CHARACTERIZATION OF A SOIL TRANSECT IN MISAMFU RESEARCH STATION (ZAMBIA)

Emmanuel Fritsch and Christian Valentin*

Abstract

To illustrate the ORSTOM approach to site characterization through the study of vertical and lateral soil volumes and their differentiating characteristics, a detailed study was made of a transect 485 m long situated on the plateau area of Misamfu Research Station. Most of the soils appear to be derived from the weathering of schists, but are also influenced by the depth to underlying quartz sandstone.

The paper describes in detail variations along the transect in soil, in associated indurated horizons, in vegetation cover and in surface features such as termite mounds. It discusses physical constraints to agriculture, including the occurrence and formation of two types of surface crust.

The ORSTOM approach, as exemplified by this study, serves to show that soil differences and soil heterogeneity are not random, but that the present characteristics of the soil are related both to long-term factors affecting soil formation and to its recent cultivation history.

Résumé

CARACTERISATION D'UN TRANSECT PEDOLOGIQUE SUR LA STATION DE RECHERCHE DE MISAMFU, ZAMBIE

En vue d'illustrer l'approche ORSTOM de caractérisation des sites par analyse des différenciations verticales et latérales des volumes pédologiques, l'étude détaillée d'un transect long de 485 m sur la zone de plateau de la Station de Recherche de Misamfu a

* Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM), B.V. 51, Abidjan, Côte d'Ivoire.

été entreprise. La plupart des sols apparaissent dérivés de l'altération de schistes, mais sont aussi influencés par les grès quartziques sousjacents. Cet article décrit en detail le long du transect les variations concernant les sols, les horizons indurés associés, la végétation, et les termitières. Il discute les constraintes physiques des sols pour l'agriculture, et en particulier la présence et la formation de deux types de croutes superficielles.

L'approche ORSTOM, ainsi qu'elle est indiquée dans cette étude, permet de montrer que les différenciations pédologiques et l'hétérogénéité des sols n'est pas aléatoire, mais que les caractéristiques actuelles des sols sont liées à la fois à des facteurs affectant la formation des sols à long terme, et aussi à l'histoire récente des cultures.

Introduction

During the first IBSRAM regional seminar (Douala, January 1986), it was clearly established that two different approaches to site characterization, far from being opposed, were in fact complementary:

- the first one, the most common, consists in identifying representative profiles;
- the other one, advocated by pedologists at ORSTOM, attempts to study the vertical and lateral differentiations of soil volumes.

As an attempt to ascertain this mutual complementarity, it was planned that a team of pedologists from ORSTOM would be sent to Zambia, the host country of the following regional seminar. Its task consisted in applying its own approach to a site which had already been characterized using the standard approach. The objective of this report is to summarize the main field observations made at Misamfu Research Station during some ten days in October 1986.

The Misamfu Regional Research Station

The Misamfu site was selected from among several others since its environmental conditions are representative of Northern Province, chosen by the Zambian government as a priority area for agricultural development. The station covers an area of 426 ha and is located 7 km north of Kasama, i.e. approximately 800 km from Lusaka. The climate is influenced by the elevation (1384 m), which results in a mean annual temperature not exceeding 19.8°C. The latitude is 10°10', and frost may occasionally occur. The mean annual rainfall is 1360 mm, occurring as storms mainly between November and April.

The area is located on the verge of a gently undulating plateau with a convex slope linking it to a flat marshy area (dambo)* in which the Misamfu stream flows. The northern boundary of the station coincides with quartz sandstone outcrops. Emphasis was put on the plateau rather than on the slopes or valley bottom areas because the agricultural experiments are situated in the summit areas, next to the laboratories.

* Dambo = broad valley bottom area.

Cuirassed and Gravelly Geological Formations

First, it seemed necessary to ascertain the geological substratum. In this respect, the two gravel quarries located on the plateau east of the station, 7 m deep and 100 to 300 m long, provided two lines of information: one on geological formations, the other on the development, degradation, and location on the plateau of the iron pan.

Observations in the worked gravel quarry

In the eastern part of the gravel quarry, which is still worked, four layers were identified from bottom to top (Figure 1):

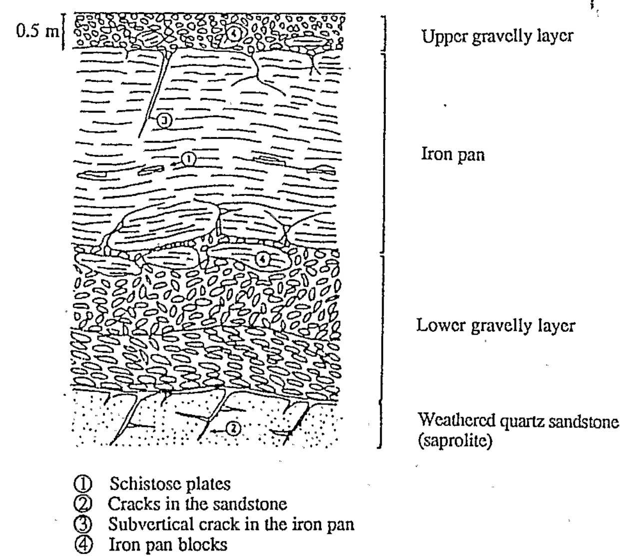


Figure 1. Section of the worked pit.

* the quartz sandstone,
* a lower gravelly layer,
* an indurated layer, and
* an upper gravelly layer.

The quartz sandstone is fractured and weathered in its upper part (sandy, friable, white to pinkish white saprolite). The fractures contain red to dusky red, clay loam material. The walls of the fractures are more strongly coloured.

The lower gravelly layer comprises two horizons. The first, which directly overlays the quartzitic saprolite, includes contiguous, coarse, flattened gravel fragments (6 cm long). Most often, the longer axis of these gravels is oriented along undulating lines, parallel to the upper limit of the quartzitic saprolite. Once broken, the gravel fragments have a schistose appearance: red to dusky red in colour, fine grained, with thin slaty fragments parallel to the longer axis. The unconsolidated material between the gravel is small in quantity, microaggregated, dusky red (10R), and clay loam in texture. This layer is overlaid by a second gravelly horizon which differs in:

- o the disappearance of the undulating oriented gravel, since the contiguous gravel is no longer aligned;
- o the occurrence in the upper part of large blocks of iron pan;
- o the gradually paler colour, from bottom to top, of the soft red (2.5YR to 5YR), strongly microaggregated, sandy clay matrix.

