Hokkaido University/ORSTOM/JICA

Pedological Environment and Agro-ecological system of the Sudano-Sahelian zone, in Niger, West Africa

西アフリカ、ニジェールのスーダン-サヘール帯における

土壌環境と農業生態系

Graduate School of Environmental Science, Hokkaido University
Thesis for Master Course

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Laboratory of Fundamental Research

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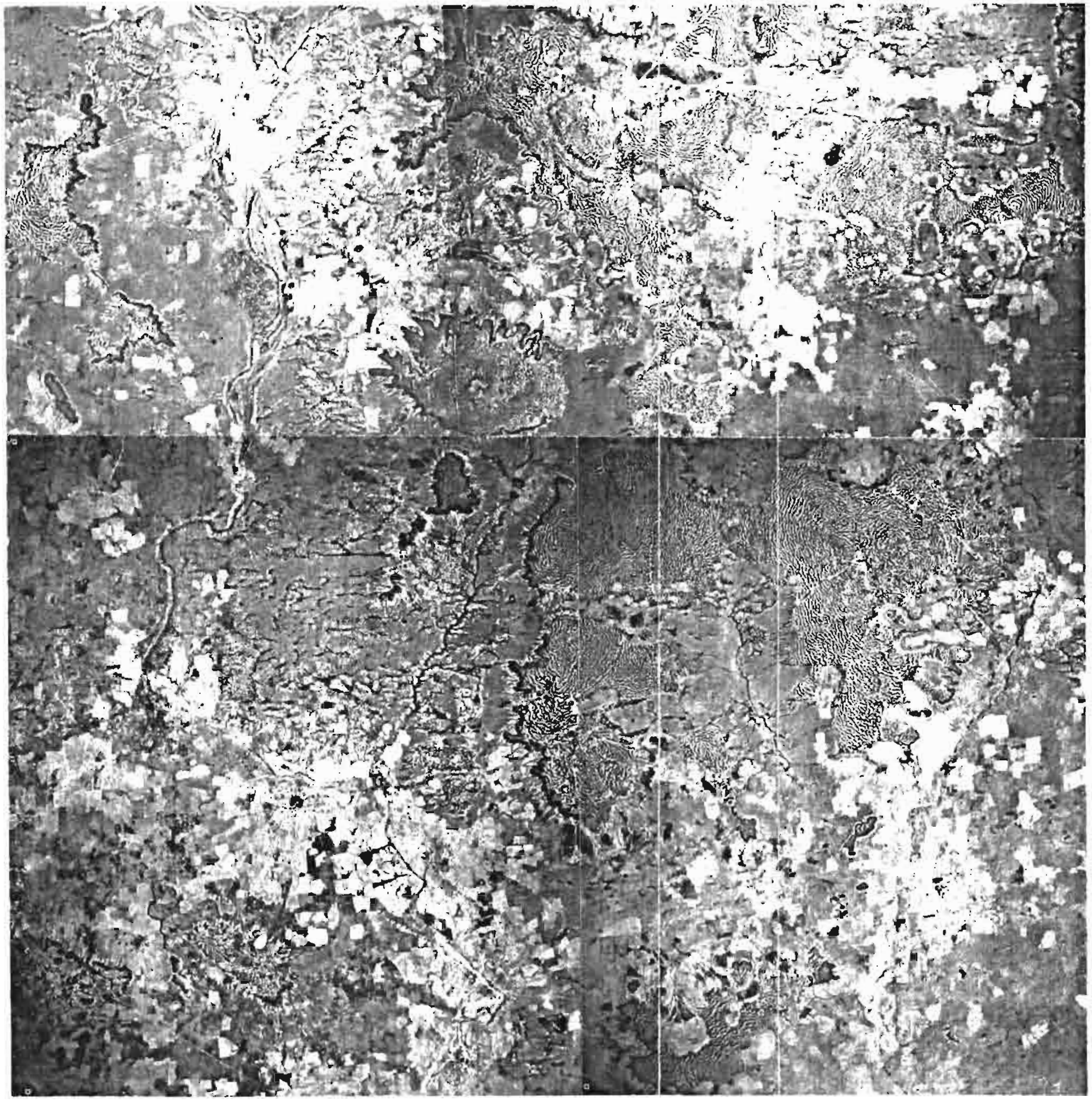
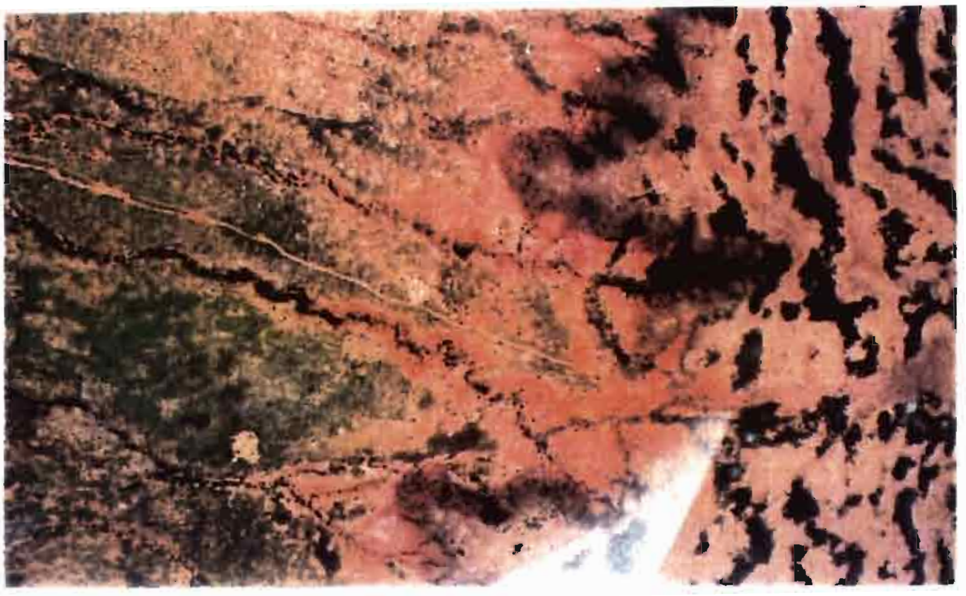


Plate 1. Air born photographs of the studied area (taken in 1975.   IGN.France)



a)

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Plate 2 View from the sky

a)Tiger bush on the plateau and hill-foot slope with gullies, 2)areolar erosion surfaces in the low tree steppe on the pediplain, and sheet and probably aeolian erosion surface along the temporal water way(taken by Mr. Monteny,B.A. ORSTOM)
c)Gardens along the V-type valley near the BZ.We see gullies,too

a)

b)

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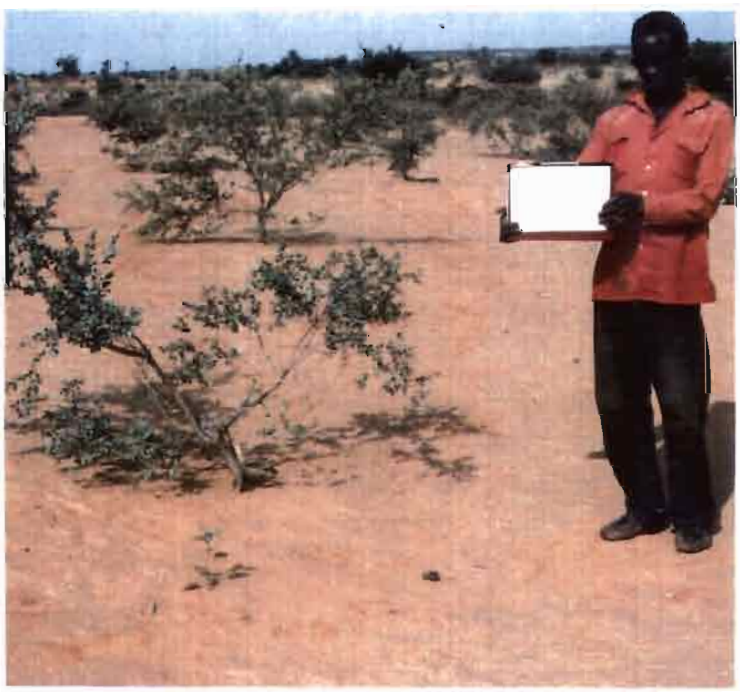

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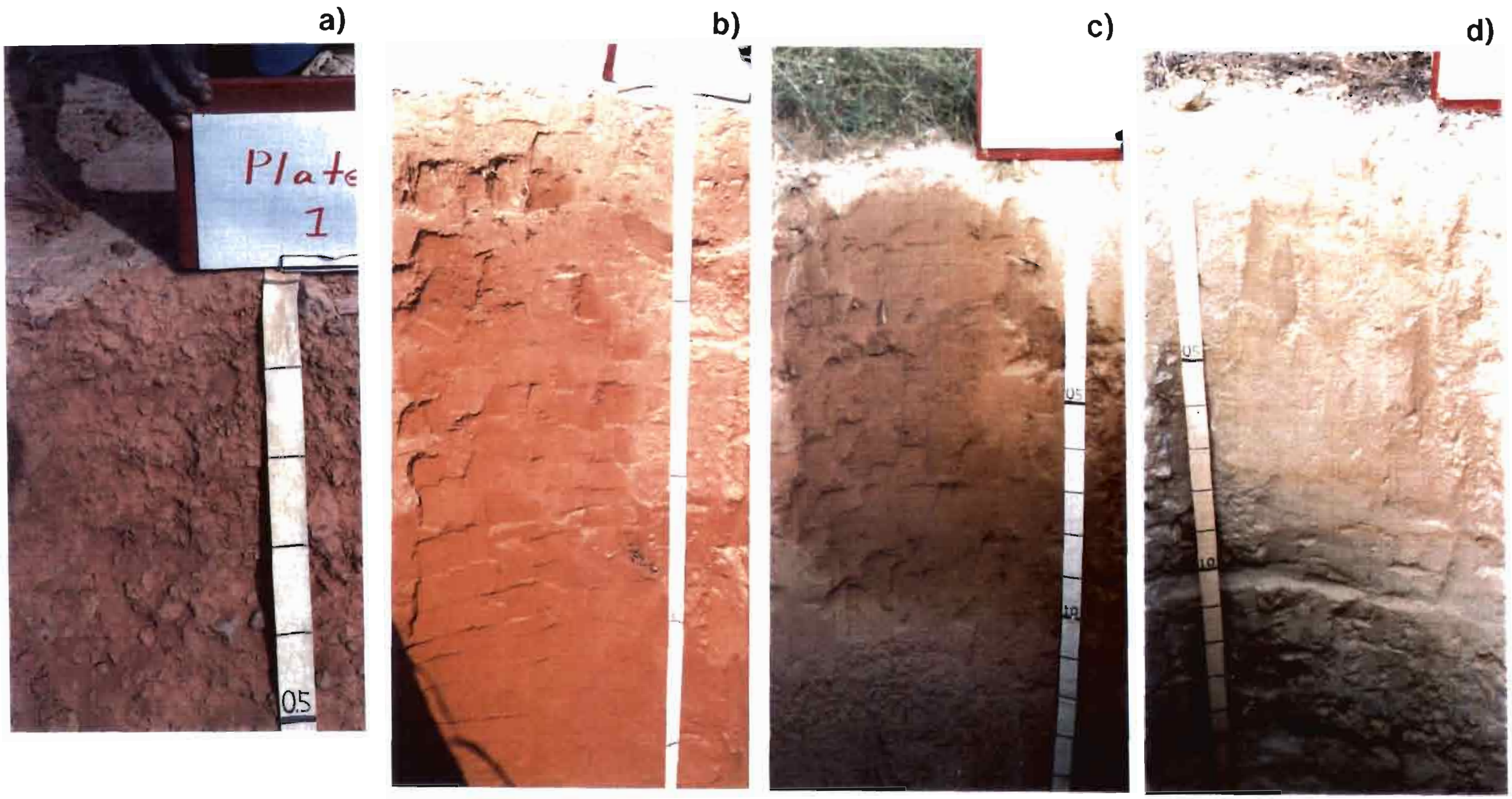
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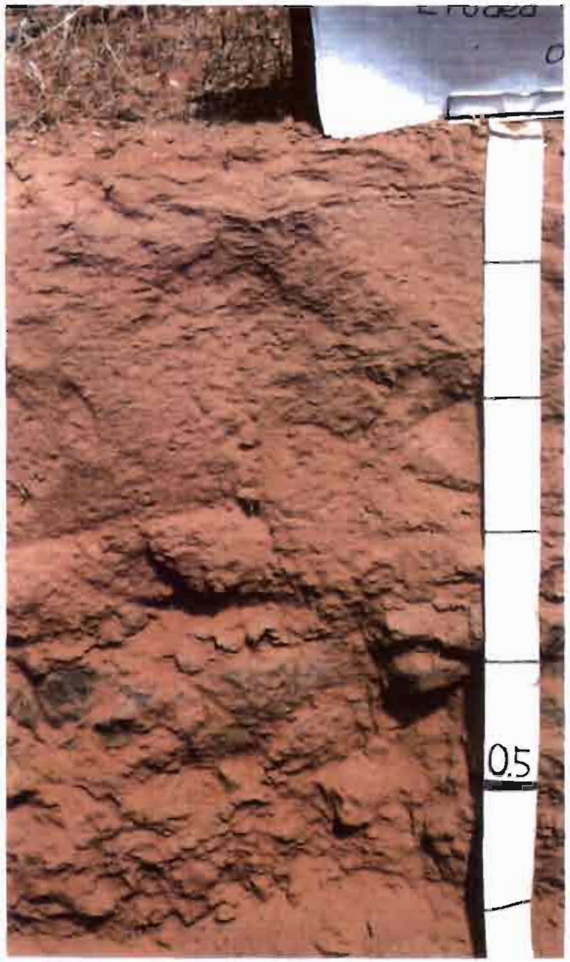

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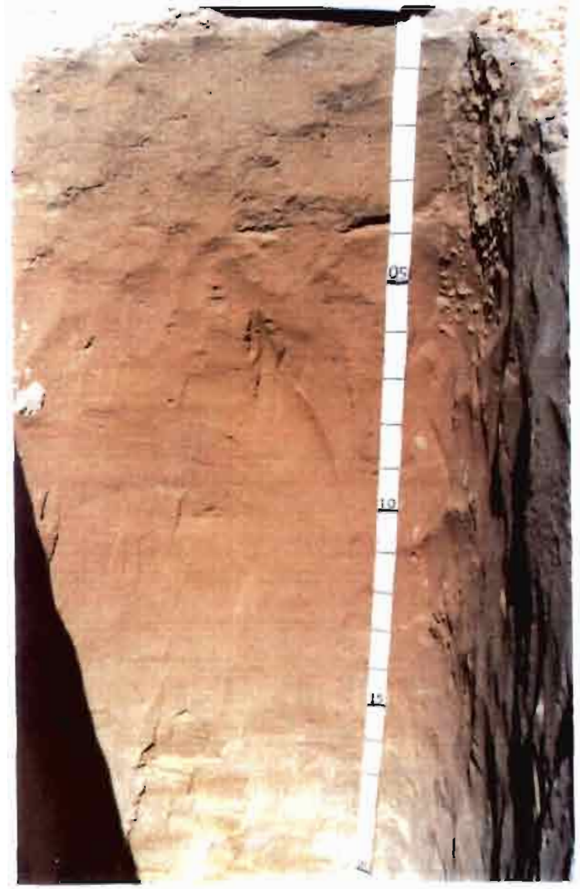

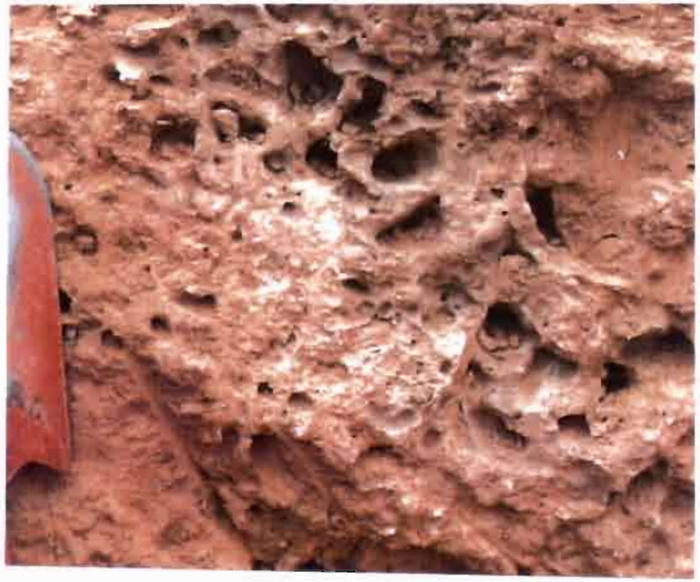
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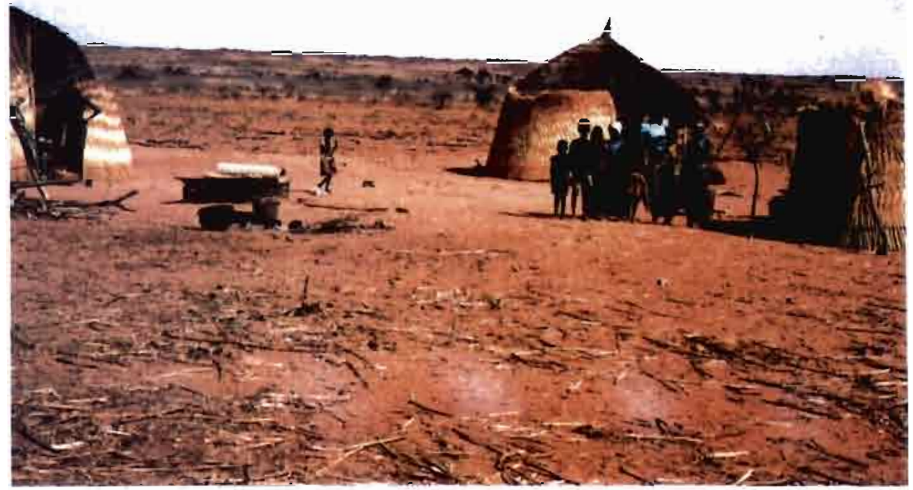

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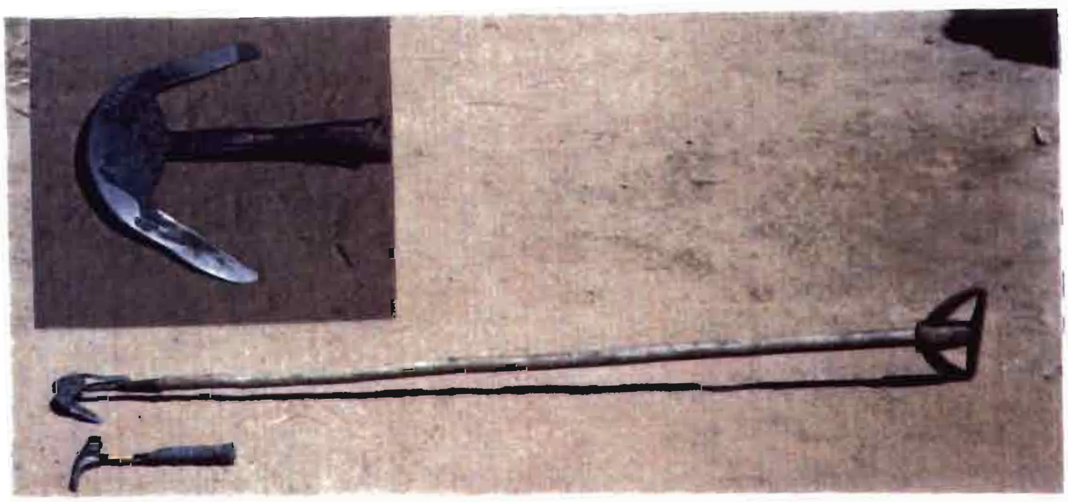

d)

Plate 11 Farming tools

a)hachet for cutting trees, b)one kind of hoes for felling millet stalks, c)one kind of hoes for digging holes, d)one kind of hoes for destroying weeds and surface crust

Abstract

The agro-ecological study of the Sudano-Sahelianzone was carried out at the central site of HAPEX-SAHEL Project in Niger, west Africa. Particularly, the geomorphological and pedological environments for agriculture were surveyed by the photo-interpretation and by the on-site research of soil and geomorphology. These work led to complete the geomorphological unit map and the soil map using GIS. The classification of the land occupation was conducted by remote-sensing analysis (SPOT). All results, including the soil analysis, made clear the geomorphological and pedological environments.

The land system of the studied area is composed of residual plateaux of Continental terminal, aeolian hill-foot slopes, pediplains with aeolian sand, alluvial terraces, dried valleys and other sand depositional form.

The land quality is strongly related to geomorphological type and the distribution of sand cover. The depth and color of sandy soil are major criteria for the definition of soil type. Almost of all sandy soils are acid and very poor in nutrition for the plant. But, the physical property of the sandy soil enables the cultivation under the rain-fed condition in the semi-arid region.

Hearing survey on the agricultural activity and the village life revealed that the agricultural system between two different tribes, Zarma (farmer) and Peul (farmer-livestock breeder), was different.

Zarma farmers cultivate millet extensively. Their agricultural system is shifting cultivation. As the yield is low, they often have to go to cities to work. With this way, they compensate their life to the fragile natural environment. On the other hand, Peul farmers cultivate millet intensively, generally on the same field. They keep livestock on a large grazing area (=fallow). Their agricultural system is stable and adapted more to the natural environment than Zarma's one. Advantages of livestock breeding are: 1)use of the dung of animals for the natural nutrients, 2)getting of milk, 3)movability of grazing area, and 4)better saving way of the property. Such an adaptability means, at the same time, that the agricultural system of Peul farmers depend on the nature more strongly than that of Zarma farmers.

The increase in population will demand an alternative agricultural system which is necessarily associated with the improvement of the present cropping system.

Key words: Sudano-Sahelian zone, Land system, Agro-ecology, Niger, Millet, Drought, Geomorphological unit map, Soil map, Remote sensing analysis, Agricultural system

Résumé

L'étude agro-écologique dans la zone Soudano-Sahélienne a été realisée sur le site central du Projet HAPEX-SAHEL en Niger, Afrique ouest. Particulièrment, l'environnements géomorphologiques et pédologiques ont été étudiés par photo-interprétation et l'étude sur le terrain. Les resultats ont realisé, en utilisant SIG, la carte des unités géomorphologiques et la carte pédologique. L'occupation de terrain vegetal a été classifiée par l'analyses de la télédétection (SPOT). Toute ces resultats avec ceux de l'analyses des sols, caractérisent l'environnement agro-écologique de cette région étudiée.

Le système des terrains est composé de plateau résiduel des Continental terminal (Ct3), des jupes sableuses éoliennes, des glacis couverts par de sables éoliens, des vallées sèches, des terrasses alluviales, et des formes sableuses éoliennes.

La qualité de terrain est lié au type géomorphologique et à la distribution de la couverture sableuse. La profondeur et la couleur des sol sableux ont été considérée comme le critère le plus important pour la classification des sols. Presque tous les sols sont pauvre à propos de la nutrition pour les plantes. Mais les caractéristiques physiques des sols sableux contribuent en culture du millet avec la pluie sous la condition climatique semi-aride de la région.

L'enquête sur l'activité agricole et sur la vie villageoise montre que le système agricole entre deux tribus, Zarma (agriculteur) et Peul (agriculteur-éleveur), est très différent.

Les paysans Zarma cultivent le millet extensivement par l'agriculture de déplacement. Leur recolte est faible, et généralement, ils doivent aller travailler aux grandes villes.

Par contre, les paysans Peul cultivent le millet intensivement, généralement au même champ. Ils élèvent du bétail sur les zones de patûrage (= la jachère). Leur vies sont plus stable et plus adaptées à l'environnement naturel, en profitant des avantages d'élevage qui sont, 1)l'application des fumés des animaux pour l'engrais, 2)la production de lait, 3)le déplacement de la zone de patûrage, et 4)le meilleur faire de provision de la propriété. À la fois, Il signifie que le système agricole des paysans Peul est basé sur la nature plus fort que ceux des Zarma.

L'augmentation de la population nécéssitera un système agricole alternatif, qui doit être lié avec l'amérioration de système cultural.

Mots clés: Zone Soudano-Sahélienne, Système des terrains, Agro-écologie, Niger, Culture de millet, Sécheresse, Carte des unités geomorphologiques, Carte pédologique, Télédéction, Systeme agricole

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要約

サヘール－スーダン地域の農業生態系調査を西アフリカ、ニジェール、HAPEX-SAHEL プロジェクトの中央観測サイトで実施した。特に、農業的土地利用の観点から、地形及び土壌環境を空中写真判読、土壌調査、地形調査、地表面状態の観察などの現地調査により把握した。こうした調査結果に基づき、地形区分図および土壌図をGISにより作成した。また、土地被覆分類をリモートセンシング解析により行った（SPOTデータ）。これらに土壌分析結果を加え、対象地域の自然環境を特徴付けることができた。

本地域のランドシステムは第三紀末までに堆積したコンチネンタルターミナルと呼ばれる残積性台地、風成緩斜面、風成砂の覆うペディプレイン、河成段丘、枯渇河川およびその他の風成地形からなる。土地の性質は地形タイプ、そして砂質堆積物の分布に強く関係している。そのため、砂質土壌の深さと色が土壌型の区分のための基準として用いられた。ほとんど全ての砂質土壌は酸性で、貧栄養である。しかし、砂質土壌の物理性の有利性がこの半乾燥地域での天水依存下での農業を可能にしている。

農業システムと農村の生活様式について聞き取り調査は、異なる生活様式を持つ２部族（ザルマ族とプール族）の農業システムの重要な違いを明らかにした。

ザルマ農家は移動耕作による粗放的農業を営んでいる。その収量レベルは低く、彼らは農業だけで生計を営む事ができず、その多くが乾季に都会にあるいは他国に出稼ぎに行く。こうして、彼らは脆弱で不安定な自然環境での困難な生活を補償している。一方、プール農家はミレットを一般に同じ場所でより集約的に栽培すると同時に、広大な休閑地（＝放牧地）に依拠して牧畜を行っている。牧畜の有利性を受益することにより、彼らの農業システムは、ザルマのそれに比べてより自然環境に適応しているといえる。牧畜の有利性とは、１）家畜糞の利用、２）ミルクなどの生産、３）放牧地の移動可能性、および、４）より優れた蓄財手段である。しかし、同時にそれは、プール農家の農業システムが、ザルマ農家のそれに比べてより強く自然に依存していることを意味する。

人口の増加は代替農業システムへの移行を必要としている。それは栽培システムの改善を伴うものでなければならない。

キーワード：スーダン-サヘール地域、ランドシステム、農業生態系、ニジェール、ミレット、干魃、地形区分図、土壌図、リモートセンシング解析、農業システム

Preface

This study was done as a research work of a master course at Graduate School of Environmental Science, Hokkaido University, Japan. And it was carried out at ORSTOM, Institute Français de recherche scientifique pour le developpement en coopération, from 11th December, 1990 to 10th December, 1992, financed by JICA's foreign training programs (JICA: Japan International Cooperation Agency).

This report was prepared for presentation to the university. At the same time, it is presented to ORSTOM as a final report of my research.

Acknowledgement

This study was accomplished thanks to a lot of helps and cooperations

At first, I thank Mr. Cornet, A., chief of MAA, ORSTOM, who received my application for study at ORSTOM. It must have been difficult to have received me exceptionally as a first student from Japan.

I thank Mr. Moreau, R., chief of UR3 (unité de recherche 3), who received me and my professors kindly, and directed me on the study in Montpellier.

I thank Mr. Valentin, C., pedologist, ORSTOM, Niamey, who directed me on the study in Niger. I remeber that we trained for karate together.

I thank Mr. Vizier, J. F., chief of the laboratory of behavior of cultivated soils, ORSTOM, Montpellier, who always helped my presentations.

I thank Mrs. Regime, C., chief of the laboratory of remote sensing analysis, ORSTOM, Montpellier, who directed me on the field of remote sensing analysis.

I thank Mr. Hoepffner, M. coordinator of HAPEX-SAHEL Project, ORSTOM, Montpellier, who helped me for the negotiation of my work.

I thank Mr. Casenave, A., director of ORSTOM, Niamey, who helped me for my stay and my work in Niger.

I thank Mr. D'herbes, J. M., phytoecologist, ORSTOM, Niamey, who helped me practically for the soil survey.

I thank Mr. Monteny, B. A., agroclimatologist, ORSTOM, Niamey, who encouraged me, and permitted me to use his air-born photographs.

I thank Mr. Lebel, T., hydrologist, ORSTOM, Niamey, who helped me for the negotiation of the on-site research.

I thank Miss. Galle, S., hydrologist, ORSTOM, Niamey, who helped me for the negotiation of the on-site research.

I thank Mr. Deconnet, J. C., hydologist, ORSTOM, Niamey, who helped a lot for taking air-born photographs.

I thank Mr. Barbiero, L., pedologist, INRA, Niamey, who helped me a lot on the soil survey.

I thank Mme. Delaune, M., chief of the laboratory of the sedimentology, ORSTOM, Bondy, and her colleagues, who received me very kindly when I came to France.

I thank Mr. Serpantie, G., agronomist, ORSTOM, Montpellier, who advised me on the situation of the Sudano-Sahelian countries.

I thank Mr. Boulet, R., pedologist, ORSTOM, São Paulo, who taught me how to study a toposequence of soil structure by the on-site research.

I thank Mr. Bellier, G., chief of the laboratory of soil physics, ORSTOM, Bondy, and his colleagues, who helped me for analysis of soil physics.

I thank Mr. Sondag, F., chief of the laboratory of soil chemistry, ORSTOM, Bondy, and his colleagues, who helped me for analysis of soil chemistry.

I thank all colleagues of the laboratory of information, ORSTOM, Bondy, who directed me seriously for the GIS.

I thank all members of ORSTOM, Niamey, who helped me for my stay and my study. I enjoyed the Nigerian life thanks to you all.

I thank all colleagues of the laboratory of remote sensing analysis, and the laboratory of information, ORSTOM, Montpellier, who helped me very friendly. Your jokes always made me laugh. I am sorry that I killed the "Sun" many times.

I thank all colleagues of the laboratory of the behavior of the cultivated soils, who helped me for analysis of soils, who took a lunch together, who took a coffee together, who taught me on the situation of Africa, who encouraged me when I was tired, who tried me to laugh, who taught me french and French life.

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I thank all members of JOCV (Japan Overseas Cooperation Volunteers) in Niger, who taught me on the situation of Niger.

I thank Mr. Sakuma, T., professor of the faculty of Agriculture, Hokkaido university, Japan, and Mrs. Sakuma, who visited me in Montpellier, and encouraged me.

I thank Mr. Kinoshita, M., JICA, who took care of me in Japan for two years.

I thank all members of JICA, Paris, who gave me important informations about France and Africa.

****

I thank Mr. Ono, Y., professor of the Graduate School of Environmental Science (Department of Environmental Structure), Hokkaido University, Japan, who directed me, helped me for the negotiation with ORSTOM, and visited me in Montpellier.

I thank all colleagues of the laboratory of Fundamental research, Graduate School of Environmental Science, Hokkaido University, Japan. You remembered me for two years. And, you gave me your continuous friendship after my return. Then, you helped me a lot for my preparation of this report.

AGAIN, THANK YOU VERY MUCH , EVERYBODY WHOM I MET IN FRANCE, IN NIGER, AND IN JAPAN

Au revoir
Kara ton ton
Sayonara

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1. General introduction

1-1 Background of the study

Since the end of the 1960s, the drought of the Sahelian region has become a subject of world-wide attention. The mass media, especially, have reported its serious impacts to the local populations. A lot of projects are still going to overcome it. Among them the Japanese government has increased the financial aids to the Sahelian countries, and continued to cooperate with them. However, France is the country which has been most intensively concerned with this region. The financial and technical aids of France support their countries still now. Many French people are working in the entire domain of their society.

As far as agricultural developments and land conservation programs are concerned, it is very important to know both natural and socio-economical conditions of the area. France has accumulated many basic information of the region. For example, ORSTOM made a lot of soil maps in this region. The topographical maps of this region was made by IGN. Therefore, it was interesting for Japanese scientists to learn about its knowledge and experiences.

1-2 Studied area

Upon the recommendation of ORSTOM/MAA, the central experimental site of the HAPEX-SAHEL Project in Niger was chosen as a studied area. Climatically, it belongs to the Sudano-Sahelian zone of West Africa, which is "one of the harshest climatic regions of the world, with low and highly variable rainfall, high soil and air temperatures, high evaporative demand and poor soils" (Sivakumar, et. al. 1991).

The geomorphology of the studied area is mainly composed of the residual plateau of the Continental terminal and the valley system. These landforms extend to the vast area in the region with the same pattern. The land surface is strongly affected by sand deposits as a result of enlargement of the Sahara desert in the past arid period. The distribution of sand cover strongly influences the land quality.

1-3 Approach to understand the natural condition

Many approaches allow to understand the natural condition suitable for agricultural developments or land conservation programs. FAO has drawn an agro-ecological zonation map of Africa. It mainly considers climatological parameters such as rainfall, temperature, evapotranspiration, available duration for cropping, etc.. It helps us to understand a regional variation of climatic condition throughout Africa, although the local condition is neglected.

FAO conducted a land evaluation study on the rain-fed agriculture as well. "Land system" and "Land facet" are two common terms encountered in this study. "Land facet" is considered as a land unit with almost the same land quality. Then, it can be maintained with the same way. "Land system" is represented by a combination of the land facets.

"Land facet" may often coincide with a geomorphological unit because geomorphology is strongly related to land characteristics such as soil type, drainage condition, and so on. The geomorphological border is often utilized for drawing a soil map. The geomorphological aspect, therefore, is the first subject to be studied. And the land quality will be characterized in each geomorphological unit.

1-3. Remote-sensing analysis

The remote-sensing analysis is nowadays one of the most available tools for land surface observation. It gives us a lot of informations about the land surface feature. This analysis can be done mainly by two methods:

1) Eye-interpretation of the images

2) Numerical data analysis

Both of them are important. As the image corresponds to the land occupation, the objects can be interpreted on it. But, if the object is unknown or its form is vague, the eye-interpretation is often difficult.

The numerical data analysis is suitable when we want to evaluate the objects quantitatively and statistically. As far as development programs are concerned, the objectives of remote-sensing analysis will be often focused on the cartography of the land occupation (erosion surface, crop field, etc.). They may contribute to the land management planning.

1-5. Objectives of the study

The objectives of the study are to understand the fundamental natural environments, especially on the pedology, and on the agricultural activities there. Such knowledges may contribute to actual development programs.

In order to realize it, the following studies were conducted:

1) The soil survey and geomorphological unit and soil mapping,

2) The hearing survey on the agricultural activities and human life in a village,

3) The remote-sensing analysis relating to the results of the soil survey,

Through the above studies, we tried to understand relations between the agricultural system and the environment, and considered the possibility, limitation, and orientation of the rural development.

2. Brief presentation of Niger

2-1. Location and natural condition

2-1-1 Location

Niger is located in the west Africa between 12 degree in north latitude and the tropical Cancer. The total surface area is 1,267,000km^2 (3.4 times of Japan). The capital, Niamey is located close to the Niger river which is the main permanent flow through all of the season (Fig. 2-1).

2-1-2 Geology

The geology is composed of very old basement zones and the sedimentary zones. The old basement zones are located at the west side of the Niger river (Liptako-Gouma region), Air massive, Damagaran Mounio areas.

The sedimentary zones are distinguished by their sedimentary age, from Paleocene to Quaternary. Oulliminden basin which occupies the south-western part of Niger, is composed of Continental terminal (Ct), which sedimented on the marine sediments on the Pliocene. The geomorphological map of the southern Niger is shown in Fig. 2-2. Most part of Niger is covered by Quaternary sand deposits. In the period of enlargement of the Sahara desert, its southern fringe advanced hundreds kilometers to the south. The fixed dune system which was formed by this southern shift of Sahara, influences strongly geomorphology, soil type, vegetation and land use. Its distribution in the west Africa is shown in Fig. 2-3.

2-1-3 Climate

The climate of Niger is characterized by a short rainy season and a subsequent long dry season. Annual rainfall distribution has a horizontal zonality, from less than 100mm to more than 800mm as shown in Fig. 2-4. The alternation of the two seasons is explained by the movement of intertropical convergence zone (ITCZ) (Fig. 2-5). In the rainy season, a humid hot air "Monsoon" reaches to Niger and gives rain (Fig. 2-6). At the same time, "line squall" type rain is very important in the semi-dry region. As shown in Fig. 2-6, the line squall occupies a high portion of the annual rainfall in the semi-dry region.

The rainfall distribution has a single peak pattern, and it concentrates from July to September. In the dry season, a dry air mass with high pressure is dominant, and it does not give rain.

The temperature has a bimodal peak pattern in the southern part, where the highest peak appears at the end of the dry season (April and May), and the secondly highest one does at the beginning of the dry season. Towards the north, its bimodal pattern becomes vague (Fig. 2-4).

2-1-4 Soil

The soil map (Fig. 2-8) shows that the northern part of Niger is occupied by the unweathered mineral soils (sand dunes, regosols, lithosols). In the central part, the imperfectly developed soils and steppe soils appear, while in the southern part, the tropical ferruginous soils spread. Their distribution almost corresponds to that of dune system of the region (cf. Fig. 2-3). It shows a horizontal zonality, depending on the annual rainfall. As interzonal soils, the hydromorphic soils and vertisols occur locally.

2-1-5 vegetation

The vegetation also shows a horizontal zonality depending on the annual rainfall. Their brief descriptions are as follows (after Jeune Afrique, 1980) (Fig. 2-9):

Sahara-Sindian region: It is characterized by isolated steppe vegetation in the depression where water accumulates. The most portion of the area has neither trees nor bushes.

Sudano-Zambezian region: It is subdivided into two zones: Sahelian zone and Sudanese zone.

Sahelian zone: Low trees (or bushes) are sporadically distributed. The trees also appear towards the south. Most of herbacious vegetation are almost annual ones, and their growth depends strongly on the rainfall. The residual plateau of Continental terminal is characterized by tiger bush. This zone is subdivided into a nomadic zone in the north and an agricultural zone in the south.

Sudanese zone: It is characterized by a perennial herbacious vegetation with more dense trees. The clear forest is also observed in the reserved area.

2-2 Population and agriculture

2-2-1 Population

The evolution and the distribution of the population is shown in Table 2-1 and Fig. 2-10, respectively. These data show a rapid increase of population during last thirty years, and its localization, particularly, in the southern part, where most of population are farmers. The population of livestock breeders are less in the south, but towards the north, the portion of livestock breeder in the population increases.

2-2-2 Agriculture

The area of the land use is estimated as follows.

	area (1000ha)	(%)
Total area	126,700	
land area	126,670	100
arable land	3,760 F	3
permanent forage	9,220 F	7
forest and bush	2,660 F	2
other land	111,030 F	88
irrigated land	14 F	0.4 *

Remark F : estimation by FAO, * : ratio to the arable land

The desertic land is included in the other land which occupies a big portion of the total area. In the Sudano-Sahelian zone, livestock breeders and farmers live together. The fallow is a grazing land for animals at the same time. The portion of the irrigated land in the arable land is only 0.4 %. It is localized, particularly, along the Niger river.

The amount of the major agricultural products is shown in Table 2-2, and in Fig. 2-10. It shows that millet culture is the most important in both surface area and amount of product. Millet can be grown in a more arid region than sorghum. The limit of millet culture is said to be an isohyet line of 300mm of annual rainfall. Sorghum is cultivated rather in the southern part. Both of them are often associated with cowpea or groundnuts.

As a cash crop, groundnuts are cultivated, particularly in Maradi and Zinder region. Their cultivation developed in the 1960s, and arrived to be the product for export. Since 1972, the production of groundnuts has decreased abruptly due to the drought, and it has not yet recovered (Fig. 2-11).

Rice culture is done mainly along the Niger river. The traditional rice culture utilizes seasonal floods. The irrigated rice culture is being developed as a national project.

2-2-3 Livestock breeding

Where agriculture is not suitable due to shortage of rainfall, the livestock breeding is extensively done. The statistics of domestic animals is shown in Fig. 2-12. Sheep and goat are raised anywhere, and cattle is mainly raised at the southern part of the isohyet of 200mm of annual rainfall. The camel is mainly raised at the northern part.

Although "transhumants" are mainly distributed at the northern part of the isohyet of 350mm of annual rainfall, they move to the southern agricultural zone in the dry season. The increase of livestocks and the overgrazing are considered to be one of main causes of land degradation.

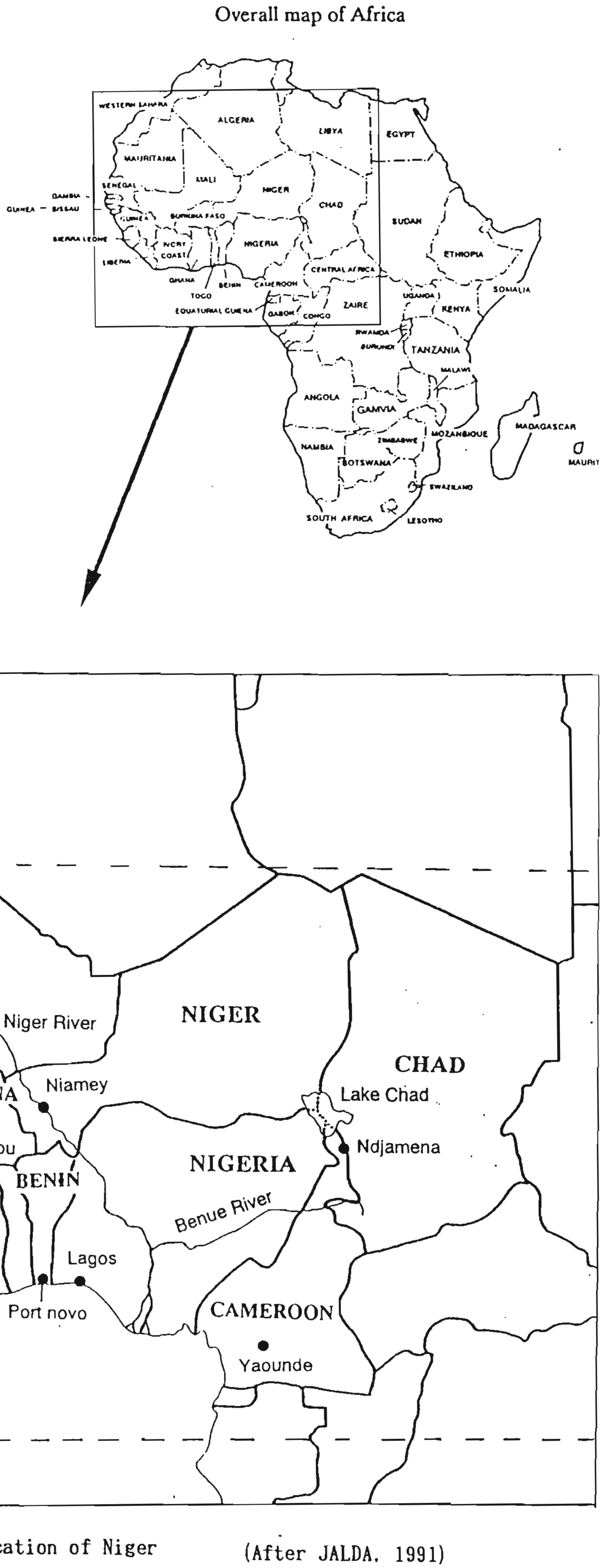


Fig. 2-1. Location of Niger (After JALDA, 1991)

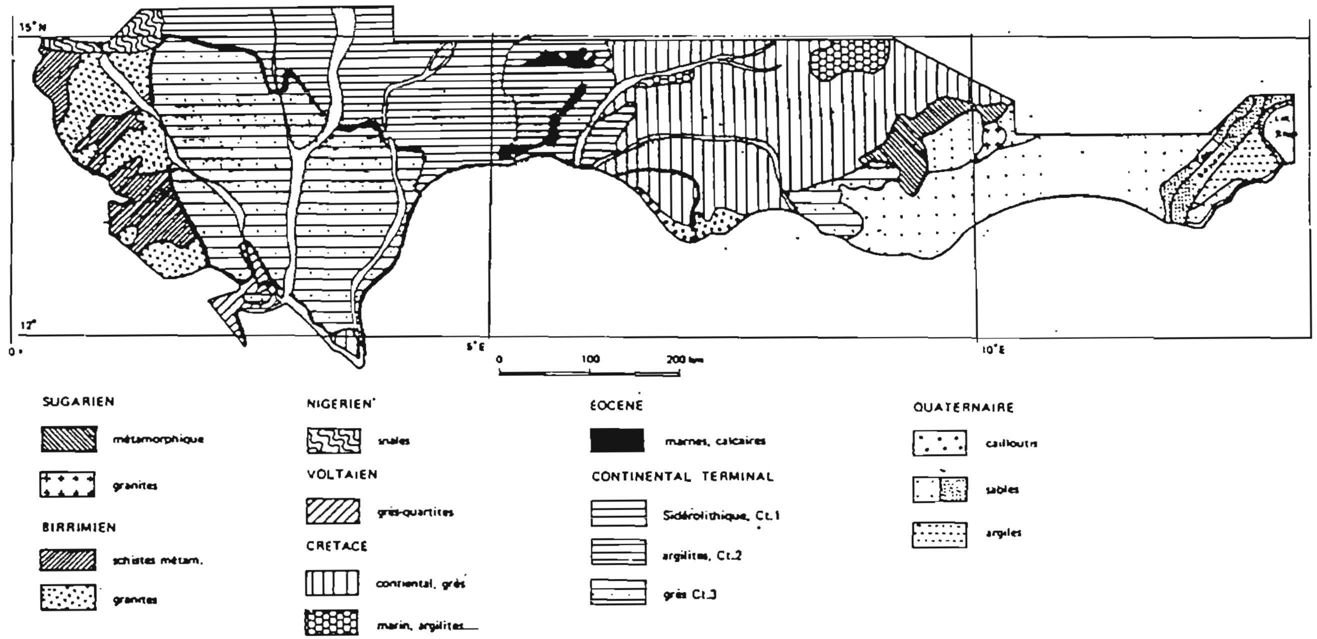
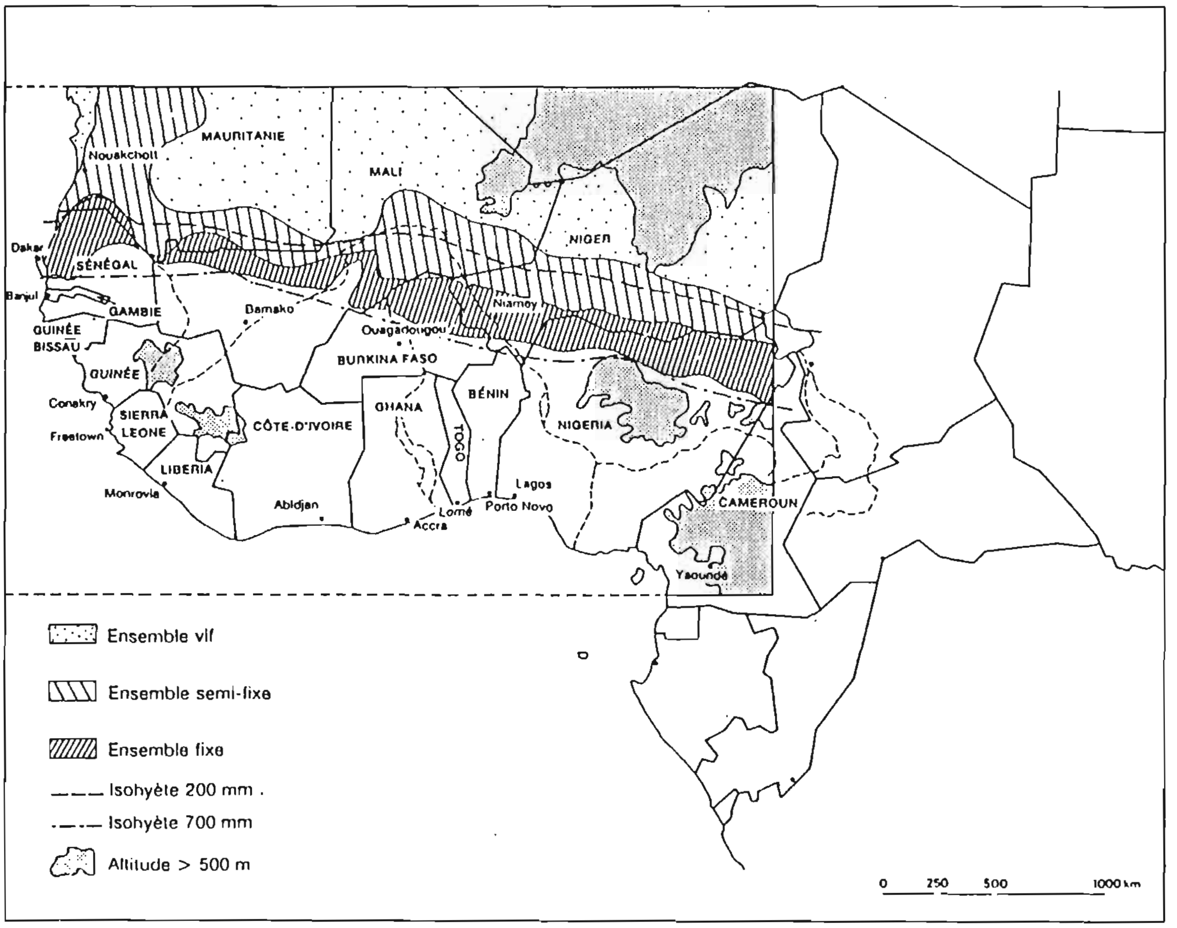


Fig. 2-2. Geological map of thre Southern Niger

(After Gavaud,1977)



Source : COURREL *et al.*, 1980.

