SOIL SURFACE CRUSTING - SOME AGRONOMIC IMPLICATIONS

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ABSTRACT

Any study on soil surface crusting for agronomical purposes should include three steps:

1. Identification and description of the problems, in combination with the study of the processes of crust formation and its subsequent evolution. Examples in Ivory Coast, Burkina Faso, and Senegal show that crusts should be studied together with environmental and socioeconomic parameters, including their variations both in space and time.

2. Quantitative characterization of crusting and crusting impacts. Notwithstanding that standardized methods are still lacking, it is necessary to assess crustability using a comparative and predictive index. Some easy methods enable measurements to be made of crust infiltrability and surface strength.

3. Crust control. Three major approaches may be distinguished: the first one aims at strengthening the bonding agents between particles, using organic residues or soil conditioners. The second way is to protect the soil surface from impacting raindrops using cover (mulch, mixed cropping). The third approach consists in selecting appropriate land use and farming practices with reference to the environmental data. This agronomical method is often sufficient to limit crusting hazards.

To implement a development strategy, it is necessary to rank the different constraints (biophysical and socioeconomic) and to establish the inter-relationships between the various factors. In this connection, crust problems should not be neglected.

RESUME

L'ENCROUTEMENT DE LA SURFACE DU SÒL - IMPLICATIONS AGRONOMIQUES

La formation de pellicules à la surface du sol entraîne de nombreux problèmes: Elles constituent une entrave à l'infiltration de l'eau, aux échanges gazeux et thermiques, et à la levée des semences. Les études dans ce domaine doivent respecter trois étapes:

1. *Identification de la nature et de la distribution de ces pellicules. Pour être pertinente, une telle analyse doit viser à mettre en évidence les relations de ces pellicules avec les autres composantes du milieu biophysique (distribution des sols dans leurs trois dimensions, position topographique, pente, microrelief, formes d'érosion, couvert végétal, activité faunique,...) et les données du système de production (calendrier cultural, itinéraires techniques, ..., mais aussi : contraintes d'ordre social et économique). De plus, la variabilité des organisations pelliculaires doit être étudiée dans l'espace (par exemple, au sein d'une unité de modelé, comme un bassin versant) et dans le temps (en fonction notamment des variations saisonnières, des fluctuations climatiques, et de l'évolution démographique).*

2. *Caractérisation et quantification des effets des pellicules. Il convient de déterminer la sensibilité des sols à l'encroûtement par un test simple. On dcit également mesurer la diminution d'infiltrabilité et l'augmentation de résistance à la pénétration que les pellicules superficielles provoquent. Ces paramètres doivent être déterminés tout au long du cycle cultural. De plus, il est nécessaire de préciser les effets de ces pellicules, non seulement sur le site d'étude, mais également à l'aval.*

3. *Choix de méthodes de lutte. Trois grandes voies qui se complètent peuvent être suivies. La première consiste à augmenter, par des apports de conditionneurs ou de produits naturels, la résistance intrinsèque des mottes. Il s'agit de l'amélioration de la stabilité structurale. La seconde méthode joue sur les facteurs externes, c'est à dire essentiellement la pluie (ou les apports par irrigation): protection du sol par paillage, système de cultures associées,... Enfin, la troisième méthode concerne le choix d'itinéraires techniques mieux adaptés (taille des mottes, microrelief,...).*

Comme pour toute étude touchant au domaine agronomique, il con-

vient d'adopter une approche globale. Les problèmes de dégradation de la surface du sol, ainsi que leurs solutions, doivent nécessairement être situés dans leur environnement biophysique et dans leur contexte humain.

INTRODUCTION

A suitable structure is just as important for sustainable agriculture as are adequate water and nutrients. When cultivated soils are unable to withstand raindrop impact without crust formation, or to tolerate wetting without slaking, they frequently suffer from erosion. Moreover, even high quality seeds may produce a very poor crop stand as a result of hard surface crust which impedes seedling emergence. Consequently much attention needs to be paid to surface soil conditions. The main objective of this paper is to provide some principles to guide surface crust studies for management. To assess the possible courses of action and to formulate appropriate strategies, planners must make best use of the available information and data, including:

1. a detailed inventory of the nature and extent of observed soil surface problems;
2. an assessment of crusting impacts at various scales, both in space and time;
3. a set of realistic methods to control surface crusting.

