dominated by two quaternary volcanoes, Irazu and Turrialba. Volcanic activity is still present and the surroundings of the volcanoes are influenced by volcanic lava and lahar flows. The lahar deposits can be considered as a sequence of overlapping tonques of variable length (Fisher and Schmincke, 1984).
The lahars found in the Cocori area are all strongly weathered and don't have fresh volcanic material in the upper layers of the profile. Age determination can be done for instance by looking at the clay mineralogy (weathering).
The Alluvial plain is characterized by fluvial sand and clay deposits of volcanic origin. In this zone volcanic bodies of the "intergraben" type can be found.
The coastal zone shows deposits of marine and fluvial origin of meandering rivers like the Colorado river (Nieuwenhuyse and de Jong van Lier, 1988).

2.5 Geomorphology

The volcanic bodies are the rests of some small conic volcanoes of plio-pleistocenic age with a height of 20 to 250m. above sea level and steep slope. Soil texture is more than 50% clay, soils are well drained and reddish and the parent material is basaltic. In the valleys the colluvial material has the same characteristics. Volcanic material is deposited mainly as lava flows, intercalated with lapilli and lahar layers.
The residual hills are parts of the volcanic bodies dissected by rivers not originating from them. They are associated with valleys were one finds fluvial deposits. The hills are about 25m. higher than the fluvial plain which is less than 20m. above sea level, the same soils are found.
In the South and West of the area, rests of an alluvial pleistocene plain can be found associated with holocene

sediments. The rests of this plain nowadays can be seen as 2 to 8m. high hills, with slopes up to 20% (residual alluvial hills). The valleys between the hills normally are poorly drained. Water is mainly drained by the two most important rivers of the area, Rio Zapote and Rio Penitencia. The texture of the soils found in this unit is variable but mostly loamy.
The fluvial plains are found between the residual hills, drainage and texture of the sediments is variable. The landform is flat to undulating.
In the North-east part of the area there is a very flat plain (slope less than 1%), which is frequently inundated and has a large extension (Nieuwenhuyse and de Jong van Lier, 1988).

2.6 Landuse

Extensive cattle-breeding is the most important agricultural activity in the area, large farms exist of which the owners sometimes don't live in the area. Maize and rice are mainly cultivated from january to june and beans (frijoles) in the relatively dry period betweem december and march. Yuca, malanga, bananas and platanos are used for self-nutrition and sometimes for cattle. Many farmers have fruit trees like coconut and guanabana, the red soils with low pH and fertility are suitable for pineapple cultivation. Cacao cultivation is becoming more important as a commercial product. Some institutes are helping with the introduction of cacao in the area, especially concerning cultivation techniques and disease (monilia) control.

3. Methods

3.1 Introduction

To describe the process of compaction of soils and to relate this to land use, it is important to know the land use history. To investigate this, farmers were interviewed and the deforestation process observed during a couple of months. Then landuse sequences were chosen on two different soil types and studied (micro)morphologically. To characterize and additionally measure soil characteristics chemical and physical methods are used.

3.2 Description of the deforestation process

To describe the deforestation process in the Cocori area a map is made. At first the plan was to use aerial photographs (black and white) of different years to draw a map of the deforestated areas at different times. But the 1960 photos showed that the area was only scarcely colonized and practically no parts were cleared from forest. Since 1960 no photos were taken untill 1985 but the 1986 thematic mapper image helped to draw the map (Fig. 5, chapter 4).

The photos used to draw the map are:

- 6-1-1960, 1:60000, PMW.
nrs. 886-887-888-889.
- 9-1-1985, 1:35000, R222 L285.
nrs. 36179-36183.
- february 1986, TM-image, LANDSAT.

To study the deforestation process both the large-scale commercial clearing as the small-scale clearing by farmers are studied.

3.3 Selection of profile sites

Selection of the sites followed clearing of forest, when a recently cleared spot was found a landuse sequence was searched on the same soil type. The landuse sequences are chosen on two different soil types, Sardina and Cedral.
The Cedral soils are clayey, reddish to brown soils, deep and imperfectly to well drained. The Sardina soils are loamy, brown (B-horizon yellow-brown), shallow to moderately deep and poorly to imperfectly drained. Both soil types are of volcanic origin.
Thirteen sites are studied and sampled and their location is indicated on the map of figure 5. Four sites are located in the residual hills (Cedral soils) and nine are located in the river plains and banks (Sardina soils).

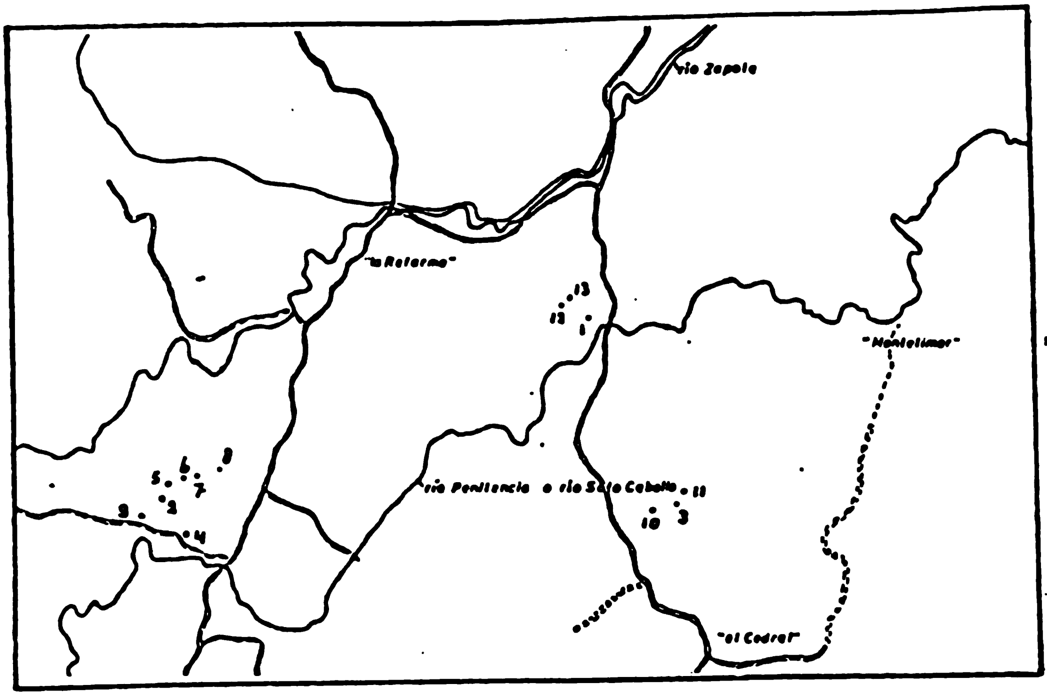

Figure 5. Location of profile sites.

Table 1 indicates the site numbers and the present and former land use:

	site number	landuse	former landuse
Cedral:			
	COC 13	forest	-
	COC 12	deforestated	forest ('87)
	COC 4	cacao	forest ('75-'78), maize, beans
	COC 1	pasture	forest ('77-'79)
Sardina:			
	COC 11	forest	-
	COC 3	deforestated	forest ('87)
	COC 10	cacao	forest ('80)
	COC 8	forest	-
	COC 7	sec. vegetation	forest ('75-'80)
	COC 6	sec. vegetation	forest ('75-'80), maize
	COC 5	cacao	forest ('75-'80), maize
	COC 2	cacao	forest ('75-'80), maize
	COC 9	pasture	forest ('72-'77)

Table 1. Selected sites and landuse-history.
()=year of deforestation.

The sites were named "COC" which is an abbreviation of "Cocori".

The Cedral sites were chosen in the hills just North of Rio Penitencia, three of them are in the Eastern part of the area and one in the Western (Fig. 5). The forest was cleared to use as grassland and possibly to grow pineapple. Clearing took place one month before investigation (COC 12). The pasture site of this sequence (COC 1), was cleared between 1977 and 1979 and since then only used for grassland. The cacao site (COC 4) was cleared between 1975 and 1978 and cleared from secundary vegetation with the use of a small bulldozer in november 1984 and then used for maize and beans (which had growing problems) and now for cacao, which is in good shape (Table 1).

The Sardina sites are found at two locations (Fig. 5):
South of Rio Penitencia, 400m. East of the Rio Colorado road sites were chosen in the undisturbed forest (COC 11), in the cleared area (COC 3) which was cleared a few weeks before and in a cacao plantation (COC 10) cleared from natural vegetation in 1980.
North of Rio Penitencia, 1km West of the Cocori road a landuse sequence was chosen that included two sites of which the regeneration after landuse could be studied under secundary vegetation. Sites were chosen in the primary forest (COC 8), secundary forest after clearing with heavy machinery between 1975 and 1980 (COC 7), secundary forest cleared with heavy machinery between 1975 and 1980 and a few years of maize cultivation (COC 6), cacao (COC 5) one year old where after maize the bulldozer not has been anymore but the surrounding of the plants have been cleared from vegetation with the machete, cacao (COC 2), one year old, where after maize the bulldozer has been to level the land and pasture (COC 9) cleared from forest between 1972 and 1977 (Table 1).
Because the two soil types Cedral and Sardina are so different they will be described and discussed seperately if necessary in the following text.

3.4 Soil profile descriptions

A pit was dug at each selected site and the soil profiles are studied with the help of the "Guidelines for soil profile description" (FAO, 1977).
Soil structure is very important in this study of compaction and therefore emphasis is on class, type and grade of structure and pore distribution in the profile. Mottles are described to give an indication of the water conditions in the profile and cutans on aggregates indicate illuviation of clay and so a less stable topsoil.
Consistence of aggregates is an important measure for the stability of structure and is given under moist and wet conditions.
Few additions were made to the guidelines: porous massive structure grade is used to divide it from other structureless types and is used for a loose porous soil where no seperate aggregates can be distinguished; evidence of compaction is

described as a general impression; thixotropicity is mentioned as an indication of andic properties.
Colours are indicated according to the Japanese soil colour charts. The Japanese hues 7.5 YR and 5YR are slightly comparable with respectively the hues 10YR and 7.5YR of the American Munsell colours.
Not every profile is measured physically or sampled for chemical, clay mineralogical and micromorphological analysis (table 2):

profile	micromorphological	chemical	clay mineralogical	physical
COC 1	+	-	-	-
COC 2	+	+	-	-
COC 3	+	-	-	+
COC 4	+	+	+	-
COC 5	+	+	-	-
COC 6	+	+	-	-
COC 7	+	-	-	-
COC 8	+	+	-	-
COC 9	+	-	-	-
COC 10	-	-	-	-
COC 11	+	+	-	+
COC 12	+	+	+	-
COC 13	+	-	-	-

Table 2. Analysis and measurements of profile-sites.

3.5 Micromorphological methods

For soil thin section sampling metal tins are used. Because there were 12 tins available at the project it was only possible to sample one horizon of 12 of the 13 profiles (table 2). Sampling this way is insufficient because micromorphological changes with depth can not be given and the variability of soils is high.
Because of the compaction study only topsoils were sampled by gently pushing the metal tins into the cleaned pit wall.
Dimensions of the tins used are 8*15*5cm.
Because of the high moisture content of these soils it would have been better to impregnate the samples as soon as possible. This was not done and the consequence was that the samples started shrinking during transport to Holland and this ofcourse can change many of the micromorphological features. Fortunately the damage was not so bad although only the upper part of the samples was suitable for thin sections (2-10cm.), these were impregnated in plastic and preapared to thin slices of soil (Jongerius and Heintzberger, 1975).
The thin sections were studied with a Leitz polarisation microscope and described according to the handbook by Bullock et al. (1985).
Not all of the micromorphological features are described but only those which are of importance for this study, like microstructure, peds, voids, basic organic components and

pedofeatures like amorphous and excrement features.
Because classification and division of the micromorphological features are explained and visualized with the help of observation matrices in paragraph 5.2 they will be discussed in that chapter.

3.6 Chemical methods

The profiles sampled for chemical analysis are indicated in table 2. Partly I analysed the samples myself, partly this was done by the MAG laboratory in Costa Rica.
The profiles were sampled by collecting horizon samples of 1 kg. which were air dried, sieved and homogenised for analysis.
Soil texture is determined with the hydrometer method; % organic matter with the Walkley-Black method; pH, potentiometrically in H2O and 0.01 M KCl; pH-NaF in 1 M NaF after two minutes to indicate the presence of "active Al" in the samples; phosphate retention with the New-Zealand method; exchangeable cations (Ca++, Mg++ and K+) with 1 M KCl; exchangeable acidity with 1 M KCl and titration with NaOH; exchangeable Al+++ with 1M KCl and colorimetry; ECEC or effective cation exchange capacity is the total sum of cations and exchangeable acid; CEC or total CEC, total extractable cations with NH4OAc, pH=7; BS (base saturation), at soil pH determined as quotient of the sum of cations and the ECEC, at pH=7 determined as quotient of the sum of cations and total CEC.
XRFS-analysis for major components was done for clay and soil.
Clay mineralogical analysis was done for COC 4 and COC 12 because in the field it was already observed that the residual hills could be of different age.

3.7 Physical methods

Infiltration measurements were done using the double ring method (Klute, 1986). Two metal rings were hammered into the ground at a site cleared from vegetation rests. Two rings are used to control the lateral movement of the water under the cilinders, measurement of the quantity of water infiltrating the soil is done in the cental ring. Disturbance of the topsoil during installing of the rings can have a large effect on the results.
It was very difficult to find good sites for the double ring method because the topsoils especially in the forest had a large amount of roots.
Ring infiltration measurements should be done in triple near to a described soil profile and at not more than 10m. distance of eachother (Landon, 1984). This was only done for COC 3 and COC 11. The basic infiltration rate is the constant infiltration rate after a period of time.

4. Deforestation

4.1 Introduction

Costa Rica's natural vegetation is tropical rain forest, except for the higher mountaineous areas. In 1940, 2/3 of the country was still under forest and only the forest of the Central valley were largely cut at that time. The continuing deforestation occurred initially in the lowland along the Westcoast (Guanacaste) but after that the North and the Atlantic Zone in the West became important.
Table 3 gives a clear view of the rate of deforestation in Costa Rica:

Total area Costa Rica	1940 forest area	1950 forest area	1961 forest area	1977 forest area	1983 forest area
50,990	34,206	28,642	23,035	16,154	8,711
rate:	1.6%	1.8%	1.9%	7.7%	

Table 3. Forest area change (km2) and rate of deforestation (%/yr.) in Costa Rica. (after Sader and Joyce, 1988).

The figures from table 3 were obtained by digitizing available map sources of forest boundaries and other landscape attributes.
The conclusion from table 3 can be that already 83% of Costa Rica's forest has been cleared and that the rate of deforestation is increasing.
Also a strong relationship was found between the overland transportation network and the forest clearing. (Sader and Joyce, 1988).
Only 7.6% of Costa Rica's total area could be considered as production forests in 1983 of which the most important parts are found in the Atlantic Zone and the Northern Zone at the moment threatened by large colonization.
In 1970 the Ministery of Agriculture installed a forest service (Direccion General Forestal) to control the forest area of Costa Rica and the activities of deforestation. Several forest reserves were planned where forest only could be cleared under concession or permissions. Outside the forest reserves also permission is needed for every tree that is cut but the DGF has no means to control this; so all the measures have had little effect up to now.
With the present-day rate of deforestation, the forest of Costa Rica one's called the most rich and beautiful of the world will have disappeared before the year 2000 !

