The results from these two experiments indicate that a combination of natural rubber soil conditioner and grass cover (or any vegetative cover) provides an effective method of erosion control. The conditioner stabilizes and protects the exposed soil surface for a reasonable period after spraying and this enables the young seedlings to grow without erosion occurring until the cover is fully established and a permanent protective layer is provided on the soil.

2.6.5. CONCLUSION

The use of natural rubber as a soil conditioner has good potential in the rubber-producing countries. Besides being effective, it is also easily available. It can be used to reclaim soils of marginal productivity and also for soil conservation purposes. Since skim latex can be used as an ingredient in the conditioner it provides an avenue for useful disposal of waste material from rubber concentrate factories. Preparation and application of the conditioner are relatively simple. It can be prepared at the site with minimum facilities.

ACKNOWLEDGMENTS

The author wishes to thank Dr. E. Pushparajah, Head of Soils and Crop Management Division, RRIM, for his helpful comments on this chapter. The kind permission granted by the Director and Board of the Rubber Research Institute of Malaysia to present it is gratefully acknowledged.

REFERENCES

Coe, B., 1962, Treatment of soil, B.P. 910, 974, published 21 Nov. 1962.
Dickenson, P. B., 1965, The ultrastructure of the latex vessel of Hevea brasiliensis, Proc. Nat. Rubb. Prod. Res. Ass. Jubilee Conference, Cambridge, 1964, p. 52.
Lim, K. H., 1975, The optimisation of the use of natural rubber latex as a soil conditioner, M.Sc. Thesis, State University of Ghent, Belgium.
Rubber Research Institute of Malaysia, 1976, Ann. Rep. Rubb. Res. Inst. Malaysia 1976, p. 90.
Rubber Research Institute of Sri Lanka, 1973, Ann. Rep. Rubb. Res. Inst. Sr. Lanka, 1973, p. 91.
Soong, N. K., and C. S. Yeoh, 1974, The use of NR emulsions for stabilising sandy soils, Proc. Rubb. Res. Inst. Malaysia Plrs' Conf., Kuala Lumpur, 1974, pp. 127–137.
Soong, H. K., and C. S. Yeoh, 1975, Latex/oil emulsions for controlling erosion of exposed soil surfaces, Proc. Inst. Rubb. Conf. 1975, Kuala Lumpur, Vol. 3, pp. 51–72.
The Natural Rubber Development Board, 1958, Improvements in and relating to soil stabilisation, B.P. 803, 012, published 15 Oct. 1958.
Vehaar, G., 1959, Natural latex as a colloidal system, *Rubb. Chem. and Tech.*, **32,** 1635.

2.7

Structural Characteristics of Ferrallitic Soils under Mechanical Cultivation in the Marginal Forest Areas of the Ivory Coast

PH. DE BLIC and R. MOREAU

2.7.1. INTRODUCTION

The Ivory Coast is at present attempting to develop in the forest and savanna zones a partially mechanized agricultural system introduced directly into the traditional peasant economy. The transformation to large-scale use of the techniques developed at the experimental stations and their adaptations to varied physical and human environments have quickly presented many problems requiring study of behaviour in actual field conditions. As far as soil properties are concerned, two complementary research projects have been conducted since 1974.

1. A study conducted over several years on paired plots in cultivated areas representative of the region.
2. A regionally widely distributed study designed to examine constraints related to the cultivation techniques (de Blic, 1976a,b).

The results presented here are concerned with the development of the structural characteristics of the soil in a village farming area.

2.7.2. ENVIRONMENTS

2.7.2.1. The Natural Environment

The village studied is situated in the central Ivory Coast. The climate consists of two dry and two wet seasons with a total annual rainfall of 1,200 mm; the rainfall is very irregular. The parent rock is granitic, the landscape slightly undulating with slopes generally less than 5 per cent. The vegetation consists of a mosaic of wooded savanna, or woodland with islands of forest more or less well preserved.

