CENTRE FOR AGRICULTURAL RESEARCH IN SURINAM (CELOS)

SOME PROFILES OF FERRALLITIC SOILS UNDER SHIFTING CULTIVATION IN SURINAM

J. Ketelaars

State Agricultural University - Wageningen (Netherlands)

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C O N T E N T S

Preface

This report deals with the influence of shifting cultivation on some soil profiles of ferrallitic soils in Surinam. It is a result of research carried out during the period October 1973 - June 1974 in the Brokopondo district with assistances of the Centre for Agricultural Research in Surinam. The research formed part of the subject 'tropical soil science' supervised by Dr. J. Bennema, professor of Tropical Soil Science at the Agricultural State University, Wageningen, the Netherlands.

A preliminary report of the investigations was published as report number 96 of the CELOS. The present paper contains more complete information as additional data about texture and micromorphology came available in the meantime.

At the completion of this report I wish to express my sincere thanks to Dr. J. Bennema for his valuable help and criticism, and to Dr. J.F. Wienk, director of the Centre for Agricultural Research in Surinam who gave me the opportunity to carry out the investigations.

I am grateful to the laboratory of the CELOS in particular to its head, Mrs. Tjon Eng Soe-Monsanto, for the indispensable contribution to the chemical analysis, to the laboratory of the Agricultural Experimental Station in Paramaribo for providing some additional chemical data and to the laboratory for micromorphology of the Agricultural State University in Wageningen for preparing the thin sections.

Ir. W. van Vuure is gratefully acknowledged for his assistance during the field work and Ir. R. Miedema for his assistance in investigating the thin sections.

A special word of thanks is due to Laurence and Gerrit Petrusi for their help and friendship during my work in Surinam.

In conclusion I thank Mr. Frans Cnoops for correcting the English text and my wife for preparing the manuscript.

SUMMARY

To study the effects of shifting cultivation on the soil soil samples were collected from seven sites representing different stages in soil use, viz. 1) more than 100 years old secondary forest, 2) two months after burning forest as under 1, 3) seven years old secondary forest, 4) two months after burning forest as under 2, 5) ca. three years old secondary forest, 6) ca. 15 years old secondary forest, and 7) over one year after burning forest as under 6.

These sites were situated near Dreipade in the Brokopondo district on well drained terrace soils of Pleistocene age, i.e. ferrallitic soils classified as Ultisols. The shifting cultivation system practised by Bushnegroes on these soils has only one cropping season with rice and cassava as main crops.

Soil samples were analysed with regard to texture, bulkdensity, organic carbon, nitrogen, CEC, exchangeable K, Ca, and Na, pH-H_2O, pH-HCl and P-Bray I. In addition, a number of samples were percolated with distilled water to obtain an idea of the mobility of various ions in the soil, such in relation to possible leaching.
The percolated solution was analysed for P, NO_3, Cl, HCO_3 and organic carbon. Finally some thin slides from undisturbed soil samples were made for micromorphological investigation.

The following results were obtained:
<u>Pore space</u>. Pore space for the first 10 cm of the heavy terrace soils was found to be 60-70% under forest, decreasing to 50-60% when used for shifting cultivation; the pore space is restored within 7 years.

The bulkdensity profiles showed a typical shape. From 0-25 cm bulkdensity increased strongly whereas from 25-70 cm it decreased slightly. Below 70 cm bulkdensity increased again. Thus the soil profiles showed a minimum pore space between 25 and 35 cm; for heavy terrace soils this minimum lay between 41 and 47%, for light ones below 40%.

The typical shape of the bulkdensity profiles might be explained by an exponential decrease of the organic matter content with depth and a strong increase in clay content between 25 and 70 cm.

The compact layer in the top soil may impede root growth of crops in shifting cultivation but it certainly will after further compaction as a result of mechanical clearing.

<u>Organic carbon</u>. The carbon profiles could be described with the equation $c=ap^b$ in which c denotes the carbon content as weight per volume and p the depth. The equation is valid from 3 to 10 cm below the soil surface depending on the stage in soil use, up to a depth of 90 to 170 cm.

Changes in organic carbon content due to shifting cultivation were limited to the upper 10 cm. Considering a profile under old secondary forest as a reference the amount of organic carbon in the upper 10 cm decreased about 15% after a second use of the profile for shifting cultivation within 7 years. The original carbon content in the upper 10 cm of the profile may have been restored after a fallow period of 15 years.

<u>**Nitrogen**</u>. The C/N ratio varied from 11.6 to 13.0. The amount of nitrogen stored in the soil under a balanced shifting cultivation is large and nitrogen nutrition of crops is satisfactory.