4.2 Deforestation in the Cocori area

4.2.1 Deforestation map

The 1960 photos didn't show deforestation but it occured to me that the whole area was more wet than nowadays can be seen. After studying photos of the surrounding area and inquiries at the Instituto Geographico Nacional at San Jose it became clear that the Chirripo river changed it's stream as a result of Irazu's volcanic eruptions in 1962. The Chirripo river is now more to the west and for instance the Chirripocito river which had it's stream in the Cocori area is now at 3km. to the West.
The map (Fig. 6) shows that deforestation has taken place along the rivers and the roads and at few spots in the Northern hills. The map does not cover the whole Cocori area but of the mapped area one can say that untill 1986 20% was cleared from forest (1200ha.).
The construction of new roads will increase the colonization and the rate of forest clearing, working in the area estimations could be made that between december 1986 untill june 1987, 700 to 900 hectares were cleared from forest vegetation (Nieuwenhuyse and de Jong van Lier, 1988).

4.2.2 Methods and reasons for deforestation

There are two reasons for clearing forest in the Atlantic Zone. The first is to obtain agriculture land or posession rights on the land, the second is timber trade thus selective clearing of forest.
For land degradation the large scale selective clearing of forest is the worst because heavy machinery is used (trucks, tractors etc.). In the Cocori area large-scale clearing is done by firms from San Jose, clearing the forest efficiently but very selective. Only 5 to 6 trees per hectare are cut with a chainsaw and removed with a bulldozer towards the road from where large trucks transport the stems to San Jose. The timber is offered at saw-mills (some of which are in the area) and these only accept good quality wood.
The result of this is that only the best quality trees are cut and of these trees only the lower part. The land degradation is mainly caused by the heavy machinery that is used, for instance the bulldozer that enters the forest to remove the wood often cannot us the same road twice because of the high groundwatertable and the bad carrying capacity of the andeptic soils. So to remove only the valuable stems 10 to 12 roads per hectare are made by the bulldozer. It is important to determine the percentage of the area compacted by the bulldozer and I estimated that 10% was severely and another 10% less compacted. A farmer mentioned that he had severe growing problems with maize planted in an area cleared the same way a year ago.
In Cocori a road commitee was installed by the people because the large trucks destroy the roads and are now only allowed in the more dry period february to april but again control

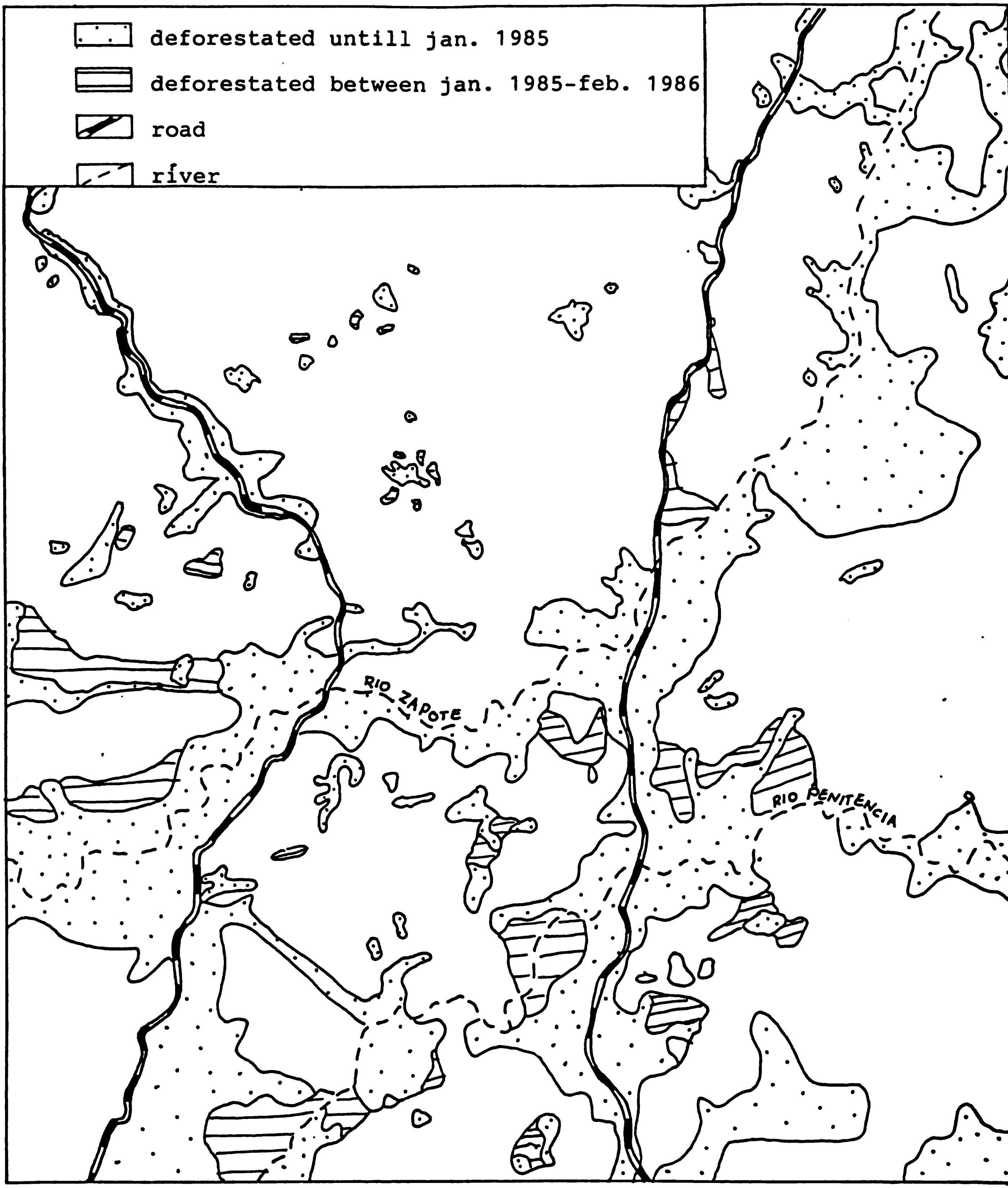

Figure 6. Deforestation map of the Cocori-area (scale 1:35,000).

over this is difficult.
The most important woodspecies for this timber trade are Cedro macho (Carapa guianensis) Laurel (Cordia alliodora), Gavilan (Peuthacletra macroloba) and the large Ceibo (Ceiba peutandra).
The timber exploitants are invited by farmers that have left parts of their land under forest or during clearing not have cut the valuable species. They are being paid per volume.
Another less devastating method of selective clearing is done by the farmers themselves. The valuable trees are cut and sawn into planks or posts and then transported with ox-carts. These can use the same road every transport so the compacted area is small.
Total clearing using a chopping-knife (machete) or chainsaw without transportation of the wood only slightly compacts the soil.
Despite compaction farmers are often advised to remove all the trees to stimulate mechanisation, but much depends on the landuse the farmer has planned.
Because plans are made to make the area north of Rio Penitencia a national forest-reserve the clearing rate increases rapidly.
After clearing farmers with agricultural objectives often wait for two years before cultivating. The reasons are not completely known but probably it is done to dry the (top)soil with the help of the sun and the secundary vegetation and to reduce acidity.

5 Morphological observations

5.1 Introduction

The morphological results are divided in field observations and micro-morphological (thin section) observations.
The Sardina soils have andeptic properties related to the occurrance in the soil of allophane (the Cedral soils also are of volcanic origin but more weathered, see chapter 6). These soils normally are very porous, have a weak development of structure elements but are stable (Bennema, 1981). Compaction produces a moderate increase in density and a large increase in strength of allophane soils (Tan, 1984). Because of the importance of linking soil thin section descriptions with field descriptions it is important that the most commonly used field size classes should be used (table 4):

	aggregates		voids
	granular, crumb	(sub-)angular blocky	
size class			
< 1mm	very fine	ultra fine	very fine
1- 2mm	fine	very fine	fine
2- 5mm	medium	very fine	medium
5-10mm	coarse	fine	coarse
10-20mm	very coarse	medium	very coarse
20-50mm	-	coarse	-

Table 4. Size classes of aggregates (Bullock et al ,1985 and FAO,1977).

5.2 Macromorphological (field) observations

Appendix A gives the field soil profile descriptions of every studied site, these are discussed in the next two paragraphs.

5.2.1 Cedral macromorphological observations

Profiles COC 1, COC 4, COC 12, COC 13.

The forest profile (COC 13) will be seen as the starting profile of this sequence to which the others will be related. Soil structure is fine crumb and granular with very fine subangular blocky in the topsoil, to very fine subangular blocky in the subsoil. Consistence is very friable to friable and very few gibbsitic nodules are found. No mottles and cutans are observed. Porosity is high and pores of every size but mainly very fine pores are found. Root distribution is normal. Biological activity is very clear especially

earthworms and ants, the topsoil could be given a wormstructure (vermiform).
The deforestated profile (COC 12) doesn't show much difference and has the same profile description except for the topsoil. Some compaction can be observed of the first few centimeters and the A horizon has a strong very fine to fine subangular blocky structure, but the porosity is still high. The biological activity has not been disturbed much by the deforestation and the A horizon can, still or already one month after deforestation, be given a wormstructure. Deeper than 90cm. thin clay cutans can be found.
The cacao profile (COC 4) is much different. The first 17cm. show evidence of compaction due to clearing of the secundary vegetation using heavy machinery (skeeler) and landuse. The A horizon (0-5cm.) has a strong fine subangular and angular blocky structure and common pores. The compacted Ag horizon (5-17cm.) is structureless and massive and has only few pores. This horizon and the underlying horizons untill 27cm. have common, red mottling as a result of waterstagnation and so pseudogley circumstances. The Btg horizon also shows mottling but is a result of biological activity eg. roots penetrating the soil cause compaction and so waterstagnation. The Bt horizons all have thin, broken clay cutans probably because of the less stable topsoil. Below 17cm. structure development is normal and very fine subangular and/or angular blocky. Many earthworms to a depth of 25cm., in the deeper horizons there is no evidence of worm activity.
The pasture profile (COC 1) is even more compacted in the first 3 cm. The surface horizon Ag1 (0-3cm.) is structureless massive, has a firm consistence and few pores. The structure of the underlying horizons is very fine subangular blocky. The surface horizon is grey coloured and common red mottles are found untill 10 cm. due to waterstagnation
Again because of the probable less stable topsoil thin, broken clay cutans are found in the Bt horizons.

5.2.2 Sardina macromorphological observations

Profiles COC 2, COC 3, COC 5, COC 6, COC 7, COC 8, COC 9, COC 10, COC 11.

Initially it was suggested that the Sardina soil types of Cocori East and -West could not be related, but if we look at profile descriptions of the two forest profiles COC 8 and COC 11, they are practically the same. Structure is very fine to fine subangular blocky to fine granular in the topsoil which changes to porous massive in the subsoil. Texture changes from loam to sand with depth. Consistence is very friable to friable except for Bg1 horizon of COC 11 which has a firm to very firm consistence for which there is no explanation. The B horizon has the typical "andic" yellowish brown colour. Porosity is very high mainly as very fine pores. No cutans. Root distribution is normal. Both the profiles have a high groundwatertable and mottling starts at 30cm. Biological activity of course is very high and the topsoil structure

could be called a wormstructure. Thixotropic topsoils.
The deforestated profile (COC 3) which is situated in the bulldozer tracks made one month before has the same profile description as the forest profiles (COC 11 is at 4 meters distance), except for the topsoil which is severely compacted.
The A1 horizon (0-12cm.) has a massive structure with some subangular blocks and only few very fine and coarse pores. Many earthworm activity can already be observed and again a firm consistence is found in the 35-45 sandy loam layer.
The cacao profile (COC 10) is not so far away from COC 3 and 11 and has a low porosity, only few fine and coarse pores can be seen. Structure development is different as well and changes from very fine to fine subangular blocky in the surface horizon to massive in the A2 horizon (12-30cm.)
Profile COC 7 with secundary vegetation is only slightly different from the forest profiles: the topsoil is somewhat angular blocky.
The other secundary vegetation profile (COC 6) shows a slightly compacted surface horizon Ag (0-5cm) that has common pores and red and grey mottling.
The cacao profile of COC 5 is between trees and therefore no heavy machinery has come here after deforestation. Compaction in the surrounding differs a great deal at short distance. The surface horizon Ag (0-5cm.) has a weak very fine angular blocky structure, only common very fine and few medium pores and red and grey mottling.
At site COC 2 a bulldozer has been used for the maize and cacao cultivation and this can be seen from the profile. The surface horizon Ag1 (0-3cm.) has a massive structure, few very fine pores, a firm consistence and red mottling. The Ag2 horizon (3-10cm.) has a very fine angular blocky structure, common very fine pores and red mottling. Striking is that only few roots are observed throughout the profile.
Finally the pasture profile (COC 9) ofcoarse shows surface layer compaction but the surface horizon Ag1 (0-4cm.) has a granular to very fine subangular blocky structure due to the abundant very fine grass roots. The Ag2 horizon (4-12cm.) is medium to coarse angular blocky, has common very fine pores, a firm consistence, a grey colour and many red mottles. The subsoil of this profile again is not different from the forest profiles.

5.3 Micromorphological observations

5.3.1 Introduction

Detailed micromorphological descriptions are given in appendix B.
The way the thin section samples were treated is influencing the observations. Some thin sections show a pattern of shrinking cracks, which is strange because much swelling clays were not expected, probably this was due to the bad treatment.

Clay mineralogy analysis changed this idea a bit because some vermiculite was found in COC 4 (chapter 6), but still the interaggregate porosity is difficult to interprete. So more emphasis came on the intra-aggregate porosity to study the density of the aggregates.
The results are given in two large matrices (table 5 and 6), which make it more easy to see changes as a result of landuse and deforestation. The matrices are quite complete although sometimes average impressions had to be given because of the large variation even in a small thin section, therefore it is necessary to examine as well the micromorphological descriptions of appendix B.
The features that are mentioned in the matrices are all of importance in the study of soil degradation and they are described according to Bullock et al. (1985) except for some observations which were differently classified.
The classification is done partly by comparing the occurrence of the feature for the whole sequence. This was done for the amorphous and excrement pedofeatures, the biological activity and the matrix density, it has a low (+) to high (+++++) classification and are relative intensities.
Amorphous pedofeatures are due to pseudogleyic circumstances caused by stagnation of water in the surface horizon. This gives ferrugineous mottling and hypocoatings especially near channels and larger voids. Some of the groundmass is completely grey coloured because of reduction, which normally can't be seen in pseudogley horizons.
Excrement pedofeatures are present in most of the thin sections. They consist of many small spherical excrements sometimes as loose discontinuous infillings of channels.