IDENTIFICATION, DESCRIPTION, PROCESSES AND EVOLUTION

Identification of the crusted areas

Relevant information on the extent and nature of soil surface crusts in a region should be gained prior to any action. It is necessary to establish relationships between crust occurrence and agroecological factors. This approach may be illustrated by two examples.

In the first one (Figure 1), inventories took the form of detailed maps (1:2,500) showing the nature and extent of a number of characteristics, which include topography, vegetation, soils (three-dimensional analysis) and soil surface features (crusted areas, marks of erosion, termite mounds) on a watershed (1.36 km^2) in northern Ivory Coast. Some relationships could be established between these biophysical parameters: where the weathered rocks are shallow, iron pans and gravelly materials outcrop them. Geologic structures govern soil features that are related to specific topography and forms of erosion. Only minor forms of crusting are observed in upslope red soils, whereas mid- and down-slope ochreous and yellow soils are more seriously crusted, in combination with a more scanty savanna vegetation. However, these relationships between deep soil and surface characteristics may be difficult to establish. Owing to the many factors involved in surface crusting, frequent discrepancies are found between the boundaries of deep and surface units. Such discrepancies may indicate some evolution trends due to climatic or land use changes. In contrast, similarity between boundaries may reflect a sort of harmonious steady state between soils, climate and land use.

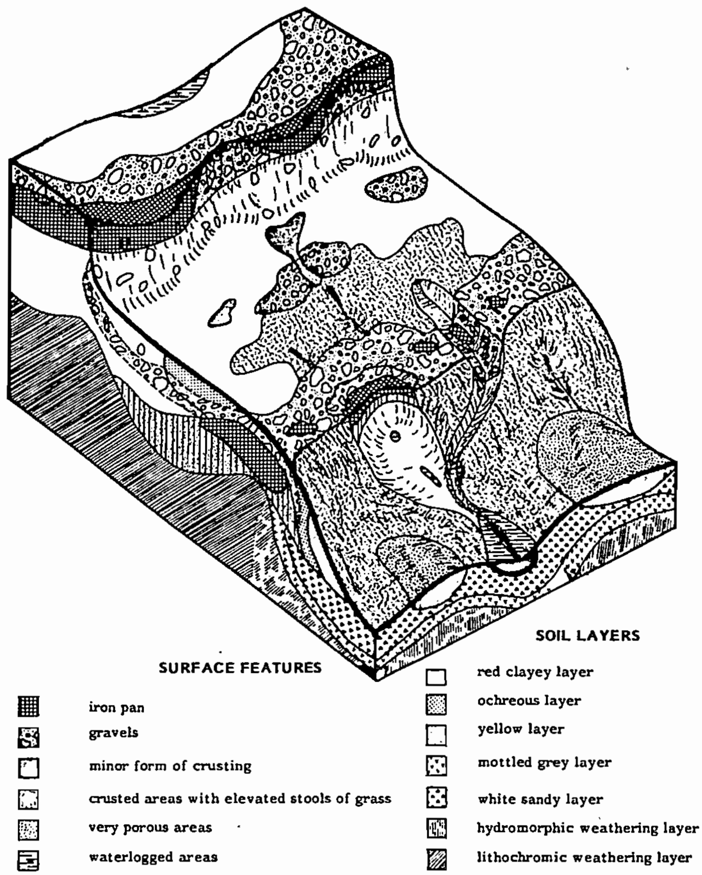

Figure 1. Soils, surface features and forms of linear erosion in a typical landscape of northern Ivory Coast (after Valentin, Fritsch and Planchon, 1986).