CEC. The contribution of the clay to total CEC appeared to amount 2.2-5.5 meq per 100 grams clay. These figures are low due to the fact that kaolinite was dominant in the clay fraction. The contribution of organic matter amounted 2.6-3.1 meq per gram carbon.

From a view-point of a regular and well balanced provision of both natural vegetation and crops with plant nutrients the actual and potential contribution of organic matter to total CEC is of special interest in respect to the contribution of the clay in the terrace soils.

Potassium. K was very mobile in the soil; over half of the amount determined by ammonium acetate percolation was water soluble. A large part of the potassium from the ash comes into the soil solution so that it is rapidly transported through the profile. Enrichment with K from the ash was found up to a depth of 30 cm after two months. Profile K_1 (two months after burning forest of more than 100 years old) was estimated to be enriched at a rate of 200 kg/ha, profile K_2 (two months after burning forest of ca. 7 years old) at a rate of 100 kg/ha. Changes in the amounts of available potassium after burning were of short duration; they had disappeared after a year.

Compensating negative charges necessary for the transport of potassium and other cations (particularly ammonium and sodium) were provided by bicarbonate and probably also by organic ions. Due to leaching part of the potassium fraction from the ash may be beyond the reach of shallow rooting annual crops.

The total amount of exchangeable potassium in the upper 100 cm of the soil under forest had been estimated at 100 kg per ha at the most.

Calcium. Calcium was rather immobile in the soil. The calcium added by the ash gave rise to an enriched top soil for a number of years. Losses due to leaching and to crop removal are small. The amounts of calcium released during the burning of the vegetation were estimated at some hundreds of kilograms per hectare provided the period of fallow was long enough.

The amount of calcium present in the soil after burning is not strongly limiting to crop growth during some years.

Sodium. Like potassium sodium was very mobile in the soil. The amount of water soluble sodium expressed as a percentage of the quantity determined with ammonium acetate percolation, increased after burning from 35 to 70%.

pH-H_2O and pH-KCl. The increased pH after burning, mainly reflecting the actual acidity (pH-H_2O) is chiefly related to the addition of calcium by the ash. The increase amounted to 0.4-1.1 pH unit in the upper 5 cm (i.e. from 4.2-5.3 at most) and was maintained as long as the top soil remained enriched with calcium, viz. about three years.

Phosphate. The amount of available phosphate (P-Bray I) in the soil under forest was very small, viz. 1-2 ppm in the upper 10 cm. This amount directly increased with the phosphate released during burning to 8 ppm at most. After two or three crops the quantity of available phosphate present at the start of the cultivation period will be exhausted. Therefore phosphate very quickly hampers a prolongation of the cultivation period.

The available phosphate left in the soil after one crop is absorbed by the developing fallow vegetation. The fraction of available phosphate is not restored until the secondary vegetation is several years old.

Micromorphology. Shifting cultivation probably gives rise to a renewed or accelerated process of clay illuviation in the studied soils. Under virgin forest, i.e. high pH values and alternated wetting and drying of the top soil being absent, this process may have stopped or stabilized at a low rate.

The proportional distribution of pores with a diameter less than 2 mm appeared to be very stable under present land use, but the total number of pores with a diameter less than 0.5 mm appeared to decrease during the cultivation period.

1. INTRODUCTION

In Surinam a wide range of different landscapes and soil types belonging to it occur. Crossing the country from the north to south a remarkable diversity can be observed. Bordering the Caribbean Sea in the north is a large coastal plain with heavy clay soils and locally superimposed sand or shell banks. South of this plain a savanna belt extends in east-west direction; here bleached and non-bleached, sandy and loamy soils occur. Finally one reaches the interior part of Surinam, largely covered by evergreen rain-forest.

The soils under this vegetation are characteristic for the humid tropical climate prevailing in this country; these are the red and yellow tropical soils, in the American soil taxonomy known as Oxisols and Ultisols. They cover the larger part of Surinam.

For centuries these soils are used for shifting cultivation by Indians and Bushnegroes. This system of agriculture has proved to be an effective adaption to the low potential of the soils in question. However, shifting cultivation is a very extensive kind of land use. A short occupation period is alternated a long fallow period. Therefore population density in areas with this agricultural system must be low. If the equilibrium between population and available land is upset the system will exhaust natural resources. The consequences are known: a vicious circle of decreasing soil fertility and decreasing harvests, accompanied with soil erosion and deterioration of the natural vegetation. In Surinam land shortage is a problem of local importance till now; but in future this may change and the need of more productive agricultural systems may become more urgent.