The peds and intra-aggregate voids are indicated in percentages:

+	20%
++	40%
+++	60%
++++	80%
+++++	100%

The average development of peds should in fact be given per ped type, this was not done to keep the matrix more simple. The classification is:

+	weakly developed
+++	moderately developed
+++++	strongly developed

The average size of aggregates for the whole thin section is (see 5.1):

+	ultrafine
++	very fine
+++	fine
++++	medium
+++++	coarse

The average intra-aggregate porosity has been classified as follows:

very dense	<2%	porosity
dense	2-5%	
rather dense	5-10%	
porous	10-20%	
very porous	>20%	

Organic matter and plant residues are given in percentages:

+	5%
++	10%
+++	15%
++++	20%
+++++	25%

Because only topsoils were sampled the average organic matter content is high.
Of course some of the forest topsoils are strongly organic pigmented.
Biological activity is a compound feature for which the % of channels, the porosity, the density of the matrix and the excrement features are important.

5.3.2 Cedral micromorphological observations

The micromorphological features of the Cedral soils are presented in table 5.
The forest thin section (COC 13) has a porous crumbstructure with moderately to strongly developed, ultrafine to medium crumbs. Voids are channels and vughs but mainly interconnected vughs. Many basic organic components and excrement pedofeatures and ofcoarse there is much evidence of biological activity. The deforestated thin section (COC 12) is practically the same but structure is mainly angular blocky (seperated with skew planes) and excrement pedofeatures and biological activity is somewhat less visible.
The thin section of the cacao profile (COC 4) shows a subangular but mainly angular blocky structure with skew planes between the angular blocks. Voids are mainly physicogene (vughs), the porosity is low and the matrix is dense. There are only few basic organic components and some mottling. Biological activity is somewhat lower.
The structure of the pasture profile (COC 1) is mainly angular blocky (skew planes) and partly subangular blocky and apedal. Voids at the bottom of the thin section are physicogene (vughs) but also interconnected vughs and channels can be found. At the bottom the matrix is dense and at the top it is porous. Basic organic components and excrement pedofeatures are relatively few. The matrix colour is grey and there are few ferrugineous hypocoatings and mottles. Biological activity is relatively low.

	COC 13 (87/169) forest	COC 12 (87/168) deforestated	COC 4 (87/162) cacao	COC 1 (87/159) pasture
microstructure	crumb	complex	(sub-)ang. blocky	complex
peds:				
crumb	+++++	++	-	-
subang. blocky	-	-	++	+
ang. blocky	-	+++	+++	+++
apedal struct.	-	-	-	+
average development of peds	++++	++	++	+++
average size of aggregates	+++	+++	++	+++
intra-aggregate voids:				
channels	+	+	+	+
intercon. vughs	+++	+++	-	++
vughs	+	+	++++	++ ++++(B)
planes	-	-	-	-
inter-aggregate voids:				
(skew) planes	-	+++	+++	+++
average porosity	porous	porous	dense	dense(B) porous(T)
dense matrix	+	-	+++++	+++
basic organic components:				
organic matter	++++	+++	+	++
plant residues	++	++	+	++
amorphous pedofeatures:				
hypocoatings	-	-	-	+
quasicoatings	-	-	-	-
mottling	-	-	+++	++
grey colour	-	-	-	++
excrement pedofeatures	+++++	+++	+++	++
biological activity	+++++	+++	+++	++

Table 5. Cedral micromorphological observations (B=bottom, T=top).

5.3.3 Sardina micromorphological observations

The micromorphological features of the Sardina soils are presented in table 6.
The forest thin sections (COC 11 and 8) have a very porous crumb structure with moderately to strongly developed, ultrafine to coarse crumbs. Voids are mainly interconnected vughs and further channels and planes. Ofcoarse there are many basic organic components and excrement pedofeatures and biological activity is high.
The deforestated profile (COC 3) shows an apedal structure which is still very porous. The crumbstructure has been compacted, no aggregates can be seen but the voids have remained, mainly interconnected vughs and some channels and planes. Basic organic components and excrement pedofeatures are largely present and biological activity is high. Part of the thin section matrix is more dense.
The profiles with secundary vegetation (COC 7 and 6) have a good crumbstructure and are very porous but the crumbs are very weakly developed. Interconnected vughs are the most important voids and some channels can be observed. COC 7 has a partly dense matrix, many basic organic components and excrement pedofeatures. COC 6 has many basic organic components, only common excrement pedofeatures and ferrugineous hypocoatings and mottling.
The cacao thin sections (COC 5 and 2) have a porous apedal structure, no loose aggregates can be seen. Voids are mainly interconnected vughs but as well vughs and channels. Few basic organic components and common excrement pedofeatures and biological activity. Profile COC 5 has some mottling and grey colouring but profile COC 2 has hypocoatings, quasicoatings, mottling and is for a large part greyish coloured.
The grassland profile (COC 9) has a porous apedal (channel) structure. Voids are mainly channels but also some vughs are found. About 5% of the matrix is more dense because of slemp. Only few basic organic components can be seen but many amorphous pedofeatures. The matrix is completely grey coloured, ferrugineous hypocoatings and quasicoatings can be seen and many ferric mottling.

	COC 11 (87/159) forest	COC 8 (87/166) forest	COC 3 (87/161) deforestated	COC 7 (87/165) sec. veget.	COC 6 (87/164) sec.veget.	COC 5 (87/163) cacao	COC 2 (87/160) cacao	COC 9 (87/167) pasture
microstructure	crumb	crumb	apedal	crumb	crumb	apedal	apedal	apedal
peds:								
crumb	+++++	+++++	-	+++++	+++++	-	-	-
subang. blocky	-	-	-	-	-	-	-	-
ang. blocky	-	-	-	-	-	-	-	-
apedal	-	-	+++++	-	-	+++++	+++++	+++++
average development of peds	+++	++++	-	++	+	-	-	-
average size of aggregates	+++	++++	-	+++	++	-	-	-
intra-aggregate voids:								
channels	++	+	+	+	+	+	+	++++
intercon. vughs	+++	+++	+++	++++	++++	++	+++	-
vughs	-	-	-	-	-	++	+	+
planes	-	+	+	-	-	-	-	-
inter-aggregate voids:								
(skew) planes	-	-	-	-	-	-	-	-
average porosity	very porous	very porous	very porous	very porous	very porous	porous	porous	porous
dense matrix	-	-	+	+	-	+	-	+
basic organic components:								
organic matter	+++++	++++	++++	++++	+++++	+	++	+
plant residues	+++	+	+	+	+	+	+	+
amorphous pedofeatures:								
hypocoatings	-	-	-	-	++	-	++	+++
quasicoatings	-	-	-	-	-	-	++	+
mottling	-	-	-	-	+++	+	++	++++
grey colour	-	-	-	-	-	++	+++	+++++
excrement pedofeatures	+++++	+++++	+++++	+++++	+++	+++	++	++
biological activity	+++++	+++++	+++++	+++++	++++	+++	++	+++

Table 6. Sardina micromorphological features

6 Chemical and physical soil properties

6.1 Chemical soil properties

The chemical results are mainly of importance in the characterisation of the soil types. Changes in chemical properties because of landuse can not be given because of a lack of sufficient data.
The Cedral chemical soil properties are presented in appendix C.
Remarkable are the clay content (>50%) and the very low pH-H2O (4.2-4.8)and pH-KCl (3.7-4.0). The pH-NaF (after two minutes) and the phosfate retention (COC 4) indicate the andic properties of this soil type.

	kaolinite	mica	vermiculite	halloysite
COC 4:				
0-5cm	++++	-	+	1)
5-17cm	++++	-	+	1)
17-27cm	++++	(+)	+	1)
27-70cm	++++	(+)	+	1)
70-100cm	++++	-	+	1)
100-150cm	++++	(+)	+	1)
COC 12:				
0-15cm	2)	-	(+)	++++
15-90cm	2)	(+)	(+)	++++
90-120cm	2)	(+)	-	++++
120-160+cm	2)	(+)	-	++++

Table 7. Clay mineralogical analysis.

NB. ++++=abundant, +++=many, ++=common, +=few, (+)= minimal or doubtful, -=not present.

1) kaolinite analysed but probably as well halloysite.
2)halloysite (7-and10 Angstrom) but probably as well kaolinite.
3) In all samples some gibbsite and goethite is analysed.

Continuous weathering of allophane rich soils makes that because of kristallisation first halloysite (Si/Al=1) and gibbsite is formed and after that kaolinite (Si/Al=1) and gibbsite (Bennema et al, 1981). From the clay mineralogical analysis (table 7) can be concluded that COC 4 with kaolinite and gibbsite is an older deposit or has been more strongly weathered than COC 12 with halloysite and gibbsite.
Most of the amorph materials will have weathered into 1:1 clay minerals (see the high clay content). The high CEC and

the andeptic properties of the two profiles indicate that still some amorph material is present in the profiles.

The Sardina chemical soil properties are presented in appendix C, the analysis done in Wageningen (COC 11 and COC 2) and in Costa Rica (COC 5,6,8) are different especially concerning the CEC.
The soils have a loamy or silt loamy texture and the topsoil has a high to very high organic matter content. The forest profiles (COC 11 and 8) have a lower pH in the surface horizon due to the presence of more organic acids. Ofcoarse these soils have the typical reactions related to andic properties: pH-NaF is high after two minutes (> 8.6) and the phosphate retention is high but only for the forest profiles it's higher than 90%. Because of the andic properties analysed (chemically), felt (thixotropicity) and seen in the field it can be concluded (though not analysed) that a large amount of amorphous material (allophane) will be present in these soils. Therefore the calculated CEC's of COC 2 and 11 which are high to very high (> 50 meq/100g in topsoils) seem to be more realistic. The amorph elements of the clay of volcanic soils normally have a large specific surface and thus a high CEC and/or AEC. Especially the specific surface of allophane is very large: 700-900 m2/g. The exchange capacity is due to the surface charge which is completely variable (Mizota and van Reeuwijk, 1987).
The very low Ca content of COC 11 might be due to the low pH in the topsoil. Base saturation depens on the CEC-analysis but for the forest-profiles base saturation is lower than 50%.

6.2 Physical soil properties

The water content of the soils at any pressure is very high because of the high content of relatively small pores related to andeptic soils. The allophane clay minerals in the soil have a large water-binding capacity. The thixotropic character of these volcanic soils is important in compaction studies. Exposure to pressure makes that water is pressed out of the soil and the soil becomes smeary, this explaines the low carrying capacity of allophane soils (Bennema et al, 1981). Drying of the soils gives a decrease in small pores and so of water content, the result of this is that the volume of the soil decreases, this explaines the shrinking of volcanic soils during drying (Tan, 1984).
Infiltration measurements were only done in the East part of the area because the double ring method is rather laborious. It should be mentioned that measurements at site COC 3 were taken in or close by the bulldozer-tracks in a severely compacted part.
The results are presented in table 8:

	basic infiltration rates (cm/hr.)			
	1	2	3	average
COC 11, forest	30	8	16	18
COC 3, deforestated	0.5	0.4	0.4	0.4

Table 8. Basic infiltration rates.

The infiltration rates show that the forest profile can easily cope with any amount of infiltration water but at the compacted site water can only infiltrate the soil very slowly, so during heavy rain showers water will rest on the soil and if there is a slope run-off and erosion is the result.

7. Discussion and conclusions

7.1 Introduction

In this chapter conclusions will be drawn from the results given in the previous chapters. The data collected are mostly qualitative; quantitative results are only given for chemical and physical properties of the soil types. Many results have to be seen as relative intensities and conclusions are therefore only applicable to this case study.

7.2 Conclusions on soil degradation

Soil degradation as a result of the impact of landuse on soil properties is described in this report mainly with the help of morphological data. The results of macromorphological as well as micromorphological investigations of the topsoils are combined in table 9.
Landuse on the soil types selected for this study changes the morphological characteristics from biogene (forest) to physicogene (pasture).
Structure (table 9) changes from crumb to a porous massive structure (sardina), seperate aggregates can no longer be seen or if compaction continues a subangular or even an angular blocky physicogene structure is formed. For the cedral soils under cacao or pasture a massive dense structure can be formed. Under the same landuse the sardina soils never become dense massive as can be seen from the porosity results. Micromorphology is important in this respect because field descriptions indicated a low porosity for the compacted sardina soils but the soil thin sections gave a different image: the sardina soils remain porous when they are used for pasture and cacao.
The Cedral forest soils are porous and change to rather dense and dense during compaction. This can be visualized with the help of photographs taken of the cedral soil thin sections. Figure 7 shows the porous unaccommodated crumbstructure of the forest profile. In figure 8 can be seen that this crumbstructure is pressed together because of compaction during deforestation. The third photo (figure 9) is of the cacao site and shows compact aggregates with a low porosity and finally figure 10 is a photo of the pasture thin section with accommodated dense angular blocks.
Void type degradation can be studied micromorphologically and a change is seen from biogene voids (channels) to physicogene voids (planes) in the landuse sequence.
The consistence when moist remains relatively constant in the sequence (very friable, friable), only the pasture profiles have a partly firm consistence.
Amorphous pedofeatures like mottling, hypo- and quasicoatings of channels and voids and grey reduced colours indicate (pseudo-) gley circumstances caused by stagnation of water in the topsoil horizons. This stagnation of water is not only

soil profile number	landuse	structure: crumb, granular	structure: porous massive	structure: subangular	structure: angular	structure: massive	porosity: very porous	porosity: porous	porosity: rather dense	porosity: dense	void types: channels	void types: intercon. vughs	void types: vughs	void types: planes	consistence: very friable	consistence: friable	consistence: firm	amorphous pedofeatures: mottling	amorphous pedofeatures: coatings	amorphous pedofeatures: grey colour.
CEDRAL:																				
COC 13	forest	+		+				+			+	+	+			+				
COC 12	deforestated	+		+	+			+			+	+	+	+		+				
COC 4	cacao			+	+	+				+	+		+	+		+		+		
COC 1	pasture			+	+	+			+	+	+		+	+		+	+	+	+	+
SARDINA:																				
COC 11	forest	+		+			+				+	+			+					
COC 8	forest	+		+			+				+	+				+				
COC 3	deforestated		+	+			+				+	+		+	+					
COC 6	sec. veget.	+	+	+			+				+	+				+		+	+	
COC 7	sec. veget.	+		+	+		+				+	+				+				
COC 5	cacao			+	+			+			+	+	+		+	+		+		+
COC 2	cacao		+		+			+			+	+				+	+	+	+	+
COC 9	pasture			+	+			+			+		+			+	+	+	+	+

Table 9. Morphological characteristics of topsoils.