Fig.2-3 Dune system in West Africa

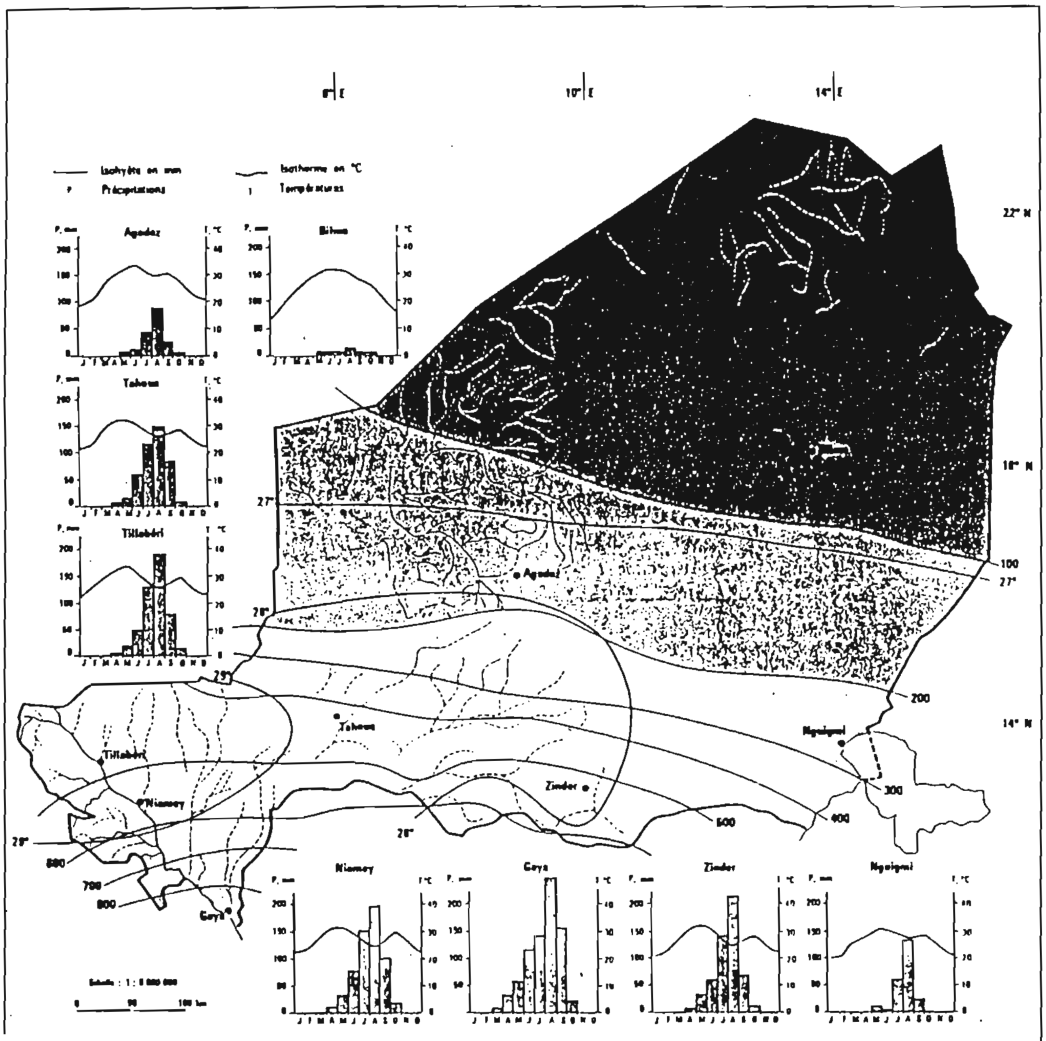


Fig. 2-4 Annual rainfall isohyets
(after les Jeune Afrique, atlas du Niger, 1980)

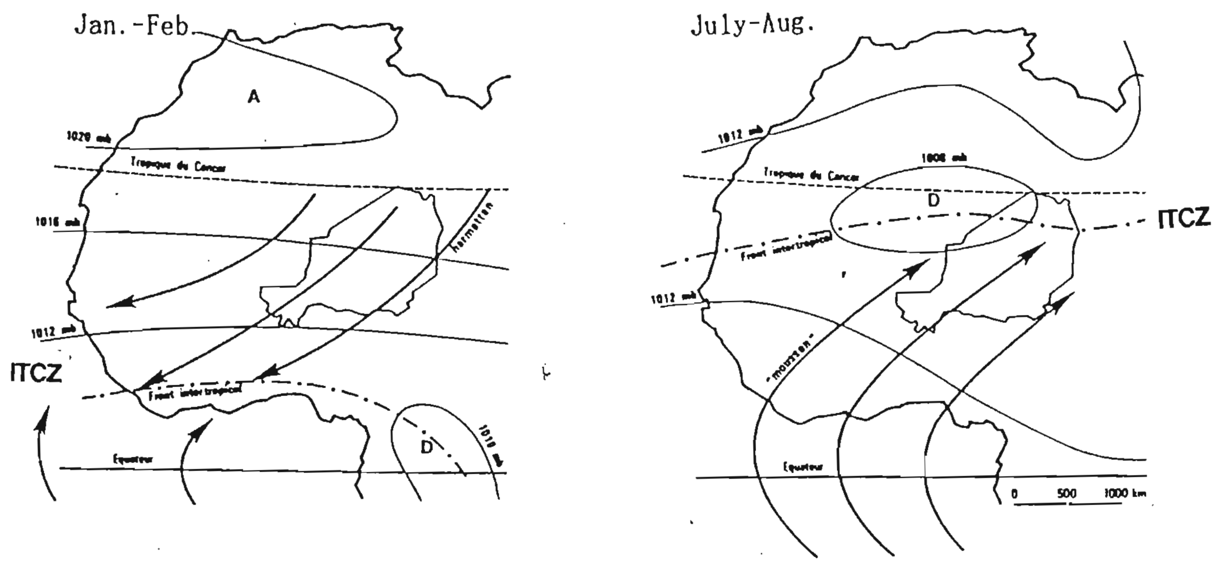


Fig. 2-5 Change of air mass diposition by the season in the west Africa
(after les Jeune Afrique, atlas du Niger, 1980)

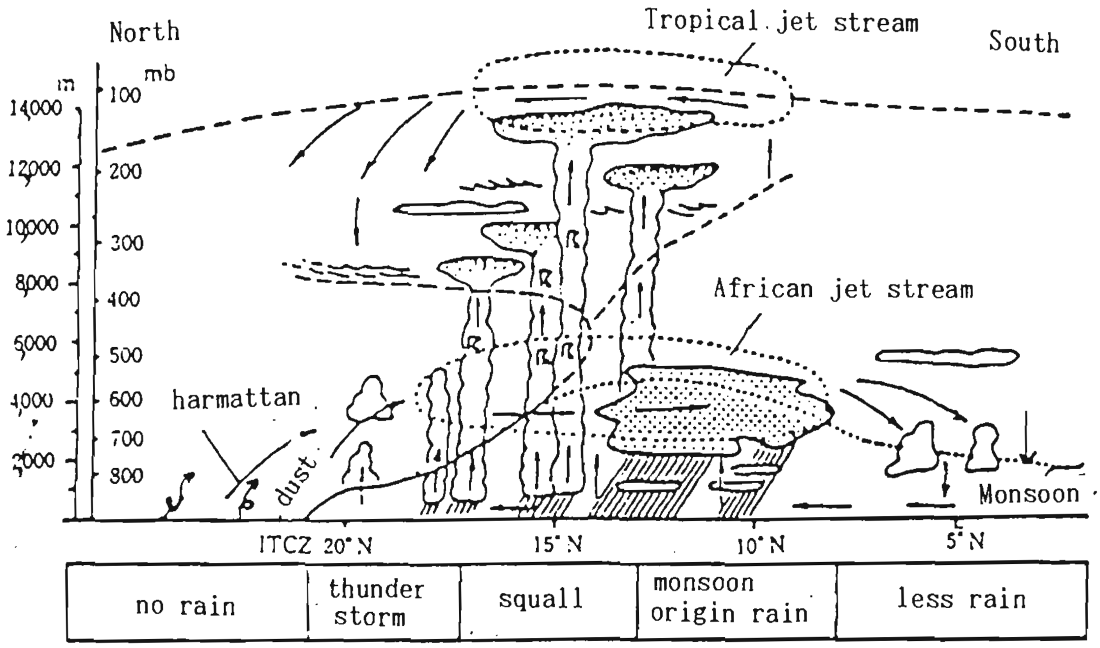


Fig. 2-**6** Atmospheric system and rainfall zone in west Africa, (August)
(after Kadomura et. al. 1992)

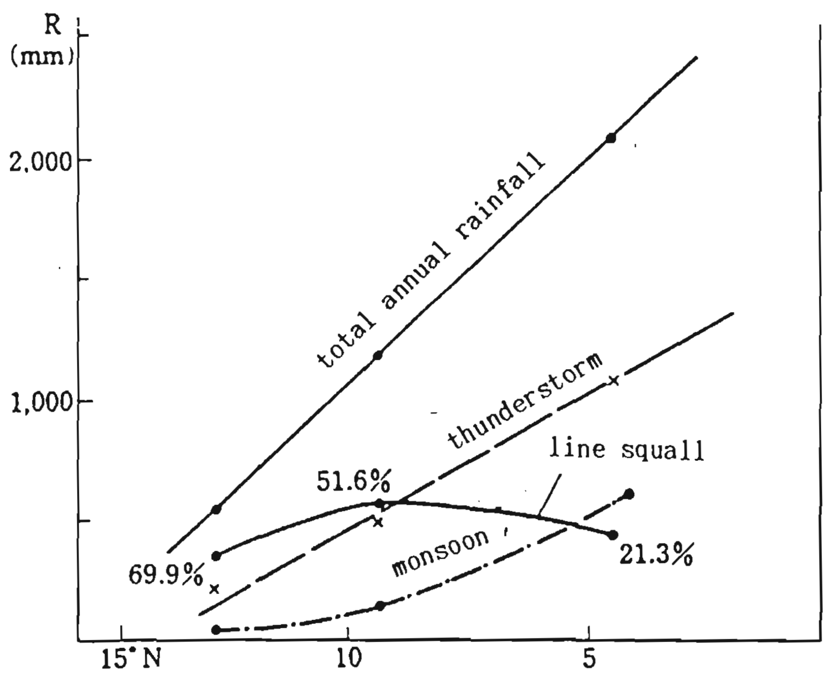


Fig. 2-**7** Separate contribution of line squalls, thunderstorms and the monsoon to the total rainfall in Nigeria (after Omotosho, 1985)

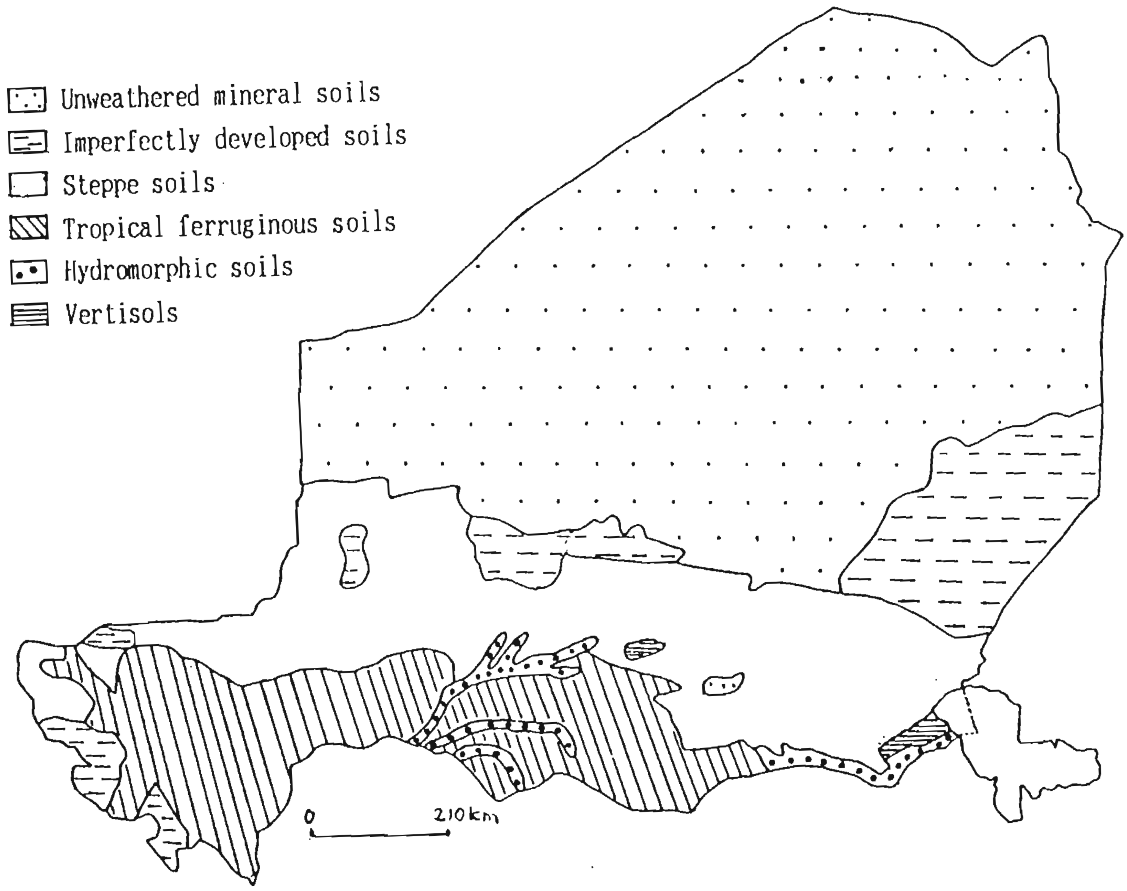


Fig. 2-8 Soil map of Niger

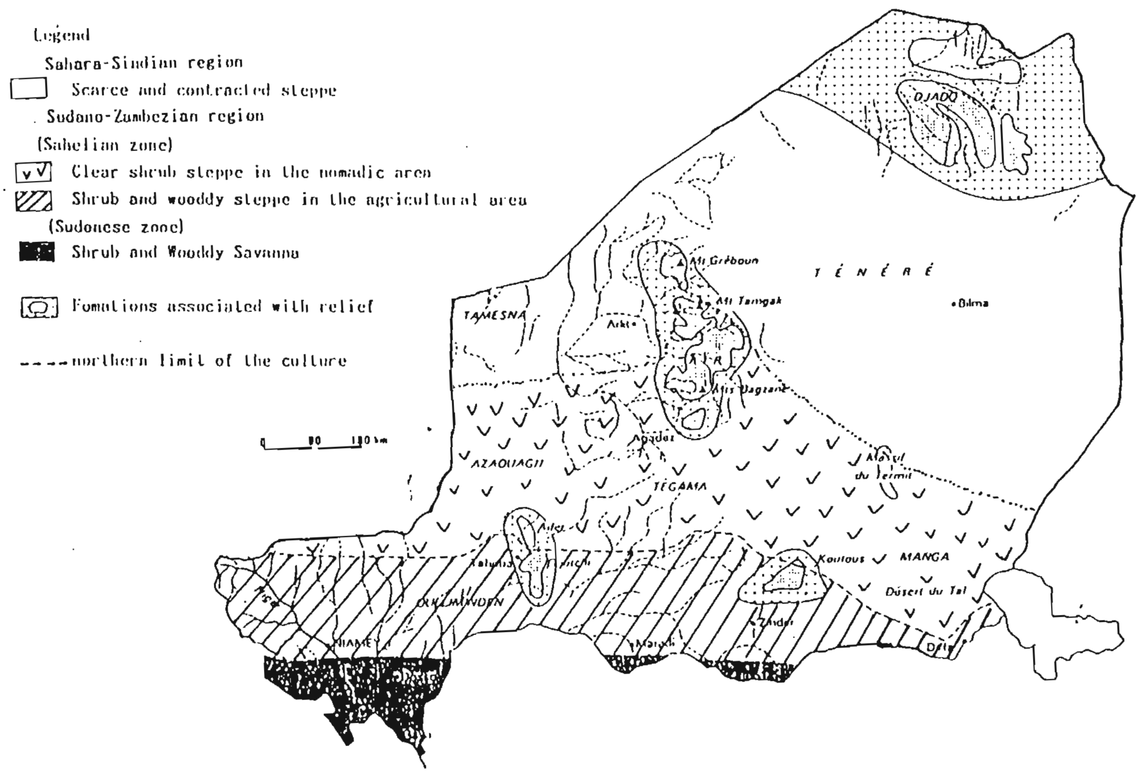


Fig. 2-9 Vegetation map of Niger

Table 2-1. Evolution of population in Niger
(after les Jeune Africa, 1980 and Tierno, 1991)

year	Population (000 habitants)
1905	1.075
1920	1.740
1930	1.860
1940	2.070
1950	2.400
1960	2.950
1970	4.024
1977	5.098
1988	7.248

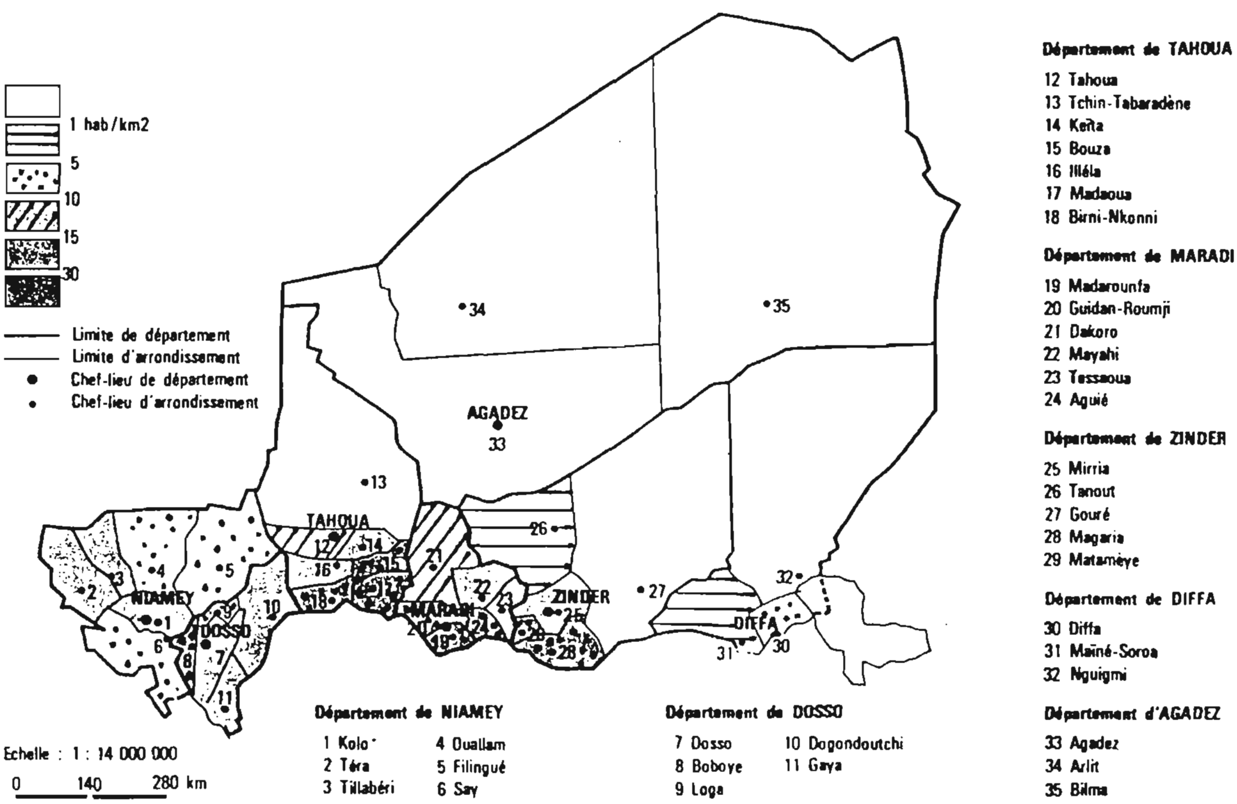


Fig. **2-10** Population density in districts (1977)
(after les Jeune Afrique, atlas du Niger, 1980)

Table 2-2. Main agricultural products
(after FAO, 1985)

Crop	Area (1000ha)	Production (1000ton)	Yield (kg/ha)
millet	3162.7	1449.9	458
sorghum	1141.2	328.8	288
cowpea	1566.3	115.4	74
groundnuts	29.8	8.5	285
banbarabeans	7.3	3.3	453
cassava	13.8	161.5	11700
cotton	5.5	4.4	798
rice	20.0	56.1	2803

(FAO, 1985)

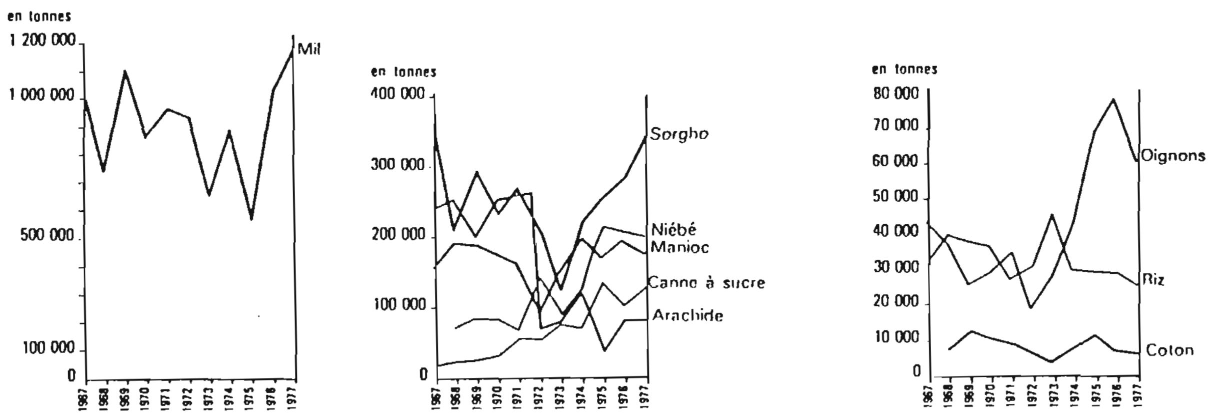


Fig. **2-11** Evolution of the main agricultural products
(after les Jeune Afrique, atlas du Niger, 1980)

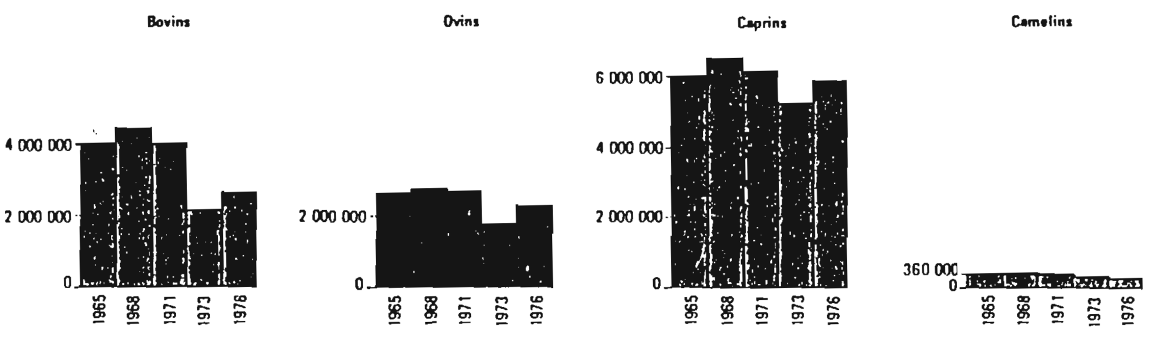


Fig. **2-12** Evolution of the number of livestock
(after les Jeune Afrique, atlas du Niger, 1980)

3. Soil survey

3-1 Presentation of the studied area

3-1-1 Location and population

HAPEX-SAHEL Project (Hydrologic Atmospheric Pilot Experiment in the Sahel) was planed by ORSTOM and other research institutes in France. Its purpose was to study the process of evaporation as well as the related water and energy balance with a view towards parameterizing regional-scale fluxes, and to study the utility of remotely-sensed data inversion methods in this context (Hoepffner et. al., 1990). The project area covers a square between 13 -14°N and 2 - 3°E. Our studied area is the central experimental site of the project, 70km far from Niamey as shown in Fig. 3-1. It covers a quadrangle of 20km by 20km. Banizoumbou is one of central villages in the studied area as shown in Fig 3-2. The local population is mainly Zarma people, who makes a living by agriculture. Apart from the village, livestock breeders live independently. Most of them are Peul people. They cultivate millet at the same time.

3-1-2. Geology

The studied area was considered to be enough representative of the land system of Continental terminal in the project area (Courault D. et. al., 1990). The land system is a combination of the plateaux and the dried valleys. Continental terminal is the continental sediment layers formed by the end of Pliocene. It is distinguished into three types as follows (Ambouta,1984):

Ct1 : Series of siderolith characterized by ferruginous clay, fine sand of non-used quartz.

Ct2 : Series of sandy clay with lignite, characterized by well-soated sand of crushed quartz. It overlaies Ct1.

Ct3 : Series of clayey sandy rock of the middle part of Niger basin. It is a mixture of kaolinitic clay including the used quartz and sandy rock with various colors.

The HAPEX-SAHEL Project area is mainly on Ct 3 (cf. Fig. 2-2).

3-1-3 Soil type

The soil map of the southern Niger with a scale of 1/500,000 by Gavaud and Boulet (Gavaud and Boulet, 1966) is only available in the studied area. Fig. 3-3 is the soil map of HAPEX-SAHEL Project area. Soils on the residual plateaux were described as "sols peu évolués d'érosion, sols régiques, faciès ferrugineux, famille sur placage sablo-argileux sur dalle localment ferruginisée (class 5)". The valley zone was described as "sols ferrugineux tropicaux peu lessivés évolués, toposéquence des vallées sur formation sableuse du moyen Niger (class 4)".

One of the purpose of this study is to understand the toposequence of the valleys in detail, and characterize it with a local scale.

3-1-4 Climate

The studied area belongs to the Sudano-Sahelian zone. The annual precipitation is between 500 to 600mm (Fig. 2-4 Les Jeune afrique ed., 1980). The data considered for the isohyet are unknown. According to the agro-ecological zonation study by Hagen et. al. (Hagen et. al., 1986), it is between 450 to 500mm as shown in Fig. 3-4. The data considered here were from 1968 to 1984. Since the end of 1960s, the tendency of less rainfall has been continued. (Fig. 3-5).

The climatological data at Banizoumbou in 1991 in the studied area is shown in Table 3-1 (Monteny,1992). The annual rainfall was 499mm from April to October. the rainfall distribution in the cropping season is shown in Fig. 3-6.

3-1-5 Vegetation

The observation of vegetation related to the toposequence in the studied area was carried out by Courault et. al. (Courault, D. et. al., 1990). The tiger bush on the plateaux is composed of Combretum micranthum, Combretum nigrican, Acacia ataxacantam, Guiera senegalensis, etc.. On the hill-foot slope, Guiera senegalensis as a fallow bush, is dominant associated with annual herbaceous species such as Zornia glochidiata, Eragrostis tremula. At the lowland, according the relief the ligneous vegetation is densely distributed locally. They are Guiera senegalensis, Bocia angustifolia, Combretum micranthum, etc.. with herbaceous species such as Eragrostis sp., Aristida sp., and Zornia sp..

3-1-6 Land use

The studied area is an agricultural zone associated with livestock breeding. Agriculture is done mainly by Zarma people, who are dominant in this area. The agricultural system is a shifting cultivation on sandy soils. The cassava gardens are made where water is expected even in the dry season. Sorghum cropping is very strict in the area due to less rainfall for that. Fallows are grazing zones for animals at the same time. Livestock breeding in this area is classified into four (Tierno, 1991):

"Farmer-livestock breeder"

"Transhumant"

"Farmer-transhumant"

"Livestock breeder in a strict meaning"

Peul people, who live in the studied area, belong to "Farmer-livestock breeder".

3-1-7 Purpose of the soil survey

The purpose of the soil survey is to characterize the land system of Continental terminal 3, considering relationships among geomorphological type, soil type, land quality and land use. And the results are combined with that of remote sensing analysis.

3-2 Material and method

3-2-1 Material for photo-interpretation

In order to make geomorphological unit map, the photo-interpretation was conducted. The air-born photographs used here were:

75 NIG 40/600 No 2684-2688, No 2764-2769 by IGN, France.

They were taken in 1975 with a scale of 62,500. The studied area is presented by the combined photographs as shown in Plate 1.

3-2-2 Drawing a geomorphological unit map

A stereoscopic observation of the air-born photographs was carried out to distinguish geomorphological unit. Delimitation of the units was done by tracing a changing position of slope angle. It was checked by the on-site research. Some geomorphological units were sometimes integrated for better recognition of the structure of the land system. The geomorphological unit map was made by the combination of four air-born photographs. The map was numerized by a digitizer to integrate it in the geomorphological information system (GIS) which was called SAVANE developed by ORSTOM, France.

3-2-3 Method of the soil survey

The soil survey was carried out in order to know the relationship between soil and geomorphological types. It was done along transects which acrossed the major dried valleys. Total number of transect was 24. The soil pits were digged and surveyed on the main geomorphological units and transitinal points. The total number of soil pit was 160. Some transects were intensively surveyed, and the others were roughly done only to confirm the soil type.

The description of profile was done by a Japanese method (Soil Survey Method Editorial Commission, 1978), which is almost same with FAO method (FAO, 1977).

3-2-4 Soil analysis

The soil samples of the representative soil profile were taken and analyzed. The representative soil profile does not have a statistical meaning here, and it was chosen by the author's judgement.

(Disturbed soil sample)

The disturbed soil samples taken from each horizon were dried in the air, crushed calmly, and passed through a sieve of 2mm. The items of analysis and their method were as follows.

a) pH (H_2O)

The 12.5ml of water was added to 5g of air-dried sample (soil water ratio; 1:2.5). After standing a few hours shaking sometimes, pH of suspension was measured with a glass electrode, agitating slowly by a magnetic agitator (ORSTOM, 1970).

b) pH(KCL)

After measuring the pH(H_2O), 0.95g of KCl was added. After shaking for a few minutes, pH was measured with the same way as pH(H_2O). The concentration of the solution corresponds to 1N KCl.

c) EC (Electric conductivity), (μS/cm)

25ml of water was added to 5g of air-dried soil. After shaking for 1 hour, it was centrifuged, then decanted. EC of the surpernatant was measured with a glass electrode. The results was converted to the value at 25° C.

d) Exchangeable cations, (me/100g)

30ml of reagent of 1M of $BaCl_2$-triethanolamin (pH8.1) was added to 2.5g of air-dried soil. After shaking for 1 hour, it was centrifuged, and then filtered. The extraction process was repeated for three times. After messing up the filtrate to 100ml, the concentrations of Ca and Mg were determined by atomic absorption, and those of K and Na were done by flame photometry (ISO, 1991).

e) Active acidity, (me/100g)

20ml of 1N KCl solution was added to 2g of air-dried soil (soil solution ratio; 1:10). After shaking for 10minutes, it was filtered. 15ml of water was added to 10 ml of filtrate. Then, it was titrated up to pH 8.5 with 0.01N NaOH, by a titrator (TACSSEL, PROCESSEUR 2) (IBSRAM, 1988).

f) ECEC (Effective cation exchange capacity) (me/100g)

As CEC was not available, ECEC was calculated by the following formula;

ECEC = Active acidity + Total exchangeable cation

g) Available phosphate, (mgP_2O_5/kg)

It was measured by OLSEN DABIN method. The air-dried sample was crushed and passed through a sieve of 0.2mm at first. 50ml of reagent for extraction was added to 1g of soil. After shaking for 1 hour, it was centrifuged (5 mins, 4000 r/mn). After adding a spoonful of pure active carbon, it was centrifuged again. 23 drops of 1N H_2SO_4 was carefully added to 20ml of extractant in order to destroy $NaHCO_3$ in it. Then, the concentration of phosphate was determined colorimetrically (method of Murphy and Riley).

h) Total nitrogen and carbon, (%)

More than 5g of air-dried sample was crushed and passed through a sieve of 0.2mm. About 1.5g of sample was precisely weighed and the concentrations of nitrogen and carbon were determined by dry combustion method, using Elemental analyzer (CHN-600, Elemental Analyzer for macrosamples, System 785-500, LECO corporation).

i) Particle size distribution, (%)

The pipet method by ORSTOM was used (ORSTOM, 1970). 20g of air-dried sample was treated on the heat plate by 30ml to 50ml of H_2O_2 (30%) to destroy the organic matter. After that, 300cm of water was added to it, then it was dispersed by sodium pyrophosphate (4%) shaking for a few hours. After messing it up to 1000ml, clay + silt fraction, then clay fraction were determined by pipet method. After washing out the fine particles, the fraction more than 0.05mm in size was dried, sieved, and then the each fraction was weighed. The particle size class used here is defined as follows.

2.00 - 0.20 mm	Coarse sand
0.20 - 0.05 mm	Fine sand
0.05 - 0.02 mm	Coarse silt
0.02 - 0.002mm	Fine silt
less than 0.002mm	Clay

The weight per 100g of each fraction was recalculated so that the sum of the weight of each fraction could be indicated by per cent.

(Undisturbed core sample)

Undisturbed core samples were taken at the representative sandy profiles. The core is 5cm in diameter, 5.1cm in height, $100cm^3$ in volume. The items of analysis and their method were as follows.

a) Saturated hydraulic conductivity, (cm/s)

After measuring the weight, the core sample was saturated with water for one night. Then, the saturated hydraulic conductivity was measured by fixed water level method, using the soil permeability measuring apparatus (Fig. 3-7) (DAIKI RIKA, DIK-4000).

The hydraulic conductivity was calculated as follows.

$$K = (L * Q) / (H * L * t),$$

where, H= Head difference (7cm)

L: Length of sample (5.1cm)

Q: Quantity of flow for time "t"

A: Area of cross section of sample ($19.6cm^2$)

t: time for measuring (120sec)

K: Saturated hydraulic conductivity (cm/s)

The temperature during the measument was between 24°C to 26.5°C.

b) pF-water content curve, (volumetric %)

After measuring the saturated hydraulic conductivity, the water content was measured at each pF condition using a pressure plate. As for water content at pF 0, It was measured before measurement of the saturated hydraulic conductivity. pF measured were 0.0, 1.8, 2.0, 2.2, 2.4, 2.6, 2.8, 3.0, and 3.1. As for the water content at pF 4.2, because of the limitation of the pressure plate, it was measured in the other apparatus using disturbed sample. The core used here was 2.7cm in diameter, 1cm in height.

c) Apparent density, (g/cm^3)

After measuring water content at pF 3.1, the sample was dried at 105 C in the oven for one night, then weighed to calculate the apparent density.

3-2-5 Method of soil mapping

After drawing geomorphological map, the soil map was made. It was performed utilizing the correspondence between the geomorphological type and soil type. Their identification was realized through soil survey and photo-interpretation. They are defined by the author considering the local situation, therefore, they are different from the general classification.

Since each geomorphological unit has the corresponding soil type(s), the soil unit could be considered as an attribute of geomorphological unit. Then, each geomorphological unit can be converted automatically to soil unit. Other thematic maps were also made by the same way.

The outline of the soil survey is shown in Fig 3-8, including other items studied.

3-3 Result and discussion on the on-site research

3-3-1 Recognition of geomorphological unit

The stereoscopic observation of air-born photographs and the soil survey enabled to recognize and distinguish geomorphological unit. The Thewy are as follows:

1. Tertiary residual plateau (Ct3)
    1a) flat plateau
    1b) gently-sloped plateau
    1c) sand mound
2. Hill-foot slope
    2a) moderate slope (about 2-4%)
    2b) gentle slope (about less than 2%)
3. Pediplain
    3a) with eroded surface
    3b) without eroded surface
4. Slope from pediplain to alluvial terrace
    4a) steep slope with eroded surface
    4b) steep slope without eroded surface
    4c) gentle slope
5. alluvial terrace
    5) no sub-division
6. Valley form
    6a) V-type valley
    6b) temporal water way with gentle slope
    6c) almost flat valley
7. Sand deposition form

7a) sand deposition form on the pediplain

7b) totally-sand covered undulating land form

7c) cordon form on the plateau

8. Depression form

8) no subdivision

9. Concave small basin

9) no subdivision

10. Inserberg

10) no subdivision

The pediplain was subdivided into two according to the surface feature, which reflects the different soil type. The geomorphological unit map is shown in Fig. 3-9.

In order to understand the geomorphological sequence and the corresponding soil types, the representative transects surveyed are described below. The location of transects is shown in Fig. 3-9.

3-3-2 Toposequence of some transects

T-1) (Fig. 3-10) This transect was most intensively surveyed. It was mainly composed of a plateau, a hill-foot slope, a pediplain and a valley form (temporal water way). The plateau of Ct3 had shallow clayey reddish brown soils on the ferruginous crust. The hill-foot slope had shallow reddish brown sandy soils. The upper part of the slope was convex form (4-5%) and main part have straight slope (3%). Then, the lower part had gentle slope (less than 2%) to reach the pediplain. The upper layer of the lower part of the lsope contained gravels and distinct transition, which suggest the colluvial deposition. The pediplain had moderately-deep bright reddish brown sandy soils on the clayey layer. Between them, there existed a sandy nodule layer.

At the pediplain of the west side, the sandy hard pan existed in place of the nodule layer. Its thickness was about 1.5m at the point of a) of Fig. 3-10 after Lamotte (Lammote, 1992). This side keeps a plane form and the dissection of the pediplain did not develop. While a stronger dissection at the east side resulted to the small mound-like land form, which makes slope in the pediplain.

The hill-foot slope at the west side was small in width. The small isolated remnant of the plateau can be called "inserberg", which had a stony surface (lithosols).

T-3) (Fig.3-11) This transect was composed of a plateaux, hill-foot slopes, pediplains, and then a dried V-type valley with an alluvial terrace. Moreover, an eroded steep slope also appeared at the north side, and it had reddish brown clayey soils with thin ferruginous crust. At the south side of the transect, the pediplain was undulating, and could be distinguished in two levels. The aeolian sand covered it deeply and the auger did not reach the underlayer (more than 3m).

On the alluvial terrace, deep white sandy soils were observed. The fine particle which gives reddish color was almost completely washed out and sand content is more than 90%. At the same time, the cemented horizon was also observed in the deep horizon (3-44). The appearance of the cemented horizon was very variable in space. It had hydromorphological features such as mottles along root pores. Near the transect, the reddish brown sandy soils with eroded surface also appeared along the valley. It may be a remnant of aeolian sandy soils (see Plate 2-3).

T-6) (Fig. 3-12) It didn't have a distinct pediplain. Then, it was composed of plateaux, and hill-foot slopes. The transition pattern between the plateau and hill-foot slope was different by side. At the east side, the plateau changed gradually to the hill-foot slope, it didn't have a distinct border such as a scarp of T-1. At the T-6-1, the ferruginous stone appeared at a shallow depth, and mottled clayey sandy rock appeared under it (Ct3?). The surface was strongly eroded. At the west side, aeolian sands covered more deeply without a distinct eroded surface, and small dune forms were observed.

On the sand mound on the plateau, the reddish brown sandy soil was observed with clayey sandy hard pan (T-6-6). It might have resulted from strong lessivage of iron materials in the ancient humid period. Or it may be alterites of Ct3.

T-5) (Fig. 3-13) In this transect, the grand sand deposition form on the pediplain was remarkable. At T-5-4, the auger didn't reach the underlayer (more than 450cm). On the sandy hill, there is a village named Tondi Kiboro. After the sandy hill, the steep slope (more than 6%) went down to the alluvial terrace. This terrace had deep white sandy soils, which was rich in coarse sand.

T-12) (Fig. 3-14) This transect was characterized by a long pediplain with deep reddish brown sandy soils at the west side, and existence of a small lower alluvial terrace. The lower alluvial terrace had deep white fine sandy soils. The sand was well soated. For example, The soil from the sand from 150cm in depth is composed of 85% of fine sand (T-12-5). This pit had a cemented calcium-accumulated horizon. At the east side, two level pediplains were distinguished and the land surface was somehow eroded, and mottled clayey soils appeared under the sand cover (T-12-8, T-12-9). At T-12-8, the sandy nodule horizon interfered between them.

The transition between the plateaux and hill-foot slopes was different by side. At the west side, the transition was distinct, but, did not have a scarp. At the east side, on the contrary, they were well distinguished by the scarp and the gully.

T-17) (Fig. 3-15) This transect did not have a pediplain, but there was an alluvial terrace-like plane land form associated with a narrow dried V-type valley. The transition pattern between the plateaux and the hill-foot slopes were similar to those of T-6.

T-18) (Fig. 3-16) This transect was characterized by a seriously-eroded pediplain, and an alluvial terrace. At the east side, the pediplain had a cemented sandy nodule layer (T-18-2). Near T-18-3, the grand continuous bare land associated with ferruginous stony surface existed. At the west side, the pediplain was undulating, and looked like two levels. The sand cover was less than 1m (T-18-8, T-18-9), and the surface was eroded sporadically.

The alluvial terrace didn't have white sandy soils, but in the deeper horizon, coarse sandy horizon which is different in particle size from aeolian sand, was observed (T-18-5). It suggests that the terrace form may have originally resulted from alluvial sedimentation, then the recent aeolian sand may have covered it.

3-3-3 River basin type and geomorphological formation

Thanks to the soil survey and the photo-interpretation, several river basin types in the studied area could be distinguished considering the existence or lack of pediplain or alluvial terrace.

Pediplain + alluvial terrace + dried valley (T-3, 5, 12, 18)

Pediplain + no alluvial terrace + temporal water way (T-1)

No pediplain + alluvial terrace + dried valley (T-17)

No pediplain + no alluvial terrace (T-6)

The existence of the pediplain or the alluvial terrace may be related to the evolution of development of river system. After the sedimentation of the Ct3, the dissection of process started. and formed pediplain. The existence of several levels of pediplain suggests the several cycles of geomorphological formation in the past. The time of deposition of aeolian sand is considered about 40,000 yBP. (Gavaud,1977) or 12,000 - 20,000 yBP. (Kadomura et. al., 1991). The existence of the sandy nodule layer (sometimes cemented) under the sand deposits suggests the strong lessivage of iron materials in the past.

The original geomorphology before sand deposition may have been modified, but still clear. Then, we can imagine the ancient geomorphology and land surface under the sand cover. The buried ferruginous stony layer, mottled clayey soil, mottled sandy rock may be ancient surfaces even though they were somehow altered. The alluvial terrace is considered as a result of alluvial sedimentation in the recent humid period(Gavaud,1977).

3-3-4. Factors for soil type definition

The soil type was defined on the process of the soil survey. And, the factors to distinguish it were considered as follows:

a) Existence of sand cover
  - sand depth
  - sand color at sub- surface horizon
  - type of underlayer of sand cover

b) Lack of sand cover (Clayey soil in general)
  - soil color

Their importance for soil characteristics are as follows

a) Sand cover

Sand cover (aeolian, alluvial) is the most important factor for the soil characteristics such as erodibility, rain water dynamics, water retention, and agricultural availability, etc..

The soil texture of sand cover varies from sand to loamy sand. The results of particle size distribution analysis were sometimes different with the soil texture on the site by hand judgement. It may have resulted from the strong impression of sand particle. As for the soil classification of soil type, the results of soil texture on the site was used. And, "Sandy soil" is defined here as "sand or loamy sandy soil by hand judgement". And, "Clayey soil" is defined as "heavier soil more than sandy loam by hand judgement, (abbreviation, s)".

b) Sand depth

The sand depth varies with geomorphological position. According to the soil survey, the sand depth on the pediplain were not deep (often less than 2m), when the land had erosion surfaces. But, when it did not have it, it was deep (more than 2m). Generally, when sand cover is deep, the soil did not show serious erosion surface except for that on slope.

The class used here to distinguish the sand depth is as follows:

deep	(more than 2m)	abbreviation	:(d)
moderately-deep	(1 to 2m)		:(m)
shallow	(less than 1m)		:(s)

It is difficult to extrapolate and generalize the sand depth in any units with a sufficient accuracy. Therefore, it is a rough indication.

c) Sand color at subsurface horizon

Generally, A horizons were decolored by leaching, and slightly enriched in the organic matter. The difference of soil color was remarkable at the subsurface horizon. The reddish brown color (2.5YR4/8 in wet condition in many cases) were observed on hill-foot slopes, on the sand mounds on the plateaux. As these soils contained a little of fine particle in the A horizon, they often had erosion crusts when the A horizon was compacted probably by run-off and raindrop. If the A horizon is removed the serious land degradation may happen due to more higher fine particle content in the subsurface horizon. In fact, the sandy soils just under scarps had a higher clay content, and the top of the slope was strongly eroded (see Plate 2-a).

The moderately-deep sandy soils on the pediplain also had rubefaction (5YR or 7.5YR). It could also form erosion crust. When the sand was deep, the sand color became same with that of the hill-foot slope (2.5YR).

The white sandy soils (10YR in wet condition) on the alluvial terrace were almost completely decolorized. Then, they seemed very permeable, and the erosion crust was not observed.

On the "cordon" form at the north-eastern part of the studied area, the bright brown (7.5YR in wet condition) sandy soils were observed. They may be more recent deposits.

The color of subsurface horizon may be a important indicator for soil characterization parent materials, and soil formation process. According to the observation of the soil profiles, the soil color was distinguished as follows.

reddish brown	(reddish more than 2.5YR)	(R)
bright reddish brown	(5YR sometimes 7.5YR)	(B)
white	(10YR)	(W)
bright brown	(7.5YR)	(Bb)

The color is that in the humid condition. Using the above factors, we indicated the soil type such as;

deep reddish brown sandy soil	=	dRs
deep bright brown sandy soil	=	dBbs

d) Soil color of clayey soil

When clayey soils appear on the surface, the land is generally very degraded with bare land except for that on the depression form (unit 8) where the water accumulates.

Clayey soils on the plateaux were generally reddish brown to bright reddish brown, but the brown clayey soils were observed as well. Clayey soils on the pediplain were reddish brown to bright reddish brown.

Then, the color of clayey soil was roughly classified into two: reddish brown and brown.

e) Underlayer

When the sand cover is shallow or moderately deep, the underlayer may influence soil formation and soil function. They often appeared on the eroded pediplains. Their types were as follows.

reddish to orange sandy hard pan (T-1-12, T-6-6, T-17-4)

mottled clayey soil (T-12-9, T-18-7 and 9)

sandy nodule + mottled clayey soil (T-1-6, T-12-8)

ferruginous stony layer or thin ferruginous crust (T-6-5, T-17-1, T-17-5)

As other features of underlayer, the sandy hard pan including the sandy nodules were observed.