This distribution is a function both of the soil characteristics and of the traditional agricultural practice. The soils are ferrallitic, moderately or weakly unsaturated; 'typical' on the plateaux and on the upper slopes, colluvial and impoverished on the lower slopes.

2.7.2.2. Agricultural Evaluation

The system of cultivation at present being put into practice has the following characteristics:

1. Complete mechanized clearing of the whole cultivated area associated with the village.
2. A five-year rotation—yams, maize/cotton, rainfed rice, two years of planted pasture of *Stylosanthes*. In the course of the rotation each crop is grown as a block of around 30 hectares.
3. Limited mechanization for the heavier work (ploughing, hoeing, seeding), but weeding and harvesting mainly manual.
4. An average cultivated area of four hectares per family.

2.7.3. METHODS

Several plots of 500 square metres were planted in April 1974 before clearing, in such a way that paired areas of cultivated and natural uncultivated land were obtained. They were on the same soil type (modal ferrallitic, with covering of fine earth of 20 to 30 cm), and two well-differentiated vegetation types—forest fallow and wooded savanna—were represented. The distribution of the plots was as follows:

P2 Forest control paired with P1, cleared forest.
P4 Savanna control paired with P3, cleared savanna.
P7 Savanna control paired with P5 and P6, cleared savanna.
The cultivated plots were as follows:

P1 and P5 cleared, then rice plus *Stylosanthes* in 1974, in pasture in 1975 and 1976 with light grazing on P1 and heavy grazing on P5. P3 and P6 cleared, then rice in 1974, yams on mounds 1975, seeded with *Stylosanthes* in August 1976.

Structural stability, particle size distribution, and chemical and organic characteristics were measured before and after clearing, then every three months, at 0 to 10, 10 to 20, and 20 to 30 cm. The 30 to 50 cm horizon was analysed once annually. Also on a yearly basis, soil profiles have been used for comparison of the structural and rooting characteristics associated with measurements of bulk density. Finally, measurements were made in 1976 of water retention and infiltration rate.

2.7.4. RESULTS AND DISCUSSION

2.7.4.1. Soil Morphology

A number of 'homogeneous structural volumes' were distinguished to assist the analysis of the profile organization. Each corresponds to a well-specified type of structure or an association of structural types; no major discontinuity—sharp pedological division, plough sole, etc.—is found in a homogeneous volume. Some simple synthetic terms, coming for the most part from 'Typologie des sols ferallitiques' (Chatelin and Martin, 1972), allowed the following structural volumes to be defined:

Amerode— Massive structure
Pauciclode— Massive structure with polyhedral components, and no clear structural fragments
Anguclode— Clear structural fragments
Grumoclode—Crumbly structure and fine rounded polyhedral structure
Heteroclode—Mixture of small rounded aggregates of various sizes and of particulate elements.

These terms can be combined amongst themselves to represent the association of several structural types (Beaudou, 1977).

The soils studied all display clear pedological differentiation in their upper part, where three horizons can be distinguished.

The humus horizon *sensu stricto* 10 cm thick is characterized by a well-developed fragmentary structure with a porosity greater than 55 per cent. In the forest control the polyhedral aggregates of a size between 1 and 3 cm define a homogeneous structure termed 'anguclode'. In savanna, some lateral differentiations were observed related to the distribution of the fine grass roots: rounded aggregates smaller than 1 cm under the grass, and angular aggregates between 1 and 3 cm between the tufts. The overall structure of the horizon can thus be defined as grumo-anguclode.

The horizon of humus penetration from 10 to 20 cm thick shows in both savanna and forest vegetation weakly developed structures of the 'pauciclode' type; the polyhedral elements, weakly defined, have a size of around 5 cm. Porosities are between 50 and 55 per cent. At about 20 to 30 cm a change can generally be seen to a material very rich in ferruginous gravel, sometimes indurated to form a hard pan. Porosities are of the order of 40 to 50 per cent under forest fallow and below 40 per cent in savanna. The gravel horizon may be more than a metre thick.