The iron pan has a lamellated, platy appearance due to the superimposition of tubular to planar pores that are roughly parallel to the land surface. When broken, the lamellae or plates appear identical to those of the gravel located above and below the iron pan: dusky red to dark red colour, fine grained, locally with white edges or reddish-yellow to dark brown mottles. Cracks occur in the lower and upper parts of this iron pan. Two main characteristics were inherited from the rock:

- o platy relicts of schist in the form of flat oriented fragments,
- o subvertical cracks of several metres with smooth walls, very probably corresponding to ancient cracks in the schist.

Iron blocks occur in the lower part of the upper gravel layer. The gravels are associated with flat schistose fragments. The soft matrix is very dark brown (0-20 cm) to brown (20-50 cm), loamy sand to sandy loam.

From these observations, it is inferred that:

- The quartzitic sandstone is overlaid by schistose formations, and the foliation of these formations is roughly parallel to the land surface.
- The iron pan was formed within the schistose formations, developing upwards from the boundary between the quartzitic sandstone and the schist. The indurated iron pan horizon has preserved to varying degrees the schistose texture and the foliated structures and cracks of the original rock. Likewise, dissolution processes which produced the platy appearance of the iron pan were guided by the structure of the schist.
- The iron pan is being dismantled both in its lower and upper parts, providing material for the gravel layer that occurs only in the western part of the gravel pit. This layer may be 7 m thick, and remains as an outcrop or near the surface.

Observations in the abandoned gravel quarry

Observations of this gravel pit provide additional information (Figure 2). The upper limit of the quartz sandstone is undulating. The cuirassed formations are seen only on the convex domes, where quartz sandstone is nearest to the surface. The iron pan may occur exposed as an outcrop or be covered by a gravel layer. Most commonly, the gravels have a schistose appearance, but occasionally they may resemble a sandstone, or a mixture of materials. As illustrated by observations in the iron pan, interbeddings of sandstone may occur within the schist. In depressions, the quartz sandstone is overlain by a gravelly layer. This layer is generally less thick (1-2 m) and of smaller-sized gravel, chiefly in its upper part (nodules of a few millimeters), and illuvation cutans. It is covered with unconsolidated material, 2 to 4 m thick, light in texture (loamy sand to sandy clay loam), and light red (7.5YR to 5YR) to red (2.5YR) in colour.

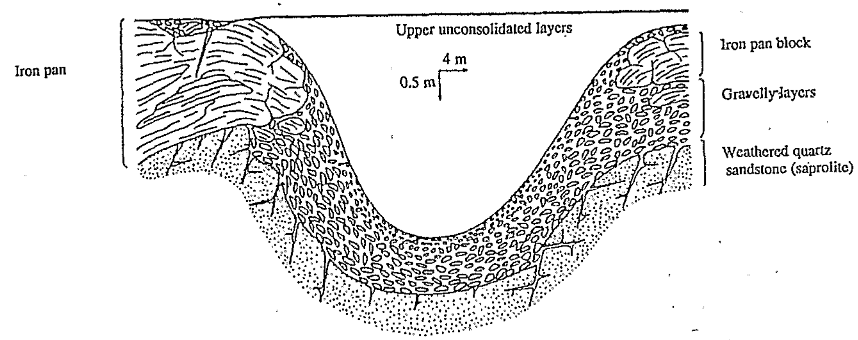


Figure 2. Section of the abandoned pit.

Finally, in this gravel pit, the areas where the quartz sandstone is near the surface and where as a result gravel and iron pan outcrop are generally inclined at a 35° angle. The distance between undulations is 60 m.

Vertical and Lateral Differentiations within the Unconsolidated Layers

Interpretation of the soil map

The soil map made by L.A. van Sleen in 1976 (Figure 3) shows that certain soil units on the plateau are distinctly east-west elongated. They may be related to one of the following features:

- Areas where the quartzitic sandstone is near the surface. Two of these areas occur on the map, units P11, P12, P13, C31 for axis la, and unit P23 for axis 1b. These areas where the basement rocks approach the surface are capped either with indurated or gravelly formations, which are thick east of axis la (the most elevated part of the plateau), or thin or absent west of axis la and along axis 1b where bedrock often outcrops.
- Depressions in the quartzitic sandstone where it is overlaid by much thicker schistose formations which have through weathering and soil formation given rise to more clay-textured soils (axis 2, soil unit P21).

This map and the observations in the gravel pits show the dominant influence of the rock formations and structures on the spatial distribution of soils. In most cases, soils derive from weathering of schists rather than quartzitic sandstone. Undulations of the latter, 500 m apart, have caused the zonation of the soils.

Transect layout

The selected transect is 485 m long. It is located on the plateau next to the buildings of the Misamfu Research Station. Starting in the north, at a rocky quartz sandstone outcrop, it cuts at right angles through four soil units, which have been defined by Van Sleen as follows:

* Lubwa sand, with some rock outcrops (C31),
* Kasama sandy loam (P14),
* Mujulira sandy clay loam (P21), and
* Misamfu sandy loam (P22).

These four units cover 0.4%, 9.2%, 4.9%, and 32.6% respectively of the whole mapped area (426 ha), the last three units being the most frequently cultivated.