In contrast to experience with the soils of the coastal plain experience with other agricultural systems on the inland soils is still scarce and of recent date. A previous attempt made by colonists in the 17th century to establish plantations was not succesful. It was not till fifteen years ago that a new attempt was made. Now there exists an experimental citrus plantation at Baboenhol, an oil palm plantation at Victoria and an experimental garden at Brokobaka. In the experiments main attention is paid to perennial crops such as oil palm, citrus, cocoa and coconut, but possibilities of grass production are also examined.

Among the various types of red and yellow tropical soils in Surinam the old terrace soils along the rivers are of special interest. The reasons therefore are their good physical characteristics, their occurrence in flat areas and their location near waterways. Chemical soil fertility does not differ fundamentally from other types of inland soils. They are poor in nutrients.

Because of the above mentioned qualities the old terrace soils along the Surinam river were of primary importance for experiments with permanent agriculture. So the experimental citrus plantation at Baboenhol and the oil palm plantation at Victoria have been established on these soils.

The present study gives attention to the old terrace soils along the Surinam river near Dreipade and the shifting cultivation system practised there by Bushnegroes.

An attempt is made to analyse the effects of shifting cultivation on the soil. For this aim seven profiles were selected and analysed in detail concerning physical, chemical and micromorphological characteristics. The obtained data will be compared with data already known of similar soils.

In the following a broad sketch of the shifting cultivation as practised by Bushnegroes will be given. Special attention will be paid to the role the soil plays in the system.

Generally speaking shifting cultivation is characterized by the following cycle:

a) clearing of the forest (or savanna vegetation) and burning of the felled vegetation in the dry season;
b) mixed cropping of food plants during some years (1-3);
c) a fallow period in which a secondary vegetation develops and soil fertility is restored naturally in whole or in part.

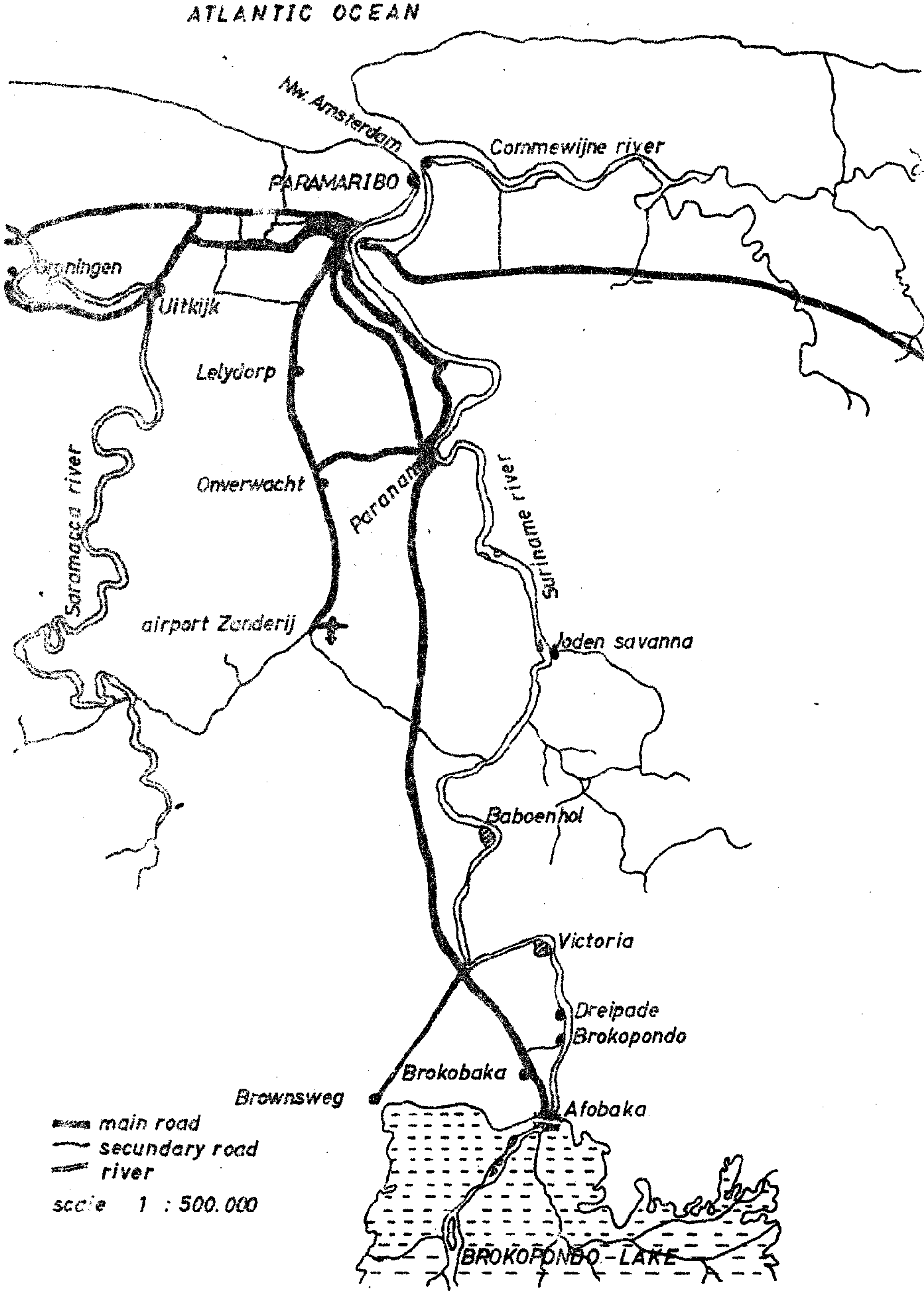
The custom of the Bushnegroes in Surinam is for men to choose a forest plot at the end of the long rainy season in August. The plots average 0.5-1 ha. Then the forest is cleared.