2.7.4.2. Immediate Effects of Clearing and Cultivation

The operations carried out at the end of May and beginning of June 1974 consisted of:

1. Felling of the existing vegetation by bulldozer.

2. Windrowing in lines 50 m apart and as far as possible on the contour.
3. Bringing roots to the surface by subsoiling at 30 cm.

After clearing, the savanna soil appeared relatively little disturbed beyond a few localized zones where trees had been removed. Disturbance was practically limited to the lines of subsoiling at 90 cm spacing. The tines partially cleared the humus horizon and threw out here and there a mixture of aggregates of fine soil which more or less covered the previous grassed surface. Under the humus horizon the action of the tines was restricted to the opening of a straight furrow with smooth walls. No gravel seemed to have been returned to the surface (Figure 2.12(a)).

The forest zone disturbance was much greater and had a greater variety of characteristics:

1. Some of the holes produced by clearing were filled in with heterogeneous materials.
2. Frequently part of the humus horizon was removed.
3. Significant disturbance occurred due to the lifting of woody roots concentrated in the top 30 cm of the soil.
4. Compression occurred due to the caterpillar tractor.
5. Termite mounds were spread.

In Figure 2.12(b) the zone produced by the lifting of roots can be seen on the right; after partial stripping of the humus horizon the heterogeneous mixture of clods and fine soil rests on the gravel horizon. The part on the left of Figure 2.12(b) is, by contrast, little affected; a band of soft earth covers the litter which has remained in place.

About one month after the subsoiling a heavy harrowing (Rome plough) completed the preparation of the soil for the first cropping. The cultivated profile (Figure 2.12(c)) was examined immediately after the Rome ploughing of the savanna soil. The soil was cultivated in rather wet conditions, and only the top 10 to 15 cm, which appeared to consist of a mixture of rather homogeneous fine earth and of aggregates smaller than 10 cm, was affected. A smooth and compact 'quasi-plough sole' marked a sharp boundary with the subsequent weakly structured horizon. Only some subsoiling lines which consisted of fine earth were cut into.

2.7.4.3. Changes under Cultivation

The plots P1 and P5 seeded with rice plus Stylosanthes after clearing have not been cultivated since then. The most notable morphological features are as follows:

1. An obliteration of the vertical differentiation in the top 20 cm in the heavily grazed zones. However, the top 5 to 8 cm are strongly compressed, with apparent densities of the order of 1.5 and with structures showing a tendency to be platy.
2. The preservation of the lateral differentiation created by the clearing operation.