From the pedogenetical point of view, these underlayers may have been formed as follows, considering geomorphological position and the past climatic change.

(**reddish to orange sandy hard pan**): It may have been formed by accumulation of iron materials in the deeper horizon associated with poor drainage condition. The plane land form with the poor drainage system may have allowed accumulation of iron (hydro)oxide under the sandy layer. As for the cemented sandy layer at T-6-6, and T-17-4, they may be weathered Ct3. We don't discuss it further here.

(**sandy nodule + mottled clayey soils**): The sandy nodule is hard and very irregular in form. It may have been formed under the better condition drainage condition than the above sandy cemented layer. Even if the clayey soil had existed under the sand deposits, when the drainage system by dissection had formed, it may have been possible (T-12-8, T-1-6). There also existed the transitional feature between cemented sandy horizon and sandy nodule as shown in Plate 9-d.

(**sandy hard layer enclosing sandy nodule**): It suggests different stage of accumulation of iron materials with different intensity, for nodule formation and for hard pan formation.

(**clayey soils**): When the sandy nodules or sandy hard pan was not formed, the the ancient clayey soils appears just under the sandy layer with a transitional horizon. The various soil color reflects the drainage condition (T-18-8, T-12-9).

(**ferruginous layer**): They appeared at the fringe of plateaux, transition between the hill-foot slope and the pediplain, and so on. Their depth is variable by topographical position. They may be colluvial destroyed ferruginous crust fragments which were formed on the process of the retreat of the scarp. Some ferruginous layer between the hill-foot slope and the pediplain may include the fragments of the ferruginous layer which was formed after the sand deposits. Under the ferruginous layer the yellow sandy rock generally appeared. It may be the alterite of the Ct3(?). Sometimes the thin ferruginous platy horizon was observed. Its formation process is unknown.

The distribution of the above underlayers is not well known. But, the rough correspondence with geomorphology is as follows.

1)Plateau clayey soil with ferruginous crust
cemented sandy layer (Ct3?)
2)hill-foot slope reddish brown clayey layer
ferruginous stone or ferruginous layer
3)pediplain nodule layer with mottled clayey layer
thin ferruginous layer with yellow sandy rock (Ct3?)
cemented sandy layer
4) alluvial terrace unknown

In this study, influences of the subsurface horizon on soil function can not be cleared. From the hydrological point of view, their permeability, water retention characteristics may be important. If the sand cover is deep, Its importance reduces since the sandy cover may have the enough water holding capacity. On the slope, the rain water redistribution by surface run-off and through flow may happen. In this case the characteristics of the underlayer in the deep sand cover may influence water dynamics.

For classifying soil type, the underlayer was not considered as its spatial distribution is not known enough.

3-3-5 Geomorphological mapping units and the corresponding soil type and major land occupation

Using the criteria for classifying of soil type as mentioned above, the soil type was defined. And the mapping unit was composed of one soil type or several soil type (association). Their relationship is shown in Table 3-2 including main land occupation,. In the table, soil mapping unit 4) is considered to be toposequence on slope. In case of 5), as the alluvial terrace includes alluvial terrace and lower part of the slope with aeolian sand deposits, the soil mapping unit was considered as a complex of two different soil types.

3-3-6 Drawing soil map

Using a geographical information system(GIS), the geomorphological unit map was converted to the soil map as shown in Fig. 3-17. Even if the soil type is same, the soil function may be different by geomorphological unit. Then, the limit of the geomorphological unit was left.

3-3-7 Characteristics of soil type and sand distribution

The results of the geomorphological unit map and the soil map show some variation in the studied area. The variation of river basin type (or toposequence of transect) was already mentioned above. As the soil type is mainly defined by the situation of sand cover, soil type distribution and sand deposition pattern are strongly related. Their characteristics were as follows:
a) The eastern part of the map was classified as totally-sand-covered unit. This part could not be separated geomorphologically because of entire sand cover. The soil type was deep reddish brown sandy soils. They may be the remnants of the ancient dune development.

b) The transition pattern from a plateau to a hill-foot slope had two types. One type was a stony scarp one, which distinguished clearly the two units. The other was a vague transition because of sand cover. The appearance of two different types may have resulted from two factors: one is the longitude, and the other is the direction of hill-foot slope. The sand deposits increase towards the east, and the appearance of scarp became limited. Towards the west, more scarps appeared. In the case of T-6 and T-17, when the scarp did not develop, the sand cover was shallower at the west fringe of the plateau than that at the east fringe. The direction of wind must be influenced such situations. It means the wind from the east blow down to the pediplain, and then drift the sand on the west side. The distribution of sand mounds on the plateaux of T-6 supports such an idea.

c) The alluvial terraces were always associated with V-type valleys. It may include washed sand deposits from the background slope. The east dried river did not develop a distinct alluvial terraces. It started from the north-eastern part of the studied area. On the contrary, the west river was developed extensively associated with alluvial terraces from the outside of the studied area.

d) The major soil types are;

1. shallow reddish brown clayey soil on the plateaux (sRc)

2. deep or moderately-deep (bright) reddish brown sandy soils on aeolian sand deposits of hill-foot slope, pediplain, totally-sand-covered undulating land form.

3. deep white sandy soils along the dried river

e) The shallow or moderately-deep sand deposits on the pediplain appeared at the west side of the plateaux, and the soil surface was often eroded(T-1-6, T-12-8, T-18-3 and so on). It may be the result of strong wind blowing down from the east. It may have affected both sand deposition and wind erosion in the past and even today. For example, at the transition area between the hill-foot slope and the pediplain at T-1, the bare eroded land was observed with sporadic small sand mound (see Plate 4-c). If it had not been for vegetation, the loose sand may not be able to remain at this position. At the east side of T-18, The land surface was widely and seriously eroded.

e) As mentioned above, the existence of vegetation is very important for sand to remain or to catch sand. Such herbaceous vegetation with small sand mounds was often observed where the erosion was in progress.

3-3-8 Other thematic maps

According to the relationship between geomorphological type and its characteristics, the other thematic maps were made automatically using GIS (Fig.3-18 to 3-21). They facilitate to recognize the distribution of each characteristics. But, as they show only the rough tendency, they should be referred critically. The characteristics of each map are as follows.

Main geomorphological unit map (Fig. 3-18): It may be useful to understand pattern of the land system.

Surface texture map (Fig. 3-19): It shows that the most part of the studied area is covered by sand. And the residual plateaux (clayey-skeleton) is distinguished clearly.

Soil material map (Fig. 3-20): It distinguished main three soil materials. And the river system is well recognized (alluvial sand). As for class 4, although colluvial sediment was considered as a parent materials from geomorphological position (depression form), it is not sure.

Sand depth map (Fig. 3-21): It shows that deep sandy area occupies a considerable portion of the studied area. They are mainly used for millet culture. It will be mentioned below.

3-3-9 Land occupation and agriculture

The land occupation observation enabled us to relate it to geomorphological unit (Table 3-2). Their characteristics are as follows.

1) The plateaux were characterized by tiger bush vegetation. The tiger bush is maintained by redistribution of rain water (Ambouta, 1984). They were sometimes dried or cut. It is said that after cutting, their recovery is very difficult. When sand mounds exist, the distribution of the pattern of tiger bush is disturbed. And the fringe of the sand mound was often characterized by a denser bush. The rain water redistribution from the sand mound may contribute to its growth.

2) The hill-foot slopes, the pediplains, alluvial terraces and valleys were occupied by alternation of fallows and millet fields. Ba (Ba, 1991) distinguished the millet field including the fallow from the natural vegetation by artificial line (border of field) and brightness on the air-born photographs. Such natural vegetation was often associated with eroded land, which is difficult to use for millet.

3) When the clayey soil appeared on the surface, the land was seriously eroded except for the depression form (unit 8). The depression unit was characterized by vigorous ligneous vegetation.

4) The alluvial sandy fan at the end of gully on the hill-foot slope was generally used for millet culture. The millet was generally grown vigorously thanks to the sufficient water supply. At the same time, the nutriment supply also may be expected.

5) The cassava gardens were observed where continuous water supply through the year is expected such as water ways, V-type valleys etc. (see Plate 2-3).

6) The ligneous vegetation on the pediplain existed along drainage system. For example around the T-1, the ligneous vegetation existed along the drainage system around the relief.

7) Around the village, the land was intensively used for millet.

3-3-10 Observation of the land degradation

The situation of the land degradation was observed by the on-site research. The results were as follows:

1) The gullies were often observed along the hill-foot slopes. At the upper part of the slope, the gullies were associated with erosion surface with convex form (Fig. 3-22, and see Plate 5-c). On the middle way, it became deep and sometimes U-type form. At the end of the gully which reaches the pediplain, the transported sands sedimented, and the gully ended. Courault et. al. (Courault et. al., 1990) called the sedimented form "alluvial fan" (see Plate 5-d). It is considered as one of slope formation processes and redistribution of sand at present. The difference of gully form between the upper part and the middle part may have resulted from coherence of soil.

2) The gully was observed on the undulating pediplain and on the slope from pediplain to the valley as well. In this case, from the top of the gully, its side was vertical and the gully form was U-type. It ended when it reached the plane form. The gully near T-3-4 was formed by the strong rainfall a few years ago (see Plate 2-c).

3) On the pediplain, the erosion surfaces were observed when the sand was shallow. Such situation was remarkable at the west side of Wankama (the pediplain which includes T-18-3). They were sometimes associated with gravels and ferruginous stones on the surface. Transition area between hill-foot slope and pediplain around T-1, was seriously eroded, and sometimes ferruginous stones and boulders were also associated. In these cases, the wind blowing down from the plateaux may influence as mentioned before.

4) The erosion surface between the tiger bush on the plateaux were described by Courault et. al. (Courault et. al., 1990). The erosion crust was clearer and whiter than the soil color itself. The gravelly or stony surfaces were often associated. In this case, the surface color became dark reddish brown.

5) The upper part of the hill-foot slope was characterized by reddish brown erosion crust. The reddish gravels and stones were also associated with it. Just under the scarp, kaolinitic reddish brown layer was sometimes appeared. All of them may be resources of fine particle to the sandy soils on the slope.

6) On the pediplain, the lime nodules were sometime associated with erosion area. At the transition area between the hill-foot slope and the pediplain near T-1-2, a small mound of lime nodule was observed associated with the eroded land (see Plate 5-b). The villagers say that the trees were dried

because of the last drought (1984/85). The toposequence across it is shown in Fig. 3-23. It shows that lime nodule appeared at a position of distinct break of the ferruginous stone line, and it was formed in the clayey horizon. Its position may have been suitable for accumulation of solute in the through flow from the slope. And its soil texture may have been more suitable to catch it than sandy texture. The lime nodule was observed just near the T-3-32 as well. In this case, because of lack of sand cover, the steep slope with lime nodule was remarkable.

7) The side of the temporal water way was often eroded strongly (see Plate 2-b). Their surface were characterized by erosion surface. The color of the surface was clearer than soil itself. Even along the V-type valley, when bright reddish brown sandy soil appeared, the surface were eroded at the side of the valley (see Plate 6-d).

8) On the pediplain, the circular erosion surfaces associated with the destroyed termite hill. The distribution of fine particle around them makes erosion crust (Casenave et. al., 1989). The termite activity contributes to movement of fine particle on the surface, which makes erosion surface after destroy of termite. Some of the circular erosion surface on the Plate 2-1 may be those of them. The termite hill was not remarkable on the deep sand.

9) Near the well, the bare lands damaged by animals were observed (see Plate 10-e).

10) An old farmer said that the vegetation on the pediplain was denser with ligneous ones before. Some areas were dried because of the past drought, and the others were cut for farming. It shows that the pediplain has some

values for farming when the sand cover enough deep. At the same time, It is easy to degrade by misuse and shortage of rainfall.

11) On the white sandy soils, the erosion crust was not observed. They may have probably resulted from its plane land form and its less fine particle content.

12) Along the main road on the way from Niamey to the studied area, the bush on the plateaux were lost to some extent. Such a situation seems to be general along the main roads because of its convenience to transport fire woods The motor trucks were collecting the firewood even inside the plateaux. It must be one of reasons of land degradation of the plateaux.

3-4 Result and discussion on the soil analysis

3-4-1 Reddish brown sandy soils (including bright reddish brown sandy soils)

The (bright) reddish brown sandy soils appeared on the aeolian sand deposits. The considerable soil formation process are as follows:

(A horizon); Lessivage of fine particle to B horizon,

Weak melanization by enriching of organic matter

Formation of loose Ap horizon by weeding of the field

Formation of lamellar structure in a fallow by alternation of sand deposition with its compaction (raindrop and run-off) (see Plate 6-a)

(B horizon); Ferrugination,

Concentration of fine particle at the deeper horizon to form hard aggregates

The reddish brown sandy soil is essentially composed of quarts sand and some ferruginous reddish grain, and fine reddish materials are coating the grain and are connecting them. When it is located on a slope, ferrugination is deep, and hematite was formed (Fig.3-19). In this case, the soil color of B horizon is more reddish than 2.5YR. When the ground water exists or through flow concentrates at the lower part of slope, sandy soft nodules are formed at the fringe of capillary water (Boulet, 1992) (see Plate 9-c). And the soil color was often bright yellowish brown (10YR7/6 in wet condition).

Under the alternative climate with a rainy season and a dry season, and when the internal drainage is poor, the accumulation of iron formed a sandy nodule or a hard pan (cemented sandy layer) . They may have happened in the more humid period in the past (Gavaud, 1977).

General characteristics

The general characteristics of the reddish brown sandy soil are summarized in Table 3-3. The results were arranged by surface horizon (A horizon) and the other one (B or BC horizon). The bright reddish brown sandy soils were also integrated with reddish brown sandy soils here because they were not very different in their characteristics.

These soil are characterized by a very low nutriment level. But, A horizon is slightly richer in nutriment than B or BC horizon.

The particle size distribution shows lessivage of A horizon to B horizon.

The characteristics of each soil profile are shown in Table 3-4 to 3-8.

3-4-2 White sandy soil

The white sandy soils appeared on the alluvial terraces. The parent material may be a strongly-washed sand. the sand is essentially composed of quartz. And the reddish ferruginous grain is very few. The sedimentation condition may have been variable according to the position. The soil formation have not developed well because of lack of alterable materials. But, the accumulation layer in the deep horizon was sometimes formed with abrupt transition. They may have resulted from strong lessivage and accumulation of fine materials from the slope. In this case, the hydromorphological features such as mottles was observed. Water percolation formed brown wavy band mottle by separation and accumulation of the colored materials.

General characteristics

Their general characteristics are shown in Table 3-9. They are characterized by a very low nutriment level as well as the reddish brown sandy soils. The deeper horizons vary in cation content as shown in the table (Min., Max. and standard error). The values of Max. are those of the accumulation layers. Their particle size distribution is also very variable with pit. They may be due to the different sedimentation condition. For example, at T-12-5, a distinct accumulation horizon of cation and fine particle in the fine sandy profiles, and it was cemented very hard. This pit was located at a lower alluvial terrace near the dried valley. The fine sand may have sedimented in the very slow flow.

The characteristics of the each profile are shown in Table 3-10 to 3-12.

3-4-3 Clayey soils

The reddish brown clayey soils appeared on the plateaux (Ct3) with the ferruginous crust. The surface was strongly eroded, and the soil contained a lot of ferruginous stones which suggests the past erosional activity. The clayey soils on the pediplain had some variation with color from reddish brown to mottled color(reddish brown, yellow, white).

The characteristics of each profile are shown in Table 3-13 to 3-15. They are poor in exchangeable cation, but slightly higher than sandy soils.

Their clay content is between 24.6 to 50.3%. At 18-8, the surface horizon is sand deposits.

3-4-4 Bright brown sandy soil

They appeared on the cordon form on the north-eastern part of the studied area. Their characteristics are shown in Table 3-16. They are very low in nutriment level as well as the other sandy soils. The fine sand ratio to the coarse sand is 0.96 in average through the profile. They are coarser than reddish brown sand. But, it is similar to that of sand mound on the plateau.

3-4-5 Saturated hydraulic conductivity and pF-water content curve

Their analysis was conducted using the undisturbed core samples of sandy soil.

The pF -water content curves are shown in Fig. 3-24(a-e). And, the main results were arranged with other physical properties (Table 3-17). Fig. 3-24 shows that they had almost the same curve except for the value of pF 0. In the case of sandy soils, on the process of saturation of core samples, the subsidence of soil surface was sometimes observed. It may also affected the humidity at pF 0.

The water content at pF 4.2 was calculated from the results of disturbed soil sample analysis. Their values were situated on the extention of the curves.

The water holding capacity was often considered as a water content from pF1.8 to pF 4.2. They are shown in Table 3-17. And, it was calculated up to 2m or to the lower limit of the sandy layer (Table 3-18). The values show that it has a high water holding capacity thanks to its depth. Fig. 3-24 shows that water is held at lower pF (less than about pF2.5). The water content between pF2.5 and pF 4.2 is sometimes used as an indicator for available water for plant. In the case of sandy soils, the value becomes very small. Payne et. al. got a value of -5.0kPs (pF1.7) as "field capacity" by the field experiment on the sandy soil in Niger. In this study, the value of water holding capacity ranged from 120mm to 273mm. 120mm is the value of sandy layer of 112cm (T-1-6). As far as water holding capacity is concerned, if the sandy layer is enough deep, the sandy soils have a high capacity enough to hold percolating water.

The saturated hydraulic conductivities were all very permeable (order between 10^{-2} to 10^{-3}cm/s) (Table 3-17).

3-4-6 Some relationships between soil properties.

a) Relationship between pH(H2O) and pH(KCl), (Fig. 3-25)

They were almost linearly related. Some alluvial soils had very high pH because of accumulation of cation such as T-12-5, C3)

b) Relationship between ph(KCl) and pH(KCl) of filtrate for active acidity measurement (Fig. 3-26)

They were not very related. At the low pH level (less than 5), pHs of the filtrates are higher than pH(KCl), and at the high pH level, they are a little lower or same. The values more than 5 of pH(KCl) are those of accumulated horizons of alluvial soils. Their difference of pH may have resulted from the influence of fine particle. When the pH (KCl) was measured, it was shaken by a magnetic agitator, which may have affected pF to some extent. At the high pH level, pHs may have been controlled by concentration of cation in the solution.

c) Relationship between pH(KCl) and active acidity, (Fig. 3-27)

The active acidities were low. And the figure shows that the active acidity reduces rapidly about pH 5. And at more than pH 5, it become very small.

d)Relationship between clay content and ECEC, (Fig. 3-28)

The ECEC is very low at all samples. ECEC per 100g clay was about 7.5me/100g of clay. Some alluvial soil samples have high compared with clay content. It suggests some cation existed at the state of precipitation indifferently from clay fraction.

e) Relationship between clay-sand ratio and fine sand-coarse sand ratio, (Fig. 3-29)

The characteristics of each soil type on particle size distribution are shown clearly on the figure.

The reddish brown (aeolian) sandy soils have low clay-sand ratios and low f. sand-c.sand ratios. The white sandy soils (alluvial) have low clay-sand ratios and variable f.sand-c.sand ratios. The clayey soils have relatively high clay-sand ratios and low f.sand-c.sand ratios. The difference of these values between different sandy soils is important to distinguish deposition type.

In the figure, the white sandy soils of T-12-5 shows unique distribution by the sorting effect.

f) Relationship between fine sand and coarse sand (Fig.3-30)

The figure also shows the difference of soil type on the distribution on it. Both sandy soils are on a same line, but the values of reddish brown sandy soils distribute in a narrower range than those of white sandy soils. Generally speaking, aeolian deposition has some sorting effect, and its particle size distribution become similar, On the contrary, those of the alluvial deposits are highly variable by sedimentation condition.

3-4-7 Mineralogical analysis

The result of X-ray analysis done at the mineralogical laboratory, ORSTOM, Bondy, is shown in Table 3-19. The major clay components were kaolinite and goethite. Kaolinite is somehow disordered. They have some characteristics according to soil type.

In the aeolian sandy soils, hematite was included in the horizons which were very reddish (T-1-2, T-6-6).

The white sandy soils included the significant quarts (T-5-6, T-12-5, C1).

As for clayey soils, kaolinite was important at the reddish brown clayey soils on the plateau (P-1-2), Goethite was one of the most important components in the reddish or mottled clayey soils (T-18-8,2B2, 2BC, T-3-32,3 T-1-3, 2C, T-1-6, 2C).

3-5 Conclusion of the soil survey

The soil survey and the photo-interpretation made clear the geomorphological types in the studied area. And the chemical and physical properties of the representative soil samples were characterized by the laboratory test. The conclusion of this chapter is as follows.

1)The land system of the studied area was mainly composed of residual plateau, of Ct3, hill-foot slope around the plateau, pediplain, and dried valley associated with alluvial terrace.

The relationship between geomorphological type and soil type were as follows.

(Plateau) shallow reddish brown clayey soils, clayey-skeleton

(hill-foot slope) deep reddish brown sandy soils

(pediplain) reddish brown sandy soils to bright reddish brown sandy soils (with variable sand depth depending on the position)

(dried valley) deep white sandy soils

(alluvial terrace) deep white sandy soils associated with bright reddish brown sandy soils

2) As another soil type, bright brown sandy soils were observed on a "cordon" form at north-eastern part of the studied area. And, at the eastern part, the totally-sand-covered area, which had reddish brown sandy soils was distinguished as a mapping unit.

3) Sand distribution controlled strongly geomorphology and soil type, land occupation and land use.

4) The sandy soils were generally very poor in every nutriment. And they were very permeable (order between 10^{-2} to 10^{-3}cm/s). The water holding capacity from pF1.8 to pF4.2 was 112mm to 273mm for the sandy layer. They depend mainly on sand depth. These values are considered high enough to hold percolating water.

5) When the sand cover on the pediplain is deep, surface degradation is not very serious. On the contrary, when the sand cover is shallow or moderately-deep, the soil surface seems susceptible to degrade, or it has already been degraded. The pediplain with moderately-deep sand deposits has more risk for land degradation because it is often cropped for some agricultural value.

6) The reddish brown clayey soils on the plateaux were strongly eroded. They had stony or gravelly surface with shallow clayey-skeleton texture. And the continuous ferruginous crust existed under the clayey horizon. They seems impermeable (see Plate 4-b).

7) The impermeable crust formation is one of limiting factor for rain water percolation (Casenave et. al., 1990). The erosion crust maybe formed on the reddish brown sandy soils and on the bright reddish brown sandy soils when A horizon is removed and B horizon appears. Even the A horizon also can form erosion crust on the surface on the slope due to raindrop and surface run-off. The white sandy soils may be very difficult to form erosion crust because of its low contents of fine particle and its plane land form. While it forms the accumulation horizon in the deeper position due to high permeability.

8) The clayey soils on the pediplain were variable in color. When they appeared on the surface, the land surface has already been eroded except for that of the depression unit.

9) The characteristics of main geomorphological units concerning water dynamics are summarized as shown in Table 3-20. Under the drought-prone condition, the crustability and land form may be the most important facter for rain-fed agriculture, therefore, the alluvial terrace with the white sandy soils is the most valuable unit.

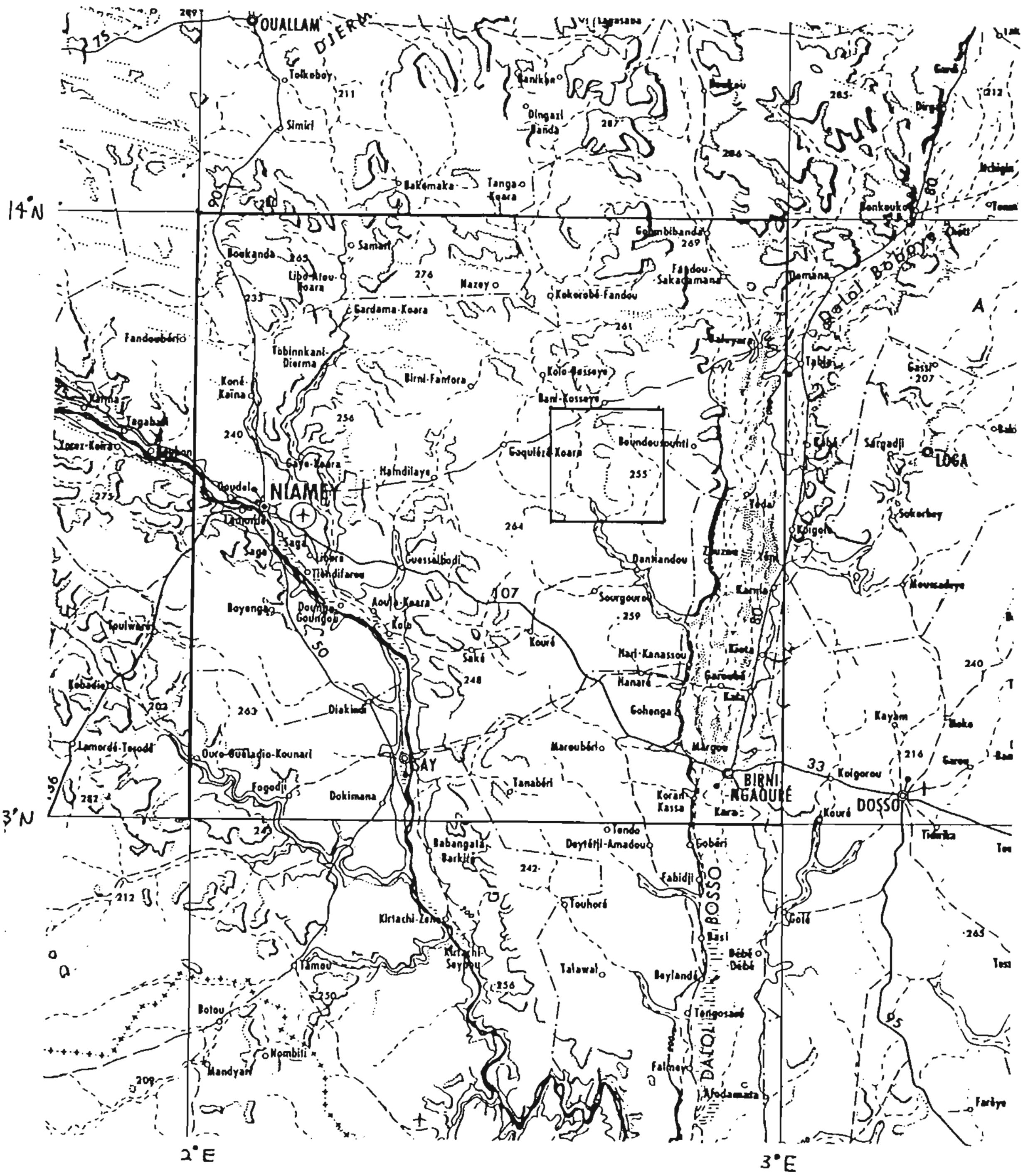
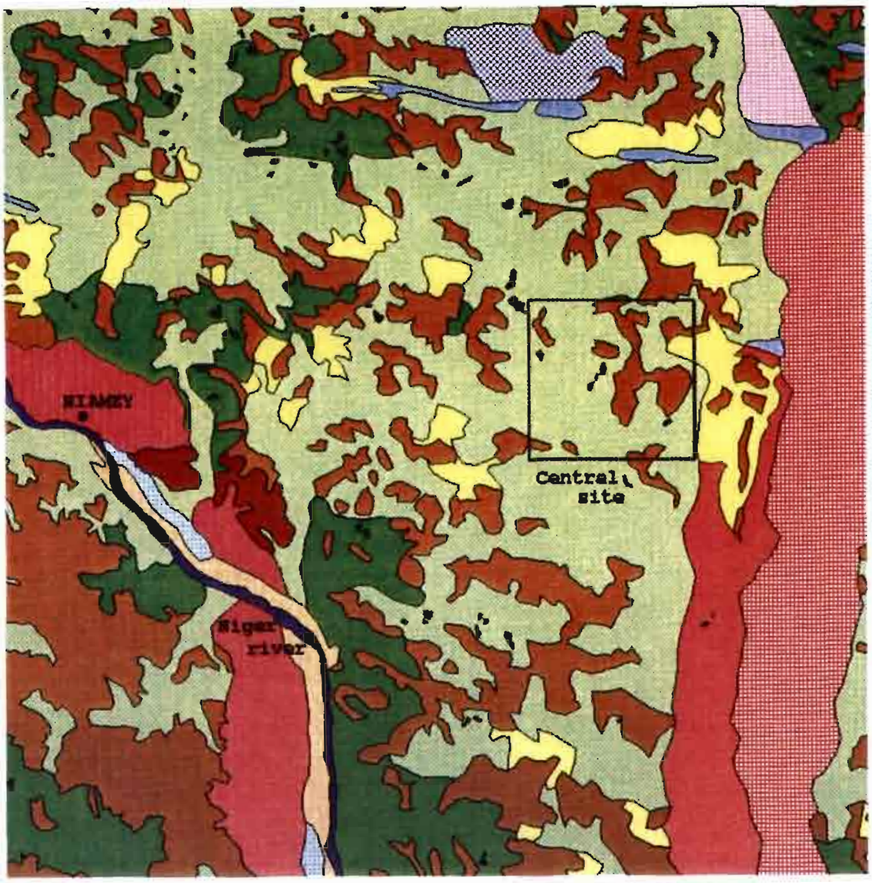


Fig. 3-1. Location of the studied are in the HAPEX-SAHEL Project site

Fig. 3-2 Topographic map of the studied area

Fig. **3-3**

HAPEX SAHEL Project
Soil map
(After GAVAUD and BOULET)



Legend

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0 7500 15000 30000 m

Sols ferrugineux tropicaux non ou peu léssives(en argile), peu lessivés peu différenciés
sur formation sableuse des vallées
1. Association à sols ferrugineux à action de nappe, à sols à gley,à sol à alcalis
13. Association à sols ferrugineux à action de nappe, à sols à peudogley,
à sols vertiques(Terrases du Niger)
sur sables paubles en argile et limon
6. Série modale(erg recents)

Sols ferrugineux tropicaux non ou peu léssives(en argile),peu lessivés évolués,
sur formation sableuse du Moyen Niger
2. Série de TANTCIA
4. Toposéquence des vallées
7. Séries tres rubéfiées de plateau
8. Associée à des sols ferrugineux peu lessivés sur colluvions argilo-sableuses(CT3)
et à des sols régiques sur sables éoliens

Sols ferrugineux tropicaux non ou peu lessivés(en argile),peu lessivés à concrétions,
sur formation sableuse des vallees seches
9. Série de FANDOU

Sols ferrugineux tropicaux lessivés, lessivés faiblement différencies,
sur mélange de sables éoliens et de produits issus de grès argileux
3. Association à sols régiques et sols ferrugineux peu lessivés

Sols peu évolués d'érosion, sols régiques,faciès ferrugineux
5. Famille sur placage sablo-argileux sur dalle localement ferruginisée

Sols minéraux bruts d'érosion, lithosol
10. sur conglomérat ferruginisé
14. sur roches diverses

Sols à psudogley à taches et concrétions, sur sables fins argileux
15. Associations des terrases du Niger à sols ferrugineux peu lessivés,
à marbrures et sols vertiques

Sols à gley d'ensemble ou de surface, sur alluvions fluviatiles
11. Association du lit majeur du Niger

12 Niger river

(digitized by HAPEX SAHEL team)

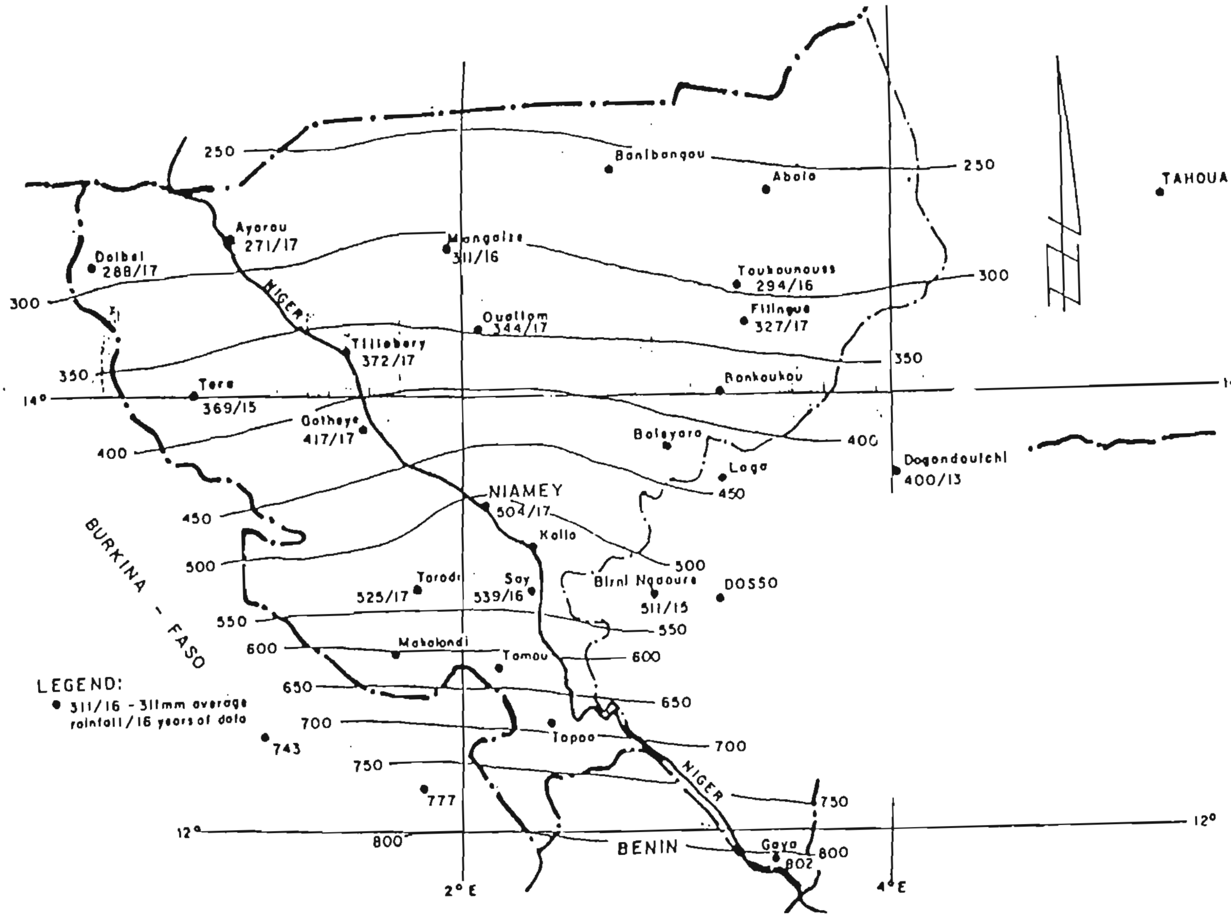
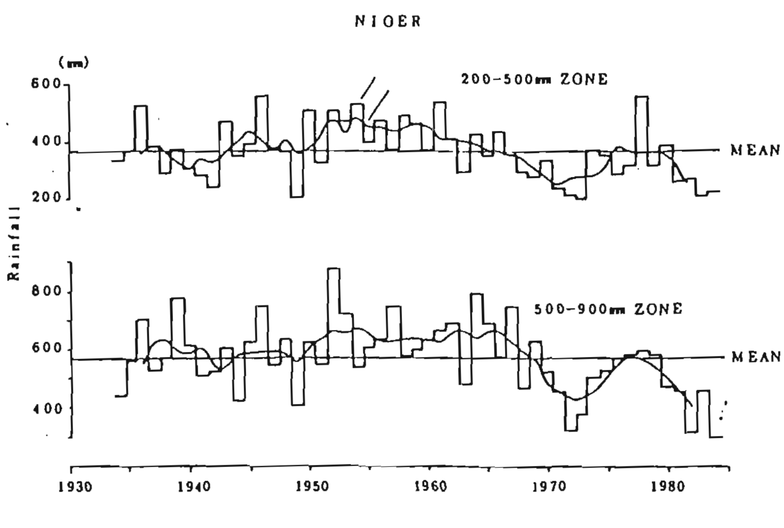


Fig. **3-4** Annual rainfall isohyets of Niamey department
(after Hagen, et. al. 1986)



Annual amounts of rainfall (A), the five year running average (B) and the mean annual rainfall for the period 1934-1984. (Todorov 1985)

Fig. **3-5** Evolution of annual rainfall for 50 years in Niger
(after Hagen, et. al. 1986)

Table 3-1. Climatical data sammary at Banizoumbou in 1991
(after Monteny, 1992)

mois 1991	Pluie nım	Rg MJm-2	Rd MJın-2	Par MJm-2	HRmin x100	HRmax x100	Ta min °C	Ta max °C	e min kPa	e max kPa	T sol min °C	T sol max °C	vitmin ms-1	vit max ms-1	ETo mm/12h	ETP mm/12h
janv		21,5	6,4	-	0,09	0,28	16,2	32,6	0,412	0,525	17,2	39,8	0,6	4,6	4,2	5,5
fev		22,4	8,4	-	0,08	0,29	18,8	38,1	0,413	0,787	20,4	47,1	0,4	4,2	4,4	5,9
mars		22,4	11,1	-	0,09	0,30	23,3	38,8	0,504	0,986	24,3	49,4	0,5	4,7	4,4	6,2
avril	26	22,6	10,6	10,2	0,18	0,54	27,3	41,0	1,192	2,216	28,6	49,8	0,7	5,0	4,4	6,0
mai	170	19,6	10,6	9,0	0,41	0,79	26,4	36,1	2,236	2,855	27,1	44,2	0,9	4,7	3,8	4,7
juin	56	22,3	10,2	10,6	0,45	0,87	25,4	35,9	2,488	3,058	27,3	44,7	0,6	4,6	4,3	5,0
juil	62	20,2	9,8	9,0	0,51	0,93	23,8	33,4	2,522	2,997	26,5	42,6	0,5	3,9	3,9	4,4
aout	150	20,8	10,0	9,1	0,57	0,97	22,9	32,4	2,575	3,084	25,9	39,0	0,4	3,4	4,0	4,4
sept	20	23,5	9,2	11,1	0,38	0,88	24,4	37,2	2,223	2,970	28,0	48,9	0,3	3,1	4,6	5,3
oct	15	22,5	9,0	10,8	0,23	0,81	22,6	38,5	1,473	2,419	27,6	49,4	0,3	3,5	4,4	5,4
nov		20,2	8,5	9,5	0,10	0,55	15,8	36,6	0,616	1,072	21,5	48,1	0,3	3,6	3,9	5,2
dec		19,6	8,1	9,1	0,11	0,40	14,2	32,1	0,500	0,671	18,5	43,5	0,4	3,9	3,8	4,9

Plui:precipitation, Rg:global solar radiation, Rd:diffuse radiation, Par:Photosynthetically-active radiation (400-720nm), HRmin and HRmax:minimum and maximum relative humidity at 2m in height, Ta min and Ta max:minimum and maximum air temperature, e min and e max: minimum and maximum vapour pressure of the atmosphere at 2m in height, Tsol:temperature of soil at 2m in depth, vit min and vit max:minimum and maximum wind velocity at 2m in height, ETo:Equilibrium evaporation ETP:Evapotranspiration

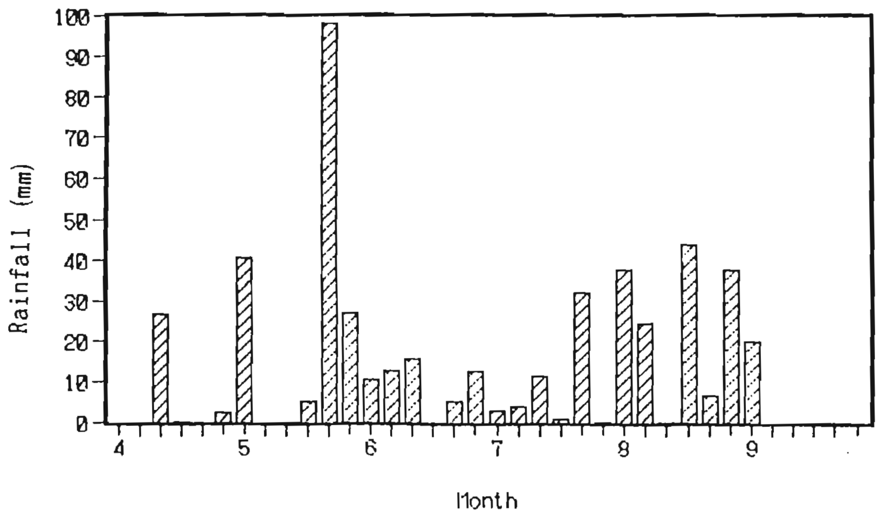


Fig. **3-6** Rainfall distribution in every five days in the cropping season at studied area in 1991 (after Monteny, 1992)

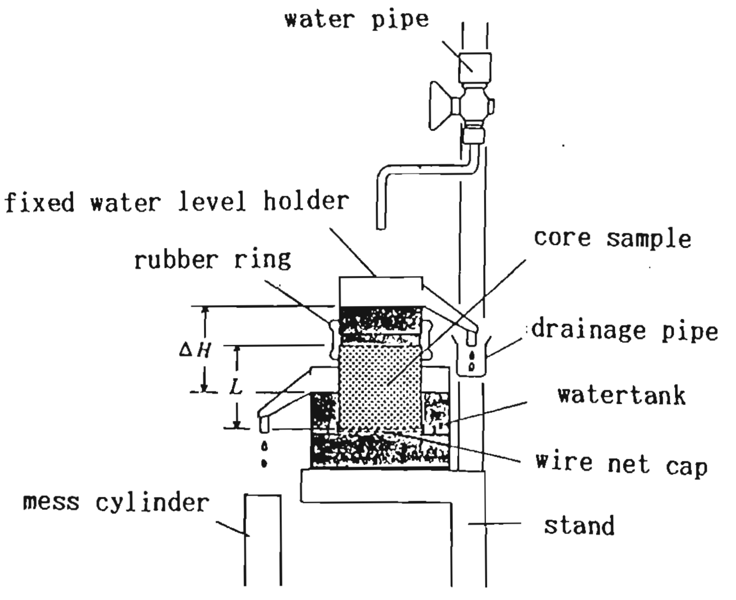


Fig. 3-7 Apparatus for measuring the saturated hydrolic conductivity (fixed water level method, DIK-4000, DAIKI RIKA)

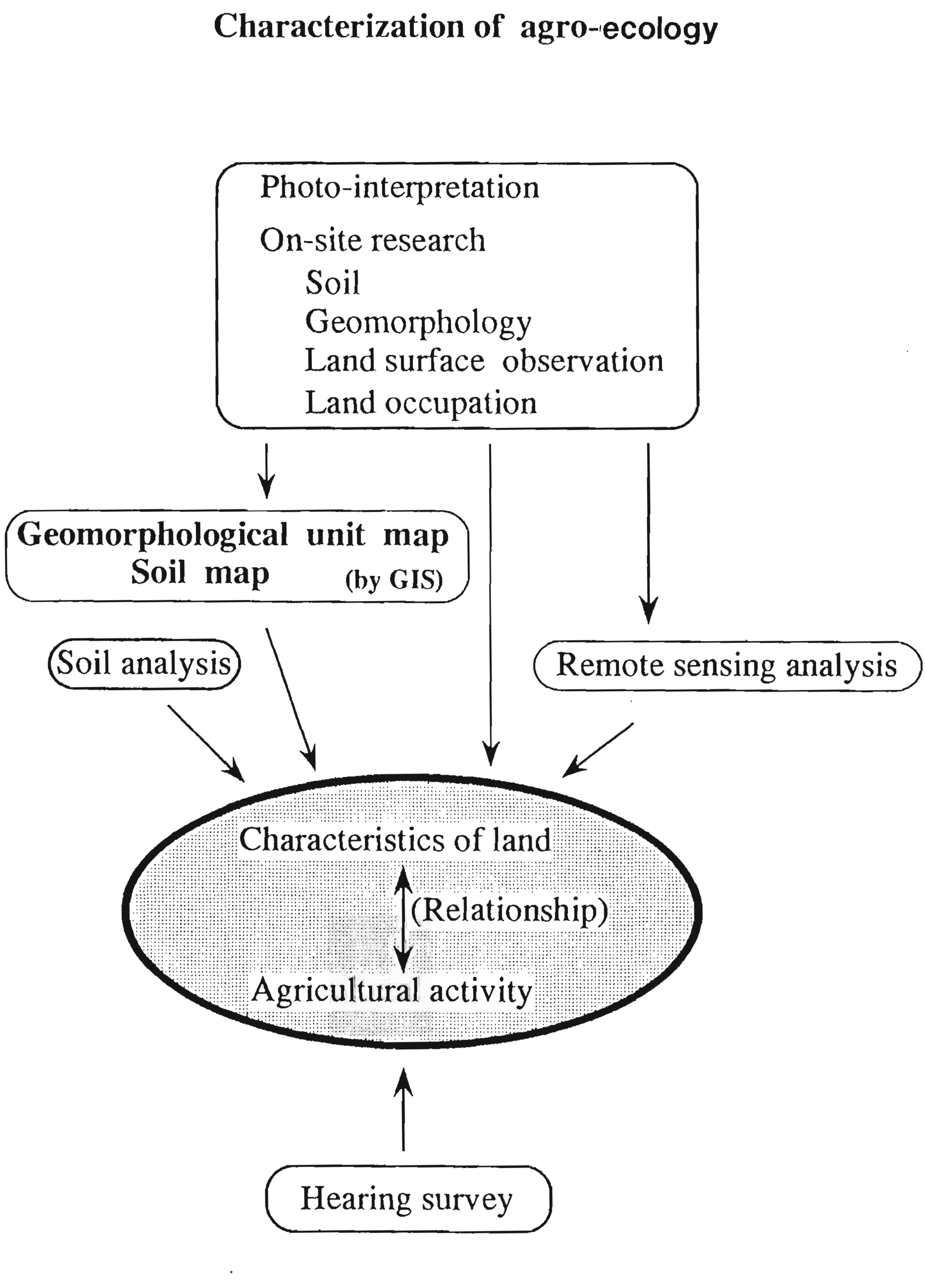
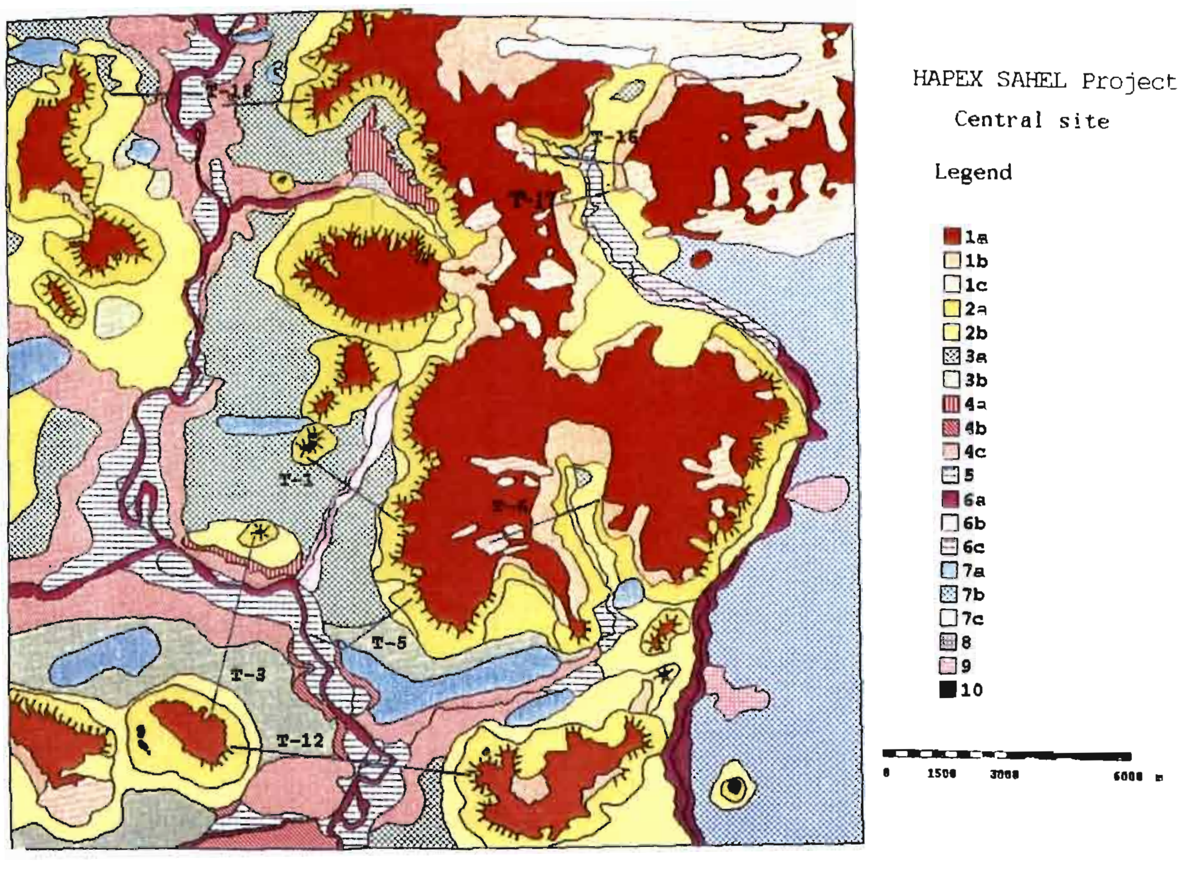