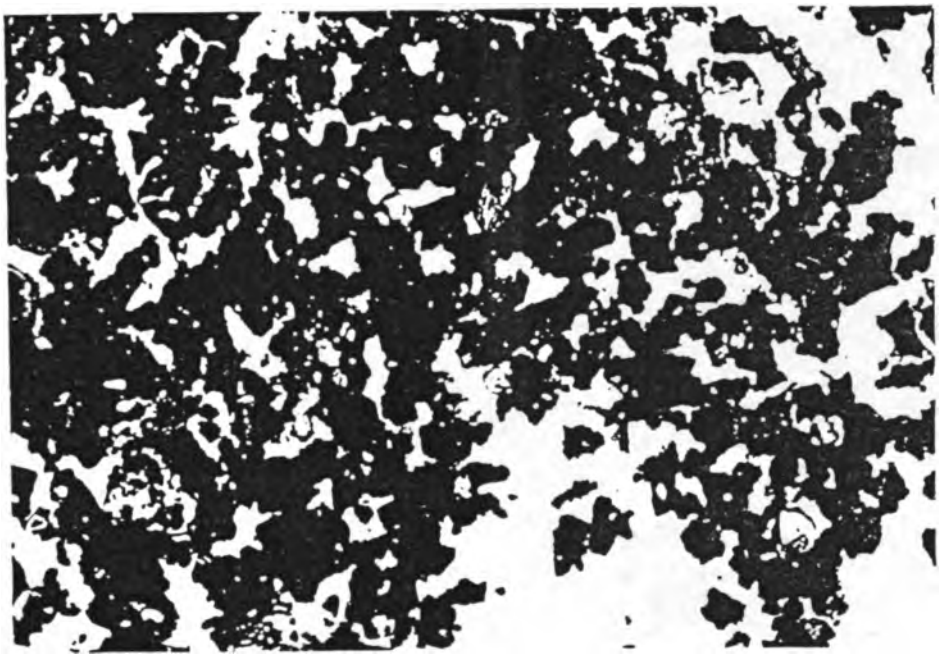

Figure 7. Topsoil forest profile (Cedral, COC 13, 87/169).

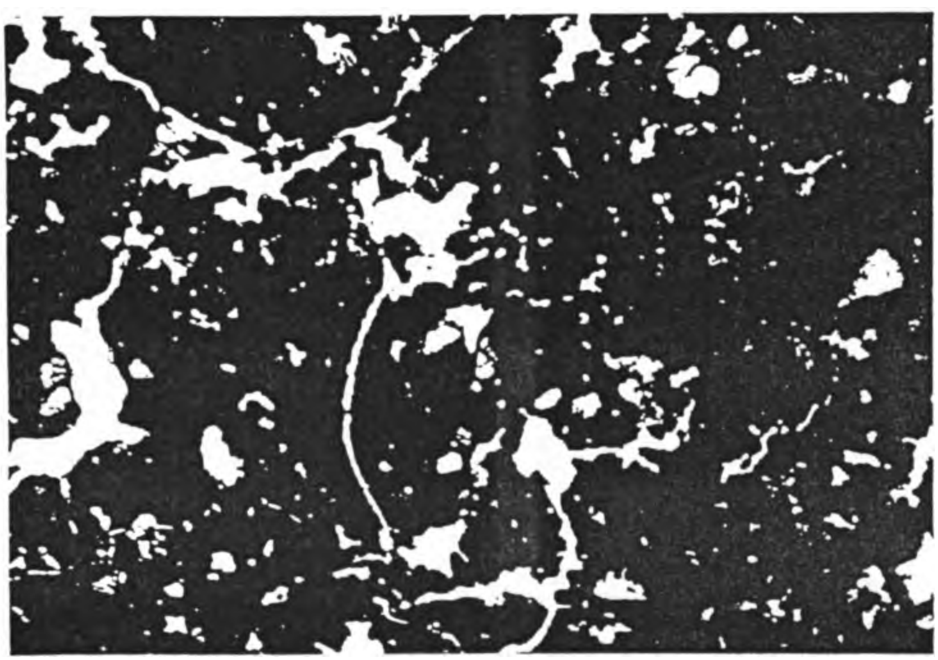

Figure 8. Topsoil deforestated profile (Cedral, COC 12, 87/168).

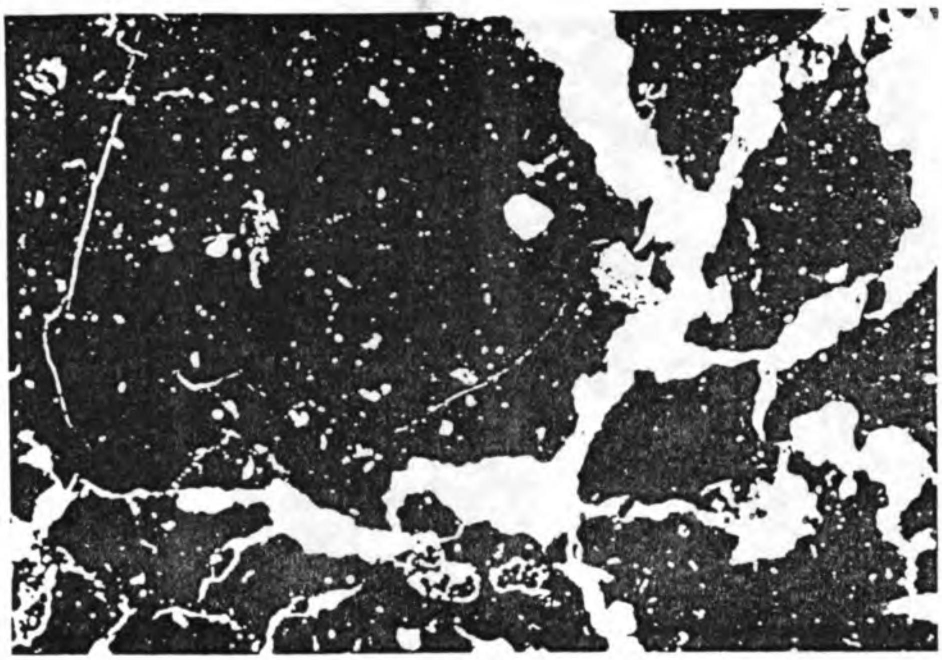

Figure 9. Topsoil cacao profile (Cedral. COC 4, 87/162).

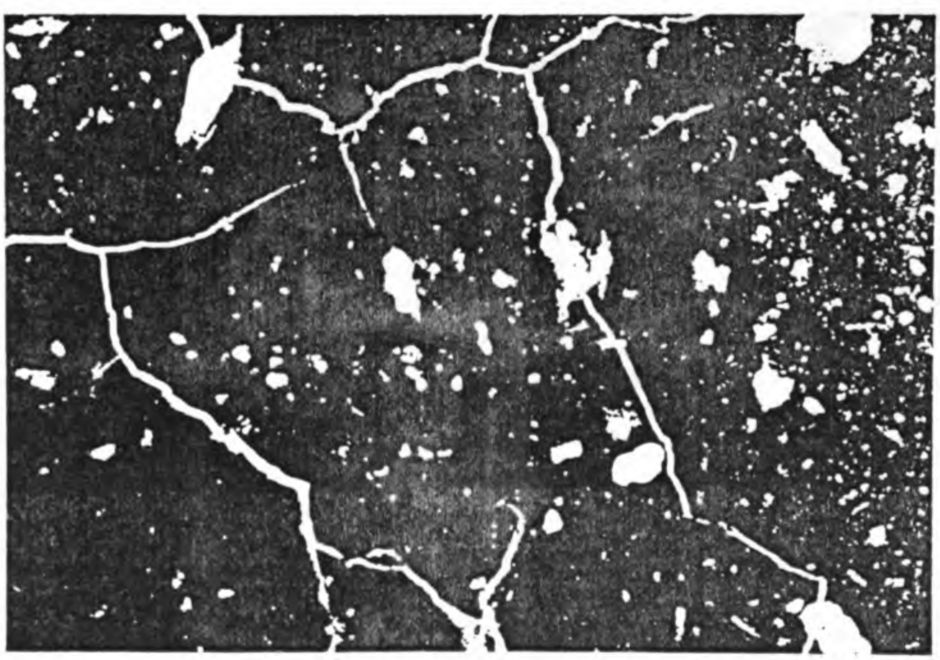

Figure 10. Topsoil pasture profile (Cedral, COC 1, 87/158).

caused by compaction of the surface layer and a decrease in porosity and so permeability of the soil (cedral), but also because of the large amount of relatively small pores of allophane soils (sardina). These are constantly filled with water and this way influencing oxidation and reduction processes in the topsoil in a very humid climate. Of course this process can cause air- and waterstress for plants, farmers in the area indeed have growing problems with crops having a shallow rooting system.
Also the biological activity decreases as a result of landuse not only because of a dense soil and problems of air- and waterstress as indicated but also because of a lack of food. For instance the important leaf cutter ant, the soil animal with the highest biological activity in the forest causing loose porous soils have requirements on the environment, and are less present if the landuse changes (Lansu, 1988). Together with a decrease in organic matter in the soil the biological activity of the soil will become less and this will have it's effect on the recovering of the soil after degradation. In thin sections biological activity can be seen for instance by looking at excremental pedofeatures (figure 11):

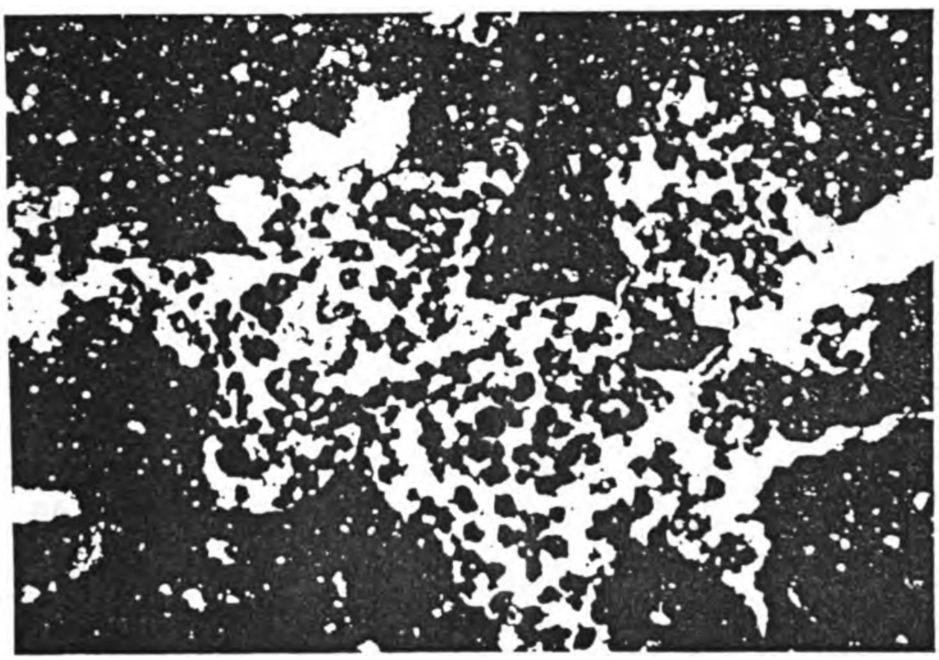

Figure 11. Excremental pedofeatures (COC 4, 87/162).

Because secundary vegetation sites were included in the sequence the recovering of soils after degradation could be studied. From the results can be concluded that a certain degree of recovering has taken place: The secundary vegetation site of COC 7 doesn't show large differences with the forest profile but has not been cultivated after deforestation. Site COC 6 where after deforestation maize was

cultivated also shows only slight changes from the forest structure and porosity but has some pseudogleyic features. The general impression is that these sites have been compacted but because vegetation is present again biological activity is increasing and the soil is becoming more biogene, the crumb-granular structure returns but the aggragates are still more dense.
Deforestation sites were included to study if degradation starts with the deforestation of a site. From table 9 can be seen that the soil structure changes during compaction and becomes physicogene blocky (cedral) or apedal (sardina) but there is no change in porosity. So deforestation even with a bulldozer has a large effect on soil properties but not on porosity of the soil, degradation is getting worse during landuse following deforestation.
An important conclusion of this study is that probably older volcanic soils (cedral) are more susceptible to compaction than the younger volcanic soils (sardina). The cedral soils are strongly weathered and the clay percentage is high, compaction decreases the porosity and a dense topsoil is formed. The sardina soils remain porous even under strong continuing compaction (pasture). In this respect it is important to mention that compaction probably is not the good word to use here because compaction is related to a decrease in bulk density and porosity. Pressure on these allophane soils makes that they become smeary because of the large watercontent but if no further pressure is exposed on the soil it can recover (Warkentin and Maeda, 1980). Further study of this problem of the difference in grade of compaction of the different soil types will be done by the project with the help of physical measurements of water movement in the soil related to morphological characteristics.

7.3 Soil taxonomy classification problems

The Cedral soils are classified as andic humitropepts (soil conservation service, 1975). At first they were classified as andepts because of the andic chemical properties analysed (appendix C), but to be classified as andepts the exchange complex should be dominated by amorphous materials. This is not the case because most of the amorphous materials have weathered into the clay-minerals kaolinite and halloysite (chapter 6). Clay illuviation is a process in the soil but a Bt-horizon is not formed to become an ultisol. So they are classified because of the warm soil-temperature regime as tropepts and because of the low base-saturation ($< 50\%$) and high organic matter content as humitropepts.
The Sardina soils have an exchange complex that is dominated by amorphous materials which can be concluded from the very high CEC's and volcanic properties (appendix C). According to the base saturation ($< 50\%$) they are classified as dystrandepts.

8. References

Allen, J.C., 1985. Soil response to forest clearing in the United States and in the tropics: geological and biological factors. Biotropica 17: 15-27.

Bennema, J. et al., 1981. Bodemkunde van de tropen en subtropen 1. Collegediktaat Landbouwhogeschool Wageningen. Wageningen, the Netherlands.

Bullock, P. et al., 1985. Handbook for soil thin section description. Waine Research Publications, Wolverhampton.

FAO, 1977. Guidelines for soil profile description. 2nd. ed. Food and Agriculture Organisation of the United Nations (FAO). Rome.

Fisher, R.V. & H.U. Schmincke, 1984. Pyroclastic rocks. Springer Verlag. Berlin.

Gudmundson, L., 1983. Hancendados, politicos y precaristas: la ganaderia y el latifundismo Guanacasteco 1800-1950. Editorial Costa Rica. San José, Costa Rica.

Jongerius, A. & G. Heintzberger, 1975. Methods in soil micromorphology; A technique for the preparation of large thin sections. Soil Survey Papers No. 10, Netherlands Soil Survey Institute. Wageningen, the Netherlands.

Koppen, W. & R. Geiger, 1954. Klima der Erde (map). Justus Perthes, Darmstadt.

Klute, A. (ed.), 1986. Methods of soil analysis. Part 1: physical and mineralogical methods. 2nd. edition. Agronomy Series No. 9. American Society of Agronomy. Madison, USA.

Landon, J.R. (ed.), 1984. Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Agricultural International, London.

Lansu, A.L.E., 1988. The impact of land use on soil structure. Thesis. Agricultural University, Wageningen. Wageningen, the Netherlands.

Marshall, T.J. & J.W. Holmes, 1979. Soil physics. Cambridge University Press, Cambridge.

Mizota, C. & L.P. van Reeuwijk, 1987. Clay mineralogy and chemistry of andosols and related soils from diverse climatic regions. International Soil Reference and Information Centre. Wageningen, the Netherlands.