Vertical and lateral soil differentiations along the transect

The transect (Figure 4) cuts perpendicularly through an undulation of the bedrock. In the upper part of the transect, the quartz sandstone outcrops, and in the lower part, it is 4 m deep. In the median part of the transect, the quartzitic sandstone is overlain by unconsolidated schistose formations, weathered in their upper parts (clay loam which is micaceous to the touch, with dusky red to strong red horizontal beds, and tarnished yellow to white veins). A thin gravelly layer (2 to 20 cm thick) occurs above these sand-

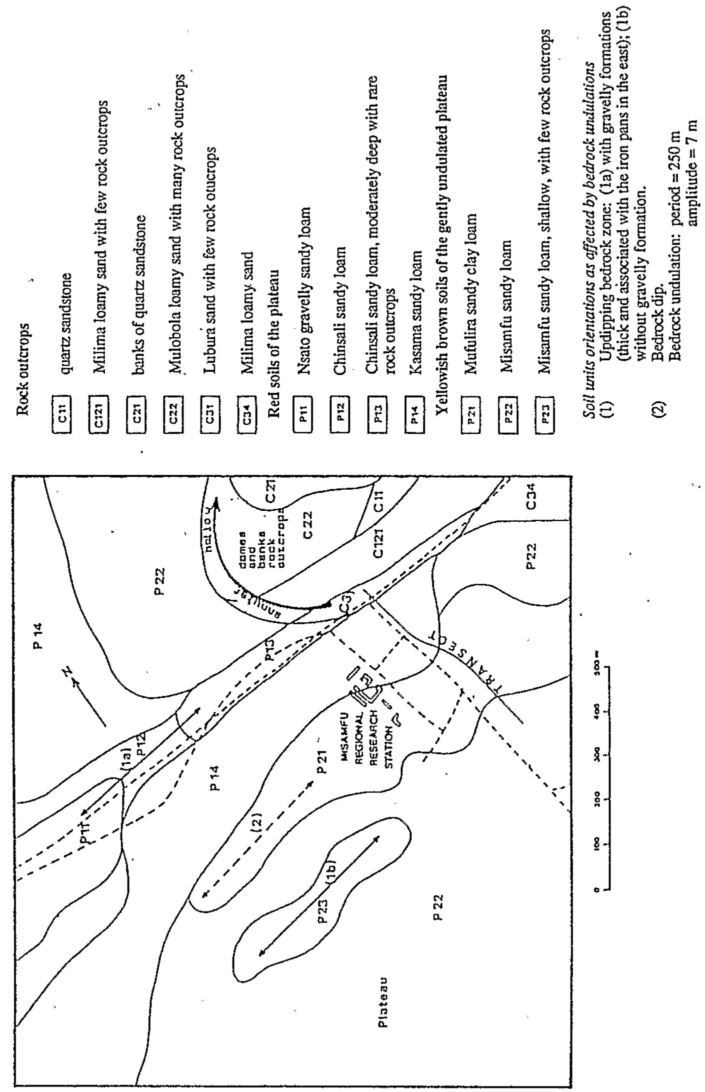


Figure 3. L.A. van Sleen soil map extract (1976) and main structural orientations.

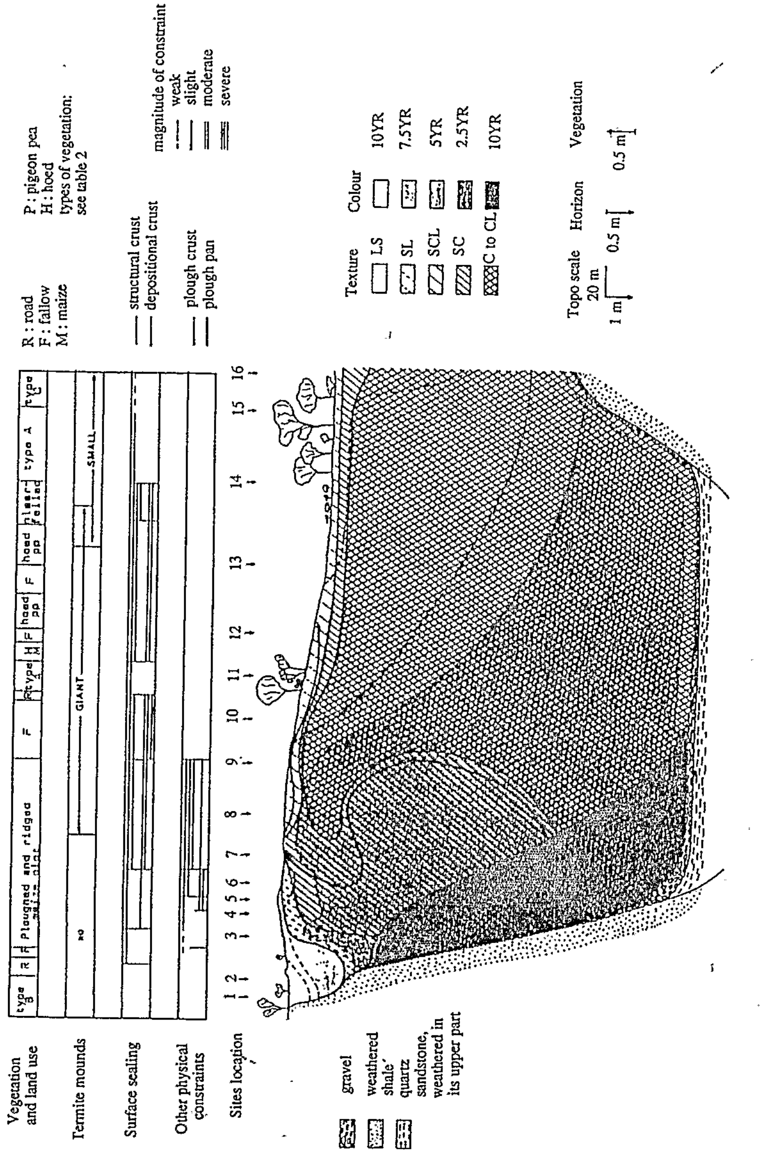


Figure 4. Vertical and lateral variations of soil colour and texture along the transect. Relationships with soil surface and tilled microprofile features.

stone and schistose formations. The gravels are generally platy with a schistose appearance, even where they are in direct contact with the quartz sandstone. In the upper part of the transect, the very thin (2 cm) gravel layer is located in the cracks and fissures of the sandstone.

In the median part of the transect, the upper unconsolidated layers have an average thickness of 7 m. There, as in the lower part of the transect, they show some slight hydromorphic features at the base (a red layer 10 to 30 cm thick with yellow mottles). Within these layers, a succession of textural, structural and colour gradients can be discerned. As shown below, these gradients result from three main transformation processes which have conferred their present arrangement on the upper unconsolidated layers.

Transformation in the upper part of the transect (profiles 1 to 9)

Laterally from the upper to lower areas, the soils show a textural and structural gradient, from sand to loamy sand, and from cohesionless to clay with a coarse subangular blocky structure. In the lower part, there is an illuvial concentration of clay (profiles 8 to 9). In the transitional zone (profiles 4 to 7) there are cutans in microaggregated layers. The soils are red, except for the topsoils and those in the upper part of the transect (mainly near the rock outcrop), where they become yellow. These lateral differentiations probably result from eluviation of clay (and to a lesser extent of iron) from the upper zone and its concentration in the lower zone in the form of cutans, and indicate an eluvial-illuvial system.