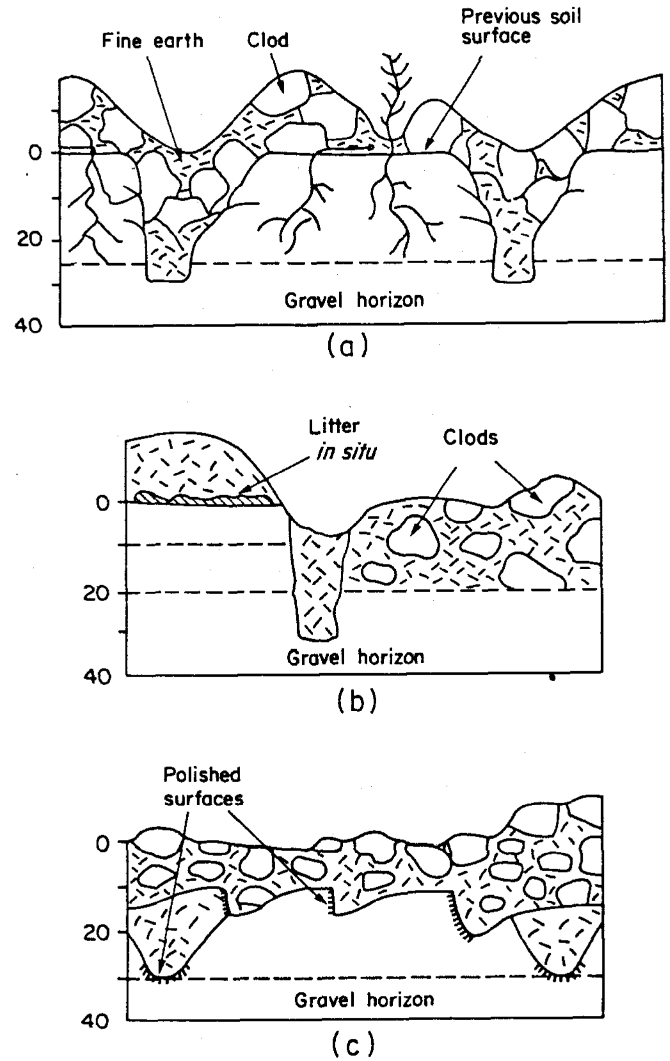

Figure 2.12 Cultivation profiles after recent clearing. (a) Savanna, subsoiled. (b) Forest, subsoiled. (c) Forest, after subsoiling and Rome ploughing

The savanna plots P3 and P6 have been cultivated and worked normally. Figure 2.13 illustrates the development of the structural and porosity characteristics in the two and a half years following clearing. The profile shown in Figure 2.13(d) has not been observed under yams, but under another treatment (rice after cotton). One of the effects of cultivation has been to superimpose a lateral differentiation on the initial pedological organization. This differentiation can clearly become predominant (Figure 2.13(a)).

Another effect is the development of a cultivation subhorizon more than 10 to 12 cm thick. This horizon is produced by all cultivation techniques, manual or mechanized. Its distribution can be very irregular (Figure 2.13(d)). Most of the roots are concentrated within it.

The lower cultivation horizon is only produced by deeper working. It is very sensitive to compaction due to tractor wheels (Figure 2.13(b) and (c)). Root development is directly related to the structural characteristics and porosity, and is particularly weak in 'amerode' regions, with porosities below 45 per cent.

Plough soles can be produced, and block completely any root penetration when they are smooth and compact (Figure 2.13(d)).

Between the upper horizons and the gravel horizons there is often an intermediate very compact horizon. This is unusual in the particular soil studied but very common within the region, and provides an obstacle almost impenetrable to roots and so a serious handicap to crop production (Figure 2.13(c)).

2.7.4.4. Structural Parameters

Total porosity

Total porosity values have been calculated starting with measurements of bulk density made at two scales: on cores of 100 to 500 cm³ taken *in situ* with metal cylinders, or on clods or fragments of 20 to 50 cm³ enclosed with paraffin wax.

Comparison of the two scales of measurement enables the structural macroporosity to be determined. Table 2.20 gives average values of porosity measured two and a half years after clearing. Porosities measured using paraffin wax several months after cultivation are given in parenthesis.

Two and a half years after clearing, the clod porosities measured after cultivation were homogeneous and of the same order of magnitude as in the horizons of natural humus penetration (10 to 20 cm). The highest values in the samples taken from the humus horizons (0 to 10 cm) showed an important porosity of biological origin.