Fig 3-8 Outline of the study



1. Tertiary residual Plateau (Ct3)
    1a) flat plateau
    1b) gently-sloped plateau
    1c) sand mound
2. Hill-foot slope
    2a) moderate slope (about 2-4%)
    2b) gentle slope (less than 2%)
3. Pediplain
    3a) with surface
    3b) without eroded surface
4. Slope from pediplain to alluvial terrace
    4a) steep slope with eroded surface
    4b) steep slope without eroded surface
    4c) gentle slope
5. Alluvial terrace
6. Valley form
    6a) V-type valley
    6b) temporal water way with gentle slope
    6c) almost-flat valley
7. Sand deposition form
    7a) Sand deposition form on the pediplain
    7b) total-sand covered undulating land form
    7c) cordon form on the plateau
8. Depression form
9. Concave small basin
10. Inserberg

Fig. 3-9 Geomorphological unit map of central site (HAPEX-SAHEL)

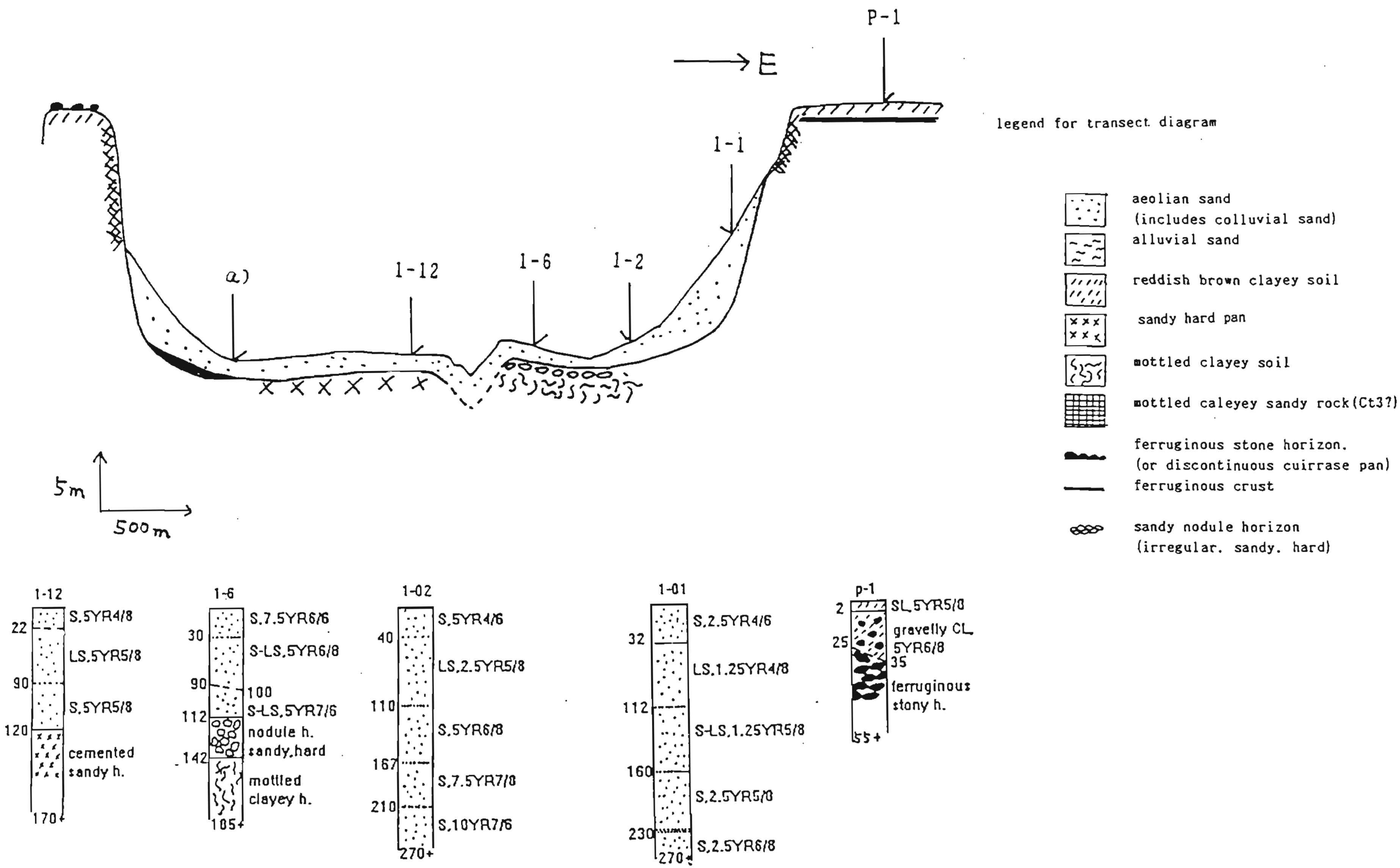


Fig. 3-10 Transect 1

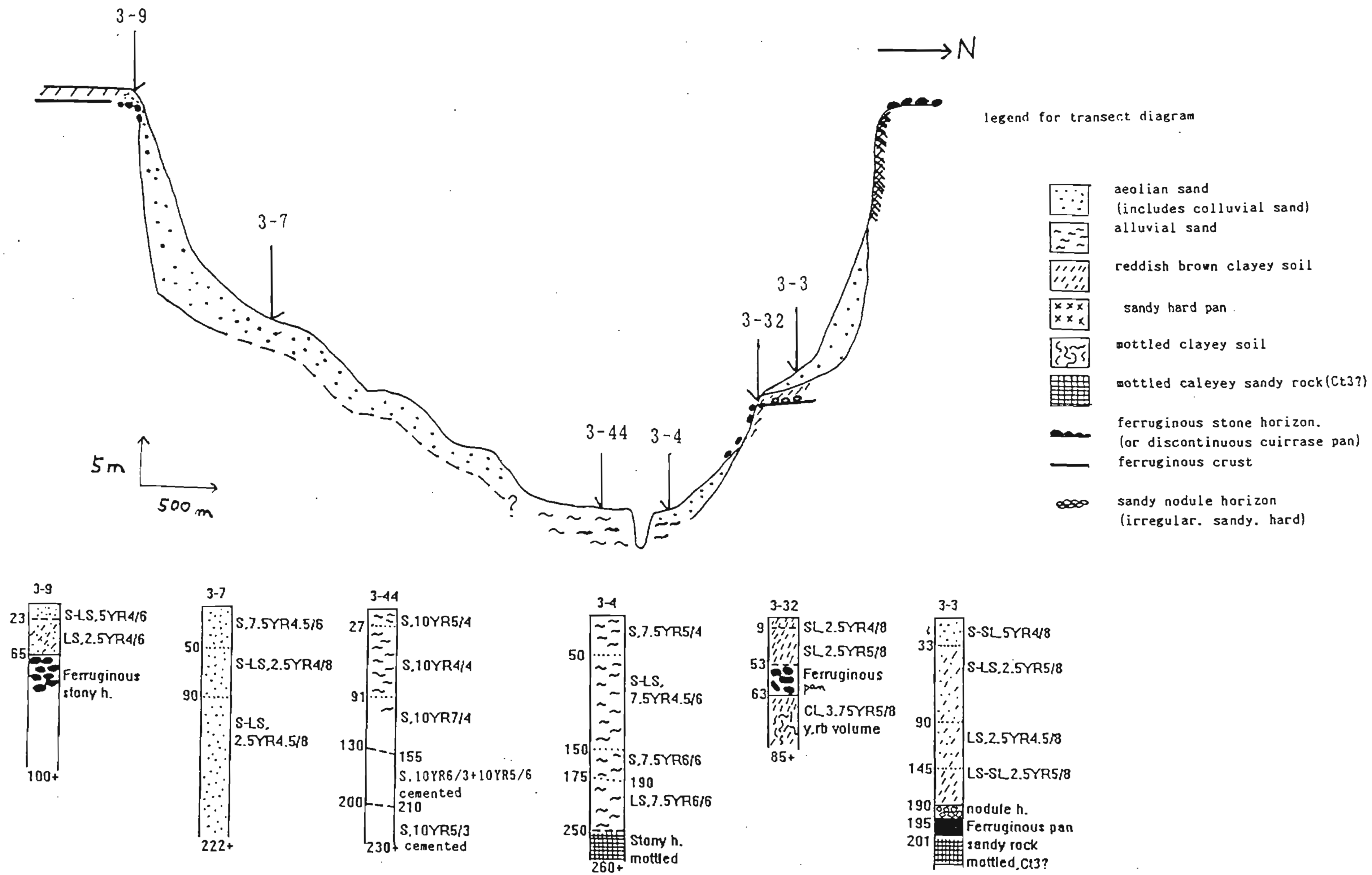


Fig. 3-11 Transect 3

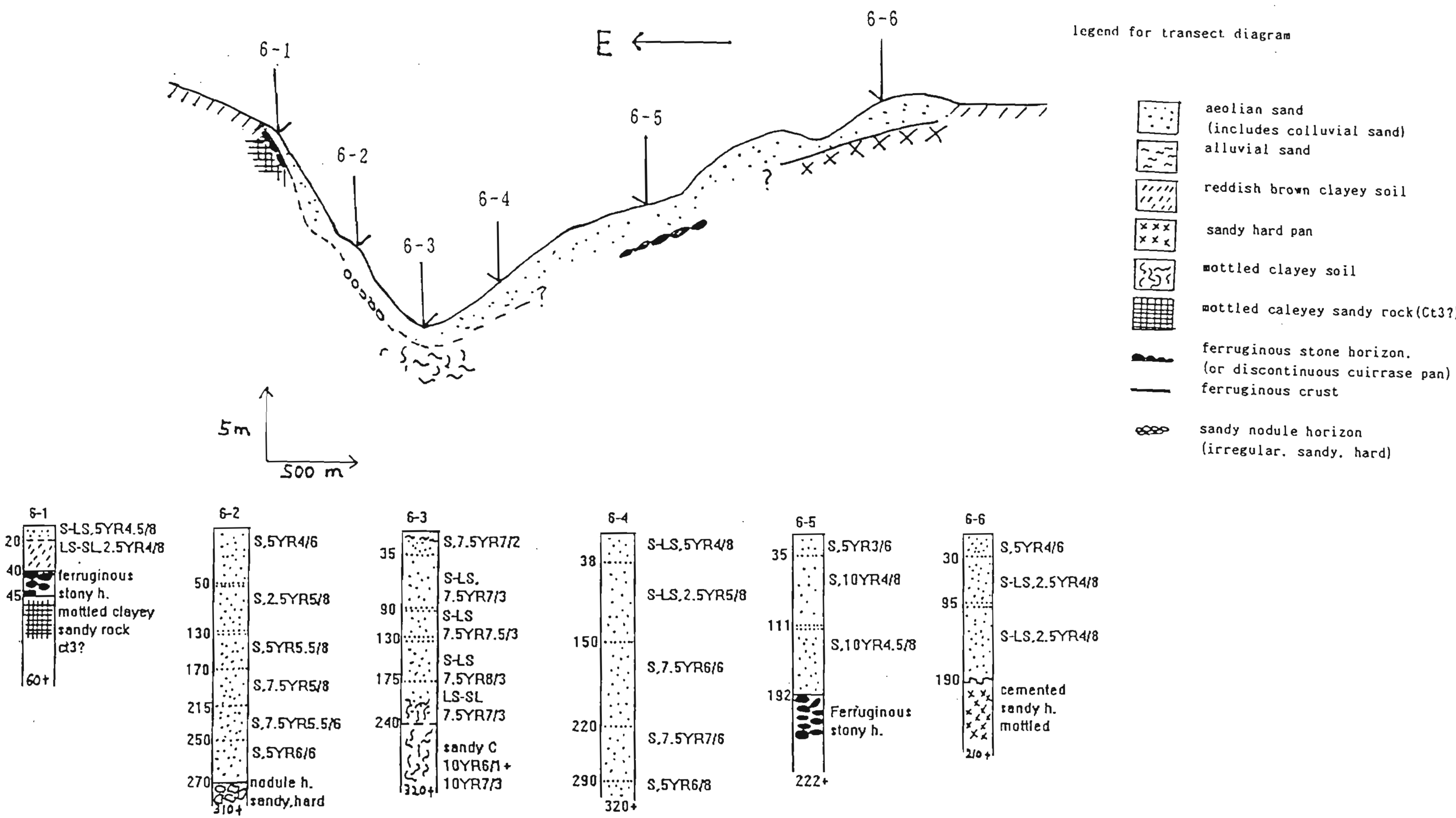


Fig. 3-12 Transect 6

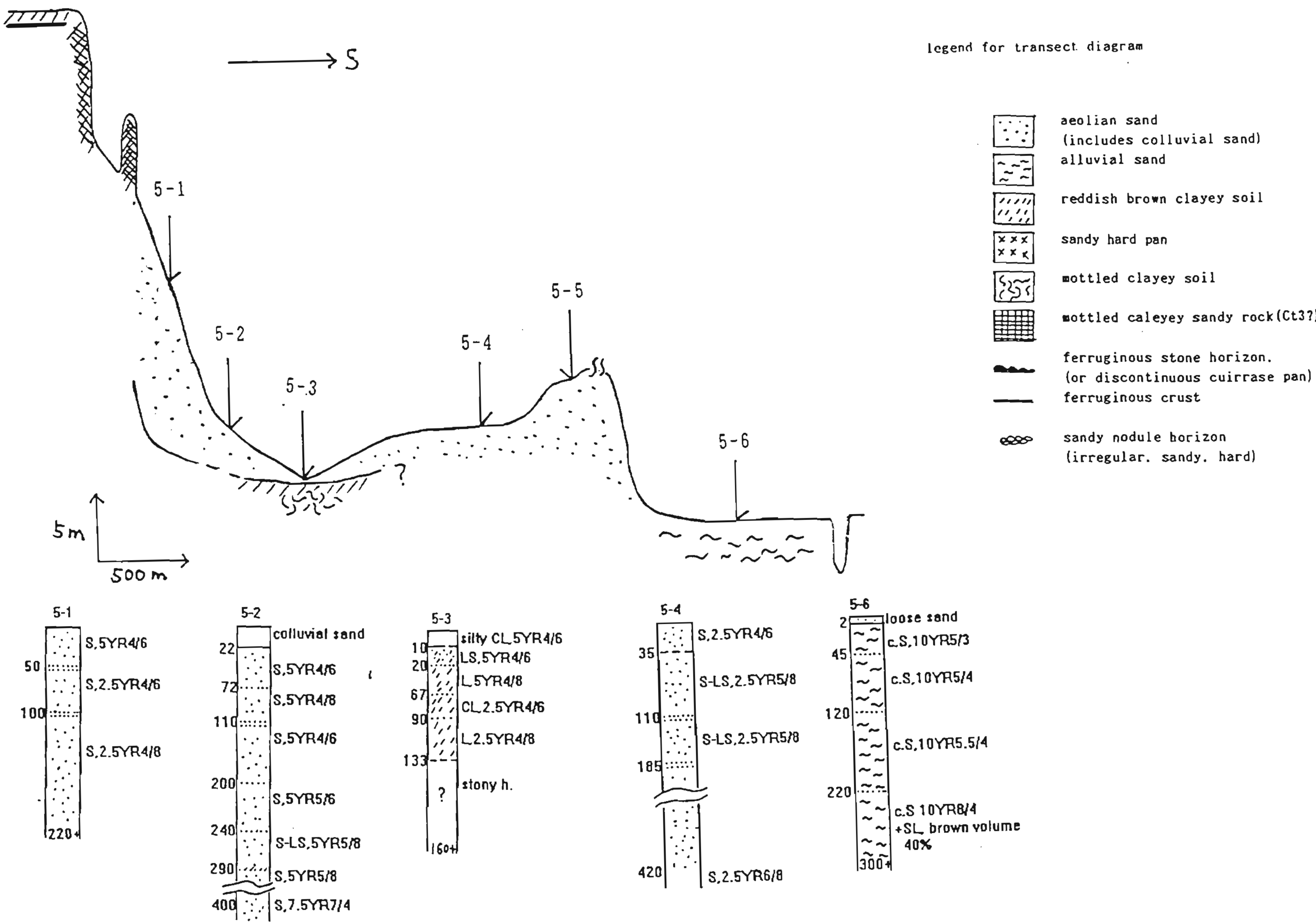


Fig. 3-13 Transect 5

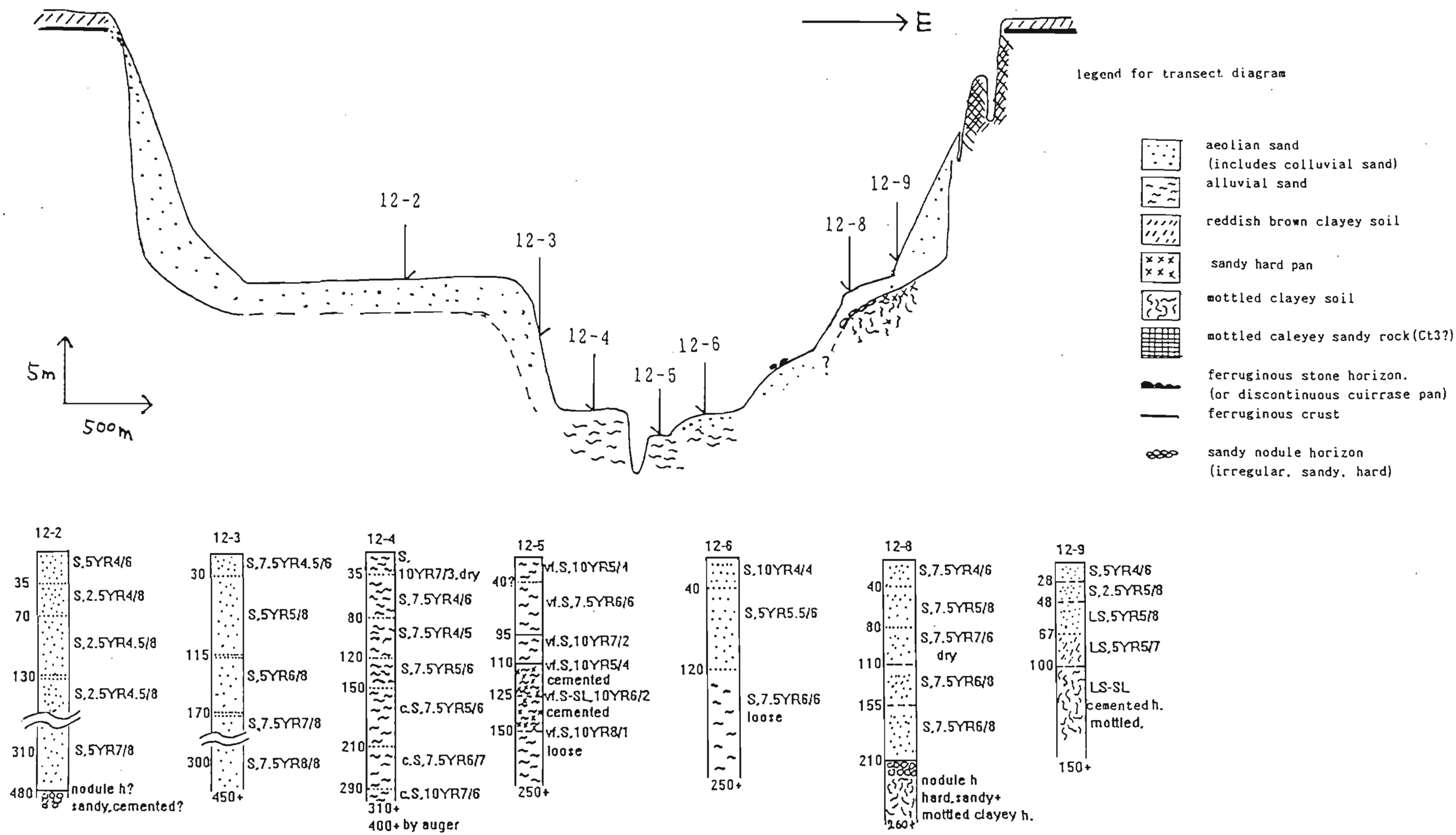


Fig. 3-14 Transect 12

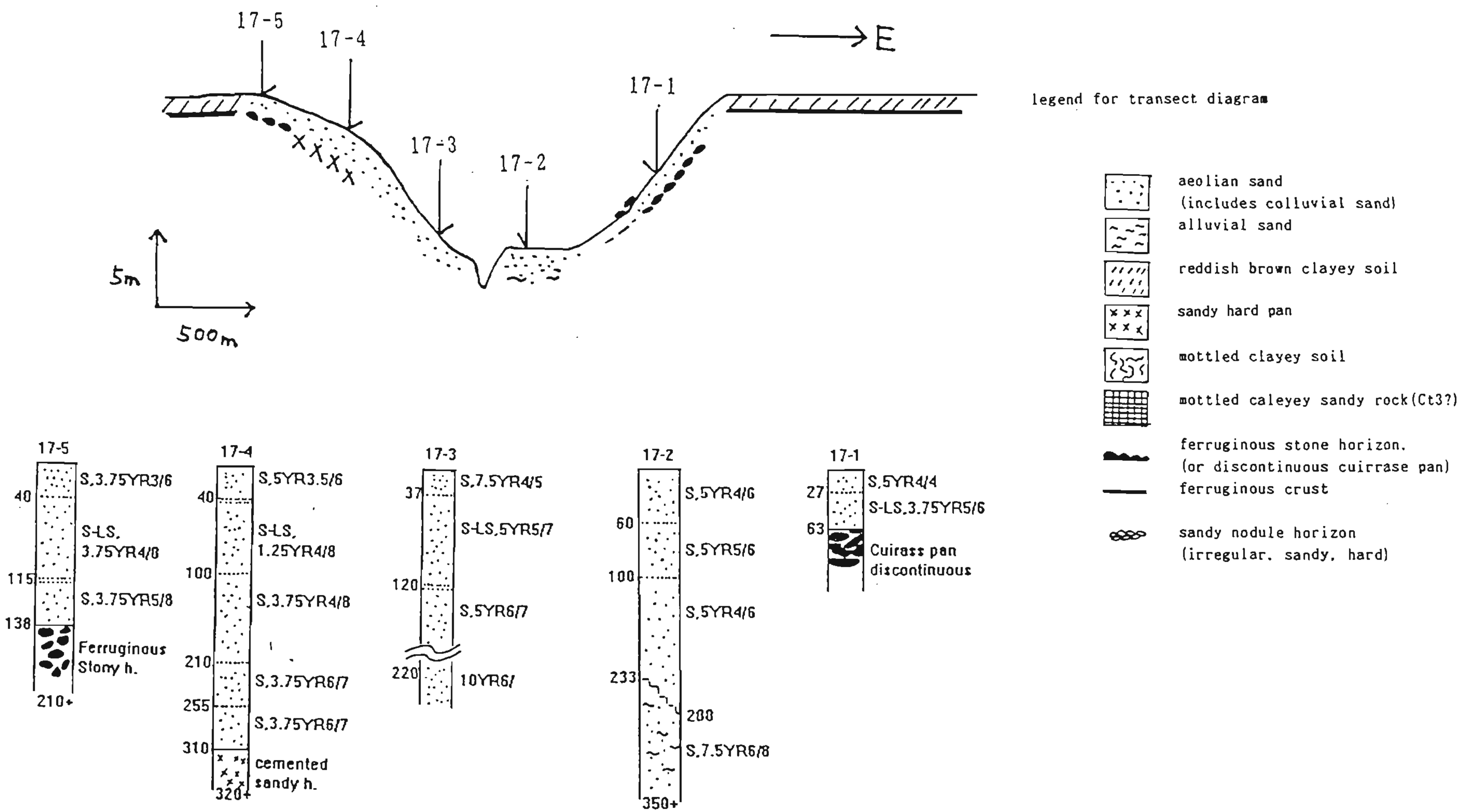


Fig. 3-15 Transect 17

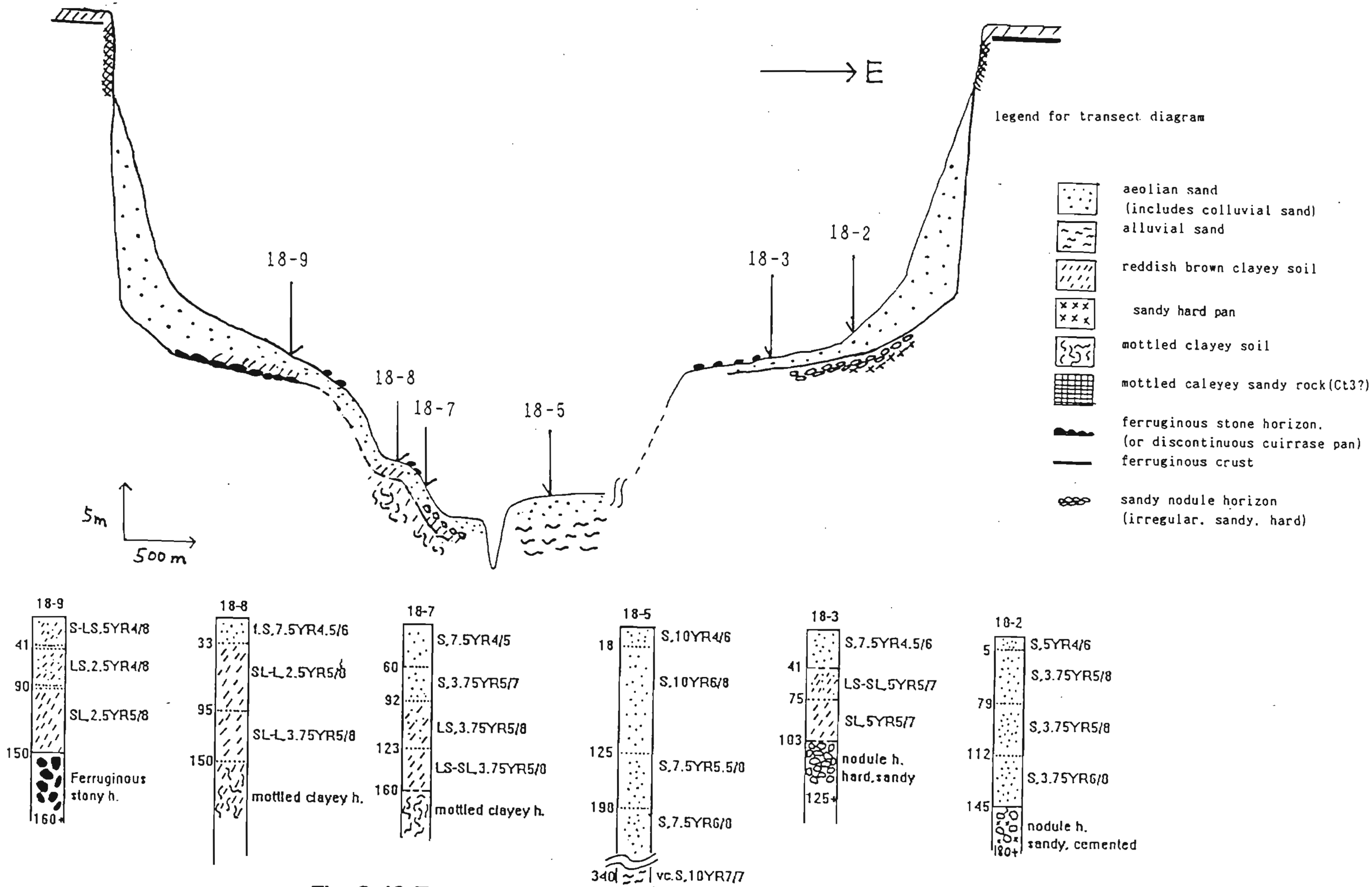


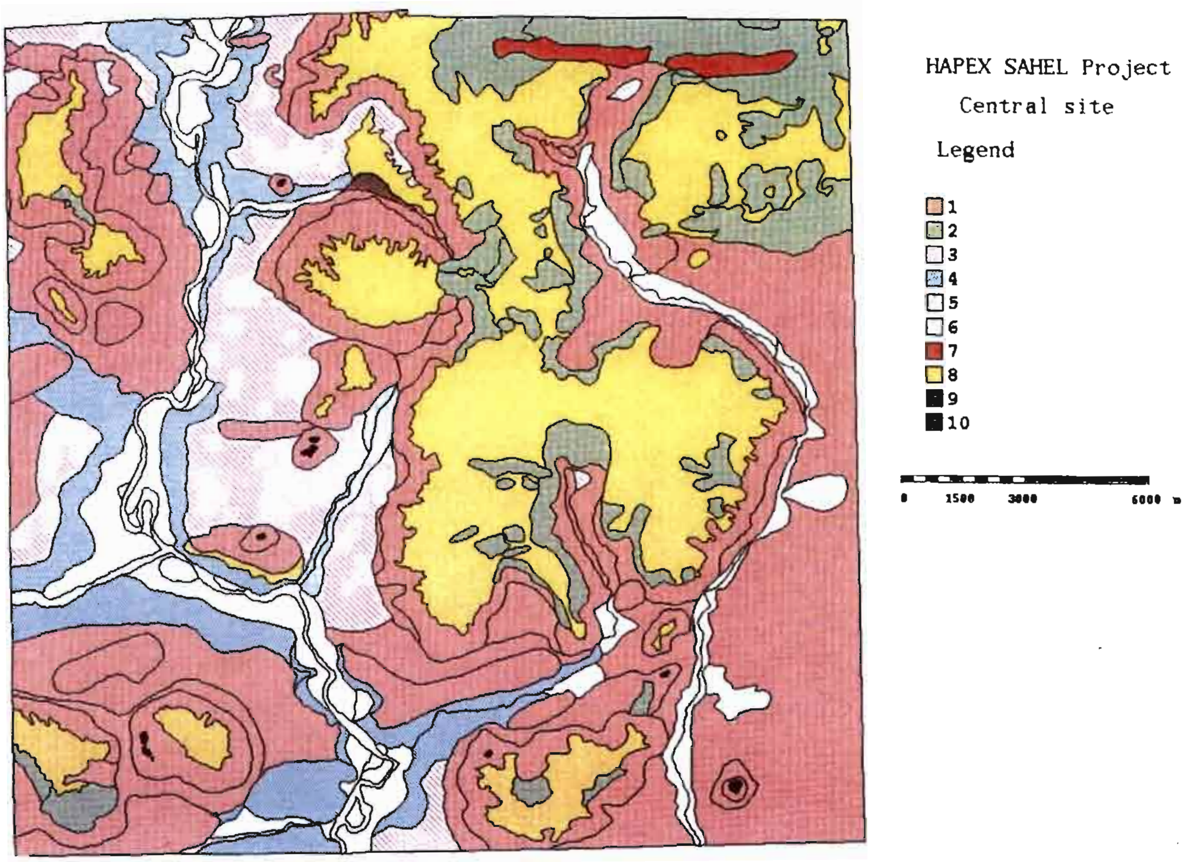
Fig. 3-16 Transect 18

Table 3-2. Rlationship among geomorphological unit, soil type and main land occupation

	soil unit	land occupation
1.tertiary residual plateau(Ct3)		
1a)flat plateau	8	tiger bush
1b)gently-sloped plateau	2	millet field or fallow
1c)sand mound	2	fallow, sometimes degaraded
2.hill-foot slope		
2a)moderate slope(2-4%)	2	millet field or fallow
2b)gentle slope(2%)	2	millet field or fallow
3.pediplain		
3a)eroded surface	3	degaraded bush, fallow, millet,
3b)non-eroded surface	2	millet and fallow
4.slope from pediplain to alluvial terrace		
4a)steep slope with eroded surface	8	bareland with soporadical Guiera
4b)steep slope without eroded surface	4	fallow
4c)gentle slope	4	fallow or millet
5.alluvial terrace		
5)alluvial terrce	6	millet or fallow
6.valley form		
6a)V-type valley bottom	6	millet or cassava
6b)temporal water valley with gentle slope	5	ligneous vagetation
6c)almost-flat valley	6	millet or fallow
7.sand deposition form		
7a)sand deposition form on the pediplain	1	millet or fallow
7b)totaly-sand-covered undulating land form	1	millet or fallow
7c)cordon form	1	millet or fallow
8.depression form		
8)depression form	9	ligneous vegetation
9.concave samlle basin		
9)concave smallbasin	6	millet or fallow
10.inserberg		
10)inserberg	10	bare land with sporadical vegetation

Soil mapping unit

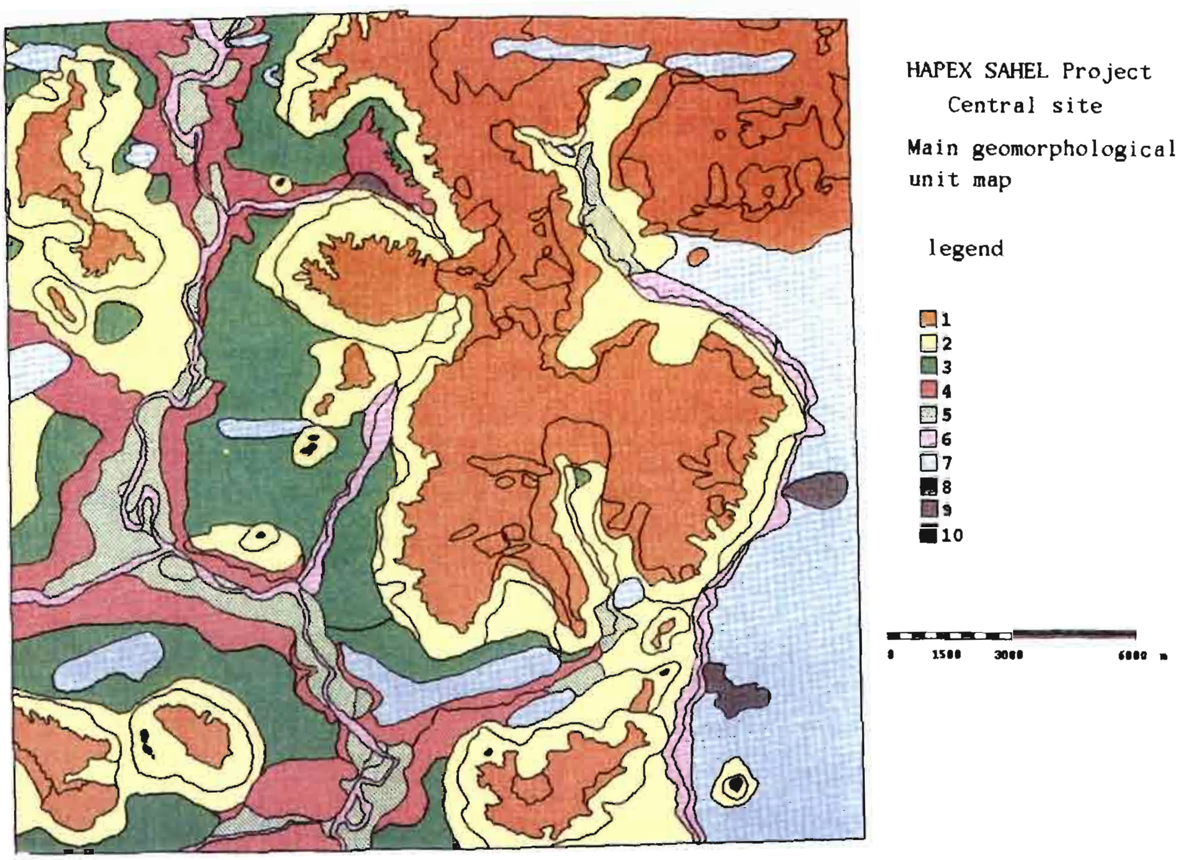
1. deep reddish brown sandy soil
2. deep or moderately-deep reddish brown sandy soil
3. moderately-deep or shallow bright reddish brown sandy soil
4. deep reddish brown sandy soil associated with deep bright reddish brown sandy soil
5. deep bright reddish brown sandy soil associated with deep or moderately-deep white sandy soil
6. deep white sandy soil associated with bright reddish brown sandy soil
7. deep bright brown sandy soil
8. shallow reddish brown clayey soil
9. brown clayey soil
10. lithosol



Soil mapping unit

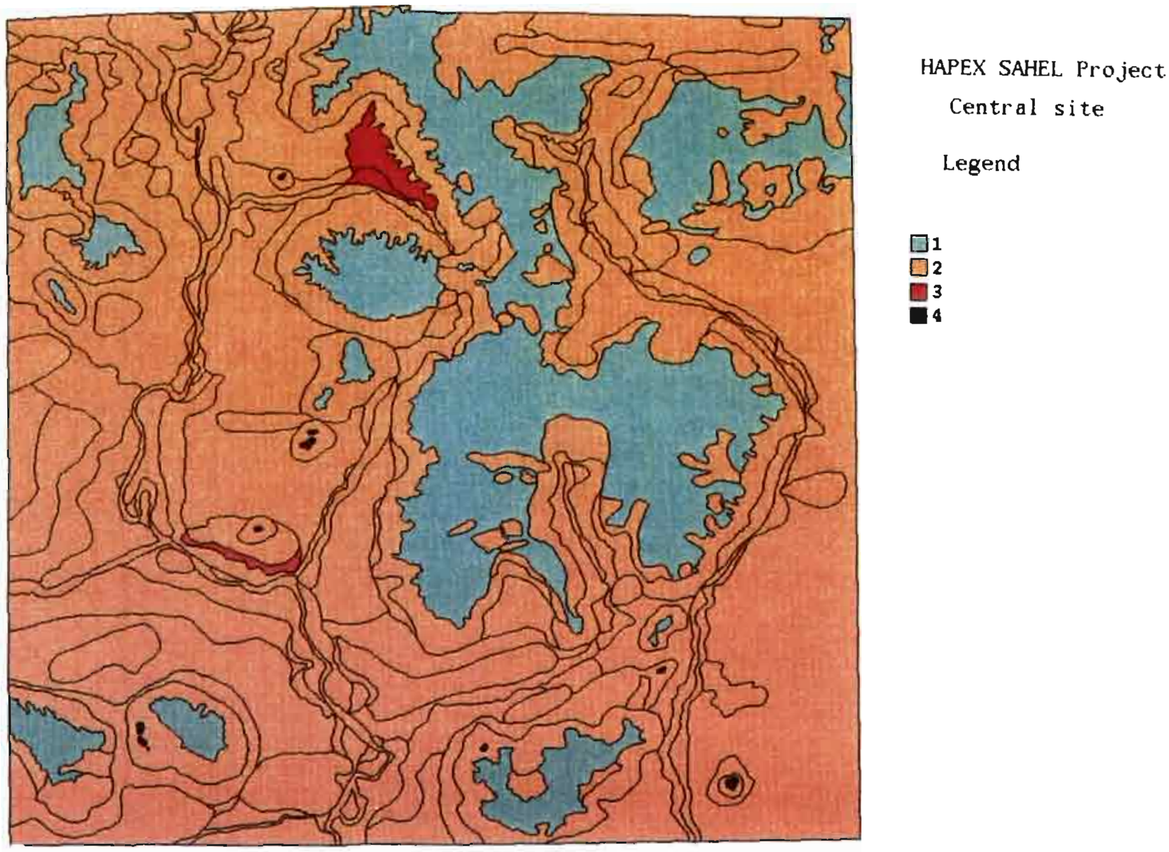
1. deep reddish brown sandy soil
2. deep or moderately-deep reddish brown sandy soil
3. moderately-deep or shallow bright reddish brown sandy soil
4. deep reddish brown sandy soil associated with deep bright reddish brown sandy soil
5. deep bright reddish brown sandy soil associated with deep or moderately-deep white sandy soil
6. deep white sandy soil associated with bright reddish brown sandy soil
7. deep bright brown sandy soil
8. shallow reddish brown clayey soil
9. brown clayey soil
10. lithosol

Fig. **3-17** Soil map of central site (HAPEX-SAHEL)



1. tertiary residual plateau
2. hill-foot slope
3. pediplain
4. slope from pediplain to alluvial terrace
5. alluvial terrace
6. valley form
7. sand deposition form
8. depression form
9. concave small basin
10. inserberg

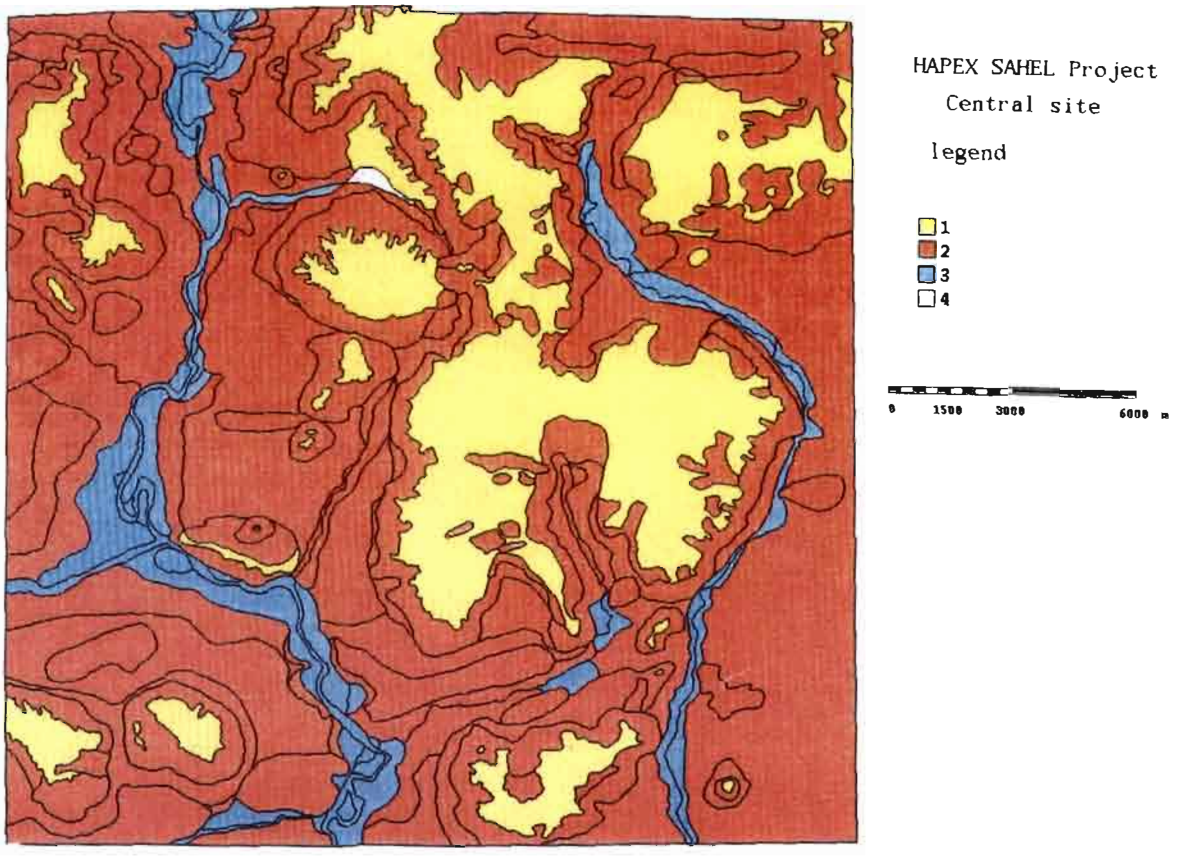
Fig. 3-18 Main geomorphological unit map



1. Cleyey-skeleton
2. Sandy
3. Clayey
4. Stony (Lithosol)

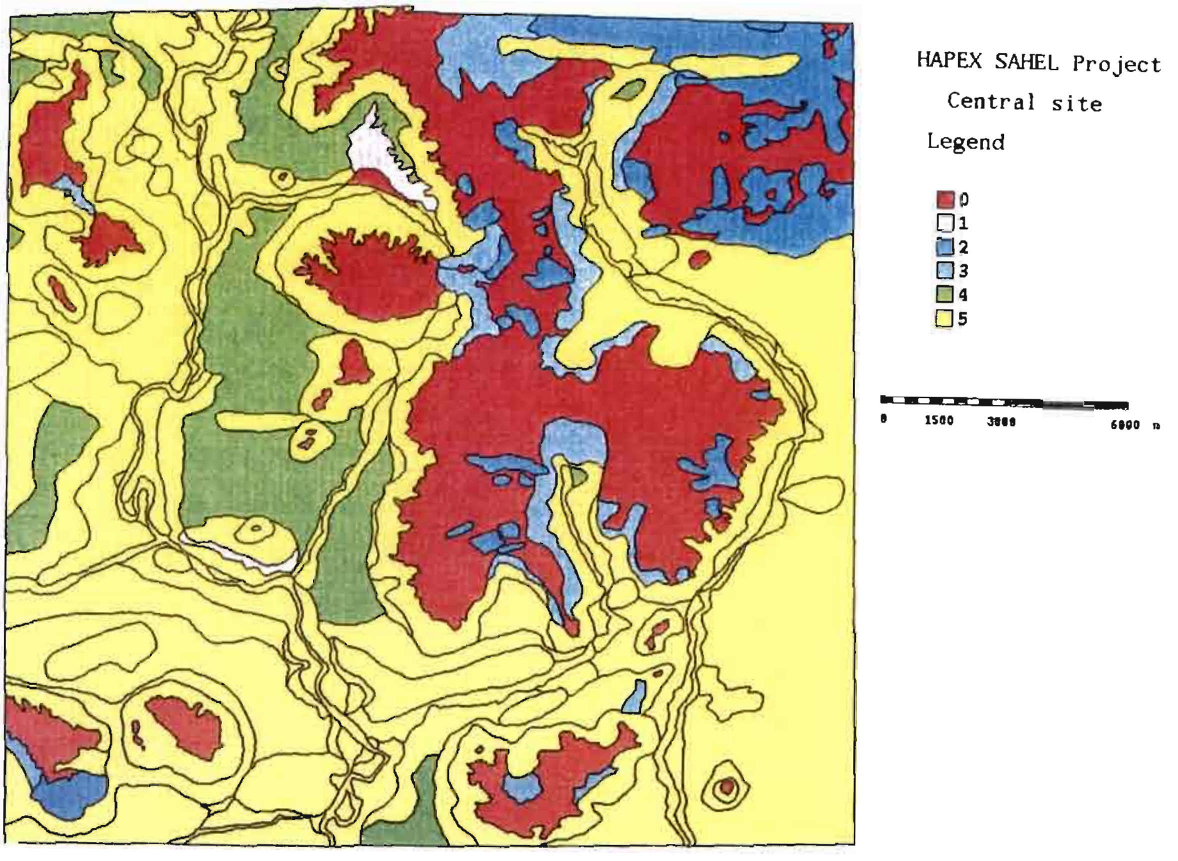
* Upper 100cm was considered

Fig. 3-19 Surface texture map (rough estimation)



1. Continental terminal (Ct3)
2. Aeolian sand
3. Alluvial and colluvial sand
4. Colluvial sediment

Fig. 3-20 Soil material map (rough estimation)



0. Almost no sand
1. Shallow (< 100cm)
2. Shallow or moderately-deep (< 200cm)
3. Moderately-deep (100 to 200cm)
4. Moderately-deep or deep (> 100cm)
5. Deep (>200cm)

Fig. **3-21** Sand depth map (rough estimation)