Usually no trees are left standing excepted palm trees which provide edible fruits. Burning only starts after the felled trees and the litter layer are dry enough to burn thoroughly. Because the dry season is irregular and unreliable in Surinam a long period may pass between clearing and burning; sometimes one will have to await a dry period in the next year. After burning the plot has to be cleared of unburnt branches.

Planting and sowing of the crops is done by women. Tillage does not extend making plant holes and covering seed. Within a short period a great variety of crops is planted or sown in a mixed culture, viz. rice, cassava, sweet potato, yams, dasheen, tania, maize, bananas, plantains, pineapple, sugarcane and some other vegetables. Rice and cassava are the most important crops. As a rule there is only one cropping season, but in rare cases rice is sown twice before abandoning the plot. Generally crops grow rapidly in the ash enriched soil. Therefore crops have a better start than the spontaneously developing vegetation. This secondary vegetation originates from seeds already stored in the forest soil and from shoots of tree stumps and from diaspores which invade the plot after burning.

Commonly weeding is restricted to what is needed for harvesting the crops. The plot is abandoned after about two years because harvesting of some crops is continued into the second year. Probably the reason for this early abandonment may have grown out of the experience that harvests will rapidly decrease and weeding will require a lot of labour during continued cropping.

The duration of the fallow period is unknown. It does not seem to be limited anyway.


ATLANTIC OCEAN
Nw. Amsterdam
Commewijne river
PARAMARIBO
Groningen
Uitkijk
Lelydorp
Saramacca river
Onverwacht
Paranam
Suriname river
airport Zanderij
Joden savanna
Baboenhol
Victoria
Dreipade
Brokopondo
Brokobaka
Brownsweg
Afobaka
BROKOPONDO - LAKE
main road
secundary road
river
scale 1 : 500.000

From an ecological point of view soil and vegetation together form an ecosystem with a complicated structure. Considering the climax vegetation, virgin forest, soil and vegetation together are in equilibrium. This is a dynamic equilibrium. Expressed as vegetative biomass the forest has reached certain proportions. NYE & GREENLAND (1960) give some figures which apply to a fallow of 40 years old. Although these figures refer to secondary forest, they will give an idea of the vegetation the farmer meets in a favourable situation. In the case of 40 years old secondary rain forest near Kade, Ghana, the total bulk of organic material contained in the vegetation (roots excluded) amounted to circa 300 tons dry weight per ha. This material contained 1781 kg N, 122 kg P, 797 kg K, 2457 kg Ca and 337 kg Mg.

The quantity of organic material on an average per annum produced in a situation of equilibrium may be assumed to equal the quantity which decomposes. This applies not only to the biomass of the vegetation but also to the organic matter of the soil. The organic matter profile - which means the organic matter content as a function of depth - is also in equilibrium under virgin forest; that is to say the rate of humus accumulation equals the rate of humus decomposition in every horizon. Most Oxisols under virgin forest have simple organic matter profiles, due to the only gradual changes in clay content with depth and due to the absence of horizons which impede root development in a mechanical way and of subsurface horizons with marked accumulation of organic matter.

Concluding one could say living processes in the ecosystem give rise to certain distribution of organic carbon between soil, litter layer and biomass itself. But the conclusion is not only valid for the element carbon; it applies also to other elements involved in these processes as nitrogen, potassium, calcium and phosphate are. The distribution is not a static one. Each element is turning continuously in a nutrient cycle between soil and vegetation. The complete cycle, together with the loss and gain processes are illustrated in Fig. 2.