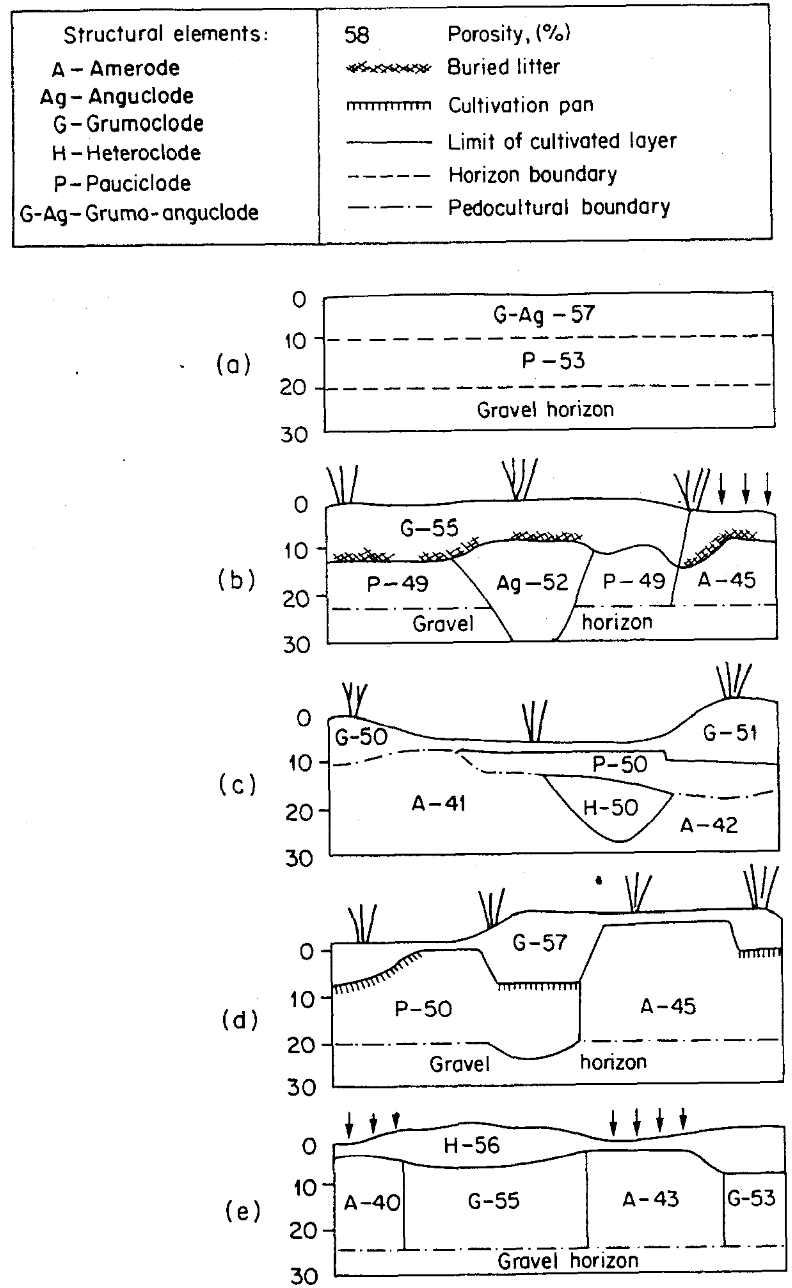

Figure 2.13 Structure and porosity of savanna soil after clearing. (a) Savanna control. (b) Five months after clearing. Vertical differentiation, subsoiling trench. (c) Five months after clearing, showing very compact intermediate horizon and the subsoiling trench. (d) Eighteen months after clearing. Vertical and lateral differentiation. (e) Thirty months after clearing. Very marked lateral differentiation

Table 2.20. Mean bulk densities determined on cylindrical cores (100–500 cm^3) and clods (20–50 cm^3)

Plot	Horizon	Porosity (%)	
		Cores	Clods*
Forest fallow	0–10 cm	58	45 (44.5)
	10–20 cm	53	39 (39)
Cleared forest	0–20 cm	47	38 (30)
Savanna control	0–10 cm	57	42 (42)
	10–20 cm	53	38 (35)
Cleared savanna (1)	0–20 cm	49	37 (39)
(2)	0–20 cm	50	39

* Figures in parenthesis refer to porosities determined several months after clearing.

The decrease in total porosity, determined using the cores, in the cultivated horizons is due to a loss of the structural macroporosity.

The clearing operations in the forest region have produced a significant decrease in the aggregate porosity compared with soils remaining under forest fallow. Two years of Stylosanthes pasture have increased the porosity from 30 to 38 per cent, that is to say to a level comparable with that of the other soils.