The second example is a typical landscape (Figure 2) in the northern Mossi Plateau (Burkina Faso) which comprises three main units:

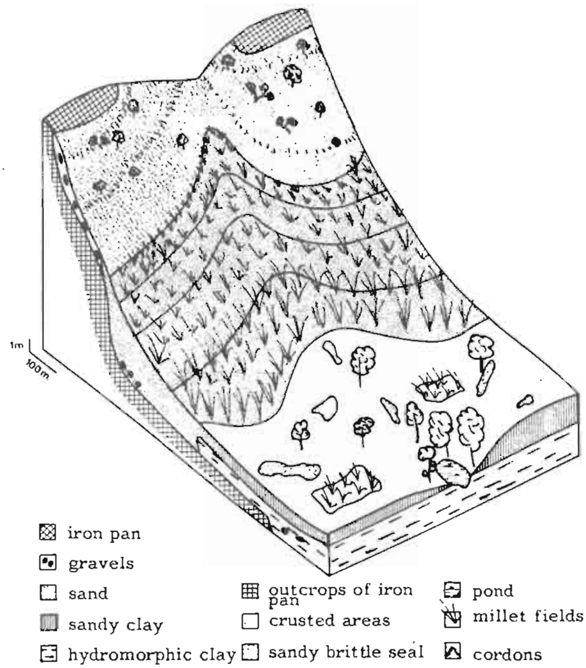

Figure 2. Soils, surface features and land use in a typical landscape of northern Mossi Plateau - Burkina Faso - (after Serpantie and Valentin, 1985).

Upslope unit (Figure 3)

An iron pan is overlaid with a skeletal soil. Despite the presence of iron gravels on the soil surface, the soil is severely crusted. The native vegetation consists of few shrub trees but the grass cover is spare or nearly absent due to the protracted drought. As a result, this unit produces excessive overland flow and erosion as betokened by microclives and pedestal features.

Figure 3. Upslope site of the landscape in Burkina Faso (see Figure 2).

Midslope unit

Unlike the previous area, the unit is completely cultivated. The boundaries of the collective fields match with the limits of the remnants of aeolian sand deposits, which are as thick as 2 m. In order to minimize erosion hazards and to increase infiltration of water, the farmers collect blocks of iron pans from the upslope unit to install low cordons at contour that reduce runoff velocity (Figure 4). These sandy soils are also vulnerable to crusting, but the brittle seal is easily broken by tramping. A more severe physical constraint is the ploughpan which develops even under low pressures, as produced by bullock-drawn implements.

Figure 4. Midslope site of the landscape in Burkina Faso (note the cordon at contour, see Figure 2).

Downslope unit

This unit is characterized by poor drainage conditions and the presence of a temporary watertable. Owing to less favourable conditions, cultivation is confined to small individual fields that keep out the numerous bare areas with sealed surfaces unfit for agriculture. In order to reclaim these barren spots, farmers cover them, usually with lopped-off branches. This sort of mulching practice has a twofold effect: it traps the wind-drifted sand, thus promoting the formation of a favourable seedbed; moreover, it attracts termites that perforate the crust, whereby infiltration is greatly enhanced.

It may be seen that on-site and off-site impacts should be considered: in this instance, advantage is reaped even from the upslope crusted zone as far as it is used as an impluvium for water-harvesting and runoff farming.

DESCRIPTION AND PROCESSES

Description

In combination with identifying the crusted areas, description of these surface crusts must be carried out. Equally important is the assessment of their mechanisms of formation. The sound principles of crust description do not differ from those of soil profile. But due to the thickness of the vertical sections, which rarely exceeds a few millimeters, the use of a field magnifier (and if necessary microscopic techniques) is required. The main parameters to be taken into account are:

1. the boundaries between microlayers in terms of continuity, distinctness and smoothness;
2. the granulometry and stoniness;
3. the porosity: cracks, vesicles, faunal voids;
4. consistency and cementation.

The areal variations of these microlayers as influenced by other factors (microtopography, top soil characters, soil cover, faunal activity) must be studied with care. Such information makes it possible to establish the interrelationships between the various surface features.