Eluviation could be the cause of the topographic inversion in the most impoverished part of the system: the highest point of the transect is located near profile 5. Particularly active along an axis perpendicular to the transect, eluviation might also have produced the annular depression located at the foot of the rock outcrop (Figures 3 and 4). This hypothesis could be tested by studying several microtransects radiating from the rock outcrop, from the upper to the lowest zones.

Transformation in the median part of the transect

This transformation starts between profiles 9 and 10. It is indicated by the soil getting lighter in colour (from red 5YR to brown 7.5YR) without any changes in texture or structure. Developing from the surface, it becomes more pronounced as it gets deeper and further down the slope, as shown by a thickening of the brown horizons, the occurrence of a yellow layer within both the humous topsoils of profiles 13 and 15, and the deep mineral horizons to a depth of 2.5 m in profile 16. Generally a lighter soil colour is attributed to an increasing impoverishment in iron with depth, and to a change in the forms of iron, with hematite dominant in the red soils, and goethite in the yellow ones. This transformation might have been initiated by a change in the hydrodynamic properties of the soil (Chauvel, 1977), and particularly by increasingly wide fluctations in the lower part of the transect between wet- and dry-season moisture conditions.

Transformation in the lower part of the transect

This last transformation appears at a depth of 1.4 m at profile 14. It corresponds to the occurrence of a strongly microaggregated structure. The upper limit of this structurally defined layer gets closer to the surface in the lower part of the transect, and outcrops in the last profile (16). In this layer, traces of faunal activity features due to termites are very numerous. It is difficult at present to say whether this termite activity is the only cause of this structure or whether other parameters are involved, such as a slight textural change. Conversely, the horizons which replace this horizon upslope and downslope have a compound structure, medium to coarse subangular blocky with a microaggregated structure in the channels or between blocks consisting of more or less coalescing microaggregates. These horizons might therefore have been formed by the degradation of the microaggregated structure.

Conclusion

Most of the plateau soils of Misamfu Research Station seem to have originated from the weathering of schists. Conversely, the zonation of the soils has been strongly influenced by the undulations of the underlying quartz sandstone bedrock, which is less easily weathered, and which outcrops in various locations on the plateau.

Iron pans have formed and been subsequently degraded. They are not numerous, and have developed in schist formations and the zones where quartz sandstone is closest to the surface. They are east-west orientated, at right angles to the bedrock undulations. These iron pans were weathered, first into gravelly layers, then into unconsolidated upper horizons which are generally thick in most of the plateau. This suggests either that iron pan formation was restricted to a few areas or, conversely, that iron pan degradation has been very complete.

The upper unconsolidated layers have themselves undergone a succession of changes which account for the present differences between soils. These transformations were also influenced by the bedrock undulations and by the major rock outcrops of the plateau. In the course of this survey, three such transformations have been observed which can be linked to the three following systems:

- o the eluvial-illuvial system in the upper part of the transect;
- o the iron-impoverishing system with goethitic evolution in the median part; and
- o a system in the lower part leading either to the development or to the degradation of a microped structure.

Soil Surface Features and Major Physical Constraints

The features which generally reflect soil constraints are the vegetation cover, the faunal activity, the surface seals, and the discontinuities within the cultivation profile. When characterizing a site, it is especially important to identify these features in view of the fact that they cannot be directly derived simply from an analysis of the soil cover. A

study which was complementary to the main pedological study was therefore undertaken, which included soil surface features* and variations in the cultivation profile along the transect.

The vegetation cover

Objectives and methods

When characterizing a site, a study of the lateral variations of vegetation cover must meet a twofold objective:

- o to distinguish those soils which, under natural conditions have the least constraints and probably the highest fertility; and
- o to establish possible relationships between soil and vegetation units so as to facilitate mapping.

Along this transect, however, the natural woodland savanna was partly cleared for agronomic trials. Even where it still remained, it was seriously disturbed by woodcutting, as evidenced by numerous mutilated trunks and branches. Despite these unfavourable conditions for putting the method into practice, several parameters were recorded:

- o the density of woody plants, in four layers;
- o the type of herbaceous layer, characterized by its continuity and its associated flat or hillock microrelief, i.e. with grass clumps developed on small 2-5 cm mounds; and
- o the percentage of total cover, visually divided into three types: woody, herbaceous and litter layer.

The major types of soil cover

The main field data are shown in Table 1.

Table 1. Data on vegetation and soil cover.

Site no.	Number of trees per layer per 1000 m²				Soil cover (%)			
	0-2 m	2-5 m	5-10 m	>10 m	woody	herbaceous	litter	Total
2	10	20	4	--	3	100	30	100
11	60	10	40	--	35	3	80	95
14	250	--	--	--	30	20	20	70
15	200	50	16	2	20	30	80	95
16	5	5	4	--	7	30	80	95

* This term refers to the vegetation cover as well as to the specific superficial soil differentiations.

Since site 14 was clear-felled a few years ago, its woody cover, consisting only of coppice shoots, must be considered separately. Since it was insufficiently protected, the soil surface has been crusted, hindering emergence of both tree and grass seedlings. Completely barren bare areas 3 m in diameter occur, covering about 30% of the whole surface.

Two main types of woody vegetation can be distinguished. The first consists of sparse small trees, and the second comprises a wider range of layers, from tall trees down to a dense understorey. Three types of herbaceous cover were also identified, so that three major types of vegetation cover were noted (Table 2).

Table 2. Main types of vegetation vover.

Vegetation type	Site	Trees	Herbaceous layer	Microrelie
A	11-14-15	tall	discontinuous	flat
B	2	small	continuous	flat
C	16f	small	discontinuous	hillocks

Relationships with the soil units

A fairly good relationship was established between these three types of cover and soil variations (Figure 4):

- Types B and C, with low trees, occur in both the upper and lower parts of the transect where the quartz sandstone approaches the surface, but the grass cover of the two types is different. It is continuous and without microrelief where the topsoil is extremely eluviated (Lubwa sand), but has discontinuous clumps on hillocks where the topsoil texture is heavier (Misamfu sandy loam).
- The cover type A seems to be associated with deep soils which occur between two sandstone undulations (Mufulira sandy clay). The understorey is too dense to permit the development of a continuous herbaceous cover, and the topsoil too light-textured for the formation of raised clumps. This type of vegetation is probably the most common on the Kasama sandy loam series, but since this part of the transect was cultivated, the relationship could not be ascertained.