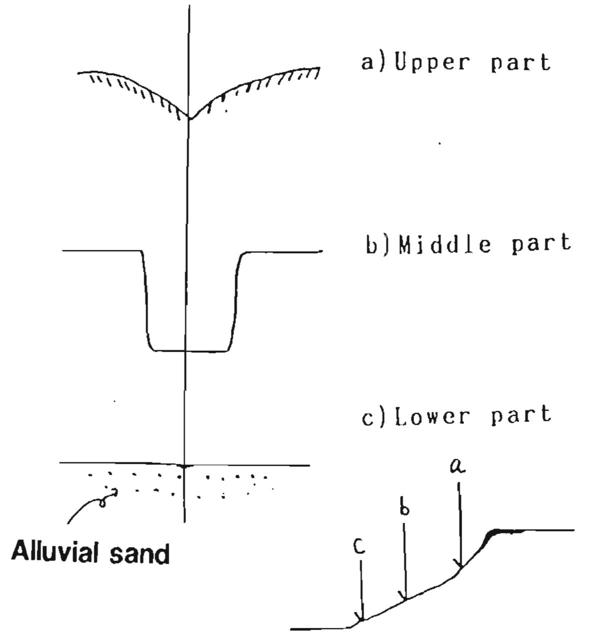


Fig. **3-22** Cross section of gully on the hill-foot slope

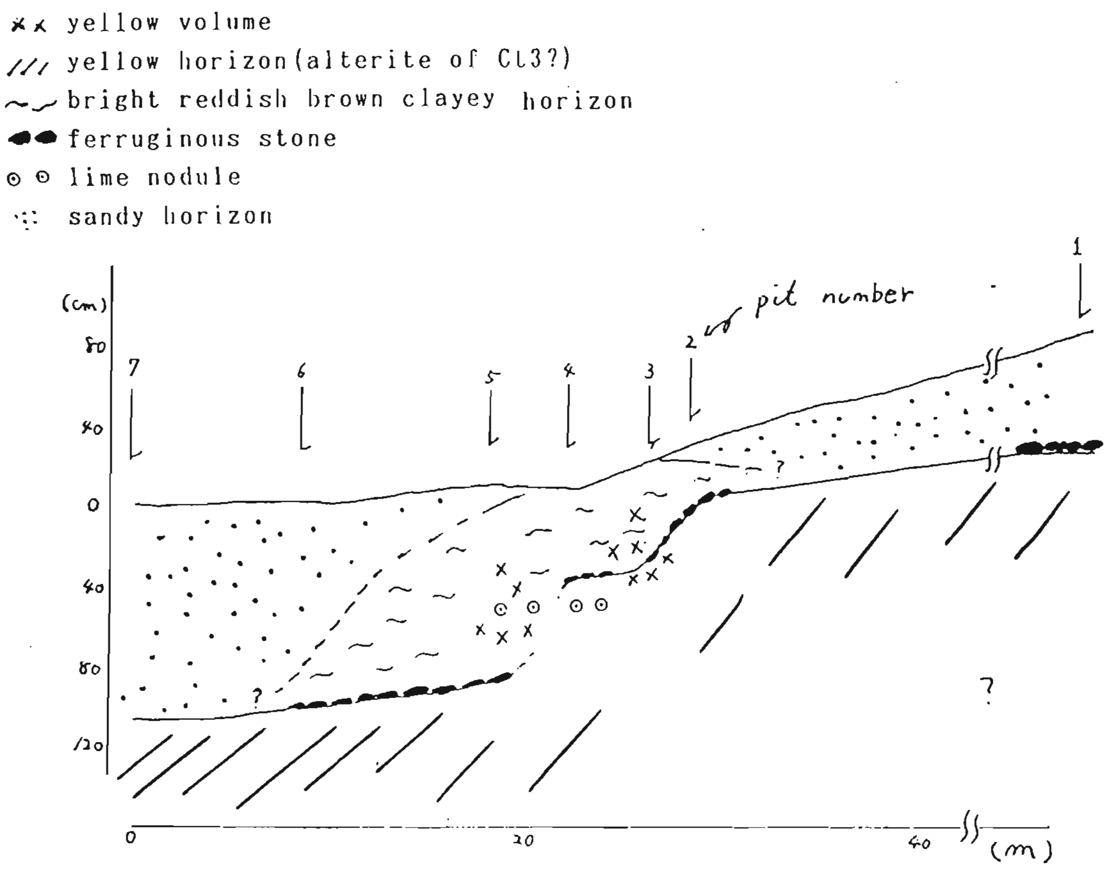


Fig. **3-23** Toposequence around the lime nodule appearance area (transition area between hill-hoot slope and pediplain)

Table 3-3. General characteristics of reddish brown sandy soils
(including brigh reddish brown sandy soils)

Reddish brown sandy soils. A horizons (sample Nb.8)

	pH (H2O)	pH (KCl)	EC (1:5)	A.ac (me/100g)	Ex. cations(me/100g) Na	K	Ca	Mg	T-B (me/100g)	ECEC	SR (%)	av.P (mg/kg)	T-C (%)	T-N (%)
mean	5.2	4.4	27.8	0.22	0.01	0.10	0.27	0.08	0.44	0.68	65.9	7.0	0.17	0.03
Min.	4.7	3.8	16.3	0.00	0.00	0.05	0.06	0.02	0.15	0.32	20.0	3.8	0.05	0.00
Max	5.9	5.2	46.4	0.60	0.04	0.17	0.96	0.16	1.21	1.47	100.0	9.9	0.30	0.07
SE*	0.4	0.5	10.9	0.22	0.01	0.05	0.31	0.06	0.38	0.35	33.5	2.0	0.07	0.02

1)A.ac:active acidity. 2)T-B:total exchangeable bases. 3)SR:base sturation ratio to ECEC.
4)av.P:available P2O5. 5)T-C:total carbon. 6)T-N:total nitrogen
7)sample Nb:Number of samples usedfor analysis
*:standard error

Reddish brown sandy soils. sub-surface horizons (sample Nb.14)

	pH (H2O)	pH (KCl)	EC (1:5)	A.ac (me/100g)	Ex. cations(me/100g) Na	K	Ca	Mg	T-B (me/100g)	ECEC	SR (%)	av.P (mg/kg)	T-C (%)	T-N (%)
mean	4.8	4.1	22.8	0.54	0.00	0.05	0.08	0.04	0.18	0.69	34.5	6.6	0.08	0.02
Min.	4.5	3.9	12.8	0.08	0.00	0.01	0.03	0.01	0.09	0.18	9.3	1.9	0.04	0.00
Max	5.1	4.3	36.5	0.97	0.05	0.09	0.12	0.17	0.31	1.07	79.5	12.5	0.11	0.05
SE	0.2	0.1	7.0	0.25	0.01	0.02	0.03	0.04	0.07	0.26	22.1	2.8	0.03	0.01

Particle size distribution. A horizons (sample Nb.7)

	clay (%)	F.silt (%)	C.silt (%)	F.sand (%)	C.sand (%)	T.sand (%)	cl/sa	Fs/Cs
mean	4.4	3.2	4.7	52.7	35.0	92.4	0.05	1.54
Min.	3.7	1.5	2.8	46.7	29.1	91.5	0.04	1.16
Max.	5.4	4.7	6.4	59.1	40.9	94.1	0.06	2.03
SE	5.6	1.4	4.9	19.4	24.4	6.3	0.09	0.30

1)F.silt:fine silt.2)C.silt:coarse silt.3)F.sand:fine sand.
4)C.sand:coarse sand. 5)T.sand:total sand.
6)cl/sa:clay sand ratio. 7)Fs/Cs:fine sand coarse sand ratio

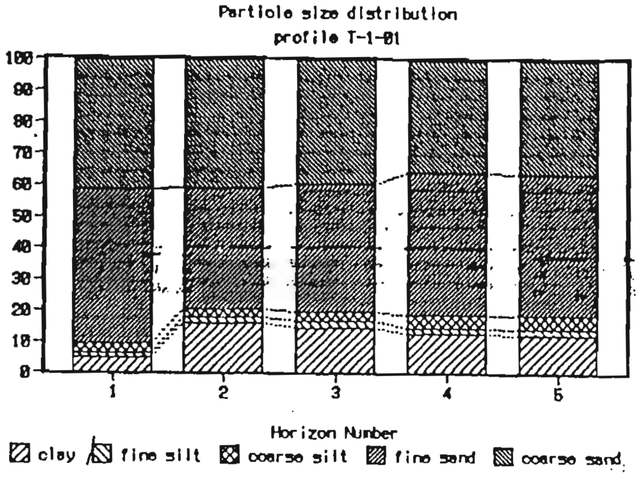
Particle size distribution. Sub-surface horizons (sample Nb.14)

	clay (%)	F.silt (%)	C.silt (%)	F.sand (%)	C.sand (%)	T.sand (%)	cl/sa	Fs/Cs
mean	11.7	2.5	3.5	44.9	37.4	85.8	0.14	1.22
Min.	7.2	1.5	1.5	38.8	31.8	82.5	0.08	0.88
Max.	15.7	3.2	5.0	51.2	45.6	89.8	0.20	1.59
SE	2.2	0.6	1.0	3.8	4.1	1.9	0.03	0.22

Table 3-4. **Characteristics** of profile, T-1-01

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.0	18.6	0.00	0.09	0.10	0.03	0.32	0.54	40.7	6.9	0.18	0.05
2	4.0	17.9	0.00	0.06	0.06	0.02	0.81	0.95	42.9	6.2	0.11	0.05
3	4.1	18.0	0.00	0.06	0.10	0.04	0.48	0.68	29.4	6.2	0.05	0.02
4	4.2	15.7	0.00	0.07	0.07	0.06	0.36	0.56	35.7	6.2	0.05	0.02
5	4.2	18.6	0.00	0.09	0.12	0.06	0.16	0.43	62.8	6.9	0.04	0.02

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	4.9	1.5	3.1	49.5	40.9	0.05	1.21
2	15.7	1.7	2.4	38.8	41.4	0.20	0.94
3	14.3	2.1	3.0	40.9	39.7	0.18	1.03
4	12.4	1.9	4.2	45.8	35.6	0.15	1.28
5	12.2	1.9	4.3	45.4	36.2	0.15	1.26



Brief description of profile

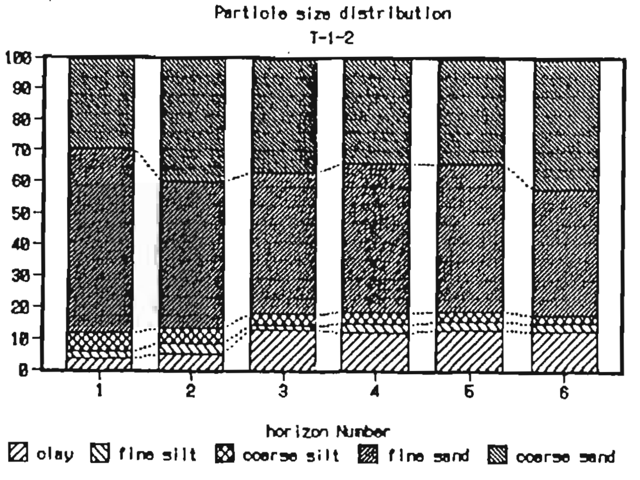
Geo-unit 2a, slope 4%, soil type, dRs
Transition area bettween erosion area and millet field.
Fine sand crust with algae

1;A. Sand, 2.5YR4/6, 32cm,
2;B21. Sandy clay loam, 1.25YR4/8, 32-112cm
3;B22. Sandy loam, 1.25YR5/8, 112-160cm,
4;B23. Loamy sand, 2.5YR5/8, 230cm
5;B24. Loamy sand, 2.5YR6/8, 270+

Table 3-5. **Characteristics** of profile, T-1-2

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.8	46.4	0.00	0.17	0.31	0.13	0.00	0.61	100	9.9	0.30	0.03
2	3.8	27.4	0.00	0.07	0.06	0.02	0.60	0.75	20.0	6.2	0.17	0.03
3	3.9	25.1	0.00	0.05	0.03	0.02	0.97	1.07	9.3	1.9	0.11	0.01
4	4.0	30.0	0.00	0.06	0.05	0.02	0.65	0.78	16.7	8.1	0.06	0.02
5	4.0	26.9	0.00	0.06	0.05	0.01	0.71	0.83	14.5	8.7	0.06	0.02
6	4.1	30.4	0.00	0.06	0.12	0.03	0.62	0.83	25.3	10.0	0.06	0.02

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	3.8	2.1	5.9	59.1	29.1	0.04	2.03
2	5.0	3.4	4.8	46.7	40.2	0.06	1.16
3	13.0	1.5	3.8	44.9	36.8	0.16	1.22
4	12.0	2.4	3.6	47.7	34.3	0.15	1.39
5	12.8	2.7	3.4	47.4	33.7	0.16	1.42
6	12.7	2.5	2.7	40.3	41.8	0.15	0.97



Brief description of profile

Geo-unit 2b, slope 0.5%, soil type dRs
Lower part of the hill-foot slope
Millet field
Loose sand as Ap horizon with colluvial sand deposit

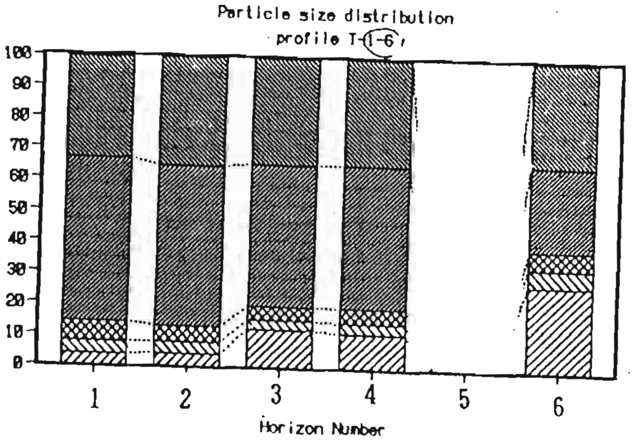
1:A11p(or colluvial sand), Sand, 0-9cm
2:A12, Loamy sand, 5YR4/6, 9-40cm
3:B21, Loamy sand, 2.5YR5/8, 40-110cm
4:BC, Loamy sand, 5YR6/8, 110-167cm
5:C1, Sandy loam, 7.5YR7/8, 167-210cm
6:C2, Sandy loam, 10YR7/6, 210-270+

*Yellow soft sandy nodule in C2 is common(size 10-15mm)

Table 3-6. **Characteristics** of profile, T-1-6

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	5.2	38.0	0.00	0.17	0.44	0.13	0.01	0.75	98.7	9.4	0.21	0.04
2	4.3	17.8	0.00	0.06	0.12	0.05	0.18	0.41	56.1	6.9	0.11	0.02
3	4.0	28.4	0.00	0.04	0.11	0.05	0.85	1.05	19.0	8.1	0.11	0.01
4	4.1	36.5	0.00	0.06	0.10	0.04	0.50	0.70	28.6	12.5	0.07	0.01
5												
6	4.3	27.7	0.00	0.03	0.45	0.33	0.36	1.17	69.2	10.6	0.16	0.03

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	3.8	4.0	6.4	52.8	33.0	0.04	1.60
2	4.1	3.7	5.2	51.5	35.5	0.05	1.45
3	12.1	3.1	4.3	45.9	34.6	0.15	1.33
4	11.2	3.2	4.8	46.2	34.6	0.14	1.33
5							
6	27.4	5.4	5.8	27.4	34.6	0.45	0.80



Brief description of profile

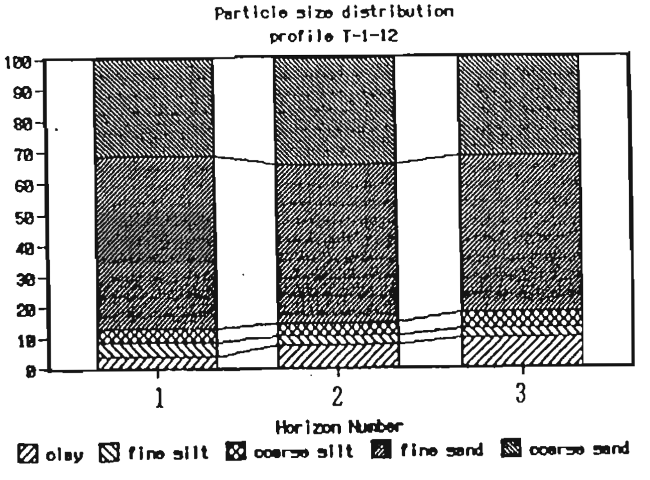
Geo-unit 3a, slope 2%, soil type, mBs
Fallow by Zuiera spps. with herbs.
Coarse sand deposits with lamellar structure (2cm depth)
with algae surface

1:A11 (2-5cm), Sand, 10YR4/6,
2:A12 (5-30/35cm), Sand, 10YR4/6,
3:B2 (30/35-90/100cm), Sandy loam, 5(7.5)YR5/8
4:BC (90/100-112cm), Loamy sand, 7.5YR6/6
5:D1 (112-142cm), Irregular yellowish nodule layer)
6:2C (142-185cm), Sandy clay, Mottled clayey layer.

Table 3-7. **Characteristics** of profile, T-1-12

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.2	16.3	0.04	0.05	0.96	0.16	0.26	1.47	82.3	3.8	0.15	0.07
2	4.1	17.8	0.05	0.02	0.04	0.02	0.50	0.18	72.2	4.0	0.10	0.02
3	4.1	12.8	0.01	0.01	0.04	0.03	0.39	0.48	18.8	3.8	0.07	0.01

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	3.7	4.7	4.4	55.6	31.7	0.04	1.76
2	7.2	3.0	3.9	51.2	34.7	0.08	1.47
3	9.5	2.9	5.0	50.7	31.8	0.11	1.59



Brief description of profile

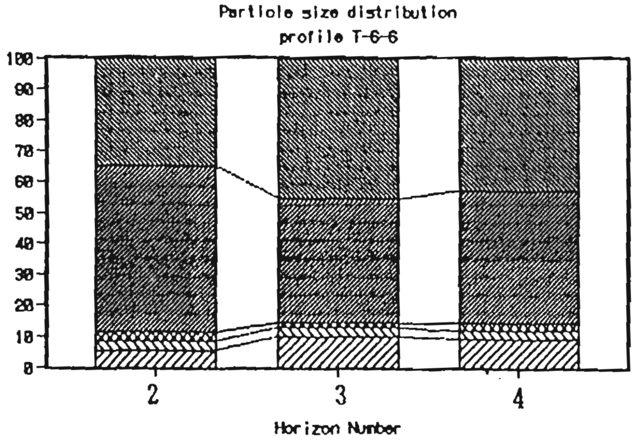
Geo-unit 3a, slope 0-0.5%, Soil type mBs
Ctenium. spps with sporadical Guiera spps.
Sand deposits with lamellar stutucture of alternative coarse and fine sand(2cm) with Algae crust on the surface

1;A (2-22), Sand, 5YR4/8.
2;B21 (22-90), Loamy sand, 5YR5/8
3;B22 (90-120), Loamy sand, 5YR5/8
4;D (120-170+), Sandy cemented layer,

Table 3-8. Characteristics of profile, T-6-6

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.8	34.3	0.00	0.11	0.12	0.09	0.00	0.32	100	7.7	0.05	0.00
2	4.0	23.3	0.01	0.06	0.08	0.02	0.41	0.58	29.3	5.3	0.15	0.01
3	4.1	24.5	0.00	0.06	0.09	0.05	0.52	0.72	27.8	4.0	0.11	0.01
4	4.3	15.9	0.00	0.03	0.11	0.17	0.08	0.39	79.5	5.3	0.05	0.00

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1							
2	5.4	3.0	2.8	53.9	34.9	0.06	1.54
3	9.9	2.8	1.5	40.2	45.6	0.12	0.88
4	9.2	2.7	2.4	42.9	42.7	0.11	1.01



Brief description of profile

Geo-unit 1c, slope 0-0.5%, soil type mRs
Millet field
Loose sand cover, or run-off crust with coarse sand and fine sand(2mm).
Existance of erosion crust surface near the pit

1;A11p?, loose sand on the surface
2;A12 (0-30), Loamy sand, 5YR4/6
3;B21 (30-95), Loamy sand, 2.5YR4/8
4;B22 (95-190), LOmay sand, 2.5YR4/8
(5);D (190-210+), Continuous sandy cemented layer

Table 3-9. General characteristics of white sandy soils

White sandy soils, A horizons (sample Nb.4)

	pH (H2O)	pH (KCl)	EC (1:5)	A.ac (me/100g)	Ex. cations(me/100g) Na	K	Ca	Mg	T-B (me/100g)	ECEC	SR (%)	av.P (mg/kg)	T-C (%)	T-N (%)
mean	5.4	4.7	18.6	0.05	0.03	0.11	0.12	0.05	0.26	0.36	85.4	4.7	0.12	0.04
Min.	4.7	4.0	16.4	0.00	0.00	0.06	0.01	0.03	0.14	0.16	60.9	0.0	0.06	0.00
Max	6.0	5.7	24.5	0.18	0.08	0.17	0.19	0.08	0.38	0.46	100.0	9.7	0.18	0.06
SE	0.5	0.7	3.2	0.09	0.04	0.46	0.08	0.02	0.10	0.14	17.1	0.5	0.05	0.03

1)A.ac:active acidity, 2)T-B:total exchangeable bases, 3)SR:base sturation ratio to ECEC, 4)av.P:available P2O5, 5)T-C:total carbon, 6)T-N:total nitrogen

White sandy soils, sub-surface horizons (sample Nb.13)

	pH (H2O)	pH (KCl)	EC (1:5)	A.ac (me/100g)	Ex. cations(me/100g) Na	K	Ca	Mg	T-B (me/100g)	ECEC	SR (%)	av.P (mg/kg)	T-C (%)	T-N (%)
mean	6.0	5.0	32.3	0.12	0.10	0.16	0.45	0.14	0.85	0.96	75.6	6.0	0.07	0.03
Min.	4.7	4.0	11.7	0.00	0.00	0.01	0.01	0.00	0.07	0.10	12.7	4.0,	0.00	0.01
Max	8.9	7.9	145.9	0.48	0.88	0.47	2.08	0.45	3.60	3.60	100.0	9.3	0.14	0.08
SE	1.5	1.3	36.4	0.17	0.24	0.17	0.63	0.17	1.10	1.05	30.8	1.33	0.04	0.02

Particles size distribution, A horizons (sample Nb.3)

	clay (%)	F.silt (%)	C.silt (%)	F.sand (%)	C.sand (%)	T.sand (%)	cl/sa	Fs/Cs
mean	2.7	2.6	5.7	48.4	40.4	94.5	0.03	2.50
Min.	2.3	2.1	3.1	35.5	11.7	92.9	0.02	0.62
Max.	3.2	3.2	9.5	71.8	57.0	95.6	0.04	6.16
SE	0.47	0.56	3.36	20.3	25.0	1.4	0.01	3.17

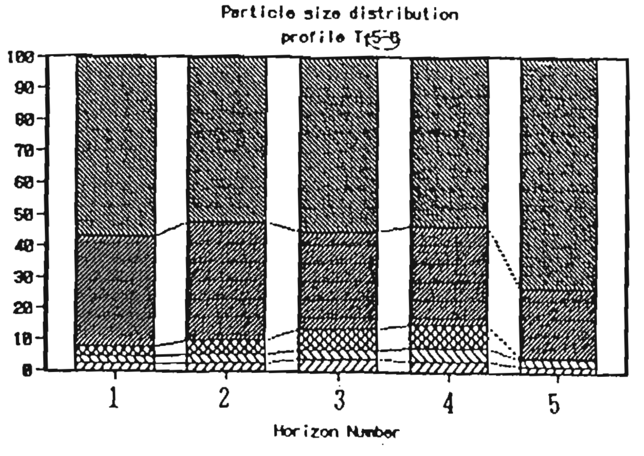
Particle size distribution, underlayer (samle Nb.12)

	clay (%)	F.silt (%)	C.silt (%)	F.sand (%)	C.sand (%)	T.sand (%)	cl/sa	Fs/Cs
mean	6.2	3.6	7.5	52.1	30.6	90.3	0.08	12.95
Min.	0.4	1.8	0.3	22.6	0.8	73.8	0.00	0.31
Max.	19.7	6.5	16.4	85.1	73.1	96.7	0.34	102.94
SE	5.6	1.4	4.9	19.4	24.4	6.3	0.09	28.90

Table 3-10. Characteristics of profile, T-5-6

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	5.7	24.5	0.00	0.11	0.19	0.08	0.00	0.38	100	9.7	0.15	0.00
2	4.5	17.0	0.00	0.09	0.01	0.04	0.02	0.16	87.5	3.1	0.06	0.04
3	4.1	15.1	0.00	0.06	0.01	0.00	0.48	0.55	12.7	5.6	0.05	0.02
4	4.2	11.7	0.00	0.03	0.08	0.02	0.16	0.29	44.8	5.3	0.05	0.01
5	4.3	13.8	0.00	0.04	0.07	0.03	0.05	0.19	73.7	7.7	0.04	0.02

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	2.3	2.1	3.1	35.5	57.0	0.02	0.62
2	2.5	2.5	4.5	38.0	52.5	0.03	0.72
3	3.8	3.0	6.6	31.3	55.2	0.04	0.57
4	3.2	4.1	7.3	31.6	53.8	0.04	0.59
5	1.8	2.2	0.3	22.6	73.1	0.02	0.31



Brief description of profile

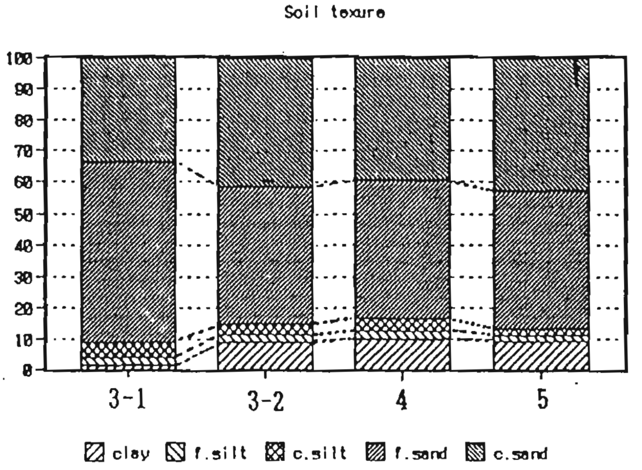
Geo-unit 5, slope 0%, soil type dWs
Millet field
Loose sand with destroyed slakking

1;A11p (0-2), Sand, white loose sand with destroyed slakking
2;A12 (2-45), Sand, 10YR5/3
3;C1 (45-120), Sand, 10YR5/4
4;C2 (120-220), Sand, 10YR5/4
5;C3 (220-300+), Sand, 10YR8/4 + bright bright mottle(40%)

Table 3-11. **Characteristics** of profile, T-3-44

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.4	16.4	0.08	0.17	0.10	0.05	0.03	0.43	93.0	0.0	0.10	0.06
2	4.0	13.4	0.17	0.22	0.13	0.06	0.36	0.94	61.7	6.4	0.11	0.08
3-1	4.6	19.6	0.00	0.06	0.06	0.04	0.01	0.17	94.1	5.2	0.03	0.04
3-2	4.2	33.2	0.01	0.38	0.34	0.19	0.08	1.00	92.0	5.8	0.10	0.06
4	7.3	50.9	0.11	0.47	1.07	0.41	0.00	2.06	100	6.4	0.11	0.01
5	6.5	29.2	0.12	0.43	1.16	0.45	0.00	2.16	100	4.0	0.04	0.05

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1							
2							
3-1	1.6	2.7	4.7	57.7	33.4	0.02	1.73
3-2	8.9	2.7	3.5	43.5	41.4	0.11	1.05
4	9.8	2.5	3.9	43.8	40.0	0.12	1.10
5	9.4	1.8	2.1	43.8	43.0	0.11	1.02



Brief description of profile

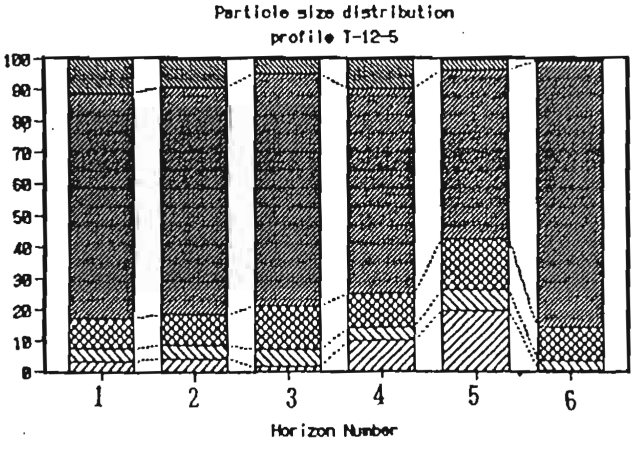
Geo-unit 5, slope 0.5%, soil type dWs
Millet field
Loose bright yellowish brown sand(2cm deep, A11p)
on the weakly-massive sand(3cm deep, A12)

1:A13 (5-27), Sand, 10YR5/4
2;C1 (27-91), Sand, 10YR4/4
3-1:C2 (91-130/155), Sand, 10YR7/4
3-2 with brown mottle phase, loamy sand, 10YR5/6
4;C3 (130/155-200/210), Loamy sand, 10YR4/4
5;C4 (200/210-230+), Loamy sand, 10YR5/3

Table 3-12. **Characteristics** of profile, T-12-5

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.0	16.6	0.02	0.06	0.17	0.03	0.18	0.46	60.9	5.9	0.18	0.04
2	4.0	15.3	0.00	0.01	0.08	0.02	0.35	0.46	23.9	6.5	0.11	0.04
3	4.2	14.1	0.00	0.01	0.06	0.01	0.02	0.10	80.0	5.3	0.05	0.02
4	5.4	43.6	0.00	0.11	0.63	0.16	0.00	0.90	100	5.3	0.11	0.02
5	7.9	145.9	0.88	0.27	2.08	0.37	0.00	3.60	100	9.3	0.14	0.01
6	4.7	13.8	0.00	0.01	0.10	0.01	0.00	0.12	100	5.3	0.00	0.03

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	3.2	3.9	9.5	71.8	11.7	0.04	6.16
2	4.2	4.6	10.0	72.5	8.7	0.05	8.34
3	1.5	5.5	13.9	74.2	5.0	0.02	14.95
4	10.0	4.2	11.0	65.3	9.5	0.13	6.85
5	19.7	6.5	16.4	54.0	3.4	0.34	15.97
6	0.4	2.9	10.8	85.1	0.8	0.00	102.94



Brief description of profile

Geo-unit 5, slope 0%, soil type dWs
Herbecious vegetation with Combretum spps.
Destroyed sllaking suraface of loose graish sand(5mm),
60% of black litter coverage on the surface

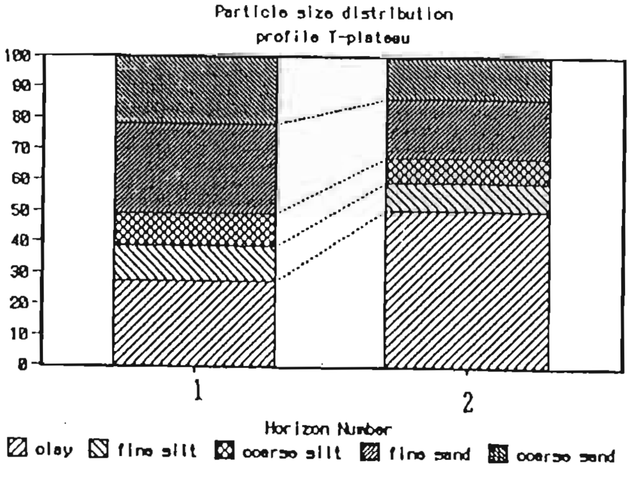
1:A (0-40?), Sand, 10YR5/4
2;AC (40?-95/100), Sand, 7.5YR6/6
3;C1 (95/100-110/115), Sand, 10YR7/2
4;C2 (110/115-123), Loamy sand, 10YR5/4, yellow mottle
5;C3 (123-150), Sandy clay loam, 10YR6/2, cemented
6;C4 (150-250+), Sand, 10YR8/1, single grain

*The alluvial terrace has two hight levels, and this pedon
is located at the lower terrace near the dried V-type valley
*The sand fraction is very fine through the profile

Table 3-13. **Characteristics** of profile, Plateau-1

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	3.7	36.3	0.00	0.23	0.52	0.21	1.11	2.07	46.4	32.2	0.36	0.06
2	3.7	26.3	0.00	0.13	0.23	0.17	3.13	3.68	14.4	13.8	0.45	0.11

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	27.2	11.2	10.8	29.0	21.8	0.54	1.33
2	50.3	9.3	8.3	18.8	13.3	1.56	1.41



Brief description of profile

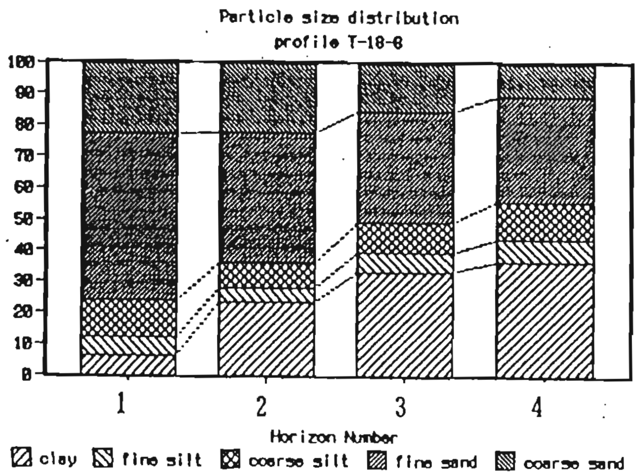
Geo-unit 1a, slope 0%, soil type Rc
Bare eroded land between tiger bushes
Erosion crust on the surface

1;B2(?) (0-2), Sandy clay, 5YR5/8
2;2C1(?) (2-25/35), Heavy clay, 5YR6/8, stony(50%)
(3);3C2(?) (25/35-55+), Stony layer of crust fragment

Table 3-14. **Characteristics** of profile, T-18-8

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P205 (mg/kg)	T-C (%)	T-N (%)
1	3.9	20.4	0.00	0.07	0.16	0.06	0.35	0.64	45.3	7.7	0.16	0.02
2	3.7	32.8	0.00	0.04	0.10	0.06	1.24	1.44	13.9	6.5	0.16	0.01
3	3.8	28.4	0.01	0.03	0.04	0.02	1.27	1.37	7.2	6.5	0.11	0.03
4	4.0	19.8	0.04	0.04	0.12	0.03	1.25	1.48	15.5	4.6	0.11	0.03

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	6.1	5.8	11.5	53.8	22.7	0.08	2.37
2	23.2	4.6	8.1	41.9	22.2	0.36	1.89
3	32.8	6.2	10.1	35.5	15.4	0.64	2.31
4	36.1	7.5	12.1	33.6	10.6	0.82	3.16



Brief description of profile

Geo-unit 3a, slope 1%, soil type sRs
Bare eroded land (70%) with with sporadical vegetation (30%) like Zuiera spps.
Run-off crust by coarse sand and fine sand on the loose sand (5mm)

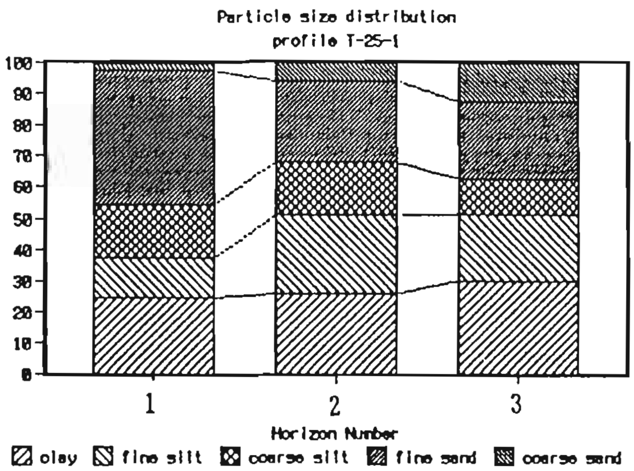
1;A (0-33), Loamy sand, 7.5YR4.5/6
2;2B21 (33-95), Sandy clay loam, 2.5YR5/8
3;2B22 (95-150), Sandy clay, 3.75YR5/8
4;2BC (150-165+), Sandy clay, 3.75YR5/8

* From 2B21, the ancient clayey soil appears

Table 3-15. **Characteristics** of profile, T-25-1

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.2	43.5	0.04	0.52	1.19	0.46	0.32	2.53	87.4	23.3	1.22	0.12
2	4.5	18.2	0.05	0.18	1.66	0.56	0.12	2.57	98.9	14.3	0.71	0.08
3	3.9	23.4	0.05	0.11	0.85	0.57	0.97	2.55	62.0	4.4	0.36	0.02

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	24.6	12.7	17.0	43.3	2.3	0.54	18.46
2	25.8	25.0	16.8	26.3	6.1	0.80	4.29
3	30.0	21.1	11.5	25.2	12.2	0.80	2.06



Brief description of profile

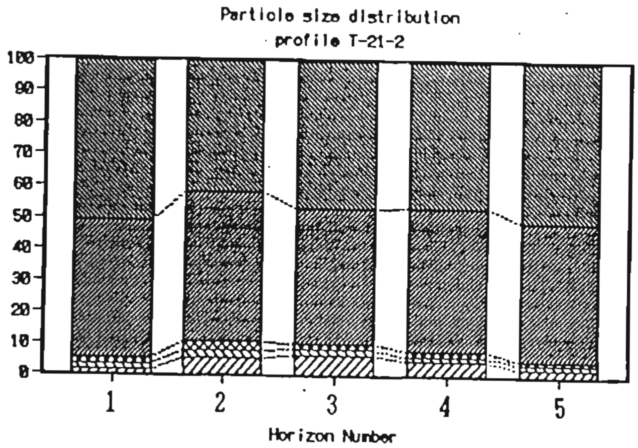
Geo-unit 8, slope 0%, soil type Bc
Dense bush with herbecious vegetation
Run-off crust covered by litters on the surface

1;A11 (0-9), Sandy clay loam, lamellar structure
by fine particle layer(7.5YR4/6) and coarse layer(7.5YR6/4)
2:A12 (9-49), Clay loam, 7.5YR4/4
3:B2 (49-80+), Light clay, 5YR4/6

Table 3-16. **Characteristics** of profile, T-21-2

No	pH (KCl)	EC (1:5)	Na	K	Ca	Mg	Active acidity	ECEC (me/100g)	V (%)	P2O5 (mg/kg)	T-C (%)	T-N (%)
1	4.8	17.8	0.00	0.07	0.14	0.08	0.00	0.29	100	7.7	0.10	0.03
2	4.0	17.0	0.00	0.04	0.01	0.01	0.48	0.53	11.3	5.3	0.11	0.01
3	4.0	13.4	0.01	0.04	0.05	0.03	0.59	0.72	18.1	5.3	0.06	0.02
4	4.4	10.2	0.00	0.03	0.03	0.02	0.21	0.29	27.6	4.0	0.01	0.03
5	4.2	15.9	0.00	0.03	0.00	0.03	0.21	0.27	22.2	7.7	0.00	0.02

No	Clay	f.Silt	c.Silt	f.Sand	c.Sand	Clay Sand ratio	fine-coarse Sand ratio
1	1.5	1.7	1.7	43.9	51.3	0.02	0.86
2	5.0	2.5	2.5	47.9	42.0	0.06	1.14
3	6.4	1.8	1.9	43.2	46.7	0.07	0.92
4	4.5	1.6	1.7	45.8	46.3	0.05	0.99
5	2.1	1.5	1.2	44.4	50.8	0.02	0.88



Brief description of profile

Geo-unit 7c, slope 0%, soil type dBbs
Millet field.
Loose sand on the surface(A11p 3cm deep)

1;A11p (0-3), Sand, loose
2;A12 (3-26), Sand, 7.5YR4/6
3;B2 (26-105), Loamy sand, 7.5YR5/8
4;BC (105-165), Sand, 7.5YR5/6
5;C (165-260+); Sand, 10YR6/6

* Existence of fossilized pland fragment.

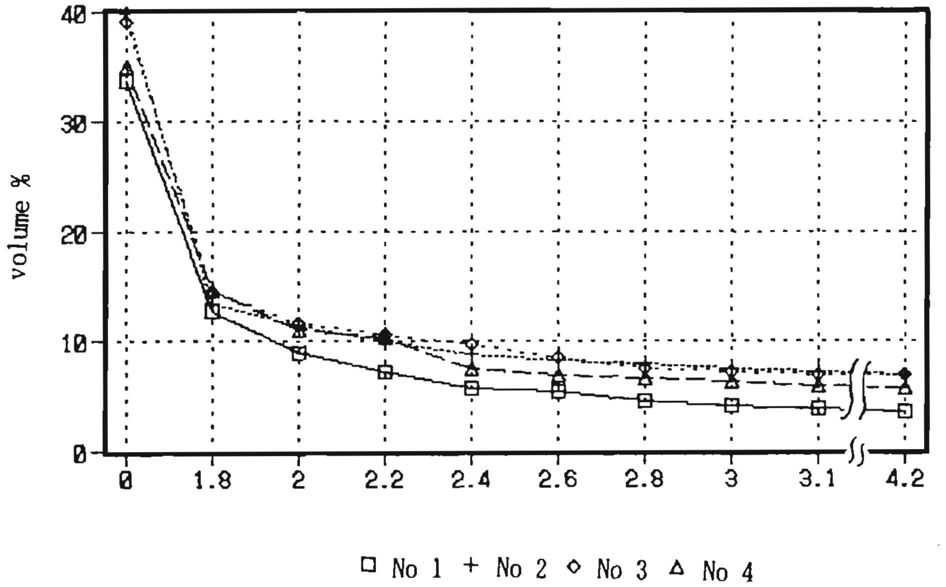


Fig. 3-24(a) pF-water content curve, pit. T-1-01

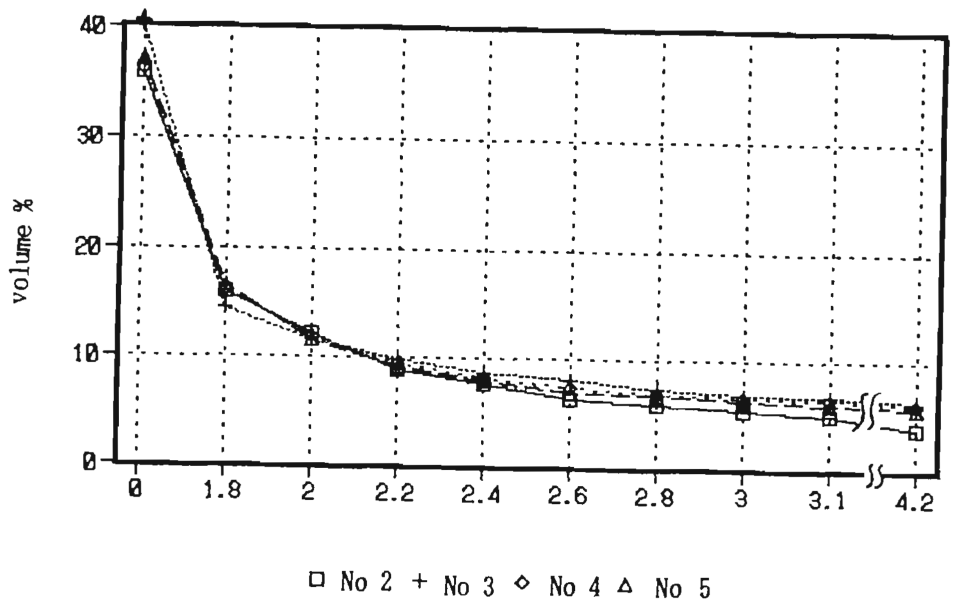


Fig. 3-24(b) pF-water content curve, pit. T-1-2

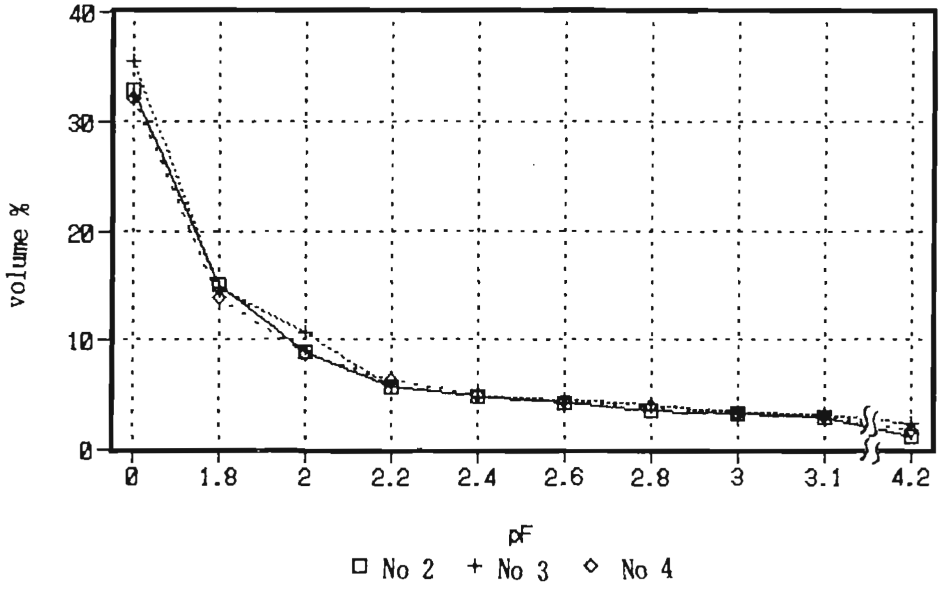


Fig. 3-24(c) pF-water content curve, pit. T-5-6

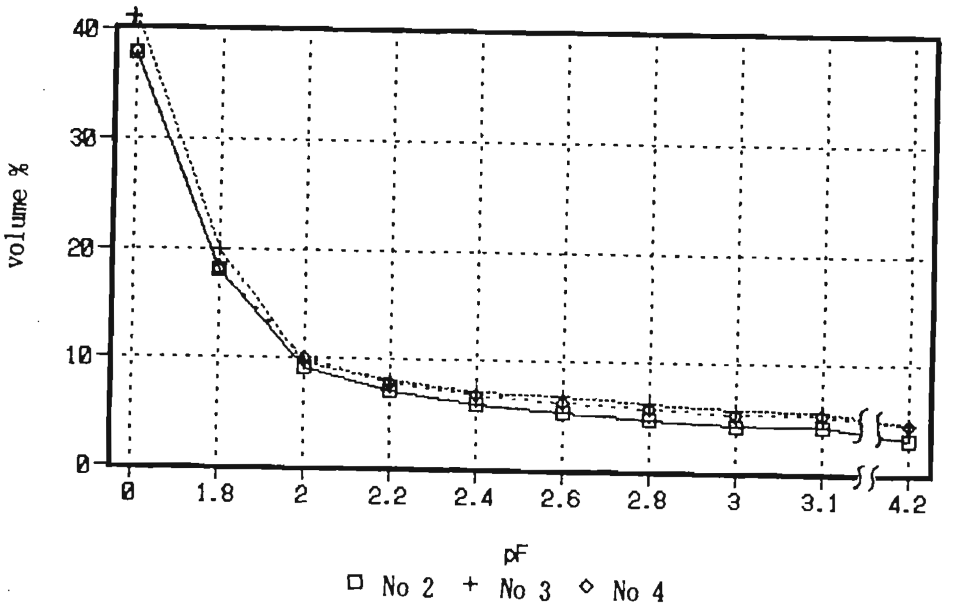


Fig. 3-24(d) pF-water content curve, pit. T-6-6

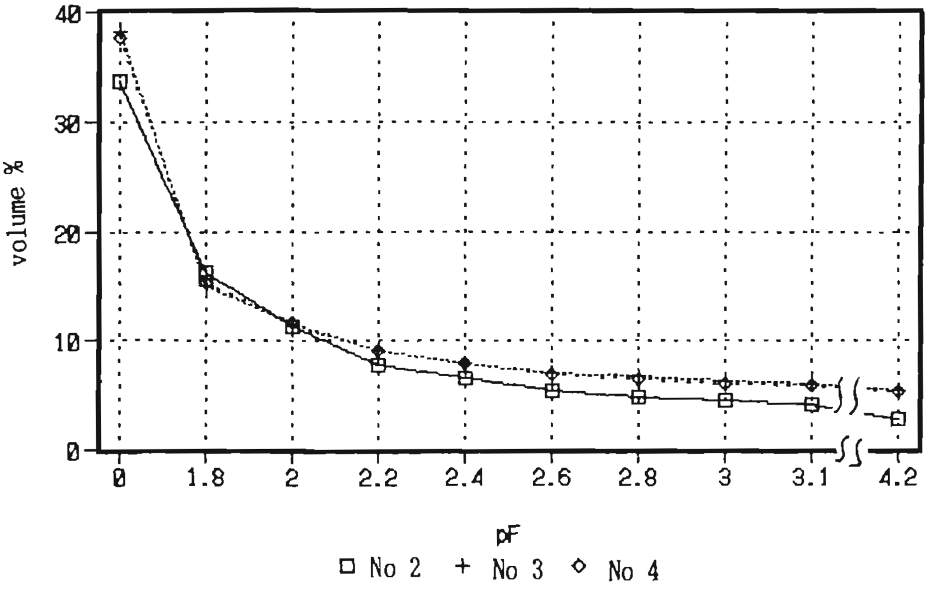


Fig. 3-24(e) pF-water content curve. pit. T-1-6

Fig 3-17 Physical and hydraulic properties of Sandy soils

Sample name	AD (g/cm3)	Clay (%)	Silt (%)	F.sand (%)	C.sand (%)	W(pF1.8) (v%)	W(pF4.2) (v%)	WHC (v%)	SHC (*10⁻³cm/s)
T-1-01.1(A)	1.61	4.9	4.6	49.5	40.9	12.7	3.5	9.2	5.6
2(B21)	1.45	15.7	4.1	38.8	41.4	13.4	7.0	6.4	11.0
3(B22)	1.41	14.3	5.1	40.9	39.7	14.4	7.0	7.4	10.0
4(B23)	1.47	12.4	6.1	45.8	35.6	14.6	5.7	8.9	5.8
T-1-2. 2(A12)	1.57	5.0	8.2	46.7	40.2	15.9	3.8	12.1	4.5
3(B21)	1.45	13.0	5.3	44.9	36.8	14.5	6.3	8.2	8.6
4(B22)	1.50	12.0	6.0	47.7	34.3	16.1	6.1	10.0	5.5
5(BC)	1.47	12.8	7.1	47.4	33.7	16.6	5.8	10.8	7.4
T-1-6 2(A12)	1.62	4.1	8.9	51.5	35.5	16.3	2.8	13.5	3.1
3(B21)	1.47	12.1	7.4	45.9	34.6	15.1	5.5	9.6	6.5
4(B22)	1.49	11.2	8.0	46.2	34.6	15.3	5.3	10.0	6.9
T-6-6 2(A12)	1.63	5.4	5.8	53.9	34.9	18.1	3.1	14.9	8.3
3(B21)	1.50	9.9	4.3	40.2	45.6	20.0	4.6	15.3	14.0
4(B22)	1.67	9.2	5.1	42.9	42.7	18.0	4.5	13.6	11.0
T-5-6 2(A12)	1.58	2.5	7.0	38.0	52.5	15.1	1.2	13.9	--
3(C1)	1.48	3.8	9.6	31.3	55.2	14.7	2.4	12.3	18.0
4(C2)	1.49	3.2	11.4	31.6	53.8	13.9	1.8	12.1	--