Processes of formation

Studies conducted under natural rainfall conditions or simulated rainfall (Collinet and Valentin, 1984) showed that great variations occur among the soils due to their texture. Contrary to what one would expect considering their porous nature, overland flow and erosion are frequently observed on sandy soils as a result of crusting that can occur even in materials virtually made of 90% sand (including more than 50% coarse sand (Valentin, 1981). In such cases, the crust comprises three well sorted microlayers (Figure 5): the uppermost is composed of loose coarse sand grains, the middle one consists of fine cemented sand grains with vesicular pores, and the lower micro-layer is a plasmic seal composed of a higher concentration of fine particles with considerably reduced porosity. It must be noted that such a pattern is just the reverse of what is observed in a sedimentary crust, where the finer particles are on the top and the coarser at the bottom.

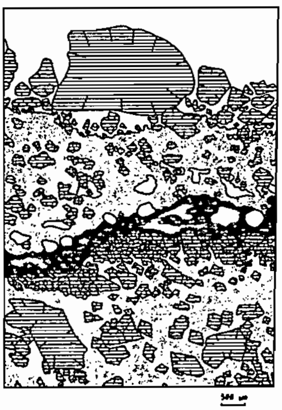

Figure 5. Drawing after a thin section from a crusted sandy soil in Agadez - northern Niger - note the three microlayers (after Valentin, 1981).

Examinations of time-sequence thin sections showed that the impact of raindrops triggers the formation of microcraters, the walls of which present a clear vertical sorting of materials. This vertical differentiation results mainly from a mechanical sieving of materials so that the finer the particles are, the deeper they are washed in.

In loamy and clayey soils, processes are more complex and result in two major types of crusts that are formed in succession: (Figure 6).

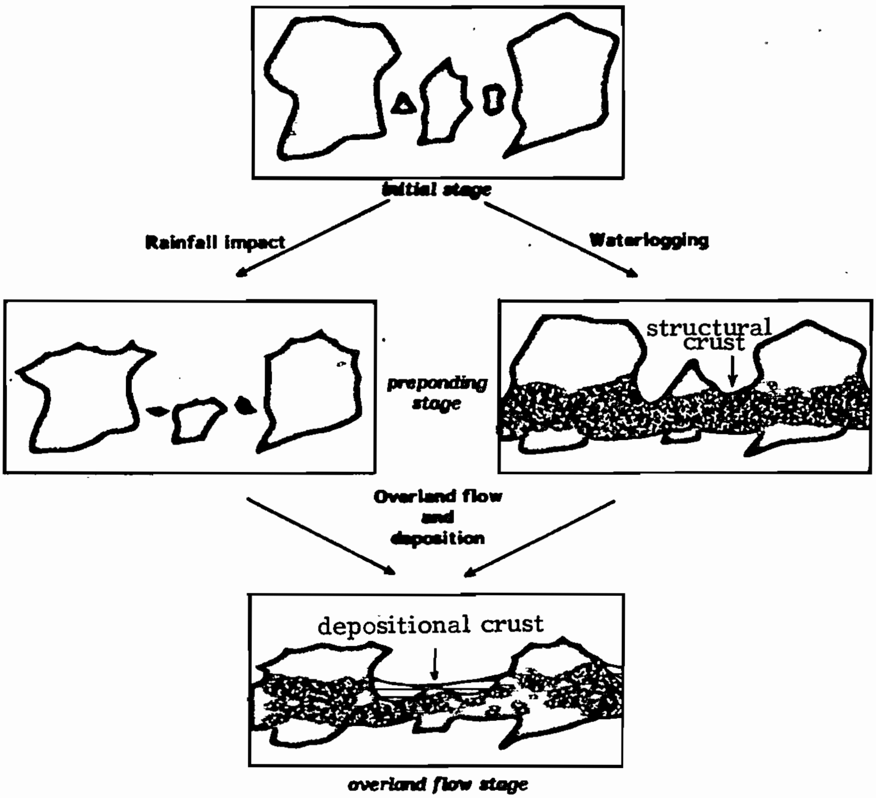

Figure 6. Schematic diagram of crust development in a tilled clay-loamy soil (after Valentin, 1981).