Infiltration rate

The parameter sought was not meant to define the hydrodynamic characteristics, but was intended as a structural measurement. It was therefore possible to simplify and miniaturize the system to allow determinations to be made on surface samples as well as within the profile. Cylinders 10 cm in diameter were distributed on the soil surface. After burying the cylinders to 2 cm and filling with water, the infiltration time for 10 cm of water was noted. Results are given in Table 2.21.

Table 2.21. Median values for infiltration of 10 cm of water

Plot	Vegetation	Time of infiltration (min)
P2	Forest fallow	0.7
P4	Savanna	2.1
P3, P6	Stylosanthes, 8 months	7.1
P1	Stylosanthes, 3 years pasture, grazed	11.6
P5	Stylosanthes, 3 years pasture, overgrazed	27.3
	Rice after cotton	8.0

Each value is the median of 15 determinations. The effect of cultivation can be seen, and especially the extreme degradation of the structure under the effects of overgrazing. Figure 2.14 shows the relation between infiltration rate and porosity. There is a good agreement between the two structural parameters.

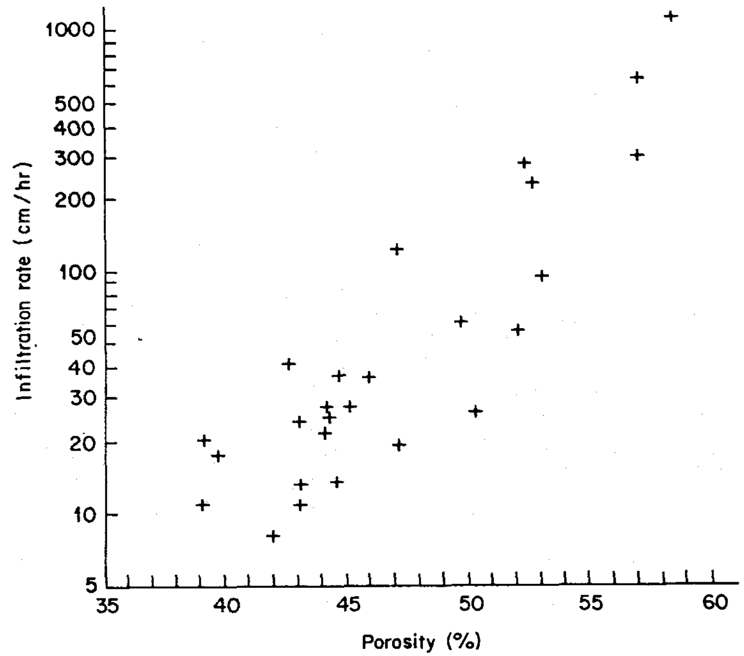

Figure 2.14 Relation between porosity and infiltration rate

Changes in structural stability

Changes in structural stability have been measured in the two years of cultivation using the test of Hénin *et al.* (1969). This consists of determination of the numbers of aggregates able to survive on a 0.2 mm sieve under water after three pretreatments, namely alcohol, benzene, or none. An index of structural instability I_s is determined which is increasingly large as the structure becomes less stable. The index has little significance if the clay content is below 10 per cent, but soils studied here were sandy clays with 17 to 26 per cent <2 μm material, so that appropriate I_s values could be obtained. Cultivation in the forest area led to a small (3–4 per cent) but highly significant increase in the amounts of clay up to 30 cm depth; the deeper horizons have remained unchanged. In savanna only the first 10 cm of P3 have shown any significant enrichment in clay, although of only 2 per cent. Values of I_s before clearing are given in Table 2.22.