Nieuwenhuyse, A. & Q. de Jong van Lier, 1988. Estudio semi-detallado de la geomorfología y los suelos de Cocorí, Zona Atlántica de Costa Rica. Field Reports No. 20. Atlantic Zone Programme. CATIE. Turrialba, Costa Rica.

Nuhn, H., 1978. Atlas preliminar de Costa Rica. Información Geográfica Regional. San José, Costa Rica.

Sader, S.A. & A.T. Joyce, 1988. Deforestation rates in Costa Rica, 1940 to 1983. Biotropica 20: 11-19.

Soil Survey Staff, 1975. Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, Agricultural Handbook No. 436. U.S. Department of Agriculture. John Wiley and Sons, New York.

Tan, K.H. (ed.), 1984. Andosols. Benchmark Papers in Soil Science, vol. 4. Van Nostrand Reinhold Company, New York.

Vleeshouwer, J.J. & W.G. Wielemaker, 1986. Verslag missie naar Costa Rica voor Trainingsproject in bodemkartering en landevaluatie. Werkgroep Costa Rica, Landbouwhogeschool, Wageningen. Wageningen, the Netherlands.

Warkentin, B.P. & T. Maeda, 1980. Physical and mechanical characteristics of andisols. In: B.K.G. Theng, (ed.), Soils with variable charge. New Zealand Soc. Soil Sci. Lower Hutt, New Zealand.

Wielemaker, W.G. (ed.), 1988. Una colonización reciente en el noreste de la Zona ATlántica: uso racional de la tierra? Atlantic Zone Programme. CATIE. Turrialba, Costa Rica (in press).

Summary

This report describes the results of a study of the impact of forest clearing and land use on morphological, chemical and physical properties of the soil.

Soil profile site studies were done in the Cocori area in the Atlantic Zone of Costa Rica. Two sequences were studied on two different soil types: Cedral (andic humitropept) and Sardina (hydric dystrandept). Emphasis is on soil structure degradation, chemical and physical data related to this degradation and possible recovering of the soil. Sites were chozen in the tropical rainforest, at parts cleared recently from vegetation, in cacao plantations and in grassland. Morphological results are partly based on soil profile descriptions and partly on soil thin section descriptions. Chemical results are based on laboratory analysis of samples and physical results came from infiltration measurements.

Conclusions are mainly based on the morphological data: soil degradation because of forest clearing depends largely on the method used for clearing, but if heavy machinery is used and the trees are transported (especially during the rain period) compaction of the soil is inevitable. Land use after clearing will increase degradation as could be concluded from the cacao and pasture sites. Compaction of the soil occurs as structure degradation, dense matrices, lower porosity, less biological activity, water stagnation in the surface horizons and void-degradation. Cultivation of plants is restricted by this compaction due to air- and waterstress. Recovering of the soil structure is possible if vegetation is given a chance to grow as could be concluded from secundary vegetation sites. Older more weathered volcanic soils are more susceptible to soil degradation as described in this thesis than younger volcanic soils.

Acknowledgements

Without the help of a lot of persons it would have been impossible to finish this thesis, I would like to thank everyone who helped me and especially:

-Wim Wielemaker, for his guidance during the fieldwork in Costa Rica, his usefull advises for the research and his comment on the first draft of this report.

-Rienk Miedema, for his stimulating participation during the micromorphological study in Wageningen.

-Johan Bouma, for his comment on the first draft and his advises on the execution of the research.

-Toine Jongmans, for his pleasant help in taking photographs of the thin sections.

-The families Lopez-Valverde and Schroeder-Vietor, for their hospitality and for making my stay in Costa Rica unforgettable.

APPENDIX A. FIELD PROFILE DESCRIPTIONS

Information on the site:

Soil profile number: COC 1
Soil name: Cedral
Higher degree classification: andic humitropept
Date of examination: 12 february 1987.
Authors: Andre Nieuwenhuyse and Gerard Baltissen.
Location: 100m. North of Rio Penitencia, 150m. West of road to Rio Colorado, 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in volcanic material of probably plio-pleistocene age deposited by laharstreams containing basalt.
Geomorphological unit: fluvial volcanic resthills (strongly weathered fluvial sediments), the surrounding landform is undulating.
Microtopography: there are differences of 30cm. in height.
Slope on which profile is sited: gently sloping (3%), site is in the middle part of a 20m. long slope.
Evidence of erosion or sedimentation: none.
Evidence of compaction: the surface horizons show grey colours and red mottling of pseudogley as a result of compaction because of cattle-breeding, they also have a bad structure and few pores.
Drainage: imperfectly drained.
Internal drainage: the surface horizons have water stagnation.
Depth of groundwatertable: >150cm.
Moisture conditions in the profile: moist throughout.
Risk of inundation: none
Presence of surface stones, rock outcrops: none
Year of deforestation: between 1977 and 1979.
Land use: pasture for cattle-breeding.
Former use: forest
Soil fauna: not much biological activity in the soil.

Brief description of the profile:

Imperfectly drained profile, almost uniform in colour (reddish brown) and texture (clay). Because of compaction the topsoil has a massive structure with few pores which changes with depth to a subangular blocky structure with many pores. Root distribution is normal.

Profile description:

Ag1 0-3cm. Greyisch brown (8,5YR 4/2) moist; common, fine, distinct, red mottles; loamy clay to clay; massive; slightly sticky, slightly plastic; firm, moist; very few, small, hard, irregular, white, gibbsitic nodules; few very fine continuous pores; abundant very fine roots; not thixotropic; abrupt smooth boundary.

Ag2 3-10cm. Brown (7,5YR 4/4) moist; common, fine, prominent red mottles; loamy clay to clay; moderate fine subangular blocky; slightly sticky, slightly plastic;friable, moist; very few, small, hard, irregular, white gibbsitic nodules; common very fine continuous pores; abundant very fine roots; not thixotropic; abrupt smooth boundary.

Bwt1 10-35cm. Reddish brown (6YR 4/8) moist; clay; moderate very fine subangular blocky; slightly sticky, slightly plastic; friable moist; broken, thin clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; many very fine and few medium pores; abundant very fine roots; not thixotropic; clear,wavy boundary.

Bwt2 35-90cm. Reddish brown (5YR 4/8) moist; common, medium, prominent, brown mottles; clay; strong very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; broken, thin, clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; many very fine and few medium pores; common very fine roots; not thixotropic; clear, broken boundary.

Bwt3 90-100cm. Reddish brown (4YR 4/8) moist; common, fine, distinct, brown mottles; clay; very few gravel, angular,strongly weathered; moderate very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; broken, thin, clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; many very fine and few medium pores; few very fine roots; not thixotropic; clear, broken boundary.

Bwt4 100-150cm. Reddisch brown (5YR 4/8) moist; common, fine, distinct, red mottles; clay; very few gravel, angular, strongly weathered; strong, very fine subangular blocky; slightly sticky, slightly plastic; very friable, moist; broken, thin, clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; many very fine and few medium pores; few very fine roots; not thixotropic.

Remarks:

occurence of pseudogley (gley colours and red mottling) in the surface horizons due to compaction. Especially the first 3 centimeters are strongly compacted and show a bad structure and few pores. There is also a difference in consistence (moist) between the surface horizons and the horizons deeper in the profile. Mottling below 35cm. because of biological activity.

Information on the site:

Soil profile number: COC 2
Soil name: Sardina
Higher degree classification: hydric dystrandept
Date of examination: 21 february 1987.
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 400m. North of Rio Penitencia, 1km. West of Cocori road; approximately 15 km. North of Cariari, Pococi,Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in quaternary fluvial sands of volcanic origin.
Geomorphological unit: former river plain, the surrounding landform is gently sloping.
Microtopography: nil.
Slope on which profile is sited: -
Evidence of erosion or sedimentation: none.
Evidence of compaction: clearly in the surface horizons as a result of deforestation and cultivating cacao and mais using heavy machinery. The topsoil is compacted, has grey reduced colours and red mottling because of pseudogley and few pores.
Drainage: imperfectly drained.
Internal drainage: top horizons show pseudogley
Depth of groundwatertable: 150cm.
Moisture conditions in the profile: moist throughout.
Risk of inundation: nil.
Presence of surface stones, rock outcrops: none.
Year of deforestation: between 1975-1980.
Landuse: cacao.
Former use: maize and secundary forest.
Soil fauna: few earthworms.

Brief description of the profile:

Imperfectly drained profile, texture changes from loam to sand and colours from brownish black to greyish yellow brown and again to brownish black with depth. Topsoil is weak (sub) angular blocky and subsoil is strong angular blocky to structureless. Pore distribution is normal except for the toplayer which is compacted. Root distribution is normal. Slightlythixotropic.

Profile description:

Ag1	0-3cm.	Brownish black (10YR 3/1) moist; common, medium, distinct, red mottles; loam; massive; slightly sticky, slightly plastic; firm, moist; few, very fine pores; few, very fine roots; slightly thixotropic; abrupt, broken, boundary.
Ag2	3-10cm.	Brown (10Yr 4/4) moist; common,fine, distinct red mottles; loam; weak, very fine angular blocky; slightly sticky, slightly plastic; friable, moist; common very fine pores; few very fine roots; slightly thixotropic; abrupt, wavy boundary.
Bg	10-40cm.	Yellowish brown (10YR 5/6) moist; few, fine, distinct, grey and orange mottles; loam to silt loam; moderate very fine subangular blocky; slightly sticky, slightly plastic; very friable moist; many very fine and common fine pores; few very fine roots; slightly thixotropic; clear, wavy boundary.
Bgc1	40-65cm.	Dull-yellowish brown (10YR 5/4); many medium distinct, grey and orange mottles; silt loam to loam; strong very fine subangular blocky and 30% porous massive; slightly sticky,slightly plastic; very friable, moist; few, small, hard, irregular, red iron nodules; many very fine and common fine pores; few, very fine roots; thixotropic; clear, wavy boundary.
Bgc2	65-90cm.	Dull-yellowish brown (10YR 5/4); moist; many medium to coarse, distinct, grey and orange mottles; silt loam to loam; strong fine angular blocky; slightly sticky, slightly plastic; very friable moist; broken, thick clay cutans; many very fine, fine and medium pores; few, very fine roots; slightly thixotropic; abrupt smooth boundary.
BCgc	90-110cm.	Greyish, yellow,brown (10YR 6/2) moist; many medium, distinct, orange and brown mottles; sandy loam; layered; none sticky, none plastic; friable moist; frequent, large, hard, irregular, red, iron nodules; many very fine pores; no roots; thixotropic; abrupt smooth boundary.
Cgc	110-150cm.	Brownish black (10YR 2/3); common, medium, distinct grey mottles; sand; structureless; few, small, soft, irregular, red, iron nodules; no roots; not thixotropic.

Remarks:

From 90cm. onwards the profile is layered at 110cm. a placic horizon of 3 mm. can be seen. The surface horizon is highly compacted.

Information on the site:

Soil profile number: COC 3
Soil name: Sardina
Higher degree classification: hydric dystrandept
Date of examination: 5 march 1987.
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 3km. North of Cedral, 400m. East of the road to Rio Colorado, 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in quaternary, layered, fluvial sand of volcanic origin.
Geomorphological unit: former riverplain, the surrounding landform is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: -
Evidence of erosion or sedimentation: none.
Evidence of compaction: site is situated in the pathway used by a bulldozer causing severe compaction in the tracks which results in few pores and a bad structure. Road has been cleared and used by the bulldozer two times.
Drainage: poorly drained.
Internal drainage: compaction might cause stagnation of water in the surface horizons.
Depth of groundwatertable: 52cm.
Moisture conditions in the profile: moist in the upper part, wet in the lower.
Risk of inundation: none
Presence of surface stones, rock outcrops: none.
Year of deforestation: 1987 (february).
Land use: cleared from forest vegetation.
Former use: primary forest.
Soil fauna: many earthworms untill 20 cm, apparantly not disturbed by bulldozer compaction.

Brief description of the profile:

Poorly drained profile, texture changes from loam to loamy sand with depth and from brownish black to dull yellowish brown. Structure is subangular blocky in the subsoil which changes with depth to structureless porous massive. Topsoil is slightly compacted and has less pores, the subsoil has a normal pore and root distribution. Thixotropic.

Profile description:

Au1 0-12cm. Brownish black (10YR 2/3) moist; loam; porous massive to moderate very fine and fine subangular blocky; slightly sticky, slightly plastic; very friable moist; few very fine and coarse pores; abundant very fine, fine, medium and coarse roots; thixotropic; clear wavy boundary.

Au2 12-20cm. Dark brown (10YR 3/4) moist; loam; moderate very fine and fine subangular blocky; slightly sticky, slightly plastic; friable, moist; many very fine and few coarse pores; abundant very fine, fine, medium and coarse roots; thixotropic; clear smooth boundary.

Bw 20-35cm. Brown (10YR 4/4) moist; loam; porous massive with a tendency to weak subangular blocky; slightly sticky, slightly plastic; friable, moist; many very fine and few fine pores; common very fine, fine, medium and coarse roots; thixotropic; clear smooth boundary.

Bgw1 35-45cm. Brown (10YR 4/6) moist; many, medium, faint, grey mottles; sandy loam; porous massive; none sticky, none plastic; firm, moist; many very fine and few fine pores; few very fine and fine roots; thixotropic; clear smooth boundary.

Bgw2 45-55cm. Dull yellowish brown (10YR 5/4) moist; many, medium, distinct orange pores; sandy loam; porous massive; none sticky, none plastic; friable, moist; many very fine pores; few very fine roots; slightly thixotropic; clear smooth boundary.

Bgw3 55-70+cm. Dull yellowish brown (10YR 5/3) moist; common, fine, distinct, orange mottles; loamy sand; porous massive; none sticky, none plastic; loose, moist; very few, small, soft, irregular, red, iron nodules; common very fine pores; no roots; not thixotropic.

Remarks:

This site is situated a few metres from site COC 11. Wormstructure is apparant in the two surface horizons and the compaction has already diminished by biologic activity allthough in the tracks the soil will be severely compacted for a long time.

Information on the site:

Soil profile number: COC 4
Soil name: Cedral
Higher degree classification: andic humitropept
Date of examination: 1 march 1987
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 50m. North of Rio Penitencia, 400m. West of the Cocori road at the finca of mr. Schroeder, approximately 15 km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in volcanic material of probably plio-pleistocene age deposited by laharstreams containing basalt.
Geomorphological unit: fluvial volcanic resthills (strongly weathered fluvial sediments), the surrounding landform is undulating.
Microtopography: differences of 20cm. in height.
Slope on which profile is sited: gently sloping (2%); site is on the lower part of a 30m. long slope.
Evidence of erosion or sedimentation: none
Evidence of compaction: the first 27cm. show evidence of compaction due to deforestation using heavy machinery (skeeler) but most of this has diminished because of biologic activity allthough especially the horizon 5-17 cm. shows occurrance of pseudogley (grey colours and mottling), is structureless and has few pores.
Drainage: imperfectly drained.
Internal drainage: the first two horizons have waterstagnation.
Depth of groundwatertable: >210cm.
Moisture conditions in profile: moist throughout.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: between 1975 and 1978.
Landuse: Cacáo, in good shape.
Former use: secundary vegetation untill november 1984, maize and beans untill june 1985.
Soil fauna: many earthworms to a depth of 25cm., in the deeper horizons of the profile there is no evidence of earthworm activity; ants to a depth of 25cm., burrows of more than 7cm. from rats or other larger animals.