For future soil surveys, it is worth noting that the tree height reflects the sandstone depth, and that the occurrence of raised grass clumps indicates a fairly heavy topsoil texture of at least sandy clay loam.

Termite mounds

The main types

Among the faunal constructions, termite mounds are probably among the least difficult to identify and to relate to changes in soils. A nonspecialist can differentiate two main types of termite mounds along the transect:

- The first type resembles a flattened dome, 1.5 m high and 20 m in diameter. Under natural conditions, these massive nests are covered with woody vegetation denser than the vegetation that surrounds them. Under cultivation, their distinctive relief is easily noted. The distance between these termite mounds varies from 40 to 60 m.
- The second type of mound is more modest in size, being more or less cylindrical up to 40 cm high, with a base diameter ranging from 15 to 35 cm. The distance between these mounds decreases along the transect from 15 m (site 14) to 2 m (site 16). The size and the shape of these mounds resemble those of *Trinervitermes* spp.

In addition, many underground termite nests were observed in the pits along the transect. Thus termite harvesting activity may be encountered even in areas where there are no aboveground mounds.

Distribution of termite mounds and relationship with the soil

Considering only the aboveground termite constructions, it is possible to distinguish four zones along the transect:

- *A zone without termite mounds (sites 1 to 7).* This absence of mounds can probably be attributed to the very light texture of the soils in the first section of the transect (sites 1 to 3). But this hypothesis does not hold for the following section (4 to 7), possibly because the area had previously been levelled for a football field.
- *A zone with giant termite mounds (sites 8 to 13).* This zone corresponds more or less to the area of deep clay soils (Mufulira sandy clay loam).
- *A zone with both giant and small termite mounds (sites 13 and 14).* Both types coexist in the area where the basement rock approaches the surface (transition between the Mufulira sandy clay loam and the Misamfu sandy loam series).
- *A zone with small termite mounds (sites 15 to 16).* This type of mound seems to be associated with the shallower clay soils (Misamfu sandy loam). As already mentioned, the microaggregated structure of these yellow soils might be due, at least in part, to intense termite activity (7 termite mounds per 100 m^2 at site 16). What is much more certain is the great importance of harvesting activity on the breaking up of surface seals (Plate 1). It should also be noted that this type of temite mound is known for being associated with poor soils. The great number of these small termite mounds in this section of the transect might reflect a particularly low soil base saturation.

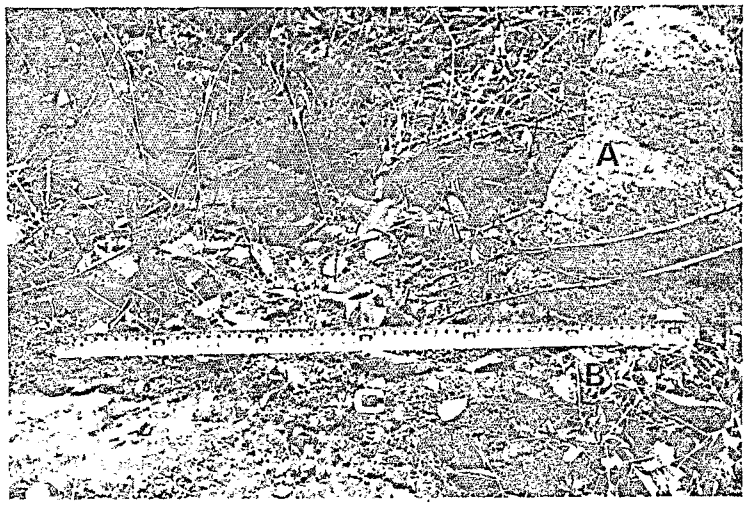


Plate 1. Small termite-mound (A), harvesting structures associated with the organic litter (B), thin structural seal underneath perforated by termites (C), site no. 15.

As with vegetation, attention paid to termite mound distribution could prove useful in indicating soil changes. A relationship between the soil properties and type of termite mound was noted along the transect.

Major physical constraints

Objectives and methods

Physical constraints are just as important for agriculture as chemical ones. That is why site characterization must include a study of the risks of physical degradation, such as surface sealing and crusting, erosion, and the formation of plough pans.

With this objective in mind, 15 profiles, 30 to 60 cm deep, were studied in detail. Each type of physical constraint was described and sketched in the field, and its coordinates carefully plotted in cross section. Ten of the profiles were of cultivated soils (cultivation profiles), and five under natural conditions. Twelve profiles were studied along the transect, two near an abandoned borrow pit, and another in the vicinity of the second Benchmark Project pit.

As shown in Figure 4, each type of physical degradation was studied separately. Their intensity was expressed at five levels: none, very slight, slight, moderate and severe. It is clear that a procedure based exclusively on macromorphological criteria should be supplemented by micromorphological studies and physical measurements. Nevertheless, even a broad study serves to indicate some general trends.

Surface crusting

Two main types of surface crust can be briefly described:

- **Structural crusts.** These consist of haphazardly arranged particles that, when dry, form a rigid microhorizon. When beginning to form, remains of aggregates are included, thus maintaining a certain degree of surface roughness. During the following stages, these aggregates, beginning with the smallest, slake and are incorporated into the crust, leaving the surface smooth, and thus favouring runoff and erosion (Plate 2). In areas particularly leached of clay, vertical sorting is usually more pronounced than in the previous case. Separation of plasma from skeletal material occurs during the earlier stages of formation. For the most developed forms, it is possible, even in the field, to distinguish three microlayers: the uppermost is composed of loose clean coarse sand grains; the middle layer consists of clean slightly cemented fine sand grains; and the third microlayer has a higher concentration of fine particles. Air vesicles commonly occur in the boundary zone between the last two microlayers.