1)AD:apparent density, 2)W(pF1.8 or 4.2):volumetric % of water content at each pF,
3)WHC :W(pF1.8)-W(4.2), 4)SHC:saturated hydraulic conductivity

Fig. 3-18 Water Holding Capacity of sandy layer

Pit No	WHC (mm)	depth (cm)
T-1-0	153	200
T-1-2	188	200
T-1-6	120	112
T-6-6	273	190
T-5-6	249	200

1)WHC:Water holding capacity
2)depth:considered until 2m or limit of sandy layer

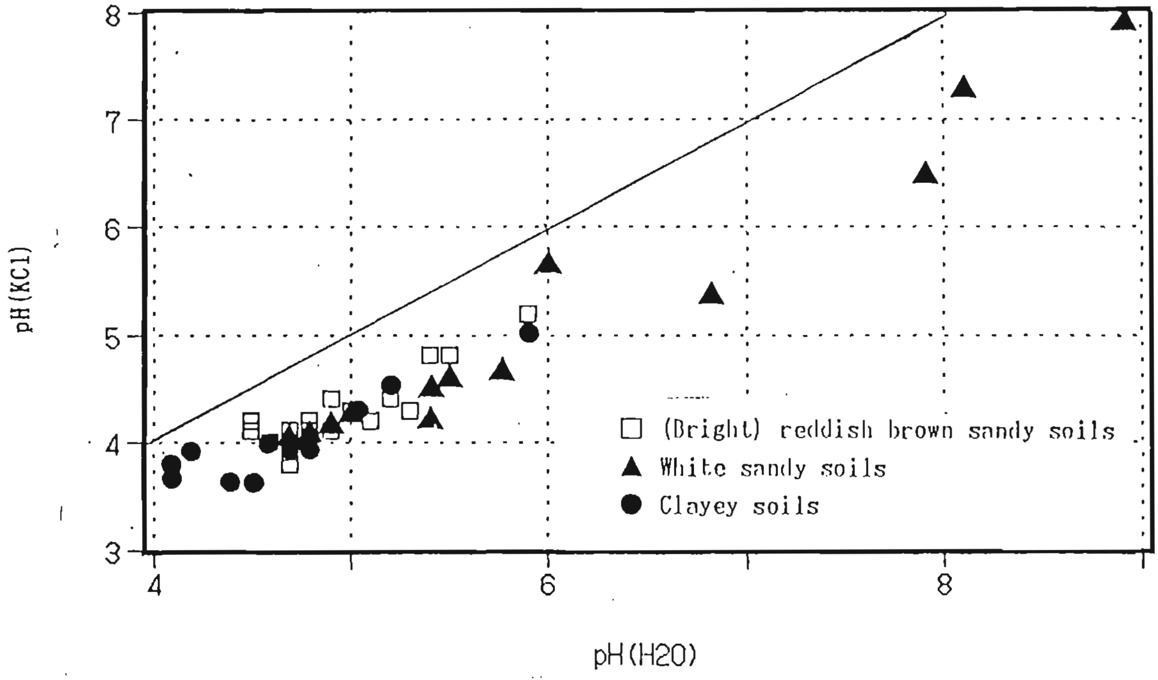


Fig.3-25 Relationship between pH(H2O) and pH(KCl)

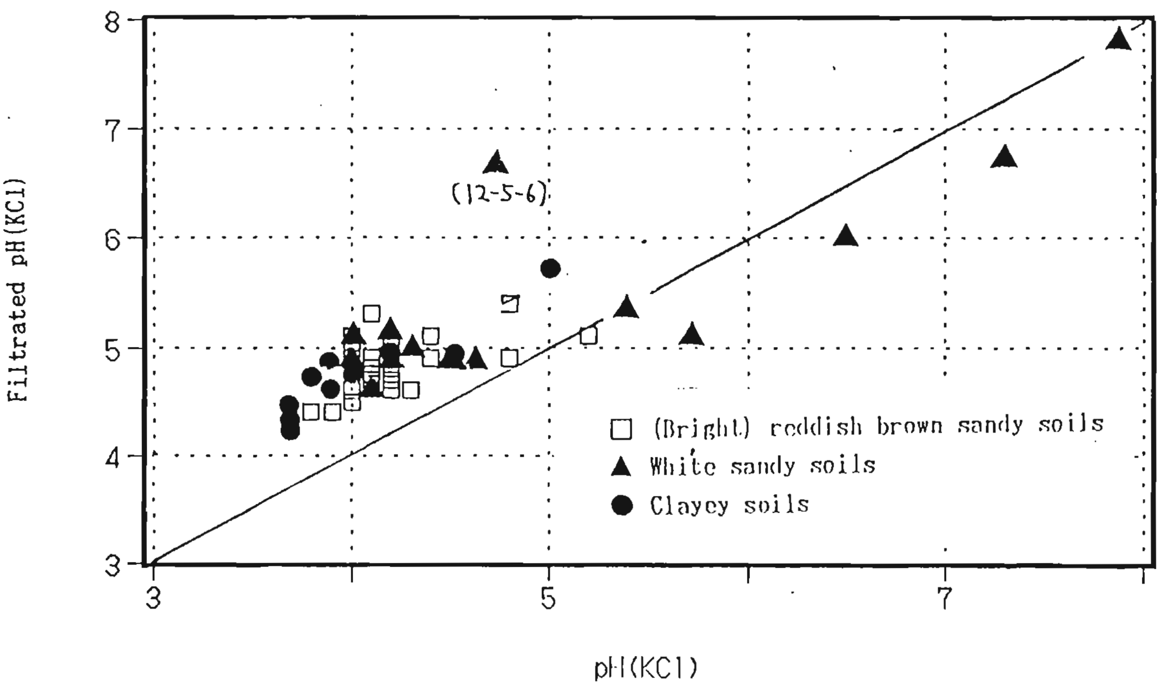


Fig. 3-26 Relationship between pH(KCl) and pH(KCl) of filtrated solution for active acidity

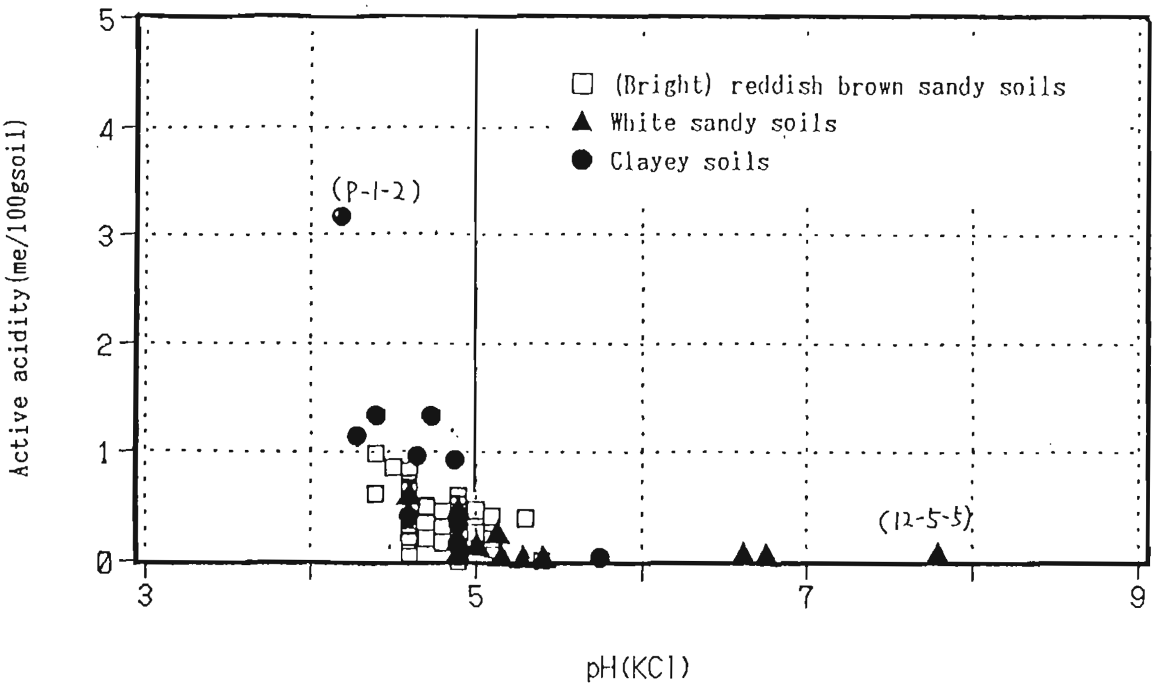


Fig. 3-27 Relationship between pH(KCl) and active asidity

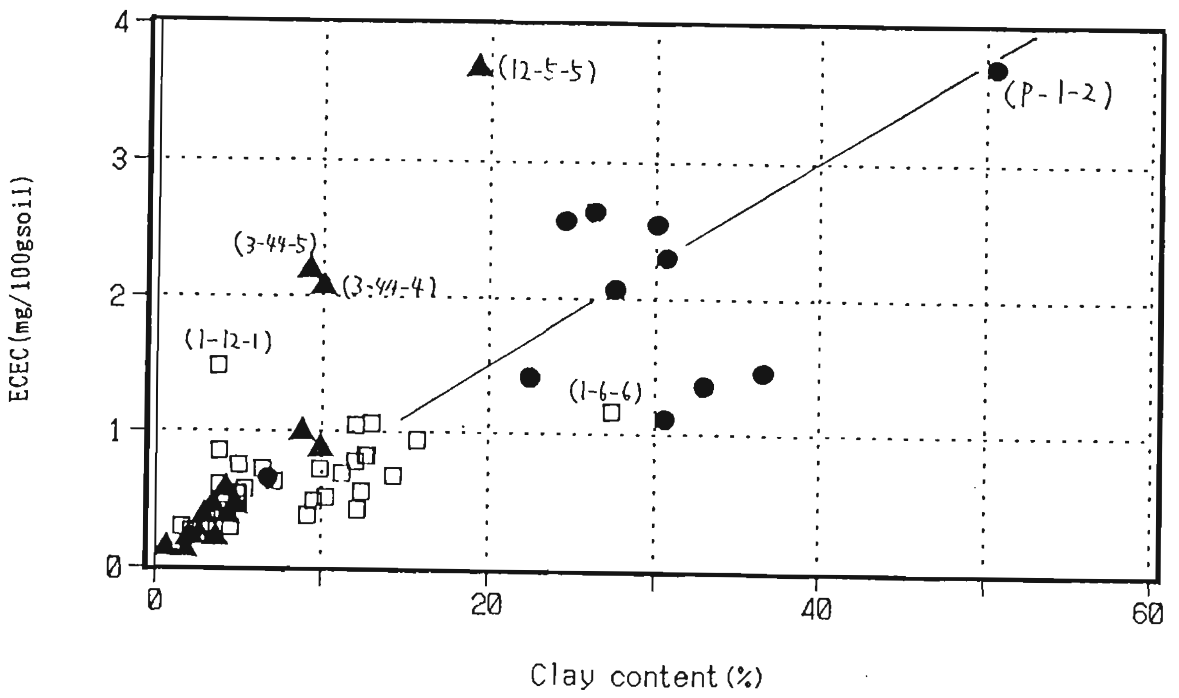


Fig. 3-28 Relationship between Clay cntent and ECEC

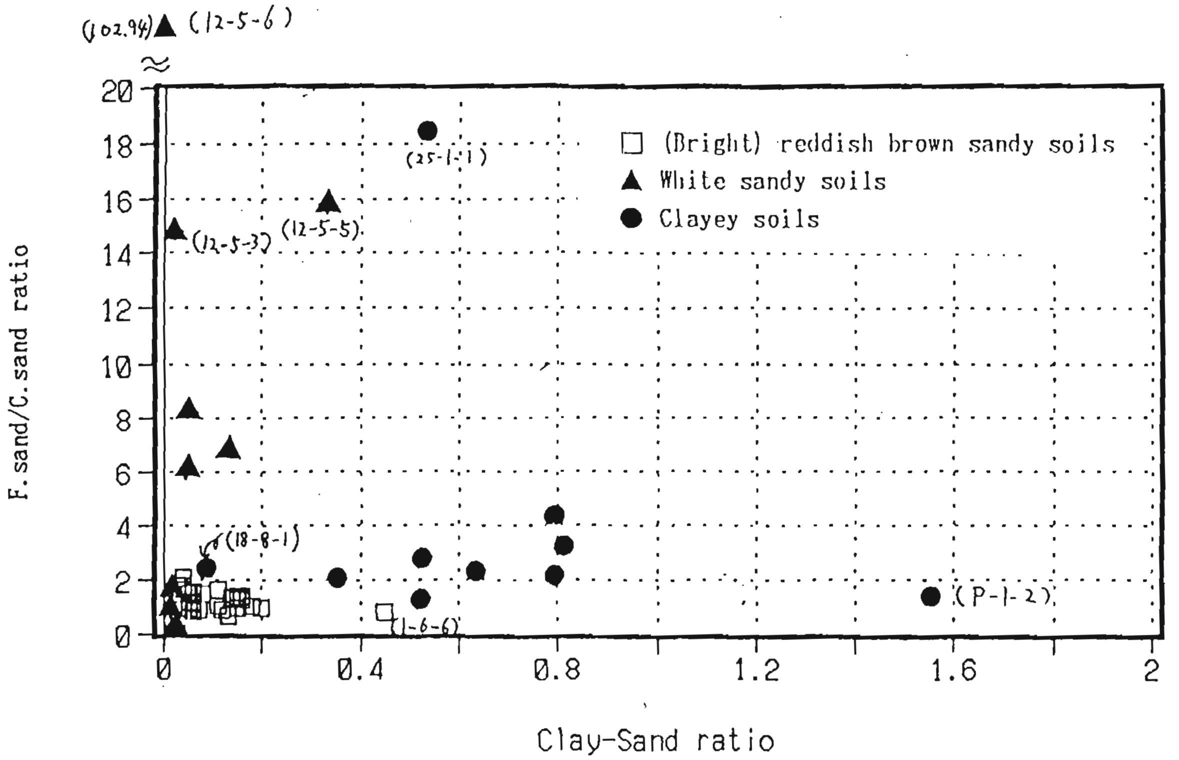


Fig.3-29 Relationship between clay-sand ratio and fine sand-coarse sand ratio

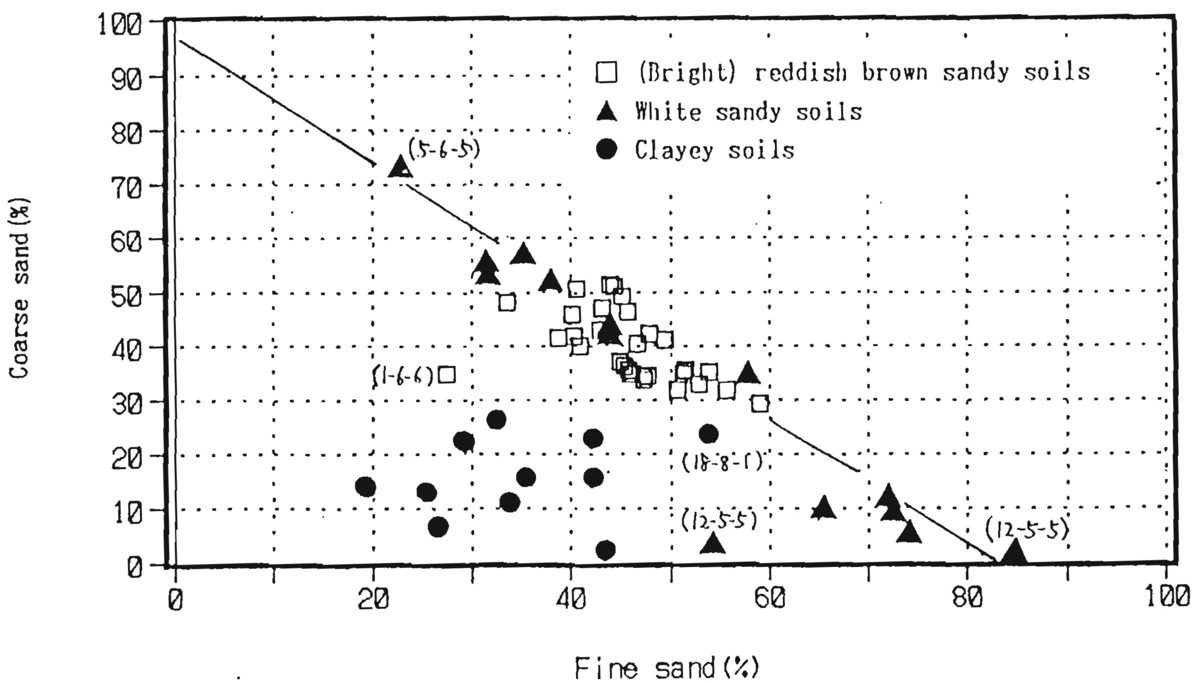


Fig.3-30 Relationship between fine sand and coarse sand ratio

Table 3-19. Mineralogy of clay fraction

Sample name		K	Kd	I	G	H	A	R	Q	S	In
Aeolian soils											
T-1-01	2(B21)	-	**	t	**	*	*	*	*	-	-
T-1-2	1(A11)	**	**	*	*	**	**	*	**	-	-
	2(A12)	**	-	t	**	**	**	**	**	-	-
	3(B21)	**	-	t	**	**	*	t	*	-	-
	4(B22)	**	-	t	**	-	*	-	*	-	-
	5(B23)	-	**	-	*	-	t	-	*	-	-
	6(BC)	-	**	t	*	-	t	-	*	-	-
T-1-3	6(2C)	**	-	t	***	-	t	t	*	-	t
T-1-6	3(B2)	**	**	t	**	-	*	t	**	-	-
	5(2C)	-	**	t	***	-	t	t	*	-	-
T-6-6	2(B21)	-	**	t	**	*	t	t	*	-	-
Alluvial soils											
T-5-6	3(C1)	**	**	t	**	-	t	t	***	t	t(?)
T-12-5	3(C1)	-	**	t	t	-	**	**	***	t	-
T-12-5	5(C3)	-	***	-	t	-	t	-	*	-	*
Clayey soils											
T-18-8	2(B2)	-	**	t	***	-	t	t	*	-	t
	4(C)	**	**	t	***	-	t	t	t	-	-
Plat-1	2(B22)	**	-	t	*	-	t	t	**	-	t
T-25	2(B21)	**	-	t	**	-	*	-	**	-	t
T-3-32	3(C2)	**	-	-	***	-	t	-	*	-	-

Remark

K:Kaolinite, Kd:disordered Kaolinite, I:Illite, G:Goethite, H:Hematite, A:Anatase, R:Rutile, Q:Quartz, S:Smectite, In:irregularly-Interstratified mineral(Vermiculite or Chlorite-Illite-Smectite)

Indication; -:null, t:trace, *:a little, **:some, ***:a lot

Table 3-20 Geomorphological unit and soil characteristics

Geomorphological unit	Soil type	Slope (Form)	crustability	permeability	erodibility	rain water redistribution
Plateau	sRc	plane	high	low	already eroded	stagnating
hill-foot slope	dRs	moderate	moderate to low	moderate to low	high to moderate	internal drainage surface run-off
eroded pediplain	m/sBs	gentle to plane	moderate to low	moderate to low	high to moderate	internal drainage, surface run-off
non-eroded pediplain	dRs	gentle to plane	moderate to low	moderate to high	moderate to low	internal drainage,
alluvial terrace	dWs	plane	low	high	low	internal drainage

Remark
The evaluation is rough indications by general knowledge and observation.
As for chemical properties, almost every soil is acid,and poor in nutrition.

4 Hearing survey on the agricultural activities

4-1 Presentation of the village studied.

The hearing survey was conducted at Banizoumbou, which is one of villages in the studied area, to know the human activities, particularly, the agricultural ones.

Baizoumbou is located on the alluvial terrace along the dried river(T-3-44). A vast undulating pediplain extends behind the village.the border of which was surveyed by Ba (Ba, 1991) (Fig. 4-1). The land surface area of the village is 2,735ha, The population is 826 habitants with 106 of household. The population density is 30.2hab./km^2. Tondi Kiboro, a neighboring village, has a population of 252 habitants for 5,975ha of land surface. The population density is shown in Table 4-1 according to several references. It shows that Banizoumbou has a higher population density compared with the average in the savanna zone. In fact, Banizoumbou is one of large villages in the studied area, where a primary school is situated. While Tondi Kiboro, which is located on the sandy hill (T-5-5), has a larger land surface compared with its population.

According to Tierno, (1991), "Banizoumbou" means "peace descend" in the Zarma language. They came from Danchiando, which is the capital of subdistrict in the area, more than two century ago. The present chief of Banizoumbou is the sixth one (1991).

The villagers live as a farmer. The chief of the village is the master of the land. which is possessed by villagers. The land is inherited only by their sons. As the heritage succeeds, the each own land becomes smaller.

Outside the village, the Peul people lives dispersedly without forming a village. Tierno, (1991) surveyed the livestock breeders in Banizoumbou and Tondi Kiboro. Fig. 4-1 shows their location. The Peul people not only breeds the livestock, but also cultivates the millet field at the same time.

They live at the side of their farms, which are not their own lands, but the villager's

4-2 Method of the hearing survey

Through one of villagers, who spoke French, questions were done to a head of 24 households. (19 of Zarma, 5 of Peul). Twenty four households correspond to 24% of total households of Banizoumbou, and five households of Peul farmer correspond to 24% of total livestock breeders in the two villages.

The hearing was conducted mainly in the village, and sometimes on the field. The hearing items were as follows:

1) Number of field and their surface area

2) Cultivated area and their annual yield in 1991, and in the past, if possible.

3) Family composition

4) Number of labor for millet farming

5) Cropping system;

    preparation of the field

    seeding time

    weeding time

    harvesting time

    fertilization

6) How to decide to stop farming to leave the field as a fallow

7) Period of farming and fallowing

8) Main reasons of yield reduction

9) Livestock breeding

10) Hopes in their lives

(Condition of the hearing survey)

Although the object for hearing was not chosen statistically, the 24% of portion to the total household may be high enough to know the actual situation. But, when the hearing survey was conducted, a lot of young men were absent by their temporal leave to the town (Niamey, Abidjan) to earn the money. Then, the average age of people questioned was 50 years old.

As for the surface area of the cultivated land, it was always vague. The translator discussed with the people, and they estimated the value.

The yield is counted by the number of bundle of harvested millet head. They said that a bundle corresponds about 12 to 15 kg. In this paper, the value of 15kg/bundle was used here for the estimation of the yield.

Since the area of cultivated land and the amount of harvest were both vague, the yield is, therefore, not very accurate. But, the results will give some important suggestions.

As for the other crops such as cassava, cow pea and so on, they were not mentioned, because their cultivated area was limited.

4-3 Result

4-3-1 Holding land and millet farm area

The holding land area, farming area, and the yield are shown in Table 4-2. Their characteristics are as follows:

1) The Zarma farmers keep and cultivates more area of land, and gets less yield than those of the Peul farmer.

2) The variation of yield of the Zarma farmers is more than that of the Peul farmer.

3) The rate of the cultivated area to the land holding area is 75% and 80% for Zarma farmers and Peul farmers, respectively.

The difference mentioned above may be considered as follows.

a) Application of the dung of animals by the Peul farmers enables them to get a higher yield.

b) As the Peul farmers live just at the side of the farm, they can manage the farm well.

c) The Peul farmers cultivate a relatively small area. It also enables them to manage the farm well.

The Zarma farmers said that every land apart from the plateaux, is possessed by some villagers. Then, in order to get a new land, they have to ask to another village to lend it. More than 70% of the holding area was cultivated. This fact characterizes the present situation of land use.

4-3-2 Farm site

The Zarma farmer have 3 farms in average in different places. And, the Peul farmer has 1.4 farms. The Zarma farmer say that to have several farms separately, is a strategy for reducing the risk of zero harvest.

The land forms around the village are intensively used. They are hill-foot slope, pediplain behind the village, alluvial terrace and dried valley. The nearer to the village, the longer period the farms are used. They are easy to be managed. If the yield is reduced, the villagers can transport the dung of animals from the village to the farm.

The land far from the village is used more roughly. The dung of animals is seldom supplied.

The Peul farmers stay at the side of their farms. They are located at the pediplain (Fig 4-1).

4-3-3 Period of fallowing

When a farmer thinks that "the land is tired", he stops farming and leaves it as a fallow. He judges it by the reduction of the yield, even if there is not other considerable reasons. The period of the fallow is 3 to 5 years. If the available farming area is not sufficient due to fallowing, the farmers often ask to the neighboring village to lend it. For example, Tondi Kiboro has a large available area, and it receives some farmers from other villages.

As mentioned above, the farms near the village are continuously used.

The Peul farmers seldom fallow the farm thanks to a lot of use of the dung of animals.

Some farmers say that 5 years of fallow is enough to recover the soil fertility, and the others say not enough.

4-3-4 Cropping system

Although the cropping system is almost the same, some differences exist in the preparation of the field and the way of fertilization

1) Preparation of the field

The preparation of the field starts after the millet farming during the dry season. The main work is to fell down millet stalks by one of hoes with a long handle (see Plate 11-b). They cut the base of the millet stalk. Such a practice has an effect to destroy the surface crust at the same time. If the low tree such as Guiera senegalensis grows, they cut it at the bottom of the trunk. When they clear the fallow, they cut down low trees by a hatchet (see Plate 11-a).

Some farmers burn the plant residues after getting them together. The others leave them on the surface.

Burning of the plant residues is done to clean the field and make it easy to work. Moreover, they say that burning reduces the damages of insects (such as stem bore). On the other hand, some farmers who don't burn the plant residues, think that they catch the sand to recover soil fertility. They say that when the loose sand on the surface is not sufficient, they leave the plant residues without burning. The others say that if the insect damage in the last cropping season was serious, they burn the plant residues

Therefore, in the preparation of the field, the farmers treat the plant residues following to three criteria; 1) convenience for work, 2) sufficiency of loose sand on the surface, and 3) extent of insect damage of the last cropping season.

2) Seeding

The farmers didn't remember the date of seeding. They said that they seeded after a heavy rainfall in April. As there was a heavy rainfall on 9th of April in 1991 (Monteny, 1992), most people answered that they had seeded by the end of April.

According to some farmers, the seeding time depends strongly on the time of rainfall. After the rainfall, when the soil is wet up to 20cm in depth, they judge that the time of seeding comes. In 1991, as the soil was wet up to 40cm, after the heavy rainfall on 9th April, they started seeding in April. But, generally, they seed in May to June. After emerging of seedling, if the rainfall stops, a lot of seedling dries up. In this case, they seed again.

Seeding is conducted without cultivation. After making a hole, they put seeds (more than 20 grains) in the depth of about 15cm. After emerging of seedling, if the number of seedling is too many, they thin them to 3-4 plant/stock (at the first weeding time).

Most of people use pesticide for the seeds before seeding. Some people put some chemical fertilizer around the hole as a starter if they have money to buy it.

The distance between plants is generally about 1m by 1m.

3) Weeding

The weeding is carried out twice before harvest. In 1991, they did the first one in May to June, and the second in July to August. Weeding is done by a kind of hoes with a long handle (see Plate 11-d). They push it in the sandy soil. The edge of the hoe cuts the root of weeds. At the same time, it destroys the surface crust to make the soil permeable.

Weeding is time-consuming work. If the labor for weeding is not enough, the farmers ask to others to help them. Some pay money (750 CFA/day=15 FF,1991). The others help each other without paying. If the seedling condition of the fields is bad, they sometimes leave them without weeding. If they couldn't weed due to some reasons, the harvest will not be expected.

4) Harvest

The harvest was done from September to October. They harvest the head of millet by a hand cutter, and collect them to make a bundle. The grain is stored in a storage house made by grass stems with a high floor.

5) Fertilization

The Zarma farmers sometimes supply the dung of animals to the field near the village. A few farmers keep their livestock in the field during the dry season if they own it. Some serious farmers collect the dung of animals in the village (it is not owned by anybody) to supply it to the farm.

Some Zarma farmers ask to the Peul farmer to stay in their farms during the dry season so that the animals drop the dung on the farm. As a reward, some Zarma farmers paid them 1 bundle of millet for a week of stay.

The dung of animals is considered to improve the soil fertility. A farmer says that if it is supplied every year, the yield can be maintained, or, moreover, it increases.

The chemical fertilizer is also considered good. But, at the same time, it is dangerous and has a risk to make plant dry up if the rain stops after the supply of fertilizer. Moreover, it is expensive, therefore, no body used it in this year.

4-3-5 Reason for reduction of the yield

As for reasons for reduction of the yield, The farmers mentioned 1) the insect damage, 2) insufficient rainfall, and 3) interruption of rainfall during the cropping. In 1991, they say that after emerging of seedling (May), the rain stopped, and a lot of seedlings dried up or were eaten by insects. And, in July, they suffered from lack of rainfall (Fig 3-6). Even though the total rainfall in 1991 was 500mm, which is considered as a sufficient amount, the yield was very low as shown in Table 4-2

They say that the continuous cropping also reduces the yield due to (1) the reduction in soil fertility and (2) increasing insect attack and weeds.

4-3-6 Livestock

The Zarma farmers keep several livestock with him as shown in Table 4-3. Most of them keep goat and sheep (goat 2.9 head, sheep 1.3 head in average, respectively). The average of number of cow is 2.9 head. But, in fact, only 5 among 17 farmers have cow. Although they possess some animals, some of them ask to the Peul farmers to keep them. The Peul farmers do not receive any rewards from them. But, in this case, the milk is given to the Peul farmers. Moreover, the dung of animals makes fertile their farms.

The Peul farmers keep at least more than 10 heads of cow except for the one, who does not have his own livestock. He lost 40 heads of cow due to the drought of 1974 and 1984. He keeps only 7 heads of cow entrusted by the Zarma farmers (Table 4-4).

For the Peul farmers, milk has a considerable importance for their nutriment. One of them says that he likes milk more than millet. Other one says that his child is growing well thanks to milk.

The livestock grazes anywhere. But, the enter of the livestock into the field is strictly prohibited during the cropping season. It is controlled by cowboys. After the harvest, the livestock can enter to the field to graze the millet stalk. It goes back to the Peul's farm in the evening. Then, the dung of animals is dropped on the farm. They often change the staying position of animals inside the farm to distribute the dung uniformly on the farm.

4-3-7 Livelihood

Millet is cultivated for self-consumption and not for selling. It is very cheap to sell (price in the village: 7500CFA/100kg = 150FF, 1991). Most of families consumed up the millet by February after the harvest. After that, they had to purchase it. They say that if the rainfall condition is good, they can harvest millet enough to feed the family.

Young men of the family go to town (Abidjan, Niamey, and so on) in the dry season to earn the money. In this case, old men prepare the land for the next cropping. If there is nobody to prepare the farm, some farmers ask it to anothers and pay for them. The others don not go to town, and prepare the farm by themselves.

Some farmers have some means to earn the money in the village by small trade, butchery, and selling fire woods and hays, handicraft and so on. Anothers have relatives who stay and work in towns, and assist their lives.

Banizoumbou looks like a pure agriculture-based village, but, most of villagers cannot make a living in the village nowadays.

4-3-8 Wish

The wishes in their lives are, 1) sufficient food for the family, 2) another wife, and 3) more children.

It seems that they consider the increase of family member to be equal to the increase of happiness. Having the more wives and children makes them happier. Moreover, the more children contribute to stabilize their life. Some children may get education to have a better work in the town to support the family. The others can help them in the farm. Their way of thinking may be very natural under their unstable environments.

However, the increase of family member causes to shortage of nutriment. Some say that it is difficult to feed the children sufficiently. But, with the difficulty for feeding, they manage the situation. And it seems that they expect a compensation after suffering.

4-4 Discussion

4-4-1 Land use system

The traditional shifting cultivation was considered as an adaptation to the natural conditions (highly variable rainfall, available large land, and low soil fertility), and the social conditions (low population density, and low development level). However, according to the increase in population, the surface area of land owned by a family decreases. The situation makes difficult the traditional system to sustain of the Zarma farmers whose land-use system is very extensive in field size. The rate of cultivation area to the holding land was more than 70%. It indicates an example of land saturation. The yield is very small and very variable with field and with year. The population density of Banizoumbou is higher than that of the region. Ba, (1991) observed the extension of the cropping area from 1950 to 1991, by interpretating the air-photographs and remote-sensing images. According to him, The farmed area increased from 332ha (11.9% of the land) in 1950 to 1950ha (71% of the land) in 1991 (Table 4-5). In fact, Banizoumbou includes the eroded pediplain which is not valuable for millet farming. As far as the available land is concerned, it seems that it is apparently getting saturated.

The farm sites were mainly on the undulating pediplain behind the village, on the alluvial terrace near the village. Additional water from the upper slope can be expected on their location. And such areas are used for a longer time.

The population pressure seems to demand a more intensive farming system using a suitable area. Therefore, a comprehensive land-use planning is urgently necessary

(Grazing in the fallow)

The grazing in the fallow is not prohibited at all. On the contrary, the farmers consider that it is good for the land, because the dung of animals makes the land fertile. However, it is very doubtful. The grazing by animals damages the vegetation and delays the reconstitution of vegetation during the fallow. The input of any materials such as organic matter and other cations by the dung on the field must be less than that under the natural condition. It may reduce in amount of reduction of any materials into the soil. The bare land as a result of grazing is susceptible to water and wind erosion. Moreover, the reduction of the grass on the surface reduces in the effect of sand catching. The destroyed soil surface by stepping increases the wind erosion in the dry season. Generally speaking, the enclosure of a land to prevent animals from damaging the vegetation has a remarkable effect for reconstitution of vegetation. But, in case of the field, it has an effect to destroy the surface crust at the same time (Ba, 1991).

As for carrying capacity for animals, Tierno, (1991) concluded in the studied area that 406.02 days of grazing was possible for the 2,213 heads of animal in the two villages (Banizoumbou and Tondi Kiboro) without considering the ligneous vegetation in 1991. It was thanks to the sufficient rainfall.

4-4-2 Competition and cooperation between Zarma and Peul farmers

As mentioned above, the Zarma and the Peul farmers live together in the same area. Their competitive and cooperative relations are as follows.

(Competition)

Land degradation by grazing in the fallow.

(Cooperation)

Supply of the dung of animals as a fertilizer into the Zarma's farm by the Peul farmer.

Small trading such as milk between the two groups.

Supply of farming land of Zarma to Peul farmers.

The land degradation by grazing was not very inconspicuous when the survey was performed (September,1991 to February, 1992). However at the end of the dry season, it would appear evidently. It is said that the conflict between the farmers and the livestock breeders happens due to a competition of land use, especially, in the drought year when the growth of the grass is not enough for grazing. Although their relation looks very friendly at present in the studied area, it is necessary to consider the improved land management before any serious conflict occurs.

It seems that the Peul farmers hope the increase of the number of livestock, their base of life. But, the number of livestock should be strictly controlled under the improved land management even though it is difficult.

4-4-3 Socio-economical conditions

Even though Banizoumbou is a pure agricultural village, the families which can make a living by agriculture are very few. Some family members or the relatives work in the town to get money. Their lives are, therefore, strongly related with the external society nowadays. This situation suggests that their life is susceptible to the change of the external environments.

The traditional millet farming is done for self-consumption and not for a cash crop. They say that even if they get a enough harvest, they do not sell it due to a low price of millet. Moreover, in the case of the bumper harvest in the whole country, the price of millet becomes lower. Such a marketing condition makes the farmers discourage (oral communication with an agronomist of Niger). Under the present socio-economical conditions, millet cannot be a cash crop in a big scale in Niger. In fact, the yield level is too low. The farmers cannot concentrate their efforts only on farming since a lot of men prefer to go to the big towns to earn the money during the dry season.

Here appears a problem of "imbalance of the socio-economical conditions between cities and villages", which is common all over the world. But, the specific problems in this region are as follows.

1) Due to the unstable natural conditions, even the self-sufficiency food supply is often difficult.

2) Due to the low development of the industrial sector, the cities are not able to absorb the people from the village. This condition forces the villages to go to foreign countries. It is a common result in the developing countries.

The villagers say that they like to live in the village quietly. They seem not to like the city life as a labor in foreign countries. It is necessary to consider how to allow them to live in their village in order to realize "a sound agricultural village".

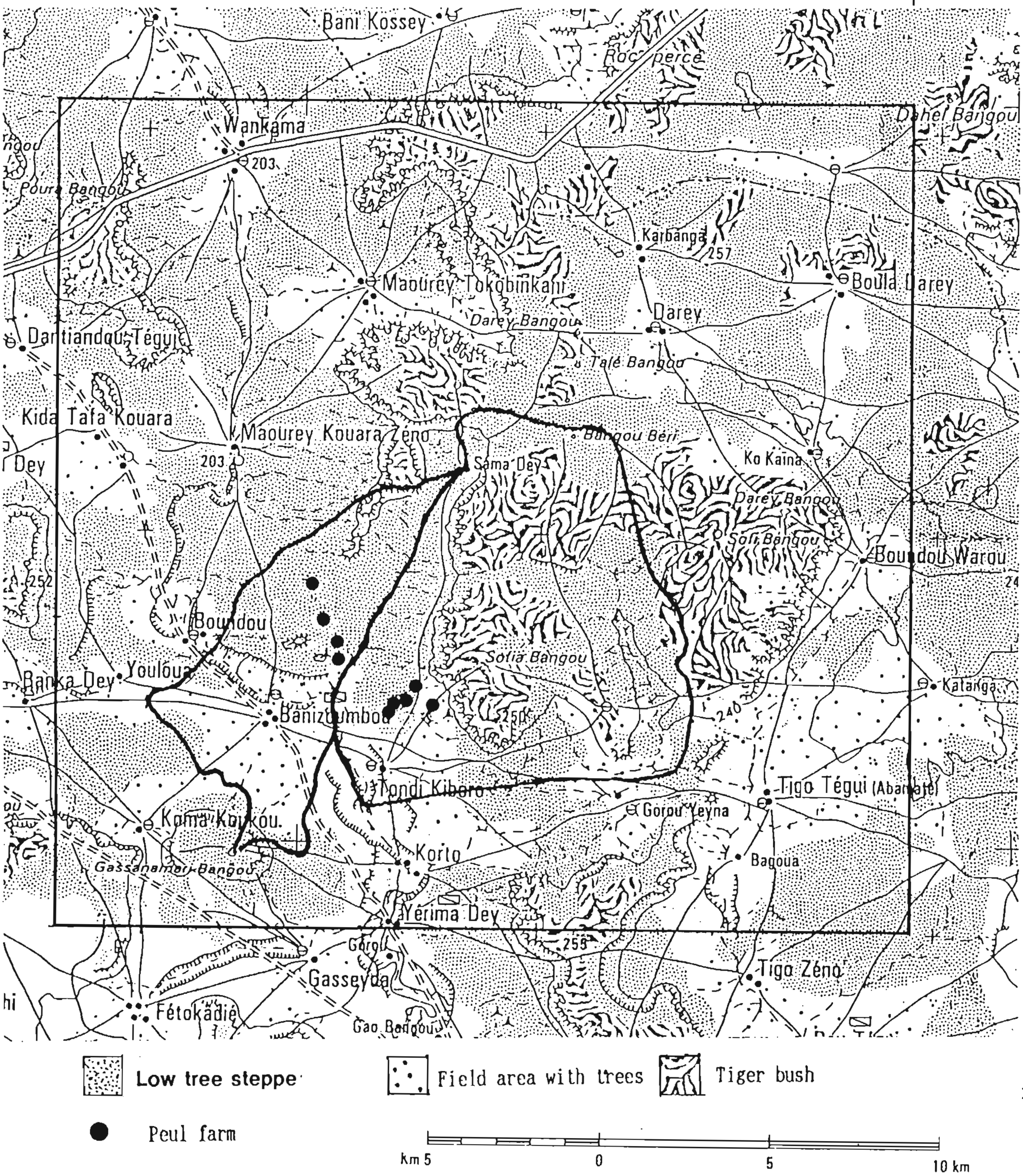


Fig. 4-1 Location of Peul farmers

(after Tierno, 1991)

Table 4-1 Population distribution

	Total surface area (10^6 km^2)	total population (* 10^6 hab.)	density (hab./km^2)
World	150	4,400	29
Africa	30	468	15.4
(% of world)	(20)	(10.8)	
Savana zone of	3	25	8
south of Sahara	(2)	(0.5)	
Banizoumbou			30.2
Tondi Kiboro			4.2

(Source:Zachariah and Conde,1981)

Table **4-2** Holding and farming area, and yield in 1991 (after hearing survey)

	Zarma			Peul		
	Land hold area (ha)	cultivated area (ha)	yield(kg/ha) (1991)	Land hold area (ha)	cultivated area (ha)	yield (kg/ha) (1991)
mean	9.2	6.9	266	4.6	3.7	476.2
Min.	4.5	1.5	14	3.0	2.5	413.0
Max.	18.0	18.0	613	7.0	5.0	579.0
SE	3.8	3.6	162	1.5	0.9	68.2

1) Land hold area includes the land which was borrowed.

2) The yield was caluculated as that 1 bundle head of millet is 15kg.

Table 4-3. Livestock of Zarma farmer

familly No	3	4	5	6	7	9	10	11	12	13	14	15	16	17	18	19
horse	-	1	2	4	-	-	-	-	-	-	-	-	-	-	-	-
cows	-	-	10	28	5	-	-	-	-	-	3	-	-	3	-	-
goat	-	3	4	2	1	1	2	-	2	2	1	-	2	2	-	-
sheep	-	-	7	2	1	-	2	-	-	-	1	-	2	-	-	-
donky	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
chicken	-	-	4	4	-	-	-	-	-	-	-	-	-	7	-	-
guinea fowl	-	-	10	10	-	-	-	-	-	-	-	-	-	5	-	-

1) No 1,2 and 8 was not available

2) No 6 is the chief of the village

3) The chicken and guinea fowl may have not been sometimes counted.

Table 4-4 Livestock of Peul farmer around the village

familly No	1	2	3	4	5	mean
cows	20	(7)	14+(15)	12	10+(2)	11.2
goat	20	-	17+(15)	14	10	11.2
sheep	24	-	55	7+(2)	20	21.2
donky	-	-	-	-	4	0.5
chicken	20	-	17	5	6	9.6
guinea fowl	3	-	8	-	-	2.2

1) The parenthesis is the number of animals enstrusted.

Table 4-5 Evolution of cropping area including fallow

Year / village	1950	1975	1991	Total surface area
Banizoumbou	332ha	1113ha	1953ha	2735ha
Tondi Kiboro	175ha	781ha	2500ha	5985ha

(After Tierno, 1991)

5 Remote-sensing analysis

5-1 Introduction

Niger is one of developing countries. There are many difficulties for getting any kinds of data. In the case of this study, the lack of topographical map with a big scale was a problem. The map with a scale of 1/200,000 was only available, and it could not serve to a geomorphological study and a land occupation study in detail.

Remote-sensing analysis is now widely used for getting a lot of informations on the land surface. SPOT numerical data have the highest resolution (20m/pixel) in the world. It was available in the studied area. The purpose of the remote-sensing analysis is to get basic characteristics of the numerical data on various land surfaces of the studied area, and to make the land occupation map. It should be related with the geomorphological unit map and the soil map.

5-2 Material and method

5-2-1 Remote-sensed data available

The remote-sensed data used here were as follows:

1) SPOT data, No. 061323, taken on 21/Feb./1991

2) SPOT data, No. 061323, taken on 01/Sept./1991

They were geometrically corrected (1B level).

5-2-2 Method

The numerical data analysis was done using the program set named "Planet" developed by ORSTOM. The main analysis conducted was as follows.

1) Characterization of the value for various land surfaces

2) Classification of land occupation

3) Classification of surface type

1) Characterization of various land surfaces

The sampling of the data on the specific area which was well known thanks to the soil survey and the air-born photographs taken by ORSTOM (August 1991) and by ourselves (February, 1992).

The composition color images by SX1, SX2 and SX3 were well corresponded to the land form (Fig. 5-1 to 3). But, it was sometimes difficult to define the target point on the image when the surface feature changed gradually.

The land surface situation recognized on the soil survey and the air-born photographs were:

1) Stony land on the inserberg

2) Bright reddish brown eroded surface on the plateau

3) Reddish brown eroded surface at the upper part of the hill-foot slope

4) Fallow with dense vegetation on the reddish brown sandy soil

5) Fallow somehow degraded by associated with bare land on the reddish brown sandy soils

6) Millet field weeded on the reddish brown sandy soils

7) Millet field non-weeded on the reddish brown sandy soils

8) Millet field vigorously grown on the reddish brown sandy soils

9) Fallow on the white sandy soils

10) Millet field on the white sandy soils

11) Eroded surface along the dried valley or temporal water way
12) Scarp at the fringe of the plateau
13) Ligneous vegetation on the plateau or on the pediplain, etc..

In order to characterize the data of various land surfaces, some indices were calculated as follows.

(Vegetation index): It is considered to be related to the chlorophyll activity of plant. There are various formula to calculate it. NDVI (Normalized Difference Vegetation Index) was used here.

$$NDVI = 128\,(1+ (SX3-SX2)/ (SX3+SX2))$$

Where SX2 and SX3 are CCT count of band 2, 3, respectively.