Brief description of the profile:

Imperfectly drained profile, almost uniform in colour (brown) and texture (clay). Structure of the toplayer is vermiform and changes to massive and (sub) angular blocky with depth. Pore and root distribution is normal except for the compacted horizon (Ag).

Profile description:

A	0-5cm.	Greyish brown (8,5YR 4/2) moist; Clay; strong fine subangular and angular blocky; slightly sticky, slightly plastic; friable, moist; common, very fine and medium pores; abundant very fine, fine and medium roots; not thixotropic; clear wavy boundary.
Ag	5-17cm.	Greyish brown (8,5YR 4/2) moist; common, fine, faint, red mottles; clay; massive; slightly sticky, slightly plastic; friable, moist; few very fine and medium pores; common very fine, fine, and medium roots; not thixotropic; clear wavy boundary.
ABg	17-27cm.	Brown (8,5YR 4/4) moist;common, fine, faint, red mottles; clay; weak to moderate very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; many very fine and few medium pores; common fine and medium roots; not thixotropic; gradual wavy boundary.
Btg	27-70cm.	Brown (10YR 4/6) moist; common, medium, distinct, red and brown mottles; clay; moderate very fine subangular and angular blocky; slightly sticky, slightly plastic; very friable, moist; broken, thin, clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; many very fine pores; few fine and medium roots; not thixotropic; diffuse wavy
Bt1	70-100cm.	Brown (10YR 4/6) moist; clay; moderate, very fine angular blocky; slightly sticky, slightly plastic; very friable, moist; broken, thin, clay cutans;very few, small, hard, irregular, white, gibbsitic nodules; many very fine pores; few fine roots; not thixotropic; diffuse wavy
Bt2	100-150cm.	Yellowish brown (10YR 5/6) moist; clay; moderate very fine angular blocky; slightly sticky, slightly plastic; very friable, moist; broken, thin, clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; many, very fine pores; no roots; not thixotropic.
*Bms	127-128cm.	Bright reddish brown (4YR 5/8) moist; hard, broken, platy iron pan; abrupt, broken boundary.

Remarks:

Mottles in Ag and ABg horizons because of gley due to compaction, mottles in horizon Btg are a result of biologic activity e.g. roots penetrating the soil cause compaction. In horizon A many wormcasts are found and due to this wormactivity compaction has diminished and the vermiform structure has returned.

Information on the site:

Soil profile number: COC 5
Soil name: Sardina
Higher degree classification: hydric dystrandept
Date of examination: 29 february 1987.
Authors: Andre Nieuwenhuyse and Gerard Baltissen.
Location: 400m. North of Rio Penitencia; 1km. West of Cococi road; approximately 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in quaternary fluvial sands of volcanic origin.
Geomorphological unit: former river plain, the surrounding landform is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: 2%, site is in the middle of 60m. long slope.
Evidence of erosion or sedimentation: none.
Evidence of compaction: because site is between trees it has not been compacted much more after deforestation because heavy machinery could not come here. But compaction differs a great deal at short distance sometimes one can see reduced colours, red mottling and few pores but as well no mottling and many pores.
Drainage: imperfectly drained.
Internal drainage: the surface horizon shows pseudogley.
Depth of groundwatertable: 100cm.
Moisture conditions in the profile: moist untill 90cm. and then wet.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: between 1975-1980.
Landuse: cacao.
Former use: maize and secundary forest.
Soil fauna: earthworms, termites, ants, mouses,rats etc.

Brief description of the profile:

Imperfectly drained profile, texture changes from loam to sandy loam with depth, colour is almost uniform (brown). Structure is weak to moderate (sub-) angular blocky. Pore and root distribution is normal. Slightly thixotropic topsoil, very tixotropic subsoil.

Profile description:

Ag	0-5cm.	Dark brown (10YR 3/3), moist; common, fine, distinct, red and grey mottles; loam; weak, very fine angular blocky;slightly sticky, slightly plastic; friable, moist; common very fine and few medium pores; common fine and medium roots; slightly thixotropic; clear, smooth boundary.
AB	5-15cm.	Brown (10YR 4/4), moist; loam; porous massive to moderate subangular blocky; slightly sticky, slightly plastic; very friable, moist; many very fine and few medium pores; common fine and medium roots; slightly thixotropic; clear wavy boundary.
Bw	15-32cm.	Yellowish brown (10YR 5/6); loam; porous massive to moderate angular blocky; sticky, plastic; very friable, moist; many very fine and common fine pores; few fine and medium roots; very thixotropic; abrupt, smooth boundary.
Bgc	32-48cm.	Brown (10YR 4/6), moist; many medium distinct grey and orange mottles; loam; porous massive to moderate very fine angular blocky; sticky,plastic; very friable, moist; very few,small, soft, irregular, red, iron nodules; many very fine and common fine pores; few fine roots; very thixotropic; abrupt smooth boundary.
BCg	48-63cm.	Brown (10YR 4/4), moist; common, medium faint, grey and orange mottles; sandy loam; weak fine granular, angular, blocky and porous massive; many very fine, fine and medium pores; few fine roots; very thixotropic.

Remarks:

Less compaction than COC 2, in the whole profile untill 60cm. there are several very large pores of biological origin.

Information on the site:

Soil profile number: COC 6
Soil name: Sardina.
Higher degree classification: hydric dystrandept.
Date of examination: 29 february 1987.
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 400m. North of Rio Penitencia, 1km. West of the Cocori road, 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in quaternary fluvial sand of volcanic origin.
Geomorphological unit: former river plain, the surrounding landform is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: -
Evidence of erosion or sedimentation: none.
Evidence of compaction: pseudogley occurs in surface horizon as a result of compaction, this horizon has few pores.
Drainage: imperfectly drained.
Internal drainage: stagnation of water in the surface horizons.
Depth of groundwatertable: 90cm.
Moisture conditions in the profile: moist untill 80cm., wet below.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: between 1975 and 1978.
Landuse: secundary vegetation.
Former use: Maize
Soil fauna: few earthworms.

Brief description of the profile:

Imperfectly drained profile, texture changes from loam to sand with depth and the colour is almost uniform (brown). Structure changes from weak to strong subangular blocky to porous massive with depth. Pore and root distribution is normal. Slightly thixotropic.

Profile description:

Ag	0-5cm.	Dark brown (10YR 3/4) moist; few to common, fine distinct, red and grey mottles; loam; moderate to strong very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; common very fine and few medium pores; common very fine, fine and medium roots; slightly thixotropic; abrupt wavy boundary.
Bw	5-30cm.	Brown (10YR 4/4) moist; sandy loam; porous massive with a tendency to weak subangular blocky; slightly sticky, slightly plastic; friable, moist; many very fine and few medium pores; common very fine, fine and medium roots; thixotropic; clear wavy boundary.
BCgc	30-80cm.	Brown (10YR 4/4) moist; Common, fine, distinct, grey and orange mottles; loamy sand; porous massive; slightly sticky, slightly plastic; very friable, moist; very few, small, soft, irregular, red, iron nodules; many very fine and common fine and medium pores; common very fine, fine and medium roots; thixotropic; clear wavy boundary.
C	80+cm.	Brownish black (10YR 3/2) moist; sand; no roots; not thixotropic.

Information on the site:

Soil profile number: COC 7
Soil name: Sardina.
Higher degree classification: hydric dystrandept
Date of examination: 1 march 1987.
Authors: Gerard Daltissen and Andre Nieuwenhuyse.
Location: 400m. North of Rio Penitencia, 1km. West of the Cocori road, approximately 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: Developed in quaternary fluvial sands of volcanic origin.
Geomorphological unit: Former riverplain, the surrounding land form is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: 1%, site is on the higher part of a 30m. long slope.
Evidence of erosion or sedimentation: none
Evidence of compaction: none
Drainage: Imperfectly drained.
Internal drainage: periodically high watertable (mottling starts at 25cm.).
Depth of groundwatertable: 150cm.
Moisture conditions in the profile: Moist untill 140cm., below wet.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: between 1975 and 1980.
Landuse: Secundary vegetation.
Former use: -
Soil fauna: earthworms

Brief description of the profile:

Imperfectly drained profile, texture changes from loam to sand with depth and the colour is brown to yellowish brown in the subsoil. Structure is moderate (sub) angular blocky to structureless (massive) with depth. Pore and root distibution is normal. Thixotropic.

Profile description:

AB 0-25cm. Brown (10YR 4/4) moist; loam; moderate very fine subangular and angular blocky; slightly sticky, slightly plastic; many very fine and few fine pores; many fine roots; thixotropic; clear wavy boundary.

Bcg1 25-40cm. Dull yellowish brown (10 YR 5/4) moist; many, medium, distinct, red and grey mottles; loam; Moderate very fine subangular blocky; slightly sticky, slightly plastic; common, fine, soft, irregular, red, iron nodules; many very fine and fine pores; common fine roots; slightly thixotropic; abrupt wavy boundary.

Bcg2 40-115cm. Brown (8YR 4/4) moist; many, medium, prominent red and grey mottles; loamy sand; porous massive; few, fine, hard, irregular, red, iron nodules; many very fine and few fine pores; few fine roots; not thixotropic; abrupt wavy boundary.

C 115-150+cm. Brownish black (10YR 2/3) moist; sand; single grain; no roots; not thixotropic.

Remarks:

at 40cm. and deeper there is stratification, at 65cm. there is an iron layer of 2mm. thickness.

Information on the site:

Soil profile number: COC 8
Soil name: Sardina
Higher degree classification: hydric dystrandept.
Date of examination: 2 march 1987.
Authors: Andre Nieuwenhuyse and Gerard Baltissen.
Location: 1km. North of Rio Penitencia, 1500m. West of Cocori road.
Geology: developed in quaternary fluvial sands of volcanic origin.
Elevation: less than 20m.
Geomorphological unit: former river plain, the surrounding landform is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: nil.
Evidence of erosion or sedimentation: none.
Evidence of compaction: none.
Drainage: poorly drained.
Internal drainage: poorly because of high groundwatertable.
Depth of groundwatertable: 77cm.
Moisture conditions in profile: moist untill 60cm., then wet.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: -
Landuse: primary forest.
Former use: -
Soil fauna: many earthworms, ants, termites, rats, mouses.

Brief description of the profile:

Poorly drained profile, texture changes from loam to sand with depth and the colour from brown to dull yellowish brown to brownish black. Structure changes from moderate to strong (sub)angular blocky to porous massive with depth. Pore and rootdistribution is normal. Slightly thixotropic.

Profile description:

A	0-12cm.	Dark brown (10YR 3/4/1) moist; loam; moderate to strong very fine subangular blocky and very fine granular; slightly sticky, slightly plastic; friable, moist; common very fine and fine and few medium pores; abundant very fine, fine, medium and coarse roots; slightly thixotropic; clear, wavy boundary.
Bw	12-30cm.	Dull yellowish brown (10YR 5/4); loam; moderate very fine (sub)angular blocky and very fine to fine granular; slightly sticky, slightly plastic; friable, moist; many very fine and few medium pores; many very fine, fine, medium and coars roots; thixotropic; clear, wavy boundary.
Bcg	30-55cm.	Dull yellowish brown (10YR 5/4) moist; sandy loam; many medium, destinct orange and grey mottles; weak, very fine (sub)angular blocky; none sticky, slightly plastic; very friable, moist; few, small, soft, irregular, red, iron nodules; many very fine pores; common fine and medium roots; thixotropic; clear smooth boundary.
BC	55-70cm.	Dull yellowish brown (10YR 5/4), moist; sand; porous massive; common very fine pores; common fine and medium roots; thixotropic; clear smooth boundary.
C1	70-105cm.	Brownish black (10YR 3/2), moist; sand; single grain; no pores; no roots;not thixotropic; clear wavy boundary.
C2	105-120cm.	Brownish black (10YR 3/2), moist; sand: single grain; 15-20% gravel; no pores; no roots; not thixotropic.

Remarks:

First 12cm. probably have a worm structure.

Information on the site:

Soil profile number: COC 9.
Soil name: Sardina.
Higher degree classification: hydric dystrandept.
Date of examination: 3 march 1987.
Authors: Andre Nieuwenhuyse and Gerard Baltissen.
Location: 400m. North of Rio Penitencia, 1km. West of Cocori road; approximately 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in quaternary fluvial sands of volcanic origin.
Geomorphological unit: former river plain, the surrounding landform is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: 1%, site is on the higher part of a 70m. long slope.
Evidence of erosion or sedimentation: none.
Evidence of compaction: very clearly as a result of cattle walking over the pasture; surface horizon shave an extreme form of compaction and so grey and red mottlingbecause of pseudogley.
Drainage: imperfectly drained.
Internal drainage: surface horizons show waterstagnation.
Depth of groundwatertable: 120cm.
Moisture conditions in the profile: moist throughout.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: between 1972 and 1977.
Landuse: pasture.
Former use: -
Soil fauna: a few earthworms.

Brief description of the profile:

Imperfectly drained profile, texture is loamy, colour changes from yellowish brown to brown with depth. Compacted layer is weak medium to coarse angular blocky and changes to subangular blocky and porous massive with depth. Pore and root distribution is normal. Slightly to very thixotropic.

Profile description:

Ag1 0-4cm. Brownish black (10YR 3/2), moist; common fine, distinct red mottles; loam; moderate very fine to fine granular and very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; common very fine pores; many very fine roots; slightly thixotropic; abrupt, smooth boundary.

Ag2 4-12cm. Grayish yellow brown (10YR 5/2), moist; many medium, prominent, red mottles; loam; weak medium to coarse angular blocky; slightly sticky, slightly plastic; firm, moist; common very fine pores; many very fine roots; thixotropic; clear wavy boundary.

BW 12-30cm. Yellowish brown (10Yr 5/6), moist; loam; moderate very fine subangular blocky; slightlysticky, slightly plastic; friable moist; many very fine and common fine pores; common very fine roots; very thixotropic; clear wavy boundary.

Bg1 30-40cm. Yellowish brown (10Yr 5/6), moist; common fine, distinct grey and orange mottles; loam; moderate to strong subangular blocky; slightly sticky, slightly plastic; friable, moist; many very fine, common fine and few coarse pores; common very fine roots; very thixotropic; abrupt smooth boundary.

Bg2 40-90cm. Brown (10YR 4/4), moist; many, coarse, distinct, clear orange and grey mottles; loamy sand; porous massive; many very fine and few fine pores; few very fine roots; not thixotropic; abrupt, smooth boundary.

C 90-120cm. Brownish black (10YR 2/3), moist; sand; single grain; no pores; no roots; not thixotropic.

Remarks:

Severely compacted and so an extreme form of pseudogley is to be seen in the surface horizons.