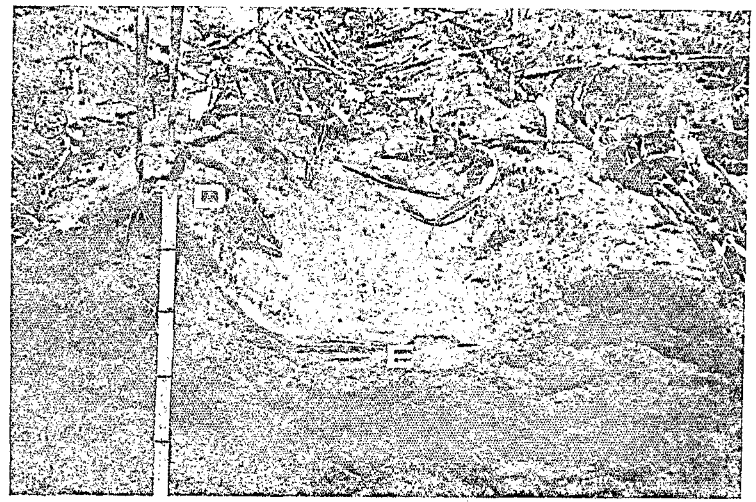
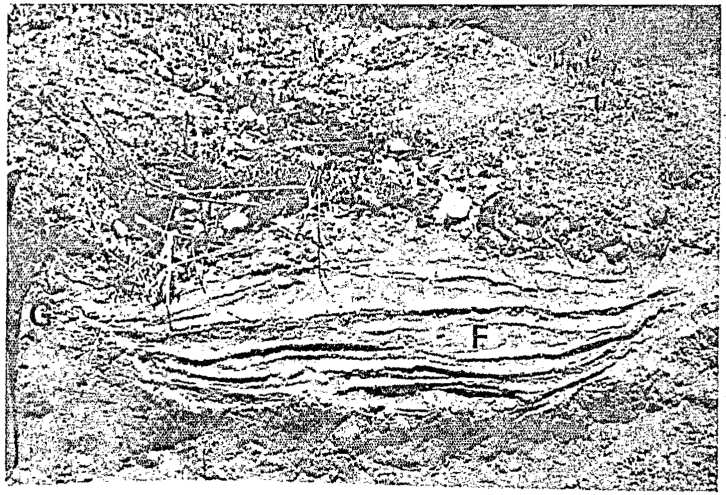


Plate 2. Ridge maize plot. In the bulk of the ridges, many fine roots have developed. The surface of the ridges is capped with a thin structural crust (D) that still includes some soil aggregates. Depositional crusts (E) were formed between the ridges. Plot located near Benchmark Project pit no. 2.

- *Depositional crusts.* These consist of well-sorted laminae formed when runoff occurs. These layered deposits, formed above structural crusts, show that runoff was strong enough to transport detached particles, but not enough to carry them outside the eroded area.

The criteria for estimating the magnitude of the crusting process in the structural crusts (Figure 4) are the strength, thickness, and degree of vertical sorting; and for the depositional crusts, the thickness, which can reach 8 cm (Plate 3).



late 3. Depositional crusts (F) between the ridges, near site 10, in a small plot that was kept bare during the rainy season. Structural crusts (G) were buried during hand-weeding which was performed after the rainy season.

Since these crusts form on the soil surface, their occurrence in a cultivation profile ıdicates that the soil was cultivated before they were formed. When a structural crust found, in a ridge or mound for example, it indicates that it has been formed by rain efore being buried during weeding. If, moreover, the present soil surface has no rusts, it must be inferred that weeding was performed after the rains. In short, pedogical features help to explain the history of the soil.

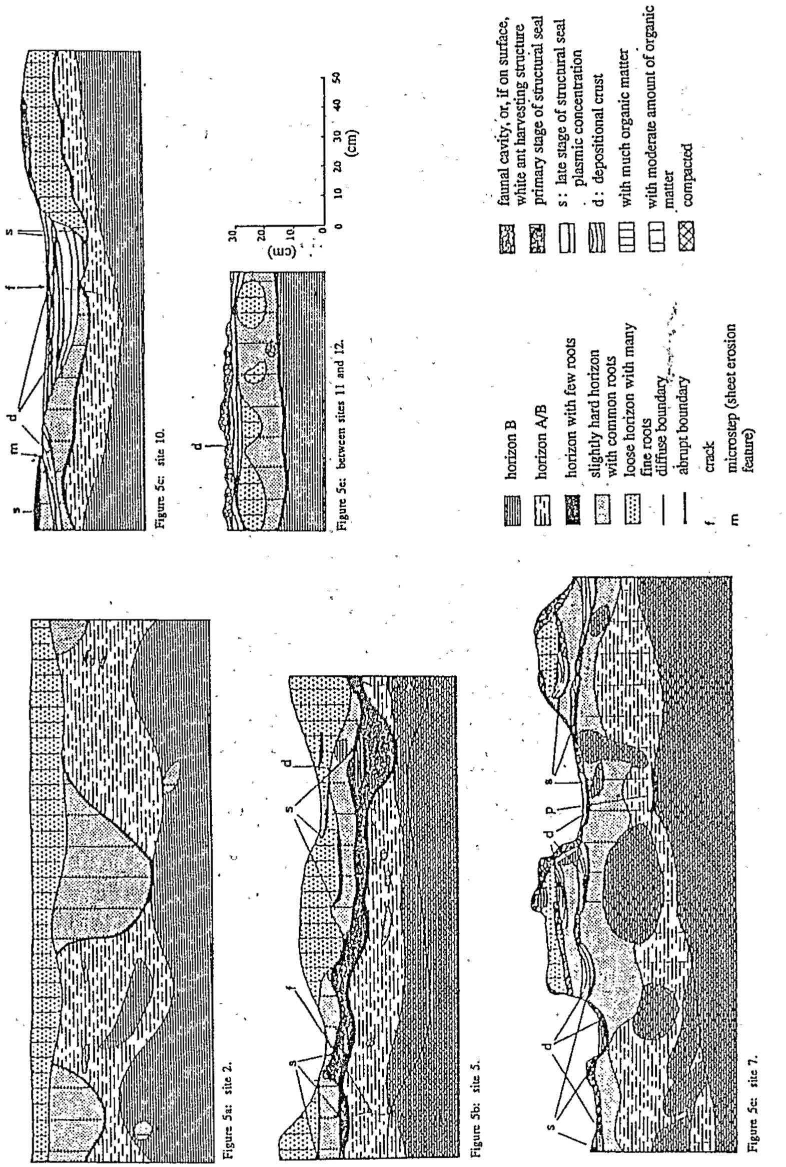


Figure 5. Variations of cultivation profiles along the transect.