* Structural crust due to slaking which may occur independently from any impact forces, provided that the structural stability is low;

* Depositional crust which is formed under overland flow. It develops once the saturated conductivity of the structural crust has sufficiently declined to be exceeded by rainfall

(or irrigation) intensity.

Broadly speaking, four major types of crust can be discriminated in the field in terms of features and genesis (Table 1).

Table 1. Main features and factors of formation of 4 major types of crust.

Type of crust	Main features	Main processes
Splash crust	vertical sorting with coarse particles on top	splash erosion, washing in, compaction by raindrop impact
Structural crust	mixed and compacted particles, includes remnants of clods	slaking, waterlogging
Depositional crust	well sorted laminae	deposition under overland flow conditions
Sedimentation crust	vertical sorting with coarse particles at bottom, when dry often curled up.	deposition in still conditions

SOIL SURFACE EVOLUTION

Medium-term dynamics

Particular emphasis should be placed on the evolution of surface crust through time. For instance, climatic variations can cause dramatic changes in soil surface features as illustrated by an example in northern Senegal (Figure 7).

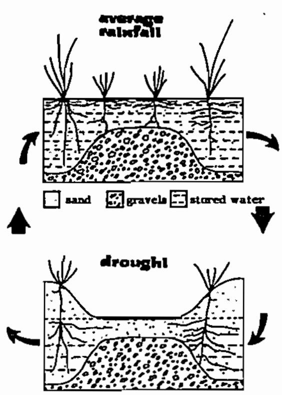

Figure 7. Schematic natural cycle of soil surface features as influenced by medium-term climatic fluctuations in northern Senegal (after Valentin, 1983).

When rainfall is sufficient, soil surface is covered with a continuous grass layer and not much sealing occurs. During periods of below average rainfall, plant communities collapse precisely where moisture shortage is the most severe, namely on shallow gravelly soils. Although in the event the case rarely occurs, rainfall is sufficient to cause the disjunction between fine and coarse particles. As a result, a splash crust (Table 1) develops where the vegetative cover is deficient; in other words, a sandy microlayer is formed above a cohesive seal. This sandy layer is easily wind-drifted and entrapped by the surviving vegetation nearby. During subsequent normally wet periods, recolonization of blowout areas is quite rapid once rains have eroded the micromounds, covering bare spots with sands. Such a cyclic pattern results from the combination of several factors which may in sum be attributed to the interactions between climate (rainfall and wind), soil and vegetation.

Long-term dynamics

An example from Burkina Faso will illustrate some long-term effects. A recent study (Albergel and Valentin, 1986) has shown that between 1956 and 1980, the cultivated land within a 12.8 km^2 watershed was doubled while fallow was halved. Such a change in land use patterns may be ascribed not only to the effect of the burgeoning population (more than 2% a year) but also, to some extent, to the drought itself as far as the farmers tend to cultivate larger areas as a way of compensation for deteriorated yields. Within the same period, annual rainfall was decreased by 44%, while runoff coefficients were increased by 50%. This hydrological alteration was blamed by the authors on so-called "sahelisation processes", namely on the occurrence of specific sahelian features within the Sudanian Zone: native shrub savanna decayed from 80% to 45% as expressed by watershed cover, while severely crusted and eroded surfaces were multiplied by 20.

This example should draw attention to the need for long-term studies which involve the interactions between climate, soil, vegetation and - not to be neglected - man.

METHODOLOGY TO CHARACTERIZE SOIL SURFACE CRUSTING

Assessment of crustability

Undoubtedly there is a need to define a sound method to assess crustability of top soil, namely to find a relevant index concerning its vulnerability to crusting. Deploey and Mucher (1981) proposed such an index which is derived from the upslope part of the Atterberg liquid limit curve: $C_{5-10} = W_5 - W_{10}$, in which W_5 and W_{10} are the water contents, in % of the dry weight, after 5 and 10 blows respectively. However, care is required in using such a predictive index since it is now well established that soil crusting depends not only on intrinsic factors but also on many external factors: soil cover, microtopography, cropping history, rainfall energy, soil moisture, faunal activity, etc. This consistency index may be useful in comparing soils, other factors being equal.