Information on the site:

Soil profile number: COC 10
Soil name: Sardina
Higher degree classification: hydric dystrandept.
Date of examination: 5 march 1987.
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 3km. North of Cedral, 400m. East of the road to Rio Colorado. Approximately 15km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: Developed in quaternary layered alluvial sand of volcanic origin.
Geomorphological unit: former river plain, flat, the surrounding landform is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: gently sloping (2%), site is on the upper part of a 30m. long slope.
Evidence of erosion or sedimentation: none.
Evidence of compaction: none.
Drainage: poorly drained.
Internal drainage: poorly because of high groundwatertable.
Depth of groundwatertable: 5 march, 63cm.; 28 march, 123cm.; 7 april (after rain), 10cm.
Moisture conditions in profile: moist untill 50cm., then wet.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: approximately 1980.
Land use: cacao (7 years old).
Former use: forest.
Soil fauna: earthworms untill 20 cm.

Brief description of the profile:

Poorly drained profile, loamy topsoil which changes to sand with depth, colour changes from brownish black to dull yellowish brown and again to dull yellowish black with depth. Structure is subangular blocky in the topsoil, subsoil is porous massive and changes to sand with depth. Low porosity, root distribution is normal, thixotropic.

Profile description:

Au1	0-12cm.	Brownish black (10YR 2/3), moist; loam; moderate to strong, very fine to fine subangular blocky; slightly sticky, slightly plastic; very friable to friable, moist; few fine and coarse pores; common fine and medium roots; thixotropic; abrupt smooth boundary.
Au2	12-30cm.	Dark brown (10YR 3/4) moist; sandy loam to loam; massive; slightly sticky, slightly plastic; very friable moist; few to common, very fine and fine pores; common fine and medium roots; thixotropic; clear smooth boundary.
Bwg1	30-50cm.	Brown (10YR 4/4), moist; few, medium, faint, grey and orange mottles; sandy loam to loam; massive; slightly sticky, slightly plastic; very friable, moist; few very fine and fine pores; few fine roots; thixotropic; clear wavy boundary.
Bwg2	50-65cm.	Dull yellowish brown (10YR 4/3), moist; common, medium, faint, grey and orange mottles; loamy sand; porous massive; none sticky, none plastic; firm, moist; few fine and coarse pores; few very fine roots; slightly thixotropic; clear smooth
Bwg3	65-90cm.	Dull yellowish brown (10YR 4/3), moist; common, fine, faint, clear, grey and orange mottles; loamy sand; porous massive; none sticky, none plastic; very firm, moist; very few, small, soft, red, iron concretions; few fine and coarse pores; no roots; slightly thixotropic; clear wavy boundary.
BCg	90-120cm.	Brownish black (10YR 3/1), moist; common, fine, distinct, sharp, orange mottles; sand; single grain; none sticky, none plastic; firm, moist; few, small, soft, irregular, red, iron concretions; no pores; no roots; not thixotropic; clear wavy boundary.
C	120-130+cm.	Brownish black (10YR 3/1), moist; sand; single grain; none sticky, none plastic; friable, moist; no pores; no roots; not thixotropic.

Information on the site:

Soil profile number: COC 11
Soil name: Sardina.
Higher degree classification: hydric dystrandept.
Date of examination: 6 march 1987.
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 3km. North of Cedral, 400m. East of the road to Rio Colorado. Approximately 15km. North of Cariari, POcoci, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in quaternary alluvial sand of volcanic origin.
Geomorphological unit: former river plain, flat, the surrounding landscape is flat or almost flat.
Microtopography: nil.
Slope on which profile is sited: flat.
Evidence of erosion or sedimentation: none.
Evidence of compaction: none.
Drainage: poorly drained.
Internal drainage: poorly because of high groundwatertable.
Depth of groundwatertable: 6 march, 50cm.; 28 march, 105cm.; 7 april (after rain), 5cm.!
Moisture conditions in the profile: moist in the upper part, wet in the lower.
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Year of deforestation: -
Land use: primary forest.
Former use: -
Soil fauna: many earthworms in the surface horizons.

Brief description of the profile:

Poorly drained profile, texture changes from loam to sand with depth and colour changes from brownish black to greyish yellow brown. Structure changes from weak subangular blocky to porous massive with depth (topsoil is vermiform). Pore and root distribution is normal. Thixotropic.

Profile description:

A	0-12cm.	Brownish black (10YR 2/3), moist; loam; moderate very fine to fine subangular blocky; slightly sticky, slightly plastic; very friable, moist; common fine and medium pores; abundant very fine, fine, medium and coarse roots; thixotropic; clear, wavy boundary.
AB	12-20cm.	Dark brown (10YR 3/4), moist; loam; weak to moderate very fine sub angular blocky; slightly sticky, slightly plastic; friable, moist; many very fine and few medium pores; abundant very fine, fine, medium and coarse roots; thixotropic; clear, smooth boundary.
Bw	20-35cm.	Brown (10YR 4/4), moist; loam; porous massive with a tendency to weak subangular blocky; slightly sticky, slightly plastic; friable, moist; many very fine and few medium pores; common very fine and fine roots; thixotropic; clear smooth boundary.
Bg1	35-45cm.	Brown (10YR 4/6), moist; many, fine, faint grey and orange mottles; sandy loam to loam; porous massive with a tendency to weak subangular blocky; none sticky, slightly plastic; firm to very firm, moist; many very fine and few fine pores; few very fine and fine roots; slightly thixotropic; clear smooth boundary.
Bg2	45-60cm.	Dull yellowish brown (10YR 4/3), moist; many, fine, distinct, clear orange and brown mottles; loamy sand; porous massive with a tendency to weak subangular blocky; none sticky, none plastic; friable, moist; very few, small, soft, irregular, red, iron nodules; many very fine pores; few very fine and fine roots; not thixotropic; clear smooth boundary.
BCg	60-90+cm.	Greyish yellow brown (10YR 5/2), moist; many, medium, distinct, sharp, orange mottles; sand to loamy sand; porous massive; none sticky, none plastic; very friable, moist; very few, small, soft, irregular, red, iron nodules; common very fine and few fine pores; no roots; not thixotropic; clear, wavy boundary.
C	90-110cm.	Grey (N 4/0), moist; sand; single grain; none sticky, none plastic; loose, moist; no pores; no roots; not thixotropic.

Remarks:

. The first two horizons have a wormstructure.

Information on the site:

Soil profile number: COC 12.
Soil name: Cedral.
Higher degree classification: andic humitropept.
Date of examination: 7 march 1987.
Authors: Gerard Baltissen and Andre Nieuwenhuyse.
Location: 200m. North of Rio Penitencia, 1km. West of road to Rio Colorado, approximately 15km.North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in volcanic material of probably plio-pleistocene age, deposited by lahar streams containing basalt.
Geomorphological unit: fluvial volcanic resthills,(strongly weathered fluvial sedements), the surrounding landform is undulating.
Microtopography: nil.
Slope on which profile is sited: gently sloping (5%), the site is in the middlepart of a 15m. long slope.
Evidence of erosion or sedimentation: none.
Evidence of compaction: only the first few cm.show a little compaction due to a walking over the soil during deforestation.
Drainage: well drained.
Internal drainage: well drained.
Depth of the groundwatertable: > 160cm.
Moisture conditions of the profile: moist throughout.
Risk of inundation: nil.
Presence of surface stones, rock outcrops: none.
Year of deforestation: 1987 (february).
Land use: just being cleared will be used for grassland and possibly pineapple.
Former use: forest.
Soil fauna: first horizon has a vermiform-(worm) structure, termites.

Brief description of the profile:

Well drained profile, almost uniform in colour (brown) and texture (clay). Structure is subangular blocky. Pore and root distribution is normal.

Profile description:

A	0-15cm.	Brown (7,5YR 4/4), moist; clay; strong, very fine to fine, subangular blocky and crumb (20%); slightly sticky, slightly plastic; friable, moist; very few, small, hard, irregular, white, gibbsitic nodules; many very fine, few medium and fine pores; abundant (very) fine, medium and coarse roots; not thixotropic; gradual smooth boundary.
ABw	15-90cm.	Brown (7,5YR 4/6), moist; clay; moderate very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; very few, small, hard, irregular, white, gibbsitic nodules; many very fine and few fine pores; common very fine, fine and medium roots; not thixotropic; clear wavy boundary.
Bc1	90-120cm.	Reddish brown (5YR 4/8), moist; clay; moderate very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; broken thin clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; very few gravel, irregular, strongly weathered; common to many very fine pores; few very fine roots; not thixotropic; clear wavy boundary.
Bt2	120-160+cm.	Brown (7,5YR 4/6), moist; clay; moderate very fine subangular blocky; slightly sticky, slightly plastic; friable, moist; broken thin clay cutans; very few, small, hard, irregular, white, gibbsitic nodules; very few gravel, irregular, strongly weathered; many very fine and common fine pores; few very fine roots; not thixotropic.

Remarks:

Very slightly compaction of first five centimeters, biological activity has not been disturbed much by deforestation.

Information on the site:

Soil profile number: COC 13.
Soil name: Cedral.
Higher degree classification: andic humitropept.
Date of examination: 7 march 1987.
Authors: Andre Nieuwenhuyse and Gerard Baltissen.
Location: 200m. North of Rio Penitencia, ikm. West of road to Rio Colorado. Approximately 15 km. North of Cariari, Pococi, Limon, Costa Rica.
Elevation: less than 20m.
Geology: developed in volcanic material of probably plio-pleistocene age deposited by laharstreams containing basalt.
Geomorphological unit: fluvial volcanic resthills, (strongly weathered fluvial sediments); the surrounding landform is undulating.
Microtopography: nil.
Slope on which profile is sited: flat or almost flat (1%), site is on the higher part of a 10m. long slope.
Evidence of erosion or sedimentation: none.
Evidence of compaction: none.
Drainage: well drained.
Internal drainage: well drained.
Depth of groundwatertable: > 110cm.
Moisture conditions in profile: moist throughout
Risk of inundation: none.
Presence of surface stones, rock outcrops: none.
Date of deforestation: -
Land use: primary forest.
Former use: -
Soil fauna: many earthworms and ants in the whole profile, the surface horizon could be called vermiform.

Brief description of the profile:

Well drained profile, almost uniform in colour (brown), and texture (clay). The crumb and subangular blocky structure of the topsoil changes at depth to subangular blocky. Pore and root distribution is normal.

Profile description:

A	0-10cm.	Brown (7,5YR 4/3), moist; clay; strong, very fine subangular blocky and fine granular; slightly sticky, slightly plastic; friable, moist; very few, small, soft, irregular, white, gibbsitic nodules; common very fine and few fine, medium and coarse pores; abundant very fine, medium and coarse roots; not thixotropic; clear, wavy boundary.
Bw1	10-90cm.	Brown (7,5YR 4/4), moist;clay; moderate fine crumb and very fine subangular blocky; slightly sticky, slightly plastic; very friable, moist; very few, small, soft, irregular, white, gibbsitic nodules; many very fine and few medium and coarse pores; common very fine, fine, medium and coarse roots; not thixotropic; abrupt broken boundary.
Bms	90-91cm.	Discontinuous, hard, nodular, iron-silica pan.
Bw2	90-110+cm.	Brown (7,5YR 4/4), moist; clay; moderate very fine subangular blocky; slightly sticky; slightly plastic; friable, moist; very few, small, soft, irregular, white, gibbsitic nodules; very few gravel, strongly weathered, basaltic; common very fine and fine pores; few (very) fine, medium and coarse roots; nor thixotropic.

Remarks:

Good structure and much biological activity especially in the surface horizons.

APPENDIX B: DETAILED MICROMORPHOLOGICAL DESCRIPTIONS.

Soil profile number: COC 1
Location: Cocori area, Costa Rica.
Horizon: Aug1,2.
Depth: 2-10cm.
Landuse: pasture.
Thin section number: 87/158.

Microstucture:

complex: subangular and vughy (top) and angular (bottom).

Peds: -subangular blocks, moderately to strongly developed, 20%, very fine to coarse, mainly fine, undulating, partially accommodated, randomly distributed.
-angular blocks, weakly to strongly developed, 70%, very fine and fine, smooth surface, accommodated, randomly distributed.

Voids:

-interaggregate: straight (skew) planes (bottom) and loose compound packing voids (top).

-intra-aggregate: -vughy: interconnected vughs, 80%, irregular, rough, random; channels, 20%, round to elongated, smooth, random.
-(sub-)angular: vughs,70%, irregular, rough, random; interconnected vughs, 10%, irregular, rough, random; channels, 20%, round to elongated, smooth, random.

Average intra-aggregate porosity: vughy, 20% (porous); subangular, 5-10% (rather dense); angular, 2-5% (dense).

Basic organic components:

organic matter, 10%; plant residues, 10%, homogeneous; no organic pigment differences.

Amorphous pedofeatures:

few ferrogineous hypocoatings, mottles and nodules; grey colouring.

Excrement pedofeatures:

few, spherical, loose, discontinuous, infillings.

Remarks:

60% of the matrix is more dense, light coloured fragments from underground. Upper part of the thin section has a more physicogene structure which might have been more dense (because of biological activity more skew planes are formed).

Detailed micromorphological description.

Soil profile number: COC 2
Location: Cocori area, Costa Rica.
Horizon: Ag1,2.
Depth: 2-10cm.
Landuse: cacao.
Thin section number: 87/160.

Microstructure:

apedal (vughy).

Voids:

Interconnected vughs, 70%, irregular, rough, random; vughs, 10%, irregular, rough, random; channels, round to elongated, 20% smooth, random (only in upper part).

Average intra-aggregate porosity: 20% porous.

Basic organic components:

10% organic matter; plant residues, 2%, homogeneous; no pigment differences.

Amorphous pedofeatures:

common ferric mottling; hypo- and quasicoatings of channels and large voids; few ferric nodules; grey colouring (top 60%).

Excrement pedofeatures:

few, spherical, small, loose, continuous and discontinuous infillings.

Remarks:

less biological activity (channels) in the bottom zone although the matrix is not more dense.

Detailed micromorphological description:

Soil profile number: COC 3
Location: Cocori, Costa Rica.
Horizon: A.
Depth: 2-10cm.
Landuse: deforestated.
Thin section number: 87/161.

Microstructure:

apedal (fissure).

fissure structure: few, if any, fully separated aggregates, (many) interconnections of planar voids.

Voids:

-interconnected vughs: irregular, 80%, rough, random.
-channels: round to elongated, 15%, smooth, random.
-planes: zig zag, 5%, smooth, random.

intra-aggregate porosity: 30% (very porous).

Basic organic components:

15-20% organic matter; plant residues, 5%, homogeneous; pigment differences: 5% is darker.

Amorphous pedofeatures:

few ferric nodules.

Excrement pedofeatures:

compacted but probably a large part consists of excrement pedofeatures, few loose discontinuous infillings.

Remarks:

-20% of matrix is more dense and is more yellow of colour.
-iron concretions because of weathering.
-much less recognisable plant residues.
-density differences around channels.

Detailed micromorphological description:

Soil profile number: COC 4
Location: Cocori, Costa Rica.
Horizon: A.
Depth: 2-10cm.
Landuse: cacao.
Thin section number:
87/162.