The nutrient cycle is of an essential value for maintenance of the forest. Maintenance is only possible if there is permanent growth and production of organic matter. The amounts of nutrients available for uptake by plants being limited, there is necessary a continuous recycling of the same mineral nutrients. Availability is a matter of special interest to the element phosphate, because total supply of soil phosphate may be large but the quantity available for uptake by plants is always small.

The rate of turnover of the elements in the nutrient cycle under forest is very rapid. Using data from Kade NYE & GREENLAND (1960) calculated the annual turnover of nutrients expressed as a percentage of the total capital stored in the vegetation as follows: N 11%, P 11%, K 32%, Ca 12% and Mg 18%. The high figure for potassium is a consequence of the high rate of leaching out of leaves by rain. Of course in younger forest the turnover is a greater proportion of the storage.

Net losses from the cycle under virgin forest will be small or even absent. Leaching of nutrients and removal by erosion is prevented by nutrient uptake and soil protection of the vegetative cover. Besides there is a certain addition of nutrients to the system in the form of rain and dust fall and nitrogen fixation due to microbial processes.

However this situation of equilibrium will change thoroughly as soon as the forest is cleared. Living processes within the ecosystem which formerly gave rise to the above mentioned distribution of elements are suddenly stopped. Plant biomass, the litter included, is burnt. Carbon, nitrogen and sulphur are lost by volatilization consequence of burning. Other elements essential to plant feeding are spread in the ash

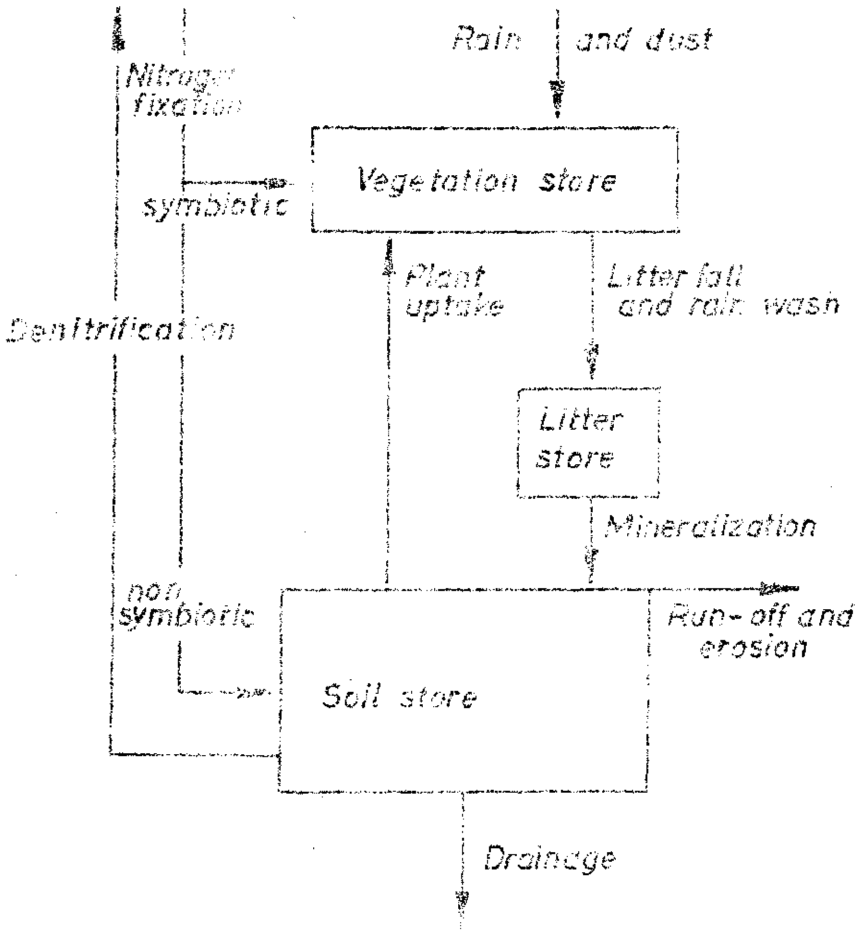


Fig. 2. The nutrient cycle in a tropical rainforest (after NYE & GREENLAND, 1960).

on the surface of the soil in the form of carbonates, phosphates and silicates. Certain amounts of nutrients are left in unburnt stumps.

The nutrient cycle is cut. Production of living organic material has stopped and probably also humus accumulation in the soil. On the