Crusting impacts on infiltrability and surface strength

Particular emphasis should be placed on quantifying the influence of surface crusting on infiltrability and soil strength. Rainfall simulators are useful instruments to assess the rapid collapse of infiltration capacity due to crust formation under rainfall conditions, but such instruments are not available everywhere. Monnier and Boiffin (1985) proposed a cheap and simple field method: the infiltrability of a wet surface crust is evaluated by measuring the steady diameters of saturating water stains formed on the surface by drip sources. The values of hydraulic conductivity thus obtained were found to be consistent with observations under rainfall.

It is much more delicate to measure crust strength as it affects seedling emergence, since so far there is disagreement about the best method to adopt: either modulus of rupture or penetration tests. For agronomical purposes, the use of a field penetrometer appears to be preferable, provided certain conditions are met: high sensibility of the instrument, numerous replications, and combined measurement of soil surface moisture.

Surface dynamics

To be useful for agronomists, the ongoing changes that take place through the entire cropping cycle must be considered as an integral part of the scheme of measurements, analysis and impact quantifications. As mentioned earlier, it may be relevant to identify the time sequence of the different types of crusts (Table 1). In this respect, it is useful to define an index for quantified studies. Such an index was recently proposed by Boiffin (1984): the diameter of the smallest discrete clod that has not yet lost its identity in the structural crust. While the structural crust develops, the values of this index increase and are consistent with other parameters, such as splash erosion and infiltrability.

In addition, other data must be collected through time: variation of microtopography, soil cover, and faunal activity. This can be easily carried out using the well established pin points method.

CRUST CONTROL

Deriving an anticrusting method from elsewhere may be uncertain since correct actions are dependent on local environmental conditions, farming practices, and socioeconomical constraints. Consequently any method must be validated for the locality. However, some principles may be transferable, even though some adaptations are required. Keeping this in mind, some techniques may be pointed out corresponding to three major approaches:

Improving the internal factors

The aim is to strengthen the bonding agents between particles within the clods. Beneficial effects can be produced by the addition of farmyard manures, crop residues, sawdust, sewage sludge and other types of waste products. In recent years, considerable emphasis has been placed on the use of chemicals purporting to influence soil surface properties favourably. But, although a number of materials, so-called "soil conditioners", are still under investigation, apparently no one material so far has all the required qualities. Indeed, such a product should be cheap, easy and safe to handle, to apply and to store, and free from any unwanted side effects, such as inactivation of herbicides or damage to crops. As a result, at present the use of soil conditioners remains confined within very specific applications.

Modifying external factors

This approach refers to the use of soil cover in minimizing or preventing the beating action of raindrops. In this respect, indigeneous anticrusting methods frequently appear efficient and should be more systematically evaluated: mulching, dense growing crops, crop rotation, strip-cropping and mixed cropping, and the overall farming system.

Besides, closer attention should be paid to soil crustability when selecting an appropriate irrigation system.

Developing appropriate surface management

Changing land use patterns may be vital to achieve some degree of land restoration. But even under a potentially unstable land-use system, significant improvement can be achieved with integration of proper tillage practices which produce minimum surface compaction. Likewise, considerable attention should be paid to seedbed preparation: in some cases, trials should be implemented to assess the optimal clod size distribution and surface roughness.

In this respect, Boiffin (1984) and many other authors have shown that the smallest clods enable the structural crust to develop fastest. Moreover it is usually preferable to install the seedling line in elevated rows rather than in depressed rows.

It would be beyond the scope of this short presentation to exhaust this crucial question. Other approaches need to be investigated, such as the selection of crust-tolerant species as recently mentioned by Soman and Bidinger (1985).