The structural stability of the upper 10 cm horizon was higher under forest fallow (P1 and P2) than under savanna (P3, P4, P5, P6, and P7). The lower horizons had similar values whatever the vegetation type. After clearing, the instability index increased in every plot (Table 2.23). The change after clearing the

Table 2.22. Values of I_s prior to clearing

	P1	P2	P3	P4	P5	P6	P7
0–10 cm	0.34	0.37	0.69	0.63	0.60	0.58	0.63
10–20 cm	0.80	0.83	0.79	0.73	0.69	0.66	0.73
20–30 cm	1.17	1.22	1.30	1.25	1.18	1.13	1.18

Table 2.23. Increase of I_s in cultivated plots compared with controls

	P1	P2	P5	P6
	%	%	%	%
0–10 cm	+ 241^{++}	+ 96^{++}	+ 67^{++}	+ 71^{++}
10–20 cm	+ 99^{++}	+ 69^{++}	+ 60^{++}	+ 73^{++}
20–30 cm	+ 68^{++}	+ 35^{+}	+ 17^{-}	+ 24^{-}

$^{++}$ significant at 1%, $^{+}$ significant at 5%, $^{-}$ not significant.

forest was greater than after clearing the savanna. On the basis of eight determinations made from June 1974 to February 1976 the increase of I_s was always significant, with the exception of the 20 to 30 cm horizon of plots P5 and P6.

Curves showing the change in I_s with time (Figure 2.15) indicate that after the end of clearing (June) and after the first seeding (July) the instability increased strongly on every plot. After forest clearing (P1) value of I_s reached its maximum following the initial cultivation. The lowest values of I_s were recorded in the second year when no cultivation took place. However, in the savanna P5 which was also laid down to *Stylosanthes* pasture, I_s did not show a maximum at the end of clearing. For the top 10 cm the variation of I_s with respect to the control plots was always higher in the cleared forest land than in the comparable savanna plots. This difference was maintained during the first year, but then tended to disappear. In plots P3 and P6 cultivation and planting of yams produced an increased degradation of the structure at the end of the second year due to the strong rains of September, in contrast with the plots P1 and P5 under planted pasture.

2.7.4.5. I_s and Organic Matter

Only the pair of plots P1 and P2 show a (negative) significant correlation between the changes of I_s (ΔI %) and that of total carbon, Δ C%:

$$0\text{–}10 \text{ cm } \Delta I_s = 185.6\text{–}6.5\ \Delta C\ (r = 0.77^{**})$$
$$10\text{–}20 \text{ cm } \Delta I_s = 80.6\text{–}3.4\ \Delta C\ (r = 0.64^{**})$$

This correlation exists only for the forest area, where the changes in I_s are greater. For the bulk of the plots, and particularly for the savanna area, the increase in I_s must be due to factors other than a decrease in the organic matter content of the soil.