Crust distribution along the transect

The observations may be summarized as follows:

- In the upper part of the transect, no crusts were observed. The very sandy surface (Figure 4) is wholly covered with the herbaceous layer (Table 2). A little lower in the transect, in the cultivated area of Kasama sandy loam series, problems relating to crusting are slight. The soil texture is still fairly light and the surface is well covered with a maize residue mulch.
- Undoubtedly the soils that are most vulnerable to crusting are the medium-textured soils of the Mufulira sandy clay loam series. In fact the most developed forms of crust were found in the clear-felled plot of this series. However, there is very little surface reorganization leading to crusting under the natural vegetation (site 11, Plate 4), and only a moderate amount under a mulch of maize or millet residues. In both cases, the litter or crop residues attract termites, which perforate the crusts (between sites 11 and 12, Plate 5).

Plate 4. *Underlying the 2 cm thick litter, a thin and discontinuous crust developed not as a result of impacting rainfall but mostly from slaking due to wetting. This crust is deteriorating due to faunal activity, site 11.*

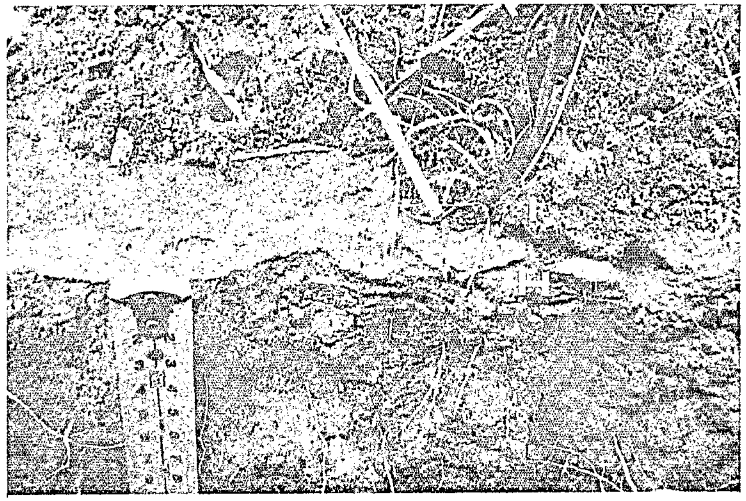
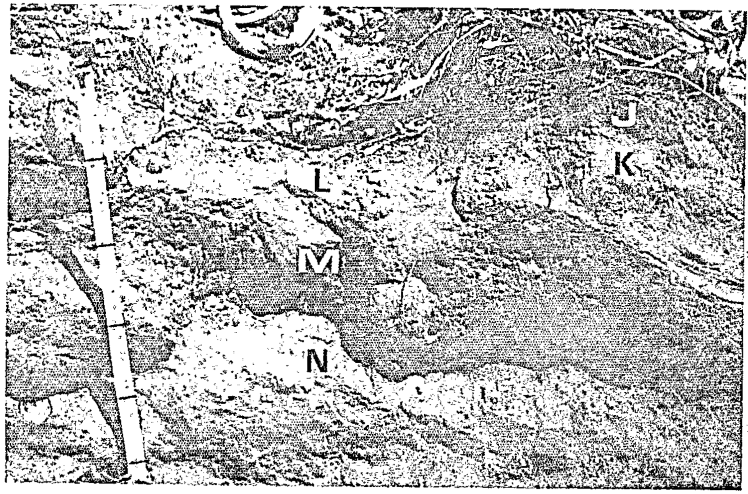


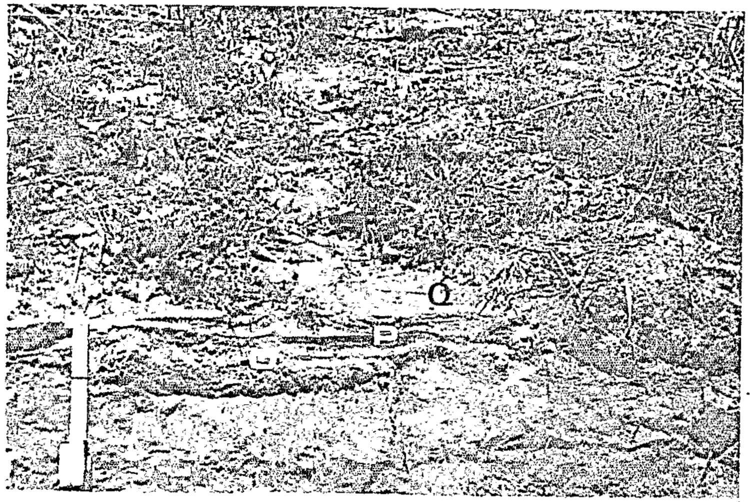
Plate 5. *Tilled profile in a hoed millet plot. As a consequence of micro-relief decay, a fairly thick depositional crust (H) was formed. attracted by millet residues, termites build typical harvesting features (I) and perforate the crust. Between sites 11 and 12, Figure 5e.*

- The lowest section of the transect (Misamfu sandy loam) seems only slightly subject to surface reorganization and crusting. The study of a cultivated area of this series, near the Benchmark Project pit no. 2 (Plate 2) shows that problems of crust formation are a little less marked than in the case of the preceding series.