As shown in the formula, when the values of SX2 and SX3 is same, it will be 128. The value of the index characterizes the extent of difference of values between SX2 and SX3.

(Soil color index): It is related to the intensity of reddish hue of the land surface. The formula used here was as follows:

$$SI =128\,(1+(SX2-SX1)/(SX2+SX1))$$

Where SX2, SX1 are CCT count of band 2, 1, respectively.

(Brightness index): It is considered as an index of the reflection intensity. If the land surface is white and dry, the reflection is high. If the land surface is wet and black, it will be low. When the soil is covered by ligneous vegetation, The index becomes low. The calculating formula used here was as follows:

$BI = (SX1^2 + SX2^2 + SX3^2)^{1/2}$

The index without the value of SX3 was also used.

5-2-3 Land occupation classification

After characterization of the representative land surfaces on the numerical data, the classifying method was considered. In order to classify the land occupation, there are a lot of methods. The method adopted depends on the land surface characteristics, the extent of the knowledge on the surface (accuracy and method of the ground truth). and the purpose of classification.

The conditions on the analysis in this study were as follows.

1)Progressive transition between different surface features

In the semi-arid condition, the vegetation density is not very high except for the concentrated ligneous vegetation. The situation of steppe vegetation is variable with land condition such as relief, topographical position, the period of fallow, the portion of erosion surface, and so on. They make it difficult to distinguish the limit between the different land occupations.

2)Lack of artificial structure

The major part of the area is occupied by steppe with bush. They were often difficult to define the location because of vague border. Compared with the land surface in developed countries or with cities, it is more difficult to recognize the land positions and the limit.

3) The dry condition of the surface

The soil surface in the studied area is generally dry. Moreover, the organic matter content of the surface soil is very small. Their condition may permit to not to consider the influence of humidity on the numerical data.

4) The accuracy of "ground truth"

The air-born photographs of the studied area and the soil survey were considered as "ground truth". In this study, the quantitative study on the soil surface feature was not carried out. Then, the analysis is indicative rather than quantitative.

After characterization of surface feature by the SPOT data, the classification was conducted by the following process. We often checked results by correspondence with photographs to get better results.

1) According to the value of NDVI, the area was divided into the water area, bare land, vegetational area.

water area : 120 < = NDVI

bare land : 121 - 141

vegetational area: 142 > = NDVI

2) Subdivision of vegetational area was conducted by the correspondence of the results with the photographs. At first, the millet fields, which were clearly separated as polygonal bare lands, included some vegetational area in them. Then, it was separated by the brightness index (BI>= 93). After that, the vegetational area was separated by SX1

grass dominant vegetation: SX1 >= 91

denser vegetation with bush: SX1 <= 90

The limit was chosen by correspondence with the lineal form of the tiger bush. More detailed distinguishing was not conducted because of lack of accurate ground data.

3) Subdivision of the bare land was conducted by the statistical method using data of the training field. Some different millet field samples on the different colored soil were considered. For the classification, the Sebestyen method was used (Rakoto et. al., 1990).

4) The water area was very small. It rested without subdivision.

The process of classification is shown in Fig. 5-4. The above process was applied to the zoomed extracted images at first, then, followed by the image studied.

5-2-4 Surface type classification

The studied area is roughly composed of "plateaux", "aeolian sandy form" and "low land (pediplain and alluvial terrace)". They have their characteristics in the remote-sensed data, particularly, those of the dry season. While those of the rainy season is strongly affected by the vegetational activity. The image of dry season is considered as a mixture of reflectance by soil surface and dried vegetation. Both the soil type and the vegetation type are related to geomorphological type. Then the total surface color may roughly correspond to the geomorphological type or soil type. We call it " surface type". If the geomorphological unit can be divided by SPOT data, it is very useful. It was conducted by the following process.

1) The hill-foot slope with reddish brown sandy soil area was separated by a value of soil color index (SI => 131 as the reddish brown sandy soil zone).
2) As for the rest of the area: the low land (which includes the alluvial white sandy area and clear pediplain) and plateau was separated by the value of SX1 (SX1 =>121 as low land, 1 =<SX1 => 120 as plateau).
3) The low land was divided into two: the clear pediplain and the alluvial white sandy area, by NDVI with Nuedyn method (Rakoto et. al. 1990).

The process of classification is summarized as shown in Fig. 5-5. The used band or index was decided by correspondence with composition color image.

5-3 Result and discussion

5-3-1 Distribution of the different surface values on the NDVI-BI plane

The distribution of the different surface values on the NDVI-BI coordinate plane is shown in Fig. 5-6. The figure gives us an idea for the possibility and difficulty of the classification. The data of the rainy season is widely varied in NDVI coordinate due to vegetational activity. They are characterized as follows.

(Rainy season)

1) The dense vegetational area with bush had a high NDVI and a low BI.
2) The millet field is relatively low NDVIs and a high BIs (No 19, 7).
3) The dark areas such as the stony land (No. 1) and the scarp (No. 4) had relatively low NDVIs and low BIs.

4) The water pond on the plateau had a quite low NDVI. This characteristics was used for classification of water area.

5) The eroded land had a low NDVI and a high BI.

(Dry season)

1) The values of NDVI were distributed in a shallow range due to lost of vegetational activity.

2) The water pond was dried up, and it was among the other soil surface.

5-3-2 Comparison of data among different land surfaces

As shown in Fig. 5-5, some land occupation such as a water area can be separated easily. The others are difficult. Some examples of CCT count and indices of different land surfaces are mentioned below.

(Tiger bush, scarp, and stony land) (Fig. 5-7)

The scarp was a steep slope with the stony surface. It is affected by the solar direction. Three land occupations had almost the same brightens indices, but the value of NDVI of the tiger bush was quite different from the others. Such a characteristic in the rainy season is lost in the dry season due to reduction of the vegetational activity of the tiger bush. Separation of the three types of land occupation, therefore, become difficult by the data of the dry season.

(Field and fallow) (Fig. 5-8)

In the first of September, 1991, Some field were weeded, and the others were not weeded. Some fields were abandoned without weeding. The data of non-weeded field became similar to that of fallow due to stronger vegetational activities. The millet field had a relatively low vegetation index value because the surface of millet field is the combination of the bare land with millet vegetation. The planting density of millet is generally low (about 1m by 1m). In this case, the influence of soil reflectance is very strong. The extent of millet growth also must influence it at the same time. They vary strongly with place in the studied area.

(Field and erosion crust) (Fig. 5-9)

The CCT counts of millet field is the complex of the reflectance of bare soil surface and millet vegetation as mentioned above. The background effect of the soil, therefore, may be strong. The comparison of the data between the reddish brown sandy field and the white sandy field shows that they were different with NDVI and BI in the rainy season. The value of the dry season had a remarkable difference of SI between them. The latter was used for surface type classification. It has been already used for separation of the hill-foot slope from pediplain by Courault (Courault,1990).

(Various vegetation) (Fig. 5-10)

They had the same reflectance pattern with a different intensity of NDVI in the rainy season, and a different intensity of BI in the dry season. The tiger bush had a very low brightness in the dry season.

5-3-3 Classification of land occupation

The result is shown in Fig 5-11. It was superposed on the geomorphological unit map. The characteristics of the result were as follows.

1) Class 3 is the grass dominant fallow area. This class was mixed with millet fields with vigorous growth, and with non-weeded fields. The location of the area was always connected with the millet field. They are considered as fallows which stopped very recently.

2) Class 1 is the denser vegetation related to tiger bush and low tree steppe. The low tree steppe is considered as a fallow which is passed for longer period. At the same time, the natural vegetational area which was not used for farming is also classified in this class. Such areas exist on the pediplain in the center of the image. The class must be subdivided into different vegetational areas, such as tiger bush, dense fallow with low steppe. It was not done due to lack of of time and detailed data.

3) Class 11 is a stony land area including stony scarps. As they could not be well separated, they are classified with a same class.

4) Five different classes for millet field were integrated in the image (yellow). Their characteristics were as follows.

a) Class 2; NDVI was more than 142, but they were considered to be millet fields on the image. It was distinguished by a bright index.

b) Class 6; It is millet fields on the reddish brown sandy soils classified statistically.

c) Class 7; It is clear the millet field on the reddish brown sandy soil classified statistically. The reason of stronger brightness may have resulted from crust formation, low planting density, or sedimentation of washed alluvial sand.

d)Class 8 and Class 10; They are millet field on the white sandy soil classified statistically. The millet fields on the white sandy soils had two numerically-different types. Class 8 is characterized by a higher reflectance than Class 10. Their difference may have resulted from the field condition.

5) Millet fields are concentrated on the alluvial terrace and at the lower part of the slope. And, on the totally-sand-covered undulating land unit intensively used as well. The farmers choose the area where water can be expected thanks to deep sand or its topographical position suitable for water accumulation.

6) Around the T-18-2 (see Fig. 3-16), the pediplain was classified by the millet field. But this unit was strongly eroded on the air-born photographs. They are mixed with the white sandy soils (Class 8 and 10) due to brightness of erosion surface. This area was not selected as one of test fields. Then, it was classified in the class of millet field on the white sandy soils, which had more similar values. It shows that "directed classification" is necessary to take all considerable samples of land surface in the studied area.

7) Class 5 is reddish erosion surface, and Class 12 is clearer reddish erosion surface. They were integrated as one class on the image.

8) The water areas (Class 13) were a few and very small in size. They were distributed on the some plateaux or near the wells. But, it is not remarkable on the image. The water area was easily separated by a low NDVI (less than 120).

5-3-4Land occupation and geomorphological type

The classification had some problems as follows.

1) The misclassification of the clear erosion surface with the millet field on the white sandy soils.
2) The misclassification of the millet field with grass dominant fallow.
3) The vegetational area was not separated in detail.

The above problems should be solved by more detailed analysis. Even though the result had such problems, It showed the tendency of land occupation. The main characteristics of land occupation associated with geomorphological type are as follows:

1) The field was distributed mainly along the alluvial terrace, and at the lower of the slope. The alluvial terrace may be the most suitable for farming. It is because of the expected water accumulation from the background slope. The rainfall can percolate easily into the soil thanks to its permeability and its plane land form. The farmers take advantage of such a characteristic and choose it selectively. We need to know the possibility of intensive farming system in this unit.

2) The hill-foot slope is used for millet more roughly. Ba (Ba,1991) observed the extension of millet field to the hill-foot slope, or sand mounds on the plateaux by the comparison of the differently-dated air-born photographs. In case that the millet grew vigorously, the background effect of the soil was not clear, and it may have been misclassified in the vegetational area as mentioned before. Such misclassification was verified by the correspondence with the air-born photographs. The hill-foot slope has some risk of land degradation such as gully and sheet erosion.
3) The pediplain was generally classified as degraded vegetation or denser vegetation. The denser vegetation includes the fallow and the natural vegetation, which rested probably long time without clearing by men due to

its less agricultural value. Such areas do not have the polygonal contrast on the photographs. All of them can be considered as grazing areas

The pediplain near the T-1, The land surface feature is very variable in space. It means that the land surface is heterogeneous. Such information may give an important indicator about the land surface.

The final objective was to quantify the each land occupation related to the geomorphological unit. But, it was not conducted as the result demanded further improvement of classification method.

5-3-5 Surface type classification

The grand unit of surface type considered were 1)moderately-clear land corresponding to degraded pediplain, 2)clear low land corresponding to the alluvial terrace with white sandy soils, 3) reddish brown sandy area corresponding to the hill-foot slope and other sand depositing area, and 4) plateau with clayey soil. Fig. 5-12 shows some correspondence with geomorphological unit even though the relation is not very clear.

The clear low land corresponds to alluvial terrace. But, it is lying across the background slope (Banizoumbou). It suggests that the influence of washed sand deposits was remarkable.

Moderately-clear land surface existed even on the plateaux. They may correspond to the clear erosion crust with sandy soils, even with the clayey soils. Such classification of land surface may be the first step for geomorphological classification by the remote-sensed data. If the geomorphological classification can be conducted by a remote-sensing analysis, it is very useful for the land system study. Using the SPOT data taken with different angle enabled to make a digital elevation model.

Fig. 5-1. Composition color image of September 1991
(SX1=blue, SX2=green, SX3=red)

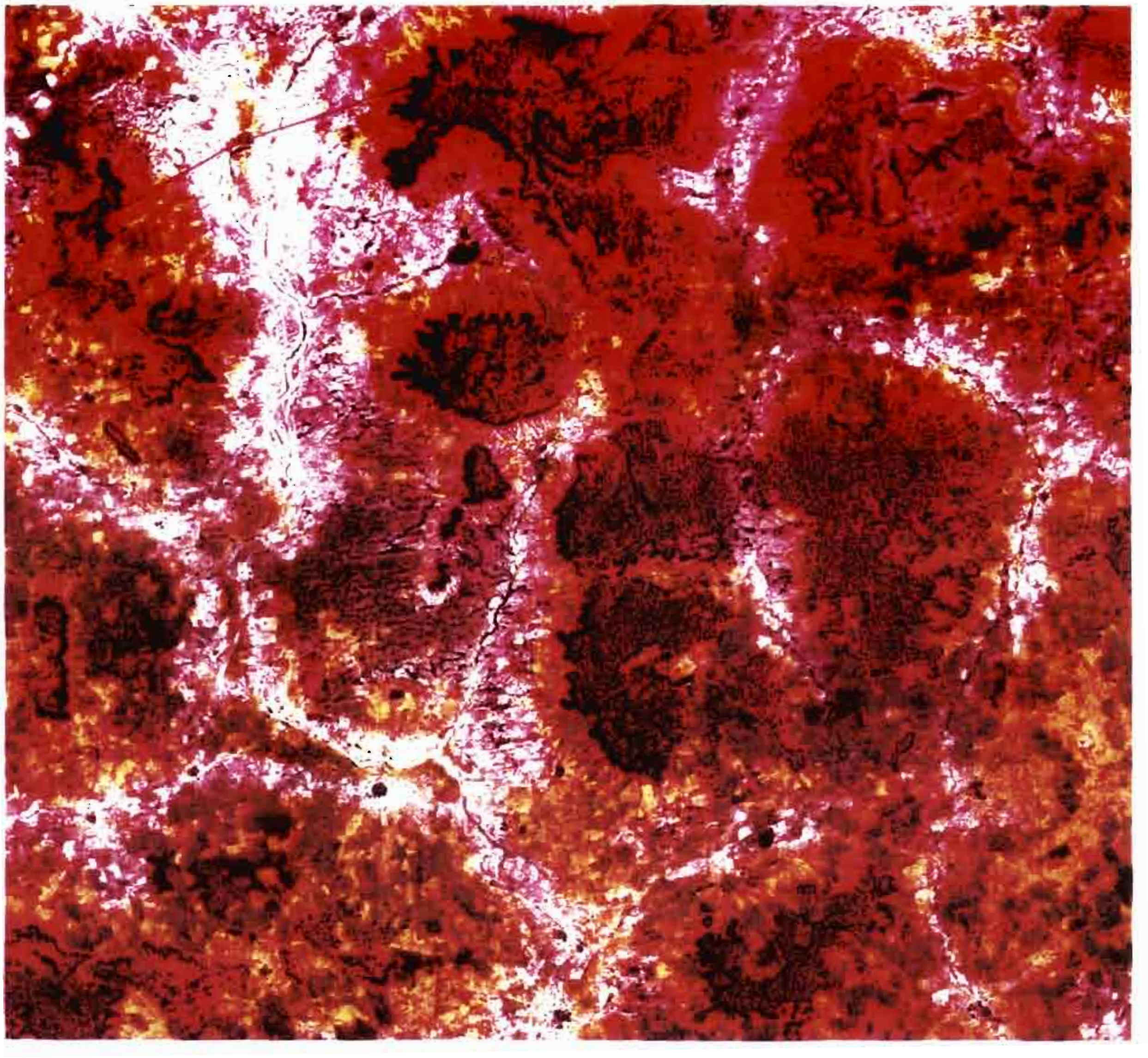
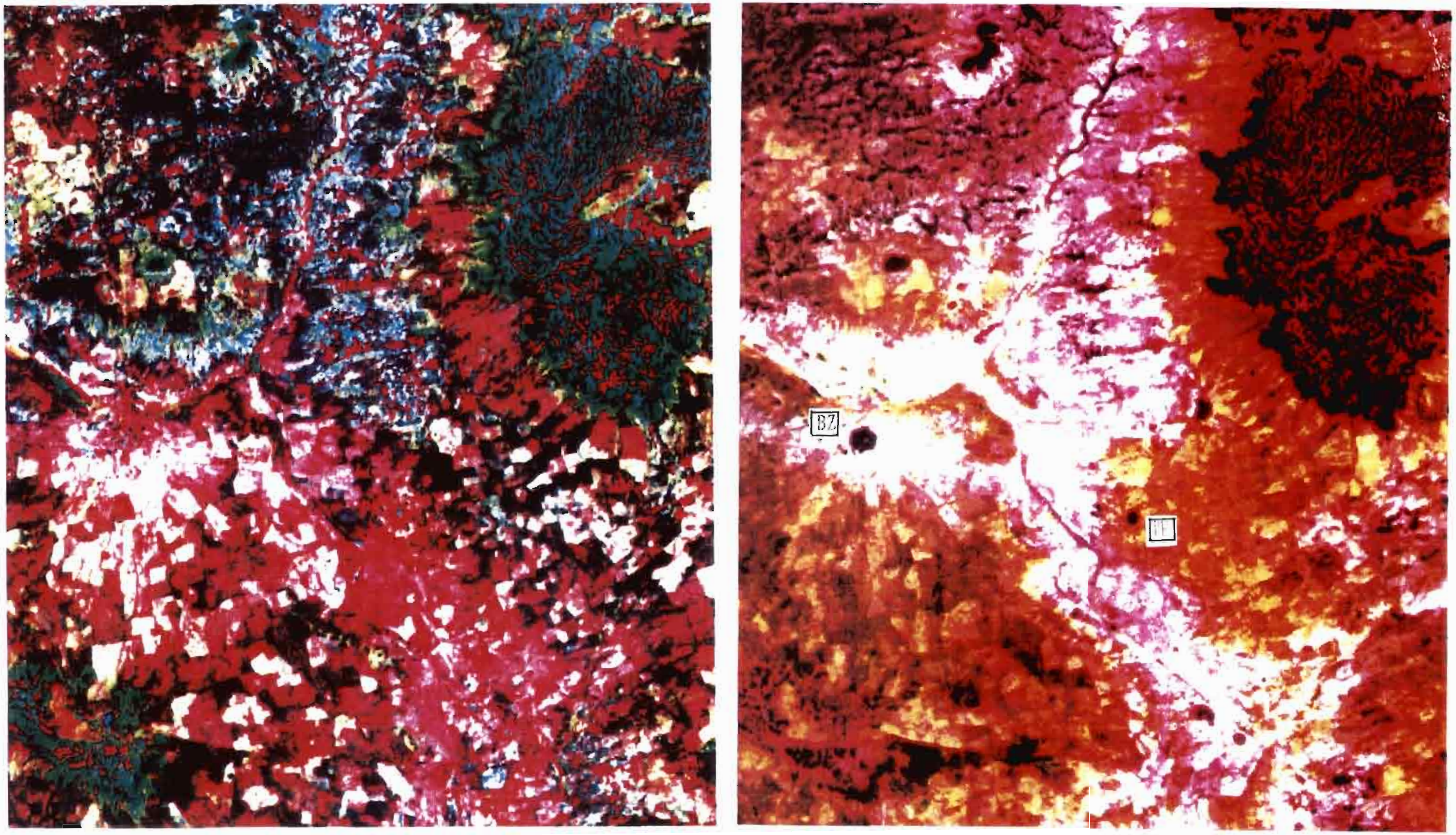
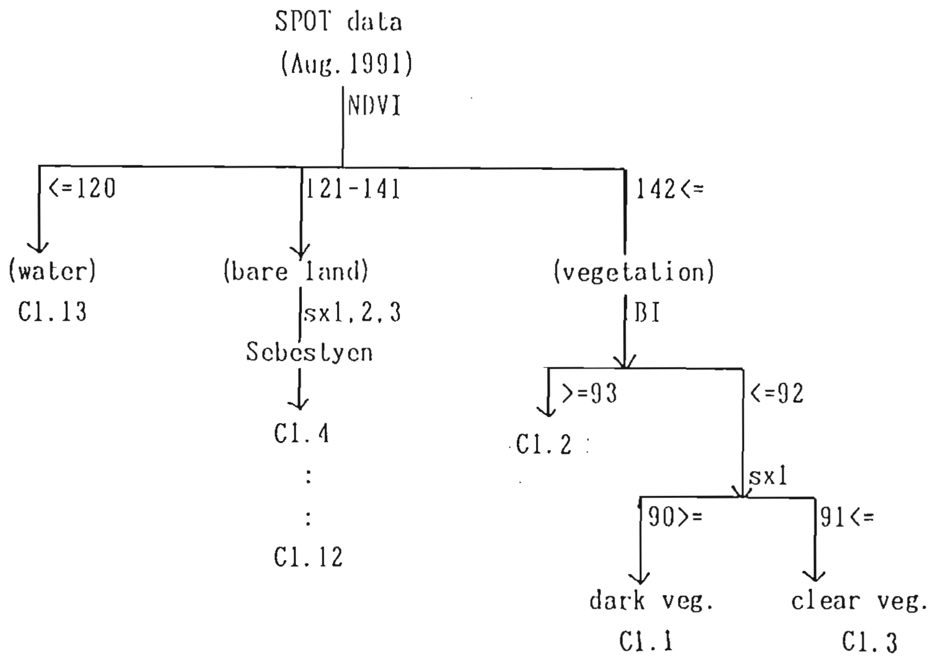


Fig. 5-2. Composition color image of February, 1991
(SX1=blue, SX2=green, SX3=red, 1 pixel =20m)



Rainy season | Dry season

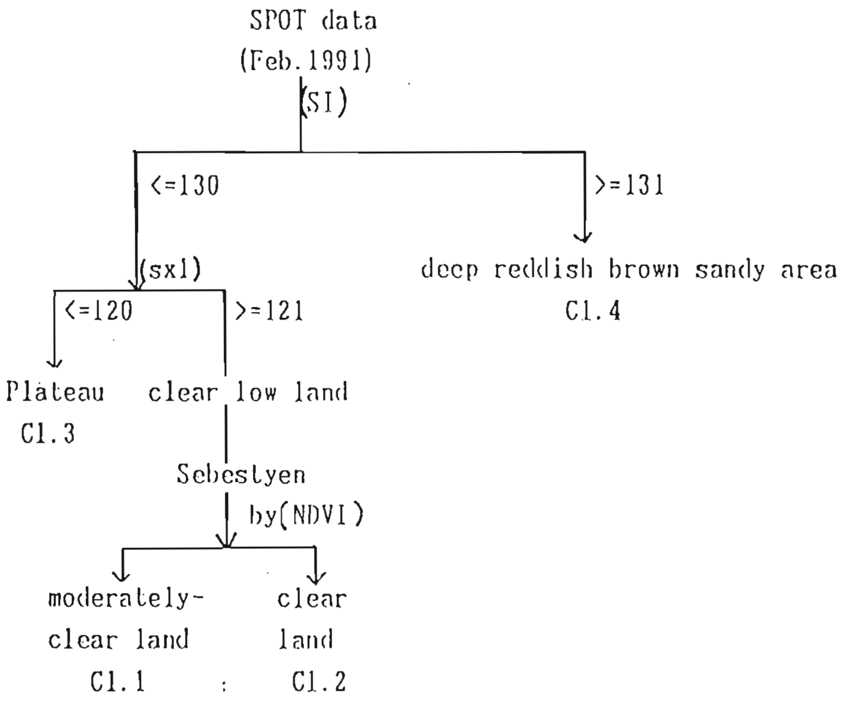
Fig. 5-3 Composition color images of test field
(zoom treatment, 1pixel=10m, BZ:Banizoumbou, TK:Tondi kiboro)



Class. 1 Dark vegetation with bush
2 Millet field in the zone classified as vegetation
3 Herbecious vegetation mixed with some millet fields
4 Erosional bare land on the plateaux
5 Reddish erosion surface
6 Millet field on the reddish brown sandy soils
7 Clear millet field on the reddish brown sandy soils
8 Millet field on the white sandy soils(1)
9 Degraded vegetation on the pediplain
10 Millet field on the white sandy soils(2)
11 Stony land and Scarp
12 Clear reddish erosion surface
13 water ponds

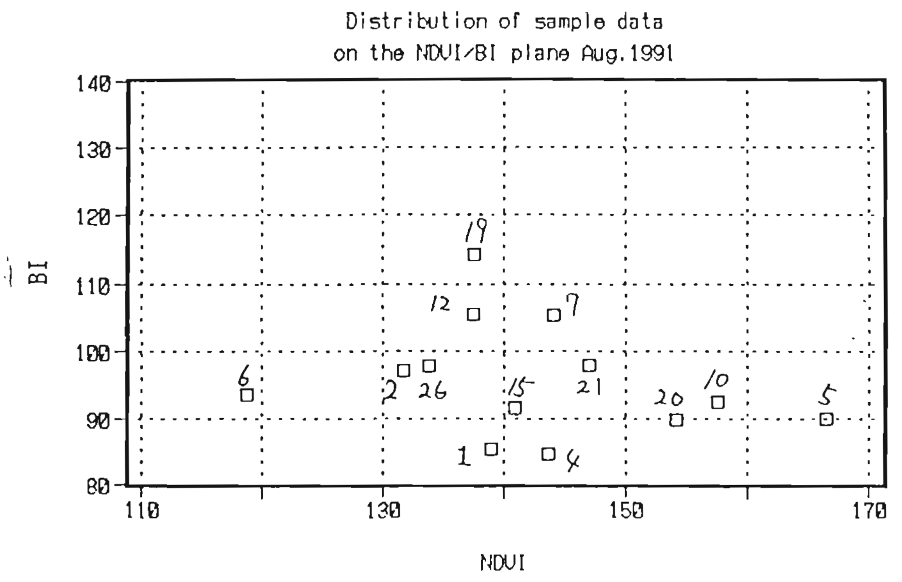
Remark
1. Five millet field classes are integrated as a millet field
2. Class 5 and 12 are integrated as a reddish erosion surface

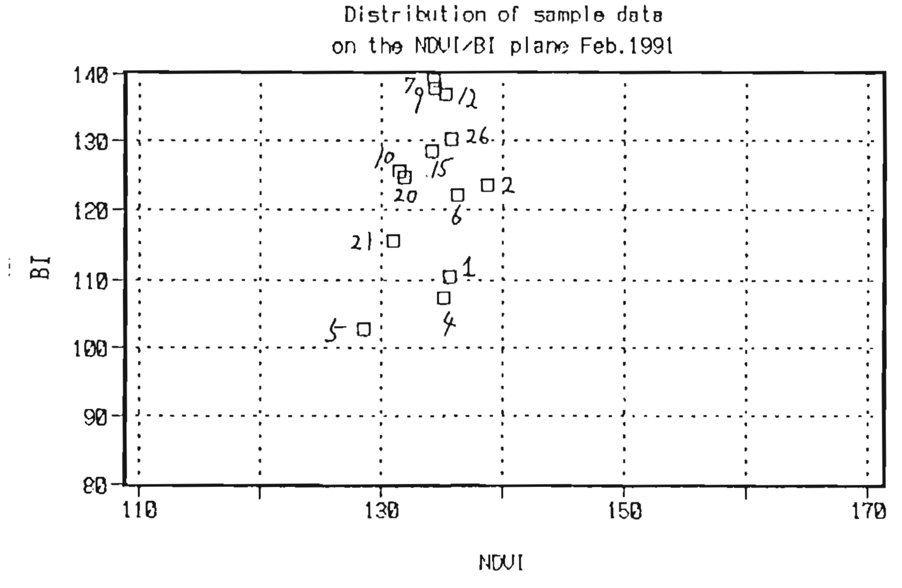
Fig. 5-4. Procedure of land occupation classification (with image of September)



Class. 1 Moderately-clear low land (degraded pediplain)
2 Clear land (Alluvial terrase)
3 Plateaux
4 Deep reddish brown sandy area

Fig. 5-5. Procedure of land surface type classification (with image of February)

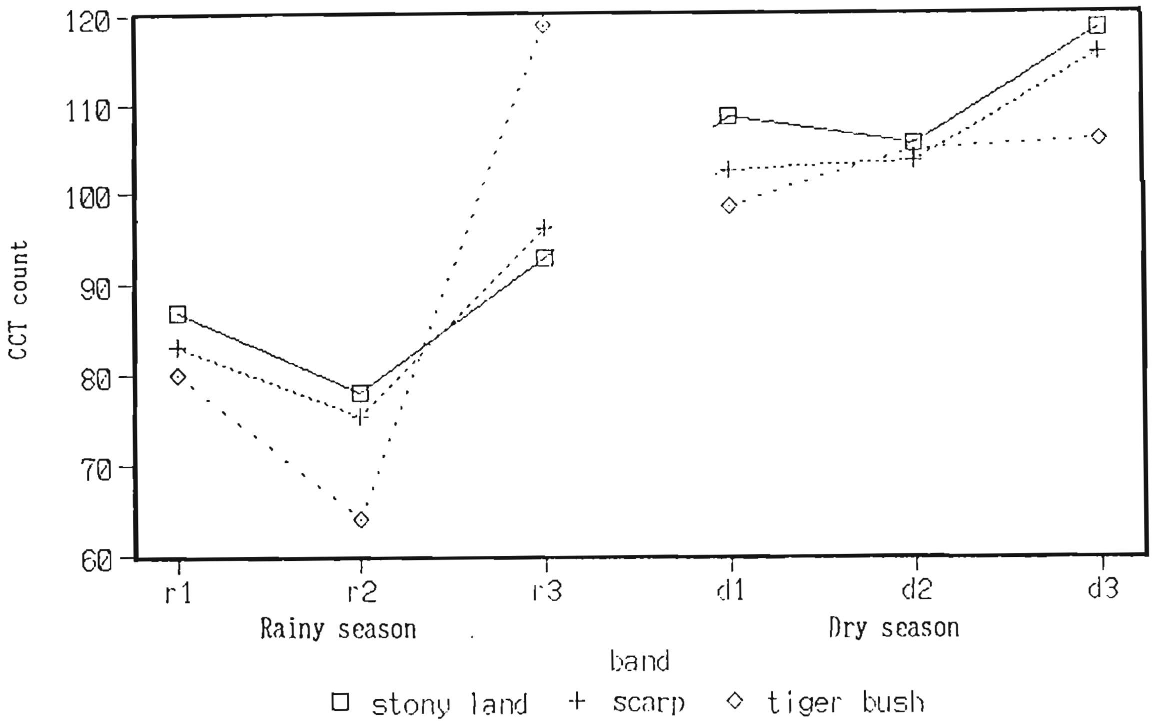




Land occupacion

1. Stony land
2. Erosional bare land on the plateau
4. Scarp
5. Tiger bush
6. Water ponds
7. Millet field on the reddish brown sandy soils
10. Fallow on the reddish brown sandy soils
12. Erosion surface along the temporal water way
15. Herbecious vegetation with sporadical low trees
19. Millet field on the white sandy soils
20. Fallow on the white sandy soils
21. Village
26. Reddish erosion area at the upper part of hill-foot slope

Fig. 5-6. Distribution of diferent surface value on the NDVI-BI plane



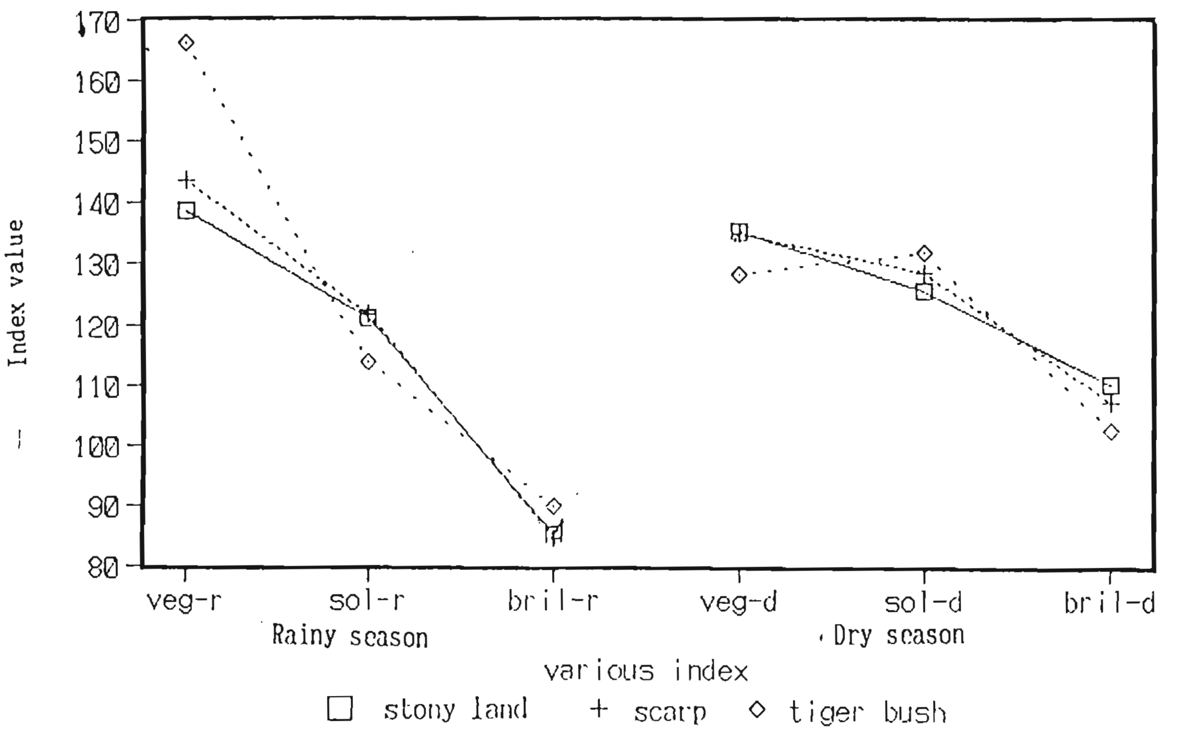
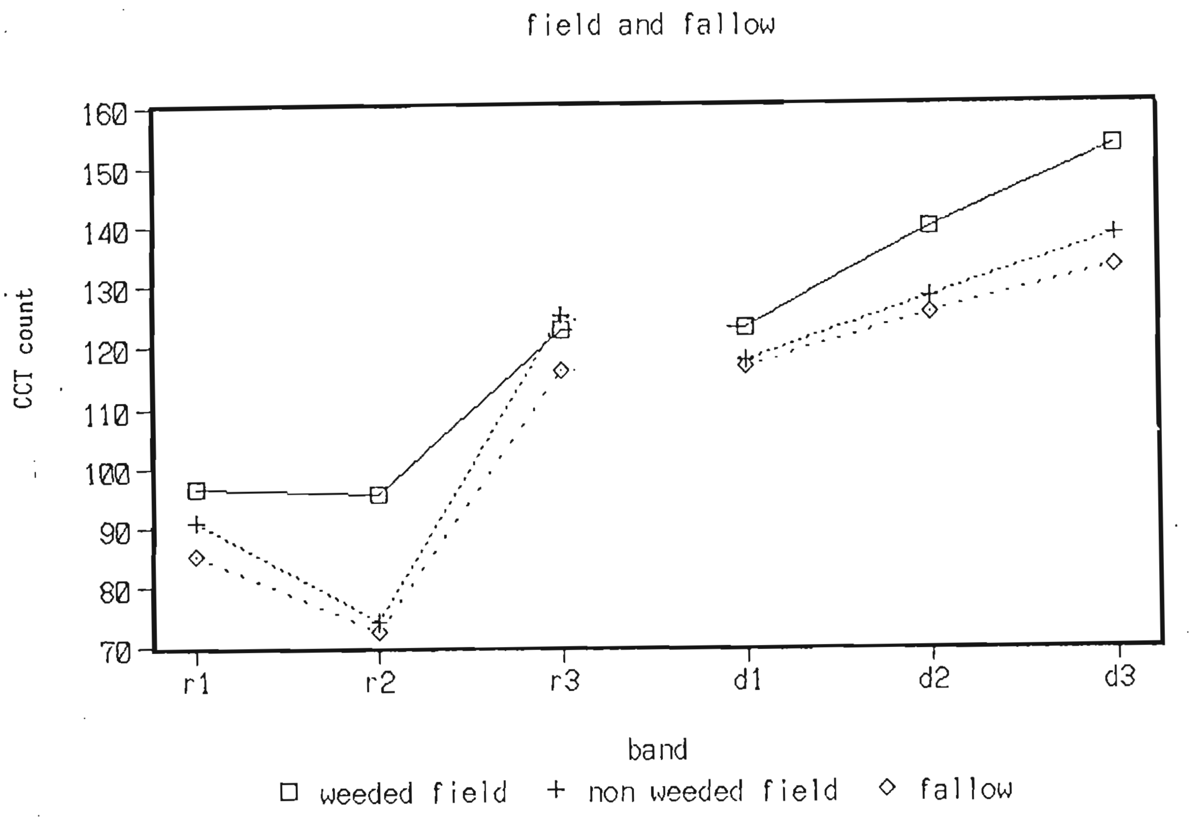


Fig. 5-7. Comparison of data among different land surface
Tiger bush, scarp, and stony land



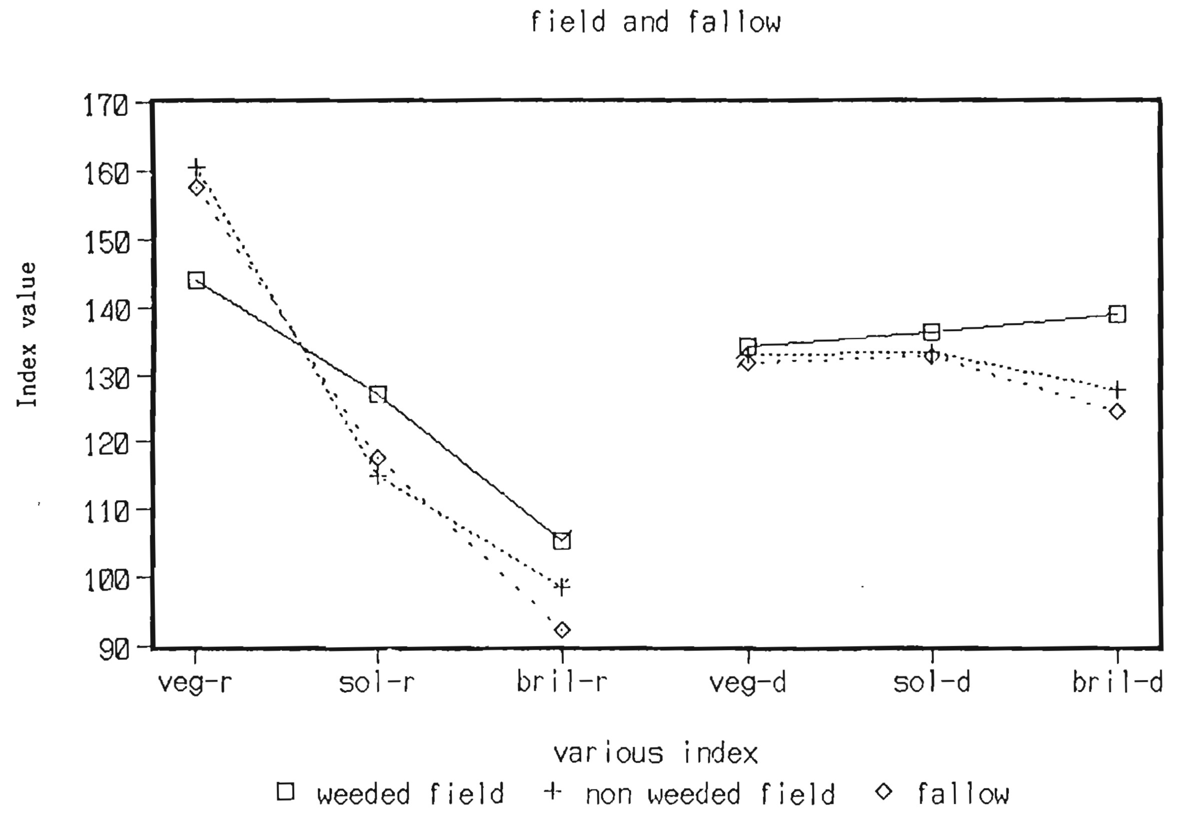
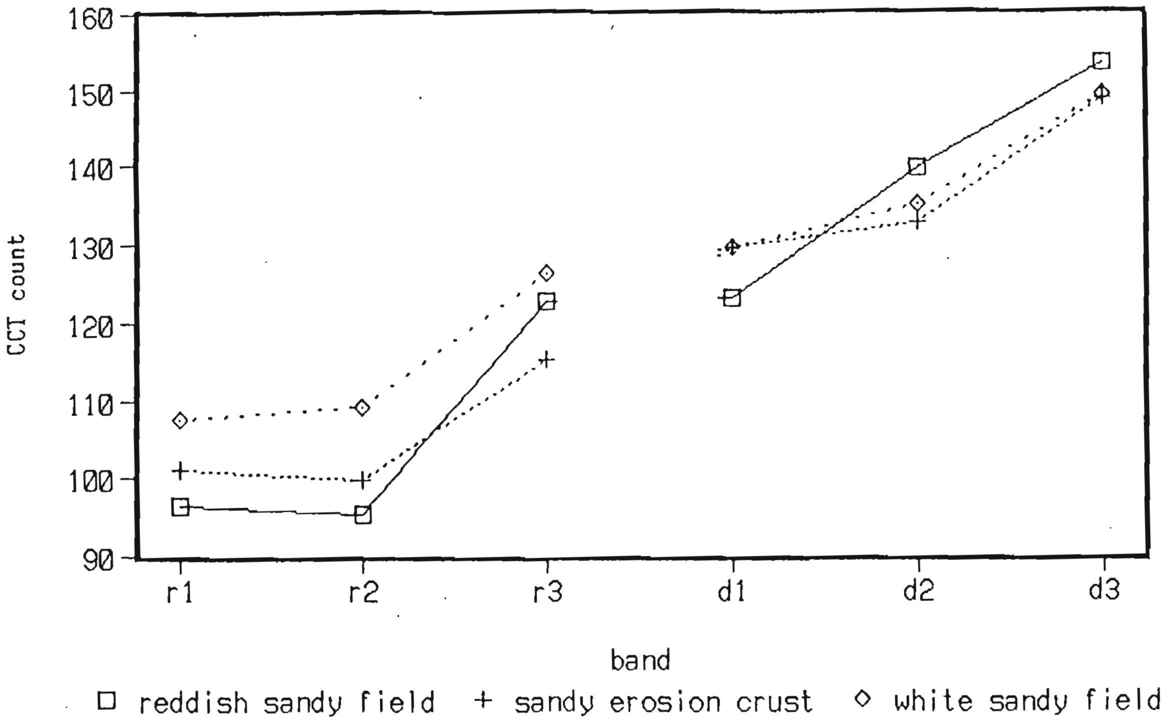


Fig. 5-8. Comparison of data among different land surface
Field and fallow



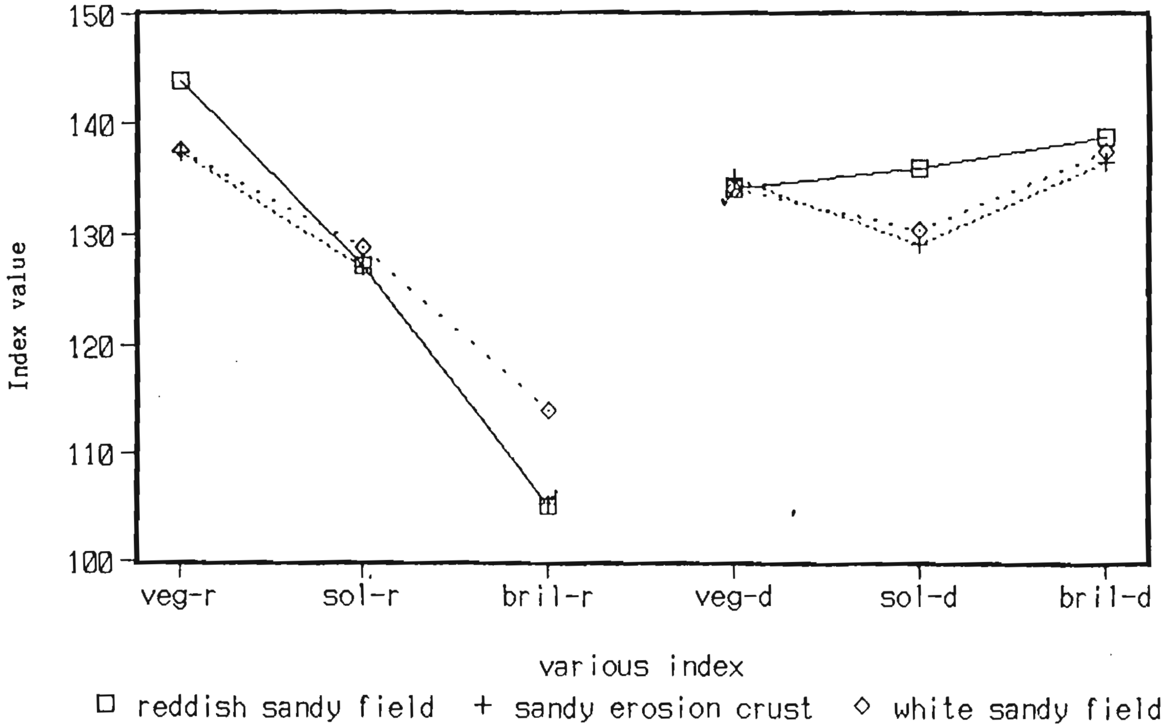
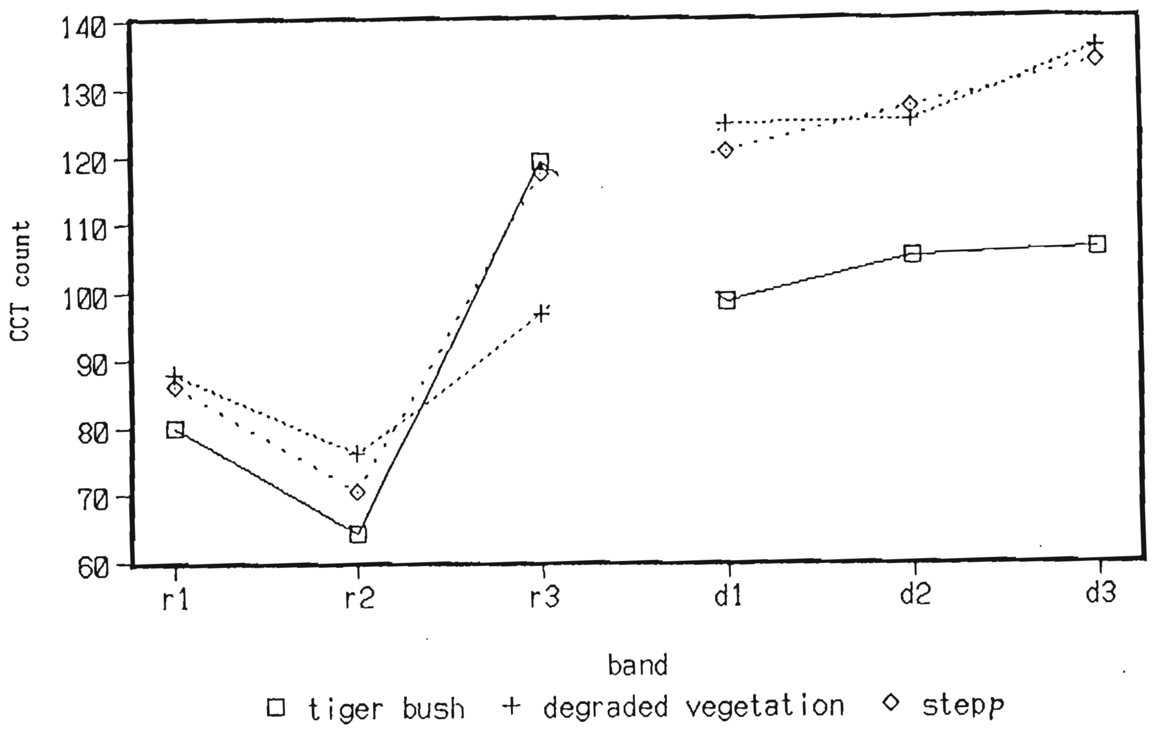