Microstructure:

(sub-)angular blocky.

Peds: -subangular blocks, moderately to strongly developed, 50%, very fine to fine, smooth to undulating surfaces, partially accommodated, randomly distributed.
-angular blocks, weakly developed, 50%, very fine to fine, smooth to undulating, accommodated, random.

Voids:

-interaggregate: skew planes between angular blocks.
-intra-aggregate: vughs, irregular, 95%, rough, random; channels, round to elongated, 5%, smooth, random.

Intra-aggregate porosity: 2-5% (dense).

Basic organic components:

5% organic matter; plant residues, 5%, homogeneous; no pigment differences.

Amorphous pedofeatures:

common mottles with diffuse boundaries, red.

Excrement pedofeatures:

common loose discontinuous infillings (spherical, small).

Remarks:

matrix is 100% dense, some recent biological activity.

Detailed micromorphological description:

Soil profile number: COC 5
Location: Cocori, Costa Rica.
Horizon: Ag.
Depth: 2-10cm.
Landuse: cacao.
Thin section number: 87/163

Microstructure:

apedal (vughy).

Voids:

-interconnected vughs, irregular, 45%, rough, random.
-vughs, irregular, 45%, rough, random.
-channels, round to elongated, 10%, smooth, random.

Intra-aggregate porosity: 15% (porous).

Basic organic components:

5% organic matter; plant residues, 5%, homogeneous; no pigment differences.

Amorphous pedofeatures:

Some vaque ferric mottling common ferric nodules, grey colouring.

Excrement pedofeatures:

common loose discontinuous infillings.

Remarks:

10% of the area is more dense probably because of slemp. Structure is less biogene but not yet physicogene.

Detailed micromorphological description.

Soil profile number: COC 6.
Location: Cocori area, Costa Rica.
Horizon: Ag.
Depth: 2-10cm.
Landuse: secundary vegetation.
Thin section number: 87/164.

Microstructure:

vague crumb structure.

peds: crumbs, weakly developed, 100%, ultrafine and medium, rough, unaccommodated, random.

Voids:

-interaggregate: loose compound packing voids.
-intra-aggregate: interconnected vughs, irregular, 70%, rough, random; channels, round to elongated, 30%, smooth, random.

Average intra-aggregate porosity: 30% (very porous).

Basic organic components:

25% organic matter; 2% plant residues, homogeneous; no piment differences.

Amorphous pedofeatures:

some ferric mottles, not homogeneously distributed; hypocoatings of channels and some large voids.

Excrement pedofeatures:

common, small, spherical excrements; some loose discontinuous infillings.

Remarks:

no difference in density.

Detailed micromorphological description.

Soil profile number: COC 7.
Location: Cocori area, Costa Rica.
Horizon: A.
Depth: 2-10cm.
Landuse: Secundary vegetation.
Thin section number: 87/165.

Microstructure:

crumb.

peds: crumb, weakly developed, 100%, mainly fine, rough, unaccommodated, random.

Voids:

-interaggregate: loose compound packing voids.
-intra-aggregate: interconnected vughs, irregular, 80%, rough, randomly distributed; channels, round to elongated, 20%, smooth, random.

Average intra-aggregate porosity: 25% (very porous).

Basic organic components:

20% organic matter; 2% plant residues, homogeneous; pigment differences occur, heterogeneously in 10% of the area more dark, clear, distinct.

Excrement pedofeatures:

biogene structure (faecal fabric); loose discontinuous infillings.

Remarks:

20% of the matrix is more dense; few loose textural infillings.

Detailed micromorphological description.

Soil profile number: COC 8.
Location: Cocori area, Costa Rica.
Horizon: A
Depth: 2-10cm.
Landuse: forest
Thin section number: 87/161.

microstructure:

crumb.

peds: crumb, moderately to strongly developed, 100%, ultrafine to coarse, rough, unaccommodated, random.

Voids:

-interaggregate: loose compound packing voids.

-intra-aggregate: interconnected vughs, irregular, 75%, rough, random; channels, round to elongated, 20%, smooth, random; planes, zig-zag, 5%, smooth,random.

Average intra-aggregate porosity: 30% (very porous).

Basic organic components:

20% organic matter; 2-3% plant residues, homogeneous; pigment, 10% of the area is a bit darker, heterogeneous, clear, distinct.

Excrement pedofeatures:

area largely consists of spherical small excrements (faecal fabric); some loose discontinuous infillings.

Remarks:

no difference in density.

Detailed micromorphological description.

Soil profile number: COC 9
Location: Cocori, Costa Rica.
Horizon: Ag1
Depth: 2-10cm.
Landuse: pasture.
Thin section number: 87/167.

Microstructure:

apedal (channel).

Voids:

-channels, round to elongated, 80%, smooth, random.
-vughs, irregular, 20%, rough, random.

Average intra-aggregate porosity: 10-20% (porous)

Basic organic components:

5% organic matter; plant residues, 5%, homogeneous; no pigment differences.

Amorphous pedofeatures:

abundant ferric mottlings and nodules, hypocoatings of channels, grey colouring 100%.

Excrement pedofeatures:

few loose discontinuous infillings.

Remarks:

about 5% of the matrix is more dense because of slemp.

Detailed micromorphological description:

Soil profile number: COC 11
Location: Cocori, Costa Rica.
Horizon: A
Depth: 2-10cm.
Landuse: forest.
Thin section number: 87/159.

Microstructure:

crumb.

Peds: crumbs, moderately developed, 100%. ultra-fine to coarse, mainly fine, rough surface, unaccommodated, random.

Voids:

-interaggregate: loose compound packing voids.

-intra-aggregate: interconnected vughs, 70%, irregular rough, random; channels, round to elongated, 30%, smooth, random.

Intra-aggregate porosity: 40% (very porous).

Basic organic components:

25% organic matter; plant residues 15% homogeneous; pigment difference: 20% of the area is a bit darker, diffuse, faint, heterogeneous.

Amorphous pedofeatures:

some ferric nodules.

Excrement pedofeatures:

thin section largely consists of excrements (feacal fabric); loose continuous and discontinuous infillings.

Remarks:

no density differences.

Detailed micromorphological description.

Soil profile number: COC 12
Location: Cocori, Costa Rica.
Horizon: A.
Depth: 2-10cm.
Landuse: deforestated.
Thin section number: 87/168.

Microstructure:

complex, crumbstructure at the top and angular blocky structure at the bottom.

Peds: -crumbs, moderately to strongly developed, 40%, ultrafine to fine, mainly fine, rough surface, unaccommodated, randomly distributed.
-angular blocks, weakly developed, 60%, very fine and fine, smooth surface, accommodated, randomly distributed.

Voids:

-interaggregate: loose compound packing voids at the top and curved (skew). Planes at the bottom.

-angular blocky, intra-aggregate: interconnected vughs, irregular, 60%, rough walls, randomly distributed; vughs, randomly distributed; channels, round to elongated, 20% , smooth walls, randomly distributed.
-crumb, intra-aggregate: interconnected vughs, irregular, 80%, rough walls, randomly distributed; channels, round to elongated, 20%, smooth walls, random.

Average intra-aggregate porosity: 10-15% (porous).

Basic organic components:

organic matter, 15%; plant residues, homogeneous 10%, rounded; no pigment differences.

Amorphous pedofeatures:

few typic iron nodules.

Excrement pedofeatures:

common spherical excrements, mainly as loose discontinuous infillings.

Remarks:

no density differences; skew planes show the physicogene structure.

Detailed micromorphological description.

Soil profile number: COC 13
Location: Cocoro, Costa Rica.
Horizon: A.
Depth: 2-10cm.
Landuse: forest.
Thin section number: 87/169.

Microstructure:

crumbstructure.

Peds: -crumbs, moderately to strongly developed, 100%; ultrafine to medium; mainly fine; undulating to rough surface; unaccommodated; randomly distributed.

Voids:

-interaggregate: loose compound packing voids.

-intra-aggregate: interconnected vughs, irregular shape, 60%, rough walls, randomly distributed; vughs, irregular shape, 20% rough walls, randomly distributed; channels, round to elongated, 20%, smooth walls, randomly distributed.

Average intra-aggregate porosity: 10-20% (porous).

Basic organic components:

organic matter, 20%; plant residues, homogeneous, visible 10%; vague pigment differences, 20% of the thin section is somewhat darker, heterogeneous, diffuse and faint.

Excrement pedofeatures:

the thin section largely consists of excrements (faecal fabric); excrements are spherical, randomly distributed and sometimes loose discontinuous infillings.

Remarks:

20% of the thin section area IS more dense.

Appendix C Chemical analysis

soil site number	depth (cm)	% orgC	% clay	% silt	% sand	pH H2O	pH KCl	pH NaF	% phosphate retention	Ca++	Mg++	K+	sum cations	Al+++	acidity	ECEC	BS eff.	CEC NH4OAc (ph=7)	BS (pH=7)
Cedral:																			
COC 4	0-5	7.2	72.0	20.7	7.3	4.6	3.9	8.8	72	5.6	1.0	3.8	10.4	2.3	6.1	16.5	0.63	46.7	0.22
	5-17	5.7	72.8	21.2	6.0	4.6	4.0	9.3	90	2.1	0.4	2.7	5.2	2.2	5.4	10.6	0.49	44.2	0.12
	17-27	3.9	74.2	19.5	6.3	4.6	4.0	9.6	89	0.2	o.2	1.8	2.2	2.3	5.5	7.7	0.29	41.3	0.05
	27-70	1.2	79.4	15.9	4.7	4.8	4.0	10.3	90	1.2	0	0	1.2	2.3	5.3	6.5	0.18	40.8	0.03
	70-100	0.6	78.3	16.6	5.1	4.6	4.0	10.1	79	3.2	0.3	0.8	4.3	2.3	5.3	9.6	0.45	36.3	0.12
	100-150	-	72.3	20.9	6.8	4.5	3.9	10.1	86	2.9	0.4	0.2	3.5	2.4	5.5	9.0	0.39	28.5	0.12
COC 12	0-15	3.4	53.3	24.3	22.4	4.2	3.7	8.6	66	10.2	0.6	2.0	12.8	3.5	7.5	20.3	0.63	45.3	0.28
	15-90	0.8	55.4	34.7	9.8	4.7	3.9	9.6	72	2.4	0.4	0	2.8	2.6	6.2	9.0	0.32	28.5	0.10
	90-120	0.2	60.3	27.9	11.7	4.8	3.9	10.2	80	0.7	0.2	2.2	3.1	3.2	6.9	10.0	0.31	26.9	0.12
	120-160+	0.42	38.8	38.2	22.9	4.8	3.9	9.9	78	3.9	0.2	3.4	7.5	2.7	6.1	13.6	0.55	20.7	0.36

Cedral chemical analysis.

soil site number	depth (cm)	% orgC	% clay	% silt	% sand	pH H2O	pH KCl	pH NaF	% phosphate retention	Ca++	Mg++	K+	sum cations	Al+++	acidity	ECEC	BS eff.	CEC NH4OAc (ph=7)	BS (pH=7)
Sardina:																			
COC 11	0-12	8.4	10.7	37.5	51.8	4.6	4.2	10.8	65	0	0.9	2.9	3.8	1.8	4.0	7.8	0.49	70.0	0.05
	12-20	4.4	13.3	36.4	50.3	4.6	4.4	11.0	91	0	0.3	2.6	2.9	0.8	1.9	4.8	0.60	69.1	0.04
	20-35	2.6	9.2	41.4	49.6	5.0	4.7	11.0	93	0	0.3	1.0	1.3	0.1	0.6	1.9	0.68	54.4	0.02
	35-45	0.8	4.2	38.2	57.6	5.5	4.8	10.8	89	0	0	1.8	1.8	0.1	0.3	2.1	0.86	52.3	0.03
	45-60	0.4	2.4	25.0	72.6	5.7	4.7	10.3	76	1.2	0.8	1.0	3.0	0.1	0.3	3.3	0.91	49.3	0.06
	60-70+	0	0.6	19.1	80.3	6.1	4.8	9.7	53	5.6	1.4	1.8	8.8	0.2	0.6	9.4	0.94	24.0	0.20
COC 2	0-3	7.7	18.6	60.5	20.9	5.6	4.8	9.1	65	18.4	3.2	10.2	31.8	0	0.4	32.2	0.99	72.6	0.44
	3-10	3.0	19.4	60.6	20.0	5.7	4.8	9.9	75	37.5	2.0	5.4	44.9	0	0.3	45.2	0.99	80.4	0.56
	10-40	1.7	23.2	57.4	19.4	5.9	4.9	10.3	80	13.5	1.6	3.6	18.7	0.1	0.2	18.9	0.99	57.0	0.33
	40-65	0.9	16.8	66.5	16.8	6.1	5.0	9.9	77	9.8	2.0	2.8	14.6	0	0.1	14.7	0.99	54.4	0.27
	65-90	0.5	21.0	67.2	11.8	6.1	5.1	9.4	67	11.1	2.6	1.9	15.6	0	0.1	15.7	0.99	55.2	0.28
	90-110	0.2	3.4	36.0	60.6	6.1	4.9	9.2	40	5.3	2.1	1.3	8.7	0	0.2	8.9	0.98	49.3	0.18
	110-150	0	0	1.6	97.8	6.1	5.0	8.9	26	1.9	0.8	0.5	3.2	0	0.2	3.4	0.94	18.1	0.17
COC 5	0-5	-	15	47	38	5.1	4.5	9.8	69	10.0	4.1	1.0	15.1	-	-	-	-	28.1	0.54
	5-15	-	15	45	40	5.0	4.4	10.5	80	6.5	2.8	0.9	10.2	-	-	-	-	24.4	0.41
	15-32	-	17	55	28	5.5	4.5	10.4	86	6.5	2.3	0.7	9.5	-	-	-	-	22.4	0.42
	32-48	-	17	67	16	5.7	4.5	11.1	84	5.1	1.2	0.4	6.7	-	-	-	-	15.6	0.43
	48-63	-	11	23	66	5.9	4.6	10.6	60	4.8	1.2	0.3	6.3	-	-	-	-	13.0	0.49
COC 6	0-5	-	13	31	56	5.1	4.5	9.8	60	10.6	3.3	0.8	14.7	-	-	-	-	19.2	0.76
	5-30	-	9	35	56	5.8	4.7	10.7	61	4.6	0.9	0.6	6.1	-	-	-	-	18.7	0.33
	30-80	-	7	21	72	6.3	5.0	10.0	51	6.1	2.1	0.5	8.7	-	-	-	-	11.4	0.76
COC 8	0-12	-	10	54	36	4.8	4.2	10.5	100	8.8	2.5	0.4	11.7	-	-	-	-	28.6	0.76
	12-30	-	12	48	40	4.9	4.3	10.7	79	3.6	1.0	0.3	4.9	-	-	-	-	23.4	0.21
	30-55	-	6	8	86	5.6	4.4	10.5	81	2.6	0.7	0.2	3.5	-	-	-	-	15.1	0.23
	55-70	-	8	28	64	5.7	4.5	10.0	50	2.5	0.6	0.2	3.3	-	-	-	-	11.4	0.29