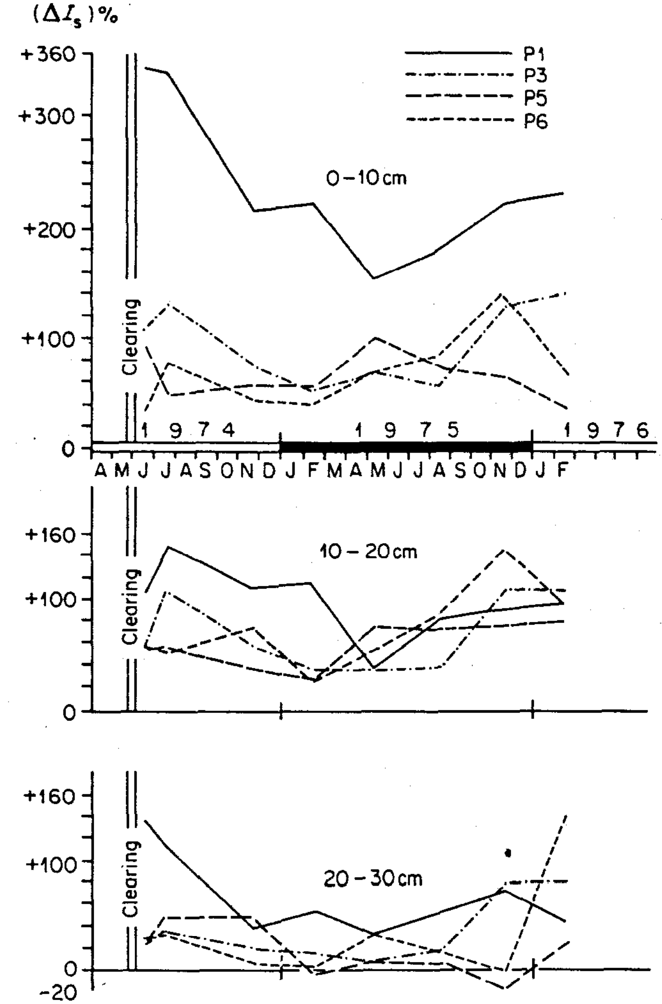

Figure 2.15 ΔI_s as per cent of control on the cultivated plots during the first two years after cultivation

CONCLUSIONS

Mechanical clearing disturbs the savanna soils only slightly, and no mixing of horizons is observed. In the forest area disturbance is clearly more important and appears especially related to the stumping of trees and bringing of roots to the surface.

The pedological differentiation of horizons is superimposed upon a lateral differentiation. The distribution and morphology of the structural volumes are directly related on the one hand to cultivation methods and on the other to soil conditions, in particular the water content at the time the soil is cultivated. Movement of tractor wheels over the soil in wet conditions produces 'amerode' regions of reduced porosity, only weakly penetrable by roots, throughout the cultivated horizon. Studies in progress show that there is a risk of maximum compaction for the soils studied, if they are cultivated near to their water holding capacity.

Overgrazing reduces spectacularly the infiltration of rain water and produces an important increase in density in the top 10 cm. The increase in density due to cultivation results essentially from a more or less total obliteration of the structural (interpedal) macroporosity. This appears clearly from micromorphological examination. The microporosity (intrapedal) is only slightly changed.

Cultivation after clearing leads to a significant increase of structural instability. This change is very rapid and appears difficult to avoid.

In natural conditions the upper horizons (0–10 cm) in the forest region show a greater structural stability than their savanna counterparts; intense faunal activity probably explains this behaviour. After cultivation the increase of I_s is proportionately more important when clearing from forest, and the observed values tend to catch up with those of the cleared savanna.

The decrease in organic matter cannot explain the general increase in the value of I_s of the cultivated soils; qualitative changes in the organic matter could be the cause.

Further recent observations (de Blic, 1976b) suggest that in the soil studied I_s could depend on the actual cohesion of the structural elements. The textural properties would thus constitute a dominant factor in relation to the structural stability.

REFERENCES

Beaudou, A. G., 1977, Note sur la quantification et le langage typologique, *Cah. ORSTOM, sér. Pédologie*, **15**, in press.

De Blic, Ph., 1976a, Le comportement de sols ferrallitiques de Côte d'Ivoire après défrichement et mise en culture semi-mécanisée: Rôle des traits hérités du milieu naturel, *Cah. ORSTOM, sér. Pédologie*, **14**, 113–130.

De Blic, Ph., 1976b, Evolution des sols après défrichement et mise en culture semi-mécanisée dans la région Centre, Enquête pédologique effectuée en 1975 sur les Ensembles de Boyakro et Brikro, ORSTOM–AVB, Côte d'Ivoire.

Chatelin, Y., and D. Martin, 1972, Recherche d'une terminologie typologique applicable aux sols ferrallitiques, *Cah. ORSTOM, sér. Pédologie*, **10**, 24–43.

Hénin, S., R. Gras and G. Monnier, 1969, *Le Profil Cultural*, 2nd edn, Masson, Paris.

PART 3

Soil – Water Relations

Vedette:

Soil Physical Properties and Crop Production in the Tropics

Edited by

R. Lal
International Institute of Tropical Agriculture,
Ibadan, Nigeria

and

D. J. Greenland
Professor of Soil Science, University of Reading,
England, and formerly Director of Research,
International Institute of Tropical Agriculture,
Ibadan, Nigeria

A Wiley-Interscience Publication

JOHN WILEY & SONS
Chichester · New York · Brisbane · Toronto