CONCLUSION

Owing to the many factors involved, a preliminary inventory should cover the broadest aspects of the physical and human environment, prior to any study of surface crusting. The necessary knowledge to any improvement or rehabilitation strategy cannot be gained without establishing the complex interrelationships between these intricate factors. Furthermore, variability in space and time should be assessed in considering the onsite and offsite impacts of soil surface crusting and its short-term and long-term dynamics. Anticrusting strategy must be seen as only one element in an overall development policy, since surface crusting is only one physical constraint among others that have to be ranked. It is important, therefore, that specialists adopt a holistic, systemic approach so they can establish the linkage between biophysical and socioeconomic factors. Such a challenge can be taken up only by interdisciplinary research teams.

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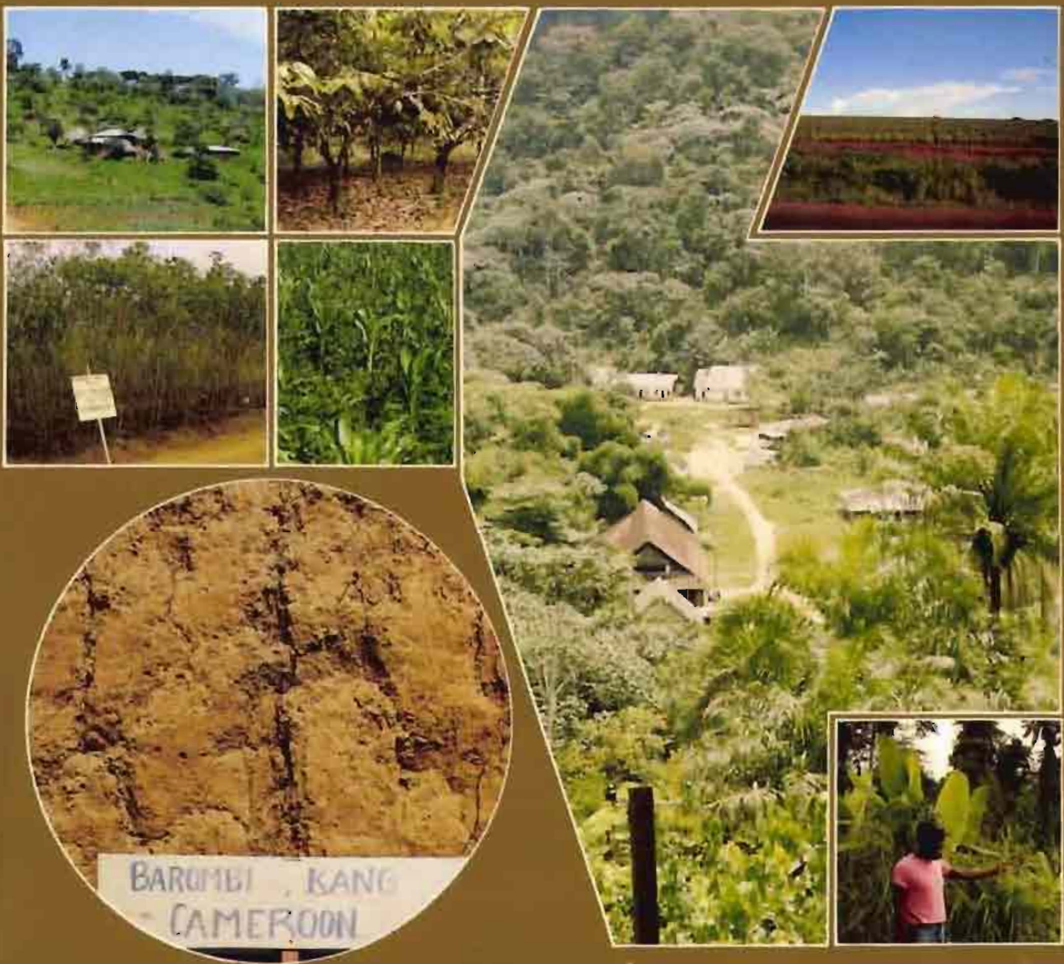

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