Fig. 5-9. Comparison of data among different land surface
Field and erosion crust



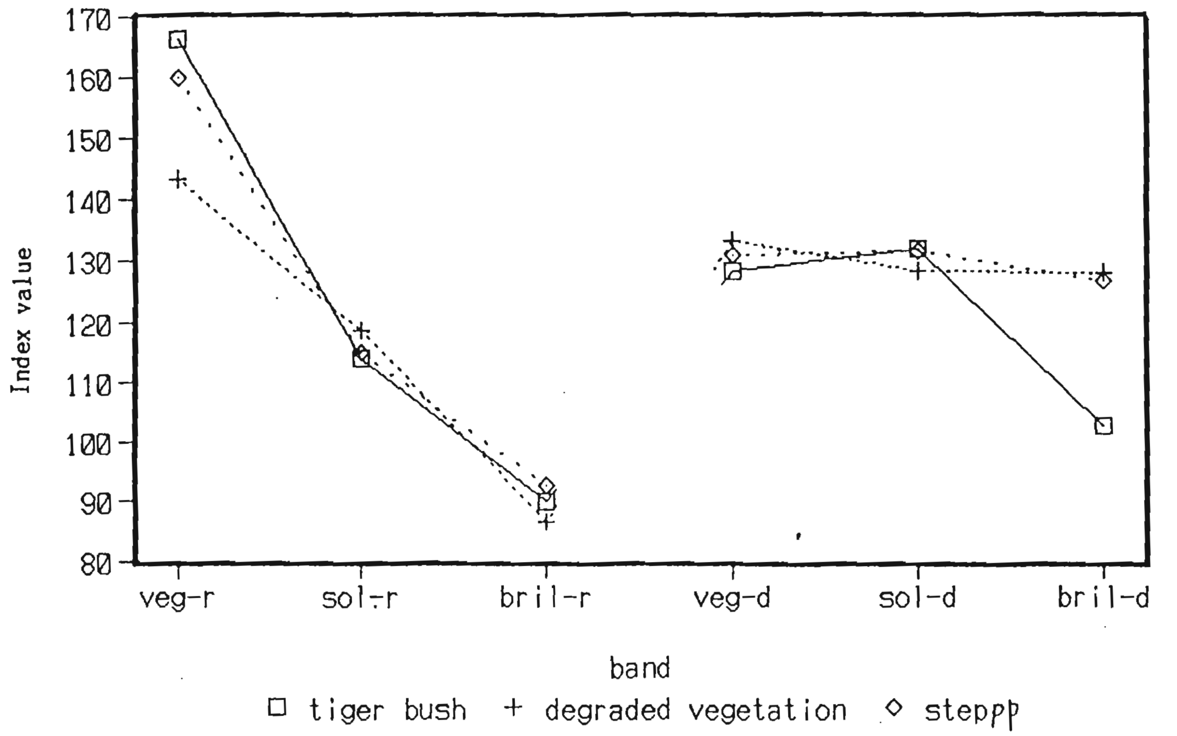
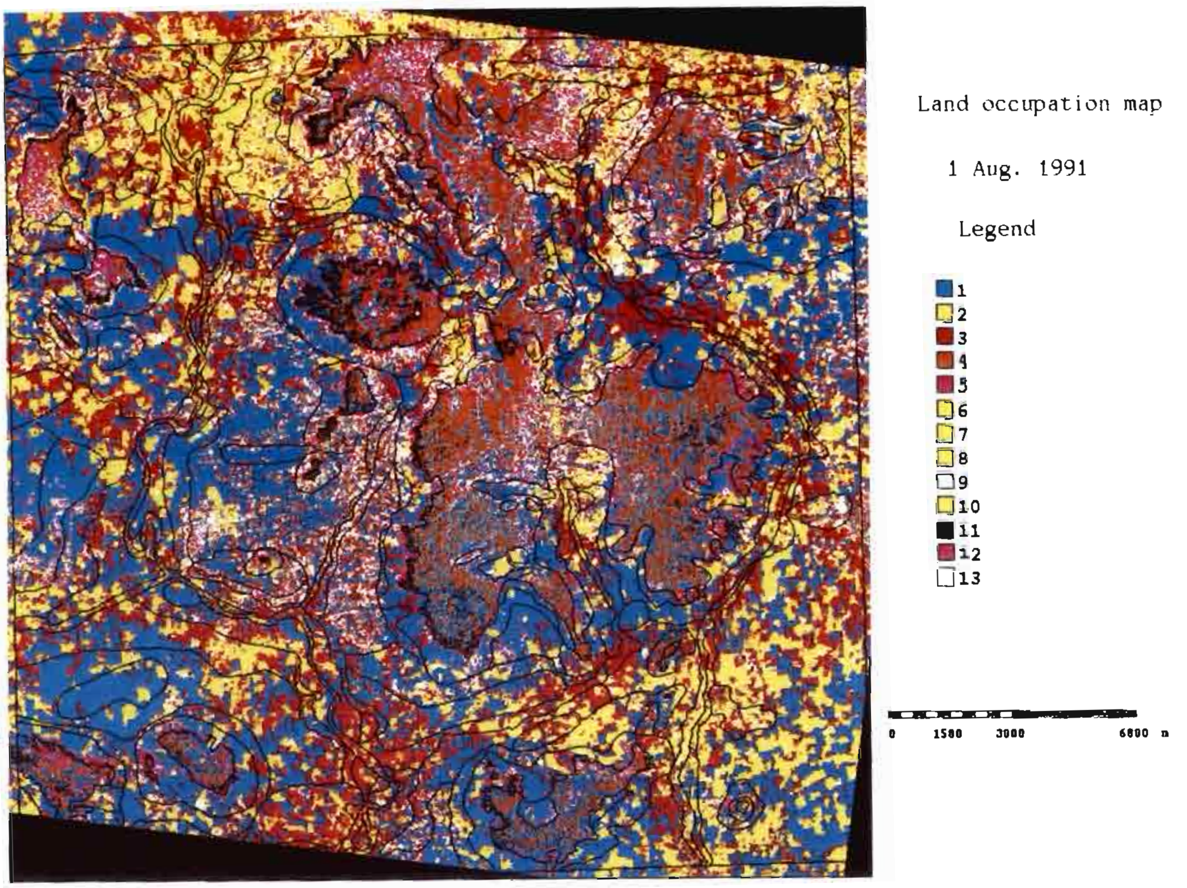


Fig. 5-10. Comparison of data among different land surface
Various vegetation

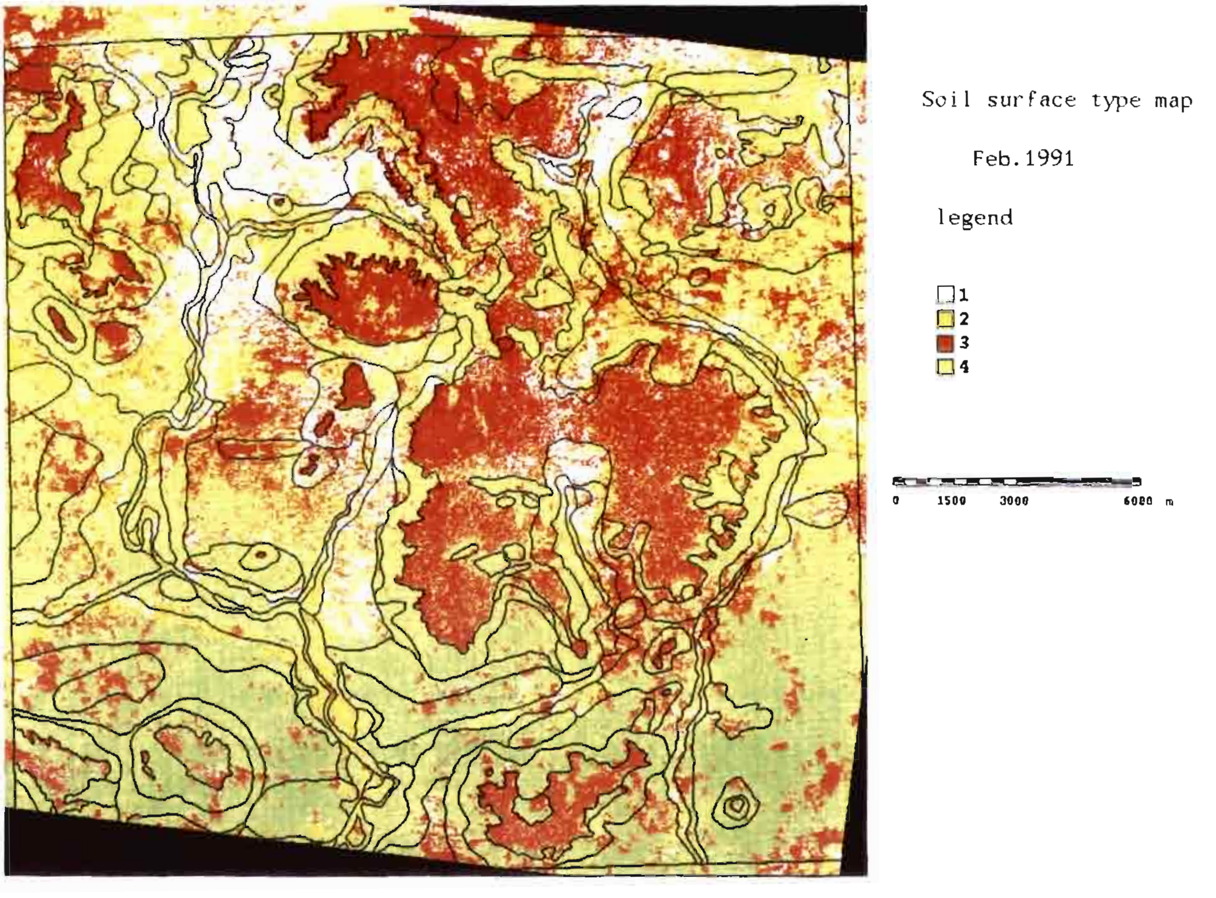


Class. 1 Dark vegetation with bush
2 Millet field in the zone classified as vegetation.
3 Herbecious vegetation mixed with some millet fields
4 Erosional bare land on the plateaux
5 Reddish erosion surface
6 Millet field on the reddish brown sandy soils
7 Clear millet field on the reddish brown sandy soils
8 Millet field on the white sandy soils(1)
9 Degraded vegetation on the pediplain
10 Millet field on the white sandy soils(2)
11 Stony land and Scarp
12 Clear reddish erosion surface
13 water ponds

Remark

1. Five millet field classes are integrated as a millet field
2. Class 5 and 12 are integrated as a reddish erosion surface

Fig. 5-11. Land occupation classification image



Class 1 Moderately-clear low land (degraded pediplain)
2 Clear land (Alluvial terrace)
3 Plateau
4 Deep reddish brown sandy area

Fig. 5-12. Surface type classification image

6 General discussion and Conclusion

6-1 Characterization of the Natural environment

6-1-1 Land system

The land system of the studied area is constituted of the following five units.

a) Residual plateaux of Continental terminal (Ct3)

b) Hill-foot slope

c) Pediplain

d) Dried valley

e) Alluvial terrace

With the thick sand cover, the separation of geomorphological unit was difficult. The river basin type varies with lack or existence of the pediplain and/or alluvial terrace.

6-1-2 Soil types and their characteristics

The soil type was classified into sandy soils and clayey soils by the existence or lack of sand cover. The sandy soils were subdivided by color of subsurface horizon and sand depth. Each soil type is generally related to geomorphological type. Therefore, the soil map was completed on the basis of the geomorphological unit map. The main soil types are, 1) reddish brown sandy soils, 2) reddish brown clayey soil, and 3)white sandy soils. The sandy soils are important for agriculture.

Sandy soils are very poor in any nutriments such as N, P_2O_5, K, Mg, Ca, K, and so on. The carbon content in A horizon is also very low (0.05 to

0.30%). And the soil structure is massive to slightly massive. But, they have a high saturated hydraulic conductivity. Its water retention characteristics may be very preferable in the semi-arid condition. The water holding capacity has high enough when sandy layer is deep (153 to 250mm/2m). Moreover, the main portion of that is occupied by low pF (pF1.8 to 2.5), which is easily available for the plant. It means that each rain shower can be easily available for plant even though the amount of rainfall is small.

On the contrary, the water holding capacity of clayey soils is generally higher than that of sandy soils. But, the strong water retention characteristics demands more water to reach the condition of low pF. In the semi-arid condition, therefore, the clayey soil may be less valuable for agriculture. Moreover, the crustability of the clayey soils is very high (Casenave et. al., 1989). It reduces seriously the infiltration rate. In fact, the farmers in the studied area do not make farms on the clayey soils. They say that the water flow away on the clayey soil, and the soil is very hard.

These facts indicate that the sandy soil is more favorable for agriculture than the clayey soil. The water availability is of the first importance. From this point of view, the sandy soil gives a basic possibility of cultivation to the habitants.

The reddish brown sandy soils appear on the mainly hill-foot slope and pediplain with deep sand. When the surface sand is lost, crust formation can occur due to the fine particles in the subsurface horizon. Erosion crust is also formed even on the surface horizon by raindrop compaction and run-off.

The bright reddish brown sandy soils appear on the pediplain which is shallow or moderately deep. They have a cemented sandy underlayer, nodule underlayer, or clayey underlayer and so on. Such layers at rooting zone must influence the soil quality. it is necessary to study whether the impermeable layer such as clayey layers under the sand can play a role to stock the percolated water in the sandy layer. But, the shallow sandy soils seem to get damage of rainfall shortage. It suggests that the underlayer such as clayey soils may play a role of water absorber rather than a impermeable layer because of their water retention characteristics. Moreover, the biological activities such as termite which is more vigorous on the pediplain than hill-foot slope, must contribute to the fine particle transportation from the underlayer to the surface. In fact, the circular erosion crust is formed on the eroded pediplain by the destruction of termite hill.

The white sandy soils have some advantages. They are not susceptible for the crust formation. The plane land form enables rain water to percolate into the soil vertically. Its topographical position can expect to receive more water by surface run-off and through flow from the background slope.

The reddish brown clayey soils on the plateau are strongly eroded in relation to the tiger bush. They are shallow, and stony and probably impermeable (see Plate 4-b). They are not available for agriculture. The reddish brown clayey soils on the pediplain also have eroded surfaces. The appearance of clayey soils on the surface without sand cover on the pediplain may be a result of erosion in the past.

The result of soil survey indicates that sandy soils are more preferable than clayey soils for agriculture in the semi-arid condition. And, among the sandy soils, deep white sandy soils on the alluvial terrace have the better soil characteristics (low crustability), better topographical position (availability of water from the background slope) and better land form (plane). The concentration of farms onto this unit support these evaluation.

6-1-3 Sand distribution

The sand deposits cover almost all studied area except for the flat plateaux. The deposition type is classified as follows.

1) "cordon" type

2) hill-foot slope

3) small sand mound type

4) totally-sand cover type

5) alluvial type

6) colluvial type (at the lower part of the hill-foot slope)

They modified the ancient surface land form and affect the soil function.

The aeolian sand is characterized by its similar sand particle component even though there are some variation. And, the uniform ferrugination occurred. The sand grain is coated by reddish fine particles and It connects the sand grain. It may contribute to water dynamics.

The alluvial sand distributes on the alluvial terrace. It may include alluvial/colluvial washed sand from the background slope. They must have deposited at lower part along the valleys, and have formed the plain together with the fluvial washed sandy sediments.

6-1-4 Classification of the land occupation by the remote sensing analysis

The classification of land occupation by analysis of SPOT data shows that the millet field is concentrated on the lowland area such as alluvial terraces, and on the totally-sand covered area. The degraded vegetation appears mainly on the hill-foot slope and the upper part of the hill-foot slope. The fallow spreads mainly on the hill-foot slope and pediplain. Those results were mostly confirmed by the on-site research. But, It was revealed that the millet field on the hill-foot slope and on the alluvial terrace was sometimes misclassified to the fallow, and the extended erosional area near T-18-2 was also misclassified to millet field on the white sandy soils.

6-1-6 Situation of land degradation

The types of land degradation observed in the studied area were as follows:

1)Surface erosion on the plateau associated with tiger bush (see Plate 4-a).

2)Surface erosion at the upper part of hill-foot slope by gully and sheet erosion (see Plate 2-a).

3)Sporadic circular surface erosion (see Plate 2-b)

4)Surface erosion around the sand mound by localization of loose sand by wind (see Plate 4-c and 5-a),

5)Surface erosion on the side of valley-side slope probably by sheet erosion (see Plate 6-d and e,).

The on-site research showed that the area which had surface erosion was always associated with a) shallow sand on the surface or appearance of clayey soils, and b) slope. A considerable portion of the pediplains has been already degraded. The relation between wind direction and the topographical position of land also affected the distribution of the land degradation.

The traditional millet cropping seems to accelerate land degradation by clearing and burning the bush which protects the land surface from the erosion.

The grazing in fallows also seems to induce the land degradation as through the following processes:

1) the stepping makes the sandy surface movable,

2) reconstruction of vegetation in the fallow is delayed due to damage by grazing and stepping

3) then, the soil receive less materials from the vegetation.

As for destruction of land surface by stepping, it can be considered as a biological cultivation, which may increase the permeability in the cropping season (Ba, 1991). In case of the fallow, their effect must be studied quantitatively. It is said that the surface vegetation cover has the most important factor to limit the extent of erosion. Negative effects by grazing may appear more clearly when the drought or the overcharge of animals take place. In the studied area, the overcharge of animals was not very obvious. The bare land by grazing is, however, sometimes observed.

Quantitative study on the carrying capacity of land for animal grazing is necessary for an improved land management planning.

6-2 Agricultural system and human life

6-2-1 Agricultural system

The hearing survey in the studied area made clear the following characteristics of the agricultural activity.

1) Zarma farmers cultivate the millet extensively at several fields by a shifting cultivation. The yield is small and very variable. The reason of cropping at several fields is to avoid zero harvest. On the other hand, the Peul farmers cultivate the millet more intensively at one site. Such a difference can be explained by the livestock holding of the Peul farmers.

2) The advantages of livestock breeding are as follows:

1)application of the dung of animals.

2)production of milk.

3)movability of the grazing area

4)better saving of the property

Peul farmers take a considerable portion of nutriment by milk. They are possible to survive by selling their livestock even when the harvest of millet is not good. Their agricultural system associated with livestock breeding is strongly based on the vast grazing area. They connect the extensive livestock breeding and intensive millet farming. It is a way to adapt to the unstable and fragile natural environments of the region. Such a system functions well as long as the availability of the sufficient grazing area is assured.

3) Most of Zarma farmers cannot make a living by agriculture. Millet is cultivated for self-supply, and they are often short of it. In order to make a living, they have go to work in the cities during the dry season. Otherwise, they have some means to get money. In fact, a lot of men go to Niamey, Abidjan in the dry season. The selling of fuel woods is one of available works that they can do in the village without difficulty. The farmer's activity such as temporal immigration is considered as their way of compensation to the present situation which does not allow them to make a living only by agriculture in the natural environment.

6-2-2 Economical factors around agriculture

The human life in the village is strongly controlled by natural conditions. At the same time, it is connected with the society of the cities economically. It is necessary for villagers to stabilize their lives under the fragile living conditions. The relations among factors around farmers can be described in Fig. 6-1. The thickness of arrow in the figure suggests a rough indication of the intensity of each relation.

As Zarma farmers cannot make a living only by millet farming, they are necessary to be connected with the surrounding economy such as local, national, or international ones, mainly through labor supply. The temporal migration from villages to cities is a general phenomenon in the world when the villages themselves have no capability to supply work. They are obliged to work even in foreign countries. The international economical situation is directly affecting their lives in this way nowadays. In fact, the Sahelian countries been been playing a role to supply of labor to the neighboring countries such as Nigeria, , etc.. For example, they go to work at plantations in Côte d'Ivoire. As long as such plantations run well, the labors are welcomed. However, once the state of the plantations becomes worse, the chance to have a job reduces. Since the neighboring countries are also developing ones, their economy is also fragile. In fact, at present, the economy of developing countries which produce the primary products is becoming worse (Côte d'Ivoire, Cameroon etc.).

On the other hand, the economical system of Peul farmers is more independent from the other economy thanks to livestock breeding. It means their life is more strongly based on the natural conditions. However, if the natural conditions become worse not to permit animal grazing, they will have to migrate somewhere.

6-3 Perspective of improvement of the village

6-3-1 Orientation to improving the cropping system and the land use system

It was emphasized that the life of Zarma farmers depends strongly on the work in cities as mentioned above. In order to stabilize their life, self-supply of millet is necessary at least. The variable rainfall and increase of population pressure make it difficult to realize even the minimum demands. Improving cropping system is very necessary to stabilize their life in the village. Introduction of alternative intensive cropping system on the most suitable land is urgently necessary. It should be associated with a sufficient area of fallow as grazing zone, which allows the livestock breeding by Zarma farmers.

It is said that the limiting factors for millet farming in the Sudano-Sahelian zone are 1) small and variable rainfall, 2) low soil fertility, 3)interruption of rainfall during the cropping season, and 4)attack by insects.

The research work concerning cropping system is focused on the improving of water and fertilization efficiency. The mechanical weeding effect by animal traction has also being studied (ICRISAT,1989).

The first step for intensive farming may be from the enclosure of better field by trees. It must encourage the consciousness of farm management. They have a habit of leaving trees between the farms as a border (see Plate 10-a). Therefore, a more intensive disposition of trees to divide the farm can be introduced without difficulty. And, the better subplots should be carefully managed. This procedure can develop various farming technics related to agroforestry.

The soil fertility must be improved by means of the dung of animals. The livestock breeding must be recommended also to Zarma farmers. In this case, control of the total number of cattle in the area must be considered in order to avoid overcharge of animals. In this way, the improving cropping system is strongly related to that of the land use system. Utilization of chemical fertilizer may be difficult under the present economical condition.

6-3-2 Perspective of rural development

A lot of rural development programs and soil conservation programs against desertification are developing in the Sahelian region nowadays. It is said that rural development and soil conservation against desertification are the same subject in the region (Rochette,1989).

Under the continuous bad condition in climate, CILLS decided the central objective of the programs against the desertification as follows:

"Achievement of new ecological and sociological balance" with the following strategies:

1) Satisfaction of basic human needs, especially on the self-supply, and

2)preservation of the land and ecological resources, and rehabilitation of their productive potentialities.

It is often said that during the development of programs, it runs well, but after the programs finish, the activities and its effects also finish or reduce rapidly. This resulted from a lack of making a living after finishing the programs. The developing programs can play a role of supply of work for villagers on behalf of working outside (oral communication with an agronomist of Burkina Faso, Bacye, B). After finishing the programs, they go to cities to get money even though the continuous land management effort is necessary. In this case, we have to judge the program did not fit the actual economical condition. A rural development program must consider how to make a living in the village even after programs.

These days, the participation of rural population from the beginning of programs is insisted (Roose et. al., 1992). The purpose of development program must encourage villagers' will that they live in the village and improve their villages by themselves. The insist of participation of rural people seems to come from such ideas. In order to improve the village life, the following three points are most important: 1)how to reorganize the will of villagers by themselves, 2)how to encourage them, and 3)how to reorganize the land use system and the cropping system.

The farmers know their own natural conditions better than visitors. A farmer showed us a sand-buried gully interrupted by a few of branches of trees. Most of the farmers know the effect of surface cover by the plants or the plant residues to fix the sand as mentioned in Chapter 4. They know places where the water is easy to stagnate. Such experiences must be respected, and their judgement also must be respected. Their will to improve their village can be encouraged only supposing such respects.

The human will is the most important resource anytime, and anywhere.

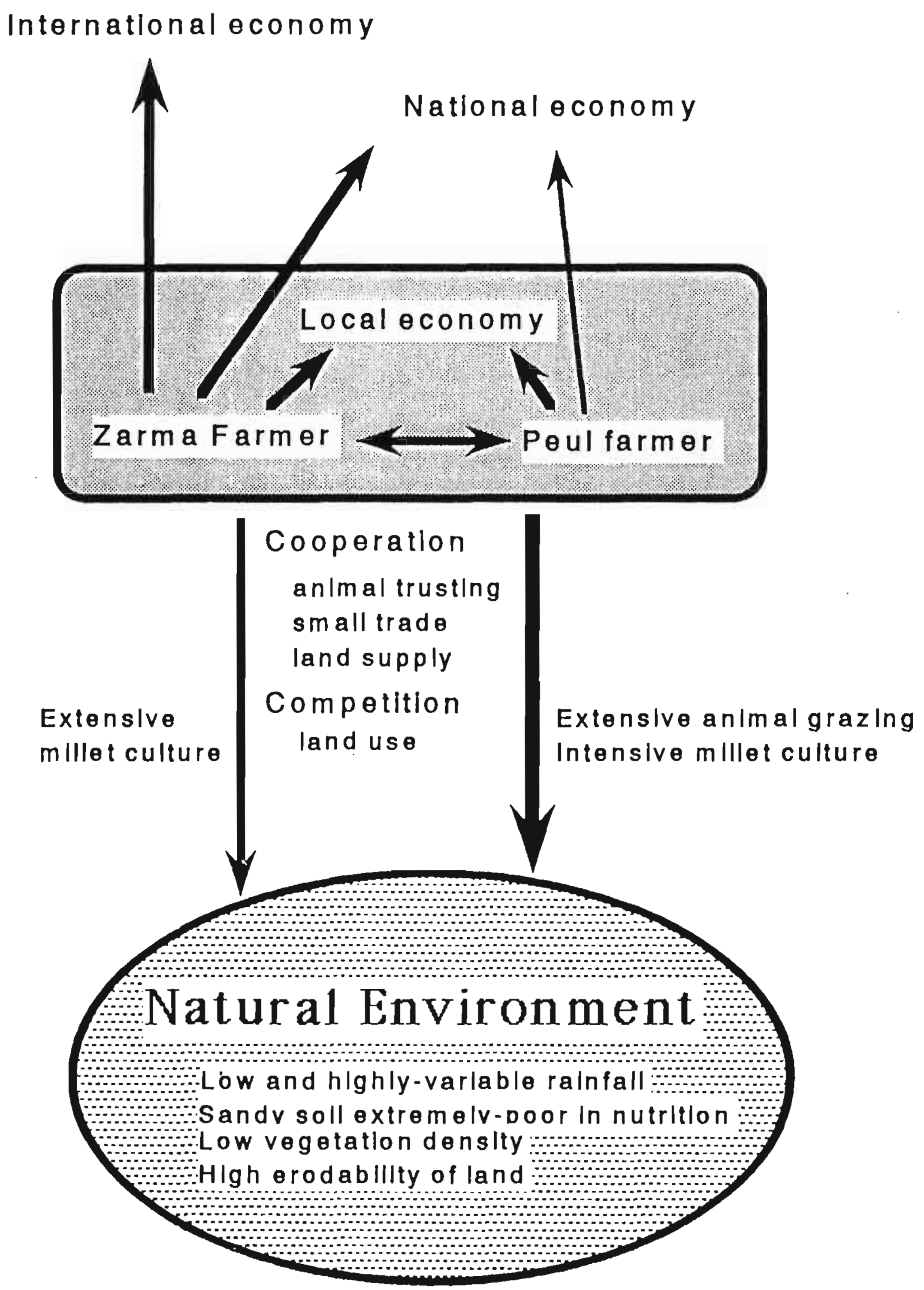


Fig. 6-1 Relationship between agriculture and the environmental factors

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Annex

Description of representative soil profiles

T-1-01 deep reddish brown sandy soil,dRs

moderate hill-foot slope, (2a); middle part, slope 4%, upper limit of millet filed, surface with destroyed slaking to loose sand (3cm)

1:A (3-32), reddish brown (2.5YR4/6, wet), orange (5YR6/6, dry) sand rich in coarse sand, weakly massive, consistence: slightly hard stickiness; null,plasticity;null, dry condition, existence of fine root transition smooth and progressive

2:B21 (32-112): red (1.25YR4/8, wet), reddish brown (1.25YR5/7, dry),loamy sand, massive, consistence: hard, stickiness: weak, plasticity weak, sem-dry condition, more fine root than precedent, interstitial pore well developed with some fine tubular pores, existence of ferruginous sub-angular gravel at 60cm of depth (5cm) transition; smooth and progressive

3:B22 (112-160), red (1.25YR5/8, wet), orange (2.5YR 6/8,dry), sand to loamy sand, massive, consistence: slightly hard, stickiness: null to weak, plasticity: null to weak, fine root:very few, interstitial pore well-developed with few tubular pore, existence of ferruginous gravel (1cm) transition: smooth and progressive

4:B23 (160-230), reddish brown (2.5YR5/8, wet), orange (3.75YR6/8, dry) sand, weakly massive, consistence: slightly hard, stickiness: weak to null, plasticity: null, fine root very few, interstitial pore well-developed with few tubular pores, transition: smooth and very progressive

5:BC (230-270+), orange (2.5YR6/8,wet), orange (3.75YR7/8, dry), sand, massive, consistence: slightly hard, common with hard granular aggregate (1cm), stickiness:weak to null, plasticity: null, fine roots very few, reach up to 250cm of depth interstitial pore well-developed, tubular pores very few

Remark
a) It is considered as typical soil type of reddish brown sandy soil in this study.

b) As the characteristics of the parent material is not well recognized, then the naming of BC horizon is temporal one.

T-1-2 <u>deep reddish brown sandy soil, dRs</u>

hill-foot slope (gentle slope, 2b) transition zone between hill-foot slope and pediplain, slope 0.5%, millet field, surface of loose sand as Ap horizon with alluvial sand deposits

1:A11p (0-9cm), loose sand layer by weeding with alluvial sand deposits, existence of week slaking, plant residues common

2: A12 (9-40), reddish brown (5YR4/6,wet), (dull) orange (5YR6/5, dry) massive with weak undulating surface, sand, consistence: slightly hard stickiness: null, plasticity: null, dry condition, interstitial pore well developed with few tubular pores, fine roots common, transition: smooth and progressive

3:B21 (40-110), bright reddish brown (2.5YR5/8, wet), orange (2.5YR6/6, dry), massive with more undulating surface than that of A horizon, loamy sand, consistence: slightly hard to hard, stickiness: weak to null, plasticity: null, dry condition, interstitial pore well developed with few tubular pores, fine roots few, existence of hard aggregates (5-10cm, concentration of fine particles), transition: smooth and progressive

4:BC (110-167), orange (5YR6.8, wet), orange (5YR7/6, dry), massive with undulating surface, sand, consistence: slightly hard, stickiness: null plasticity: null, dry condition, interstitial pore well developed with few tubular pores, fine roots very few, transition smooth and progressive

5:C1 (167-210), yellow orange (7.5YR7/8, wet), (light) yellow orange (7.5YR8/7, dry), massive with smooth surface, sand, consistence: slightly hard, stickiness: null, plasticity: null, dry condition, interstitial pore well developed with few tubular pores, existence of reddish brown ferruginous hard gravels, fine roots very few transition smooth and progressive

6:C2 (210-270+), bright yellowish brown (10YR7/6,wet), light yellow orange (10YR8/4), massive with smooth surface, sand, consistence: slightly hard, stickiness: null, plasticity: null, dry condition, interstitial pore well developed with very few tubular pores, fine roots very few, common with yellow spheric sandy nodules (10-15mm), which is hard, but can be broken by finger

Remark

a)The formation of nodule at C2 horizon suggests that it is the zone of the capillary fringe.

T-5-6 deep white sandy soil(dWs)

alluvial terrace (5), slope 0%, millet field, surface of loose sand as a Ap horizon

1:A11p (0-2), loose white sand with destroyed slaking

2:A12 (2-45), dull yellowish brown (10YR5 /3, wet), dull yellow orange (10YR7/2,dry), weakly massive, sand, consistence: slightly hard, stickiness:null, plasticity:null, semi-dry condition, interstitial pore well developed with common fine tubular pores (5%), fine roots common,

3:C1 (45-120), dull yellowish brown (10YR5/4, wet), dull yellow orange (10YR7/3,dry), weakly massive, sand, consistence:slightly hard, stickiness:null, plasticity:null, semi-dry condition, interstitial pores well developed with few tubular pores, fine roots common

4:C2 (120-220), dull yellowish brown (10YR5.5/4, wet), light gray to dull yellow orange (10YR7.5.2,dry), weakly massive, sand, consistence: slightly hard, stickiness:null, plasticity:null, semi-dry condition interstitial pores well developed with few tubular pores(1%), fine roots few(1%) up to 200cm, existence of wavy brown band (5mm in width), existence of spheric mottles by clay concentration,

5:C3 (220-300+), light yellow orange (10YR 8/4, wet), light gray (10YR8/2, wet) associated with bright brown mottle volume (40%), massive, sand consistence: hard, stickiness: null, plasticity: null, semi-dry condition, interstitial pore well developed with few tubular pores(1%), no root, wavy bright brown mottles are remarkable

Remark

a)The brown mottle suggests separation and accumulation of fine particle.

T-1-6 moderately-deep bright reddish brown sandy soil, mBbs

Pediplain with erosion surface (3a), slope 2%,fallow by Zuiera sp. with herbaceous vegetation, surface of deposited coarse sand with lamellar structure (2cm) followed by algae black surface

1:A11 (2-5), brown (10YR4/6, wet), light yellow orange (10YR 8/3.5,dry), massive, sand, consistence: slightly hard, stickiness: null plasticity:null, dry condition, interstitial pore well developed with common tubular pores, fine roots few transition: smooth and progressive

2:A12 (5-30/35), brown (10YR4/6, wet), light yellow orange (10YR8/3.5, dry), massive, sand to loamy sand, consistence: hard, stickiness: weak, plasticity: null, semi-dry condition, interstitial pore well developed with very few tubular pores fine roots few, transition: smooth and progressive

3:B2 (30/35-90/100), bright brow (7.5YR5/8, wet), dull orange (7.5YR7/4, dry), massive, sand to loamy sand, consistence: hard, stickiness:weak, plasticity:null, semi-dry condition, interstitial pore well developed with very few tubular pores,fine root almost null transition smooth and rapid

4:BC (90/100-112), orange (7.5YR6/6, wet), light yellow orange (7.5YR8/4, dry), massive, sand to loamy sand, consistence: hard, stickiness:weak, plasticity:null, semi-dry to dry condition, interstitial pore well developed, transition: smooth and abrupt

5:Ccn (112-142), irregular yellow nodule layer (1-10cm, yellowish brown (10YR6/8, dry) inside dark brown on the surface, dark brown sub-round nodules (3-5mm) few, transition:irregular and abrupt

6:2C (142-185+), cemented layer composed of clayey volumes with various color (mottled) such as white, yellowish brown, orange, reddish brown, very hard, angular blocky,
sub-round nodule (3-5mm) common

Remark
a) The naming of fifth horizon is questionable

T-6-6 moderately-deep reddish brown soil ,mRs

sand mound on the plateau(1c), slope 0-0.5%, millet field, surface with run-off crust by coarse sand and fine sand sporadic erosion crust near the pit

2:A12 (0-30) horizon:reddish brown(5YR4/6,wet), bright reddish brown(5YR5.5/6, dry), massive, sand, consistence: hard, stickiness: null, plasticity: null, wet, interstitial pore well developed with some tubular pores, fine roots common transition smooth and progressive

3:B21 (30-95), reddish brown(2.5YR4/8,wet), bright reddish brown (2.5YR5/8,dry), massive, loamy sand to sand, consistence: hard, stickiness: weak, plasticity: null, semi dry condition, interstitial pore well developed with some tubular pores, fine roots few, existence of semi-rounded gravel (10mm) transition: smooth and progressive

4:B22 (95-190), reddish brown (2.5YR4/8, wet), orange (2.5YR6/8, dry) massive, loamy sand to sand, consistence: hard. stickiness: weak plasticity:null, semi dry condition, interstitial pore well developed with some tubular pore, fine roots few, existence of hard sub-angular aggregates(5-10mm)at the lower part transition irregular and abrupt

5:C (190-210+), continuous clayey sandy cemented layer, semi-weathered mosaic color with yellow, reddish brown, white, weathered orange, orange sand is in the pores

T-1-12 moderately-deep bright reddish sandy soil, mBs

pediplain with erosion surface (3a), slope 0-0.5%, herbacious vegetation with sporadic Zuiera sp. lamellar structure surface with three alternative layer by fine sand and coarse sand (2cm), algae crust on the surface

1:A (2-22), reddish brown (5YR4/8,wet), orange (7.5YR6/6,dry) weak sub-angular blocky (5cm), sand, consistence: hard, stickiness: null, plasticity: null, semi-dry condition, interstitial pore well developed with few tubular pores, fine roots common, transition smooth and clear

2:B2 (22-90), bright reddish brown (5YR5/8,wet), orange (5YR6/7,dry) massive, sand, consistence: firm, stickiness:weak to null, plasticity:null, moist condition, interstitial pore well developed with few tubular pores, fine roots common, transition smooth and progressive

3:B22 (90-120), :bright reddish brown (5YR5/8,wet), orange (5YR7/6, dry) massive, sand, consistence: friable, stickiness: null, plasticity:null, moist condition, interstitial pore well developed with very few tubular pores, fine roots very few transition irregular and abrupt

4:C (120-170+), continuous sandy cemented layer, variously colored with dark reddish brown, reddish brown, yellow orange loose sand occupies the medium tubular pores

Remark
a)The vegetational pattern in this grand land unit looks like that of ancient erg.

T-21-2 deep bright brown sandy soil, dBs

cordon form, (7c), near the top of cordon, slope 0%, millet field loose sand on the surface (3cm)

1:A (0-26), brown (7.5YR4.5/6, wet), dull orange (7.5YR6/4, dry) massive, sand rich in fine sand, consistence:soft, stickiness: null, plasticity:null, dry condition, interstitial pore well developed with few tubular pores, fine roots few transition smooth and progressive

2:B2 (26-105), bright brown (7.5YR5/8, wet), bright brown (7.5YR5/6, dry) massive, sand, consistence: soft, stickiness: null, plasticity: null semi-dry condition, interstitial pore well developed with few tubular pores, fine roots few to common,

3:BC (105-165), bright brown (7.5YR5/6, wet), orange (7.5YR6.5/6, dry) weakly massive to loose, sand, consistence:soft, stickiness:null, plasticity:null, moist to semi dry condition, interstitial pore well developed with few tubular pores, fine roots few, existence of fossilized plant fragment (3-5mm) at 150-160cm in depth.

4:C (165-260+), bright yellowish brown (10YR6/6), light yellow orange (10YR8/4,dry), weakly massive to loose, sand, consistence: loose, stickiness: null, plasticity: null, moist to semi dry condition, band-typed yellow mottle (7.5YR8/8, semi-dry): 40%, interstitial pore well developed, fine root very few, arrive up to 230cm

T-12-5 deep white sandy soil, dWs

lower alluvial terrace (5), slope 0%, herbaceous vegetation with Combretum sp, destroyed slaking surface, loose gray sand (5mm), 60% of black litter coverage on the surface

1:A (0-40?), dull yellowish brown (10YR5/4, wet), dull yellow orange (10YR7/3, dry), weakly massive, fine sand, consistence: soft, stickiness: null, plasticity: null, dry condition, interstitial pore well developed with few tubular pores, fine root few, transition sooth and clear

2:AC (40?-95/100), orange (7.5YR6/6, wet), dull orange (7.5YR7/3, dry) massive, fine sand, consistence: hard, stickiness: null, plasticity: null, dry condition, existence wavy brown mottle, interstitial pore well developed with common tubular pores, fine roots few transition smooth and abrupt

3:C1 (95/100-110/115), dull yellow orange (10YR7/2), white (9/0,dry) weakly massive to single grain, fine sand, consistence: loose, stickiness:null, plasticity:null, dry condition, interstitial pore well developed with few to common tubular pores, fine root common, transition smooth and abrupt

4:C2 (110/115-123), dull yellowish brown (10YR5/4, wet), dull yellow orange (10YR7/2,dry) massive cemented, very fine sand with some course sand, consistence: very hard, stickiness:null, plasticity:null, dry condition, yellow mottle(vague border, 40%) interstitial pore well developed with common tubular pores, fine roots very few, transition: smooth and abrupt

5:C2 (123-150), grayish yellow brown (10YR6/2,wet), dull yellow orange (10YR7/2, dry), massive (cemented), sandy loam with fine sand, consistence: very hard, stickiness: null, plasticity: null, dry condition, existence of white fine mottle (2mm), fine roots very few, existence of ligneous root (2cm), transition: smooth and abrupt

6:C3 (150-250+), light gray (10YR8/1, wet), white (9/0,dry) single grain, fine sand, consistence: loose, stickiness: null, plasticity: null, dry condition, existence of wavy brown mottle (10YR7/6,dry) with texture of loamy sand to sandy loam and yellow mottle, fine root very few, arrive up to 210cm, existence of ligneous root(10cm)

T-25-1 brown clayey soil Bc

depression form(8), slope 0%, dense bush with herbaceous vegetation, run-off crust covered by litters on the surface

1:A11 (0-9), lamellar structure by fine particle layer and coarse particle layer fine particle layer brown: (7.5YR4/6, wet), dull orange 7.5YR6/4, dry), silty loam, stickiness: weak, plasticity: weak, coarse particle layer, dull orange (7.5YR6/4,wet), orange (7.5YR7/6, dry), sand, stickiness: null, plasticity: null, medium platy structure by the above two alternative layers tubular pore few, rich in litter, fine roots few, yellowish brown mottle around the tubular pores. consistence: extremely hard

2:A12 (9-49), brown (7.5YR4/4, wet), dull orange (7.5YR6/4, dry), massive, silty loam, consistence: extremely hard, stickiness:weak, plasticity: weak dry condition, tubular pores few, reddish brown mottle around the tubular pores, fine roots few

3:B2 (49-80+), reddish brown (5YR4/6, wet), orange (7.5YR6/6), massive with irregular surface, weakly sub-angular blocky(2-5mm), Clay loam consistence: extremely hard, stickiness: medium, plasticity: medium, dry condition, common in tubular pores, fine roots few, light gray mottles around the tube.

Remark
a)The fraction of coarse layer at A11 horizon is fine sand.
b)The mottle around the tubular pore suggests water stagnation.

T-3-44 deep white sandy soil,dWs

alluvial terrace (5), slope 0.5%, millet field, loose bright yellowish brown sandy surface (A11p, 2cm) on the weakly massive sand (A12, 3cm)

1:A13 (5-27cm), dull yellowish brown (10YR5/4, wet), dull yellow orange (10YR7/4, dry), weakly massive, sand, consistence: slightly hard, stickiness: null, plasticity: null, dry condition, interstitial pores well developed and fine tubular pores common, fine roots few,

2:C1 (27-91), brown (10YR4/4, wet), dull yellow orange (10YR6/3, dry) massive, sand, consistence: slightly hard, stickiness: null, plasticity: null, dry condition, interstitial pores well developed and fine tubular pores common, fine roots few, 3:C2 (91-130/155), dull yellow orange (10YR7/4, wet), light gray (10YR8/2, dry) with brown mottle phase (10YR5/6, wet, 10YR6/3, dry) massive, sand, consistence: slightly hard but brown phase is harder than white phase, stickiness: null, plasticity:null, interstitial pores well developed and fine tubular pores common, fine roots few brown mottle phase with band form (5-10cm width), this horizon partially penetrates up to 230cm

4:C3 (130/155-200/210), brown (10YR4/4, wet), dull yellow orange (10YR6/3, dry), massive, sand, consistence: hard, stickiness: null, plasticity: null, semi-dry condition, interstitial pores well developed and fine tubular pores common, fine roots very few, trace of lamellar structure

5:C4 (200/210-230+), dull yellowish brown (10YR5/3, wet), dull yellow orange (10YR7/2, dry), massive, sand, consistence: extremely hard, stickiness: null, plasticity: null, semi-dry condition, interstitial pores not well developed and fine tubular pores few brown mottle around the fine tube, existence of yellowish brown materials

Plateau-1 (bare land), shallow reddish brown clayey soil,sRc

flat plateau (1a), slope 0%, bare land between tiger bush vegetation, pale orange (5YR8/3,wet), orange (5YR7/6,dry) erosion crust (2mm)

1:B2(?) (0-2cm), bright reddish brown (5YR5/8,wet), orange(5YR7/6, dry), massive with irregular surface to sub-angular blocky (5-10mm) ,sandy loam, consistence: hard, stickiness:weak, plasticity:weak dry condition, interstitial pore well developed but less than that of sandy soil,tubular pores few, fine root very few(non active)

2:2C1(?) (2-25/35), orange (5YR6/8, wet), orange (5YR7/6, dry), granular structure well developed, clay loam skeleton, interstitial pores developed, tubular pores few, fine roots very few(non active) angular to semi-round gravels and stones(5mm to 50mm) common (50%)

3:3C2(?) (25/35-55+), angular to semi-round stone layer, ferruginous crust fragments, dark reddish brown color is dominant associated with bright brown and reddish brown color,

Remark
a)The ferruginous gravels and stones are distributed on the surface.

Plateau-2(in the bush) shallow reddish brown clayey soil,sRc

flat plateau (1a), slope 0%, tiger bush,two to three structural crust (ST2?) 5mm in depth,covered by litter

1:A (0-2cm), reddish brown (5YR4/6, wet), bright brown (7.5YR5/6, dry), fine sub-angular blocky structure moderately developed (5-10mm), sandy loam to clay loam, consistence: hard, stickiness: weak, plasticity: weak, dry condition, interstitial pores well developed and fine to coarse tubular pores common, aggregates by biological activity common, fine roots common, existence of tree root, ferruginous gravels few(2%)

2:B2 (2-33), bright reddish brown (5YR5/8, wet), orange (5YR6/6, dry) fine to medium sub-angular blocky well developed (5-15mm), clay loam, consistence: hard, stickiness: medium, plasticity: weak, dry condition, interstitial pores moderately developed, tubular pores few, fine roots common, ferruginous gravel and stones common(40%)

3:2C1(?) (33-45), discontinuous ferruginous layer, cracked in block form, existence of root of trees

4:2C2(?) (45-70), moderately continuous ferruginous crust layer, tendency to crack horizontally, lighter in weight than other crust fragment, existence of root of trees

5:2C3(?) (70-90), almost continuous ferruginous crust layer, existence of fine roots and tree roots in the cracks,

6:2C4(?) (90+), continuous ferruginous crust layer, extremely hard

T-18-8 shallow reddish brown sandy soil, sRs

pediplain with eroded surface(3a), slope 1%, bare land (70%) with sporadic Zuiera sp. structural crust with vesicular pores,coarse sand(1mm)/fine sand(1mm)/ loose sand(5mm)

1:A (0-33cm), (bright) brown(7.5YR4.5/6, wet), (dull) orange (7.5YR6/5, dry), massive, sand rich in fine sand, consistence: slightly hard, stickiness: null, plasticity: null, dry condition, interstitial pores well developed, fine tubular pores few, fines roots few, transtion smooth and clear

2:2B21 (33-95), bright reddish brown(2.5YR5/8), (dull) orange(3.75YR6/8) medium sub-angular blocky structure well developed, sandy loam to loam, consistence: hard, stickiness: weak, plasticity: weak, fine tubular pores few (5%), fine root few (3%), transition: smooth and clear

3:2B22 (95-150), bright reddish brown (3.75YR5/8, wet), (dull) orange (3.75YR6/8), medium sub-angular blocky well developed (10-20mm) sandy loam to loam, consistence:hard, stickiness: weak, plasticity: weak, semi-dry condition, fine tubular pores few(5%), fine roots very few (<1%, up to 120cm), existence of yellow volume at the lower part of the horizon, transition: smooth and clear

4:2BC (150-165+), bright reddish brown (3.75YR5/8,wet), dull orange (5YR6/8,dry), massive, loam to clay loam, consistence: very hard, stickiness: medium, plasticity: weak, dry condition, fine tubular pores few, no root, white, bright brown and dark reddish brown materials are cemented. fine aggregates by biological activity common,

Remark
a)The B21, B22 and BC horizons are maybe, ancient soil.
b)The A horizon is different from aeolian deposits in soil texture.