The distribution of the depositional crusts does not correspond to that of the structural crusts. The most developed examples occur in site 10, in an area under fallow. In the area still cultivated, weeding results in some reformation of the ridges, whereas in the part under fallow, old ridges have been eroded over a longer period. As a result, the microrelief of cultivation has almost disappeared, promoting accelerated removal of the material by erosion (Figure 5d, Plate 7). The most marked erosion features occur at this site (a microstep is shown in Figure 5d).



te 6. *Tilled profile, site no. 7, Figure 5c. A consolidated thick structural crust (J), which corresponds to the former surface during the rainy season, was buried by a soft unsealed layer while hand hoeing after the wet season. Between the ridges, depositional crusts (L) developed. Underneath compacted blocks (M) and a plough pan (N) were excavated with a brush.*



·7. *Tilled profile in the fallow plot; site 10, Figure 5d. Three former landsurface levels can easily be recognized: the older one, underlain by a structural seal (O), indicates the former shape of the ridges, the second with a much less undulated micro-relief (P), corresponds to the late rainy season after cropping. The present surface (Q), with virtually no perceptible microrelief, fosters sheet erosion.*

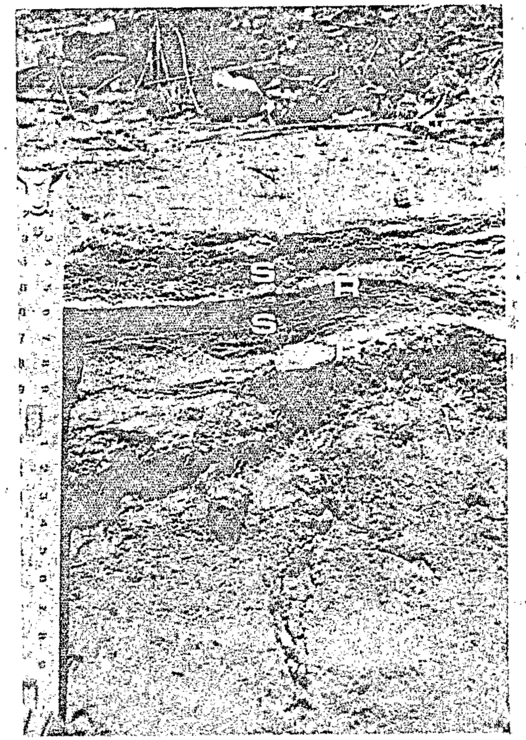


Plate 8. *Detail of the previous plate (site no. 10, figure 5d). Example of a polygenic crust: a couple of structural (R) and depositional crusts overlay a similar older couple. The lowermost one was formed during the cropping year, whereas the most recent one developed under fallow conditions. The whole surface seems porous due to numerous vesicles, with a diameter up to 2 mm.*

The same processes seem to be involved, but to a lesser extent, in the hoe-cultivated plot between sites 11 and 12 (Figure 5e, Plate 5). In both cases, these degradations may be ascribed very probably to the gradient which, between sites 9 and 13, is the highest in the transect.

Two main points need to be emphasized:

- the intensity of formation of structural crusts depends mainly on the texture of the topsoil, the vegetation cover, and the faunal activity;

- o the depositional crusts are related to the gradient, but also to the cropping operations and history of cultivation.

Plough pans

The study of cultivation profiles along the transect shows that the risk of pan formation increases with the clay content of the soil (sites 5 and 7, Figures 5b and 5c). These cultivation-induced pedological features were not found either in the sandy soils of the upper section of the transect (Figure 5a), or in the heavier soils cultivated with a hoe (between sites 11 and 12, Figure 5e, Plate 5). The use of heavy machinery on Mufulira sandy clay loam risks degradation of the cultivation profile. It remains to assess the optimal soil moisture range for working these soils (Proctor trials, Atterberg limits).

Conclusions

Two conclusions may be drawn from this study of soil surface features and the main physical constraints:

- It is the soils of the median zone of the transect (Mufulira sandy clay loam) which appear to have both the highest fertility (as denoted by the woody cover) and the greatest degradation hazard when cultivated.
- The present characteristics of the surface soil and the plough layer reflect fairly well the textural variations along the transect. However, some limits differ due to the influence of past tillage and present land use. Discontinuities due to cultivation are superimposed on vertical and lateral soil variations resulting from soil forming processes (Plate 9). These differentiations, related to soil forming and degrading processes which can be very rapid, must not be neglected when characterizing a site. They influence to a great extent the water supply, aeration, and rooting of crops.

General Conclusions

To conclude this report, it is appropriate to compare the two approaches used to characterize the Misamfu site.

The first, which is the conventional approach, has produced a soil map based on the representative profile concept. It is of direct use for agricultural purposes insofar as it separates soils which behave differently when cultivated.

The second approach, used in this study, reveals the complexity of the soil mantle, affected both by slow soil-forming processes and by rapid modifications of the surface soil. By relating soils to the underlying formations, hypotheses were formulated which need to be confirmed by analyses and micromorphological studies. In relating the surface and plough layer features to present and past land use, this approach has also drawn attention to constraints or risks of constraints for crops.

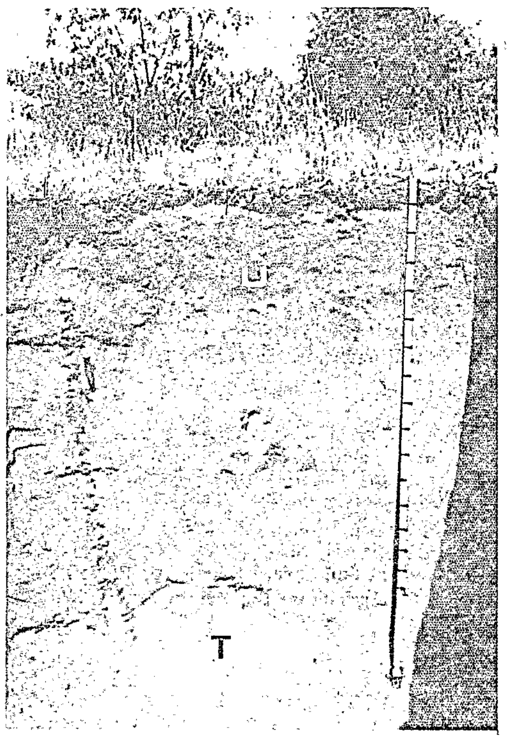


Plate 9. Site no. 2, figure 5a; this example illustrates the need to include in a site characterization the deep features (here occurence of the sandstone bedrock (T) under a very much eluviated soil) as well as the topsoil and surface features (marks of past tillage (U).

Can we conclude that one approach is better than the other? To do so would mean not considering the issue properly. The approach based on soil series enables the agronomist to extrapolate, at least partly, trial results obtained on a research station. It yields statistical data on soil heterogeneity. The most valuable contribution of the more recent approach is to demonstrate that such heterogeneity is not random, but, on the contrary, arranged and controlled by pedogenetic and anthropic history and influences. It shows that vertical and lateral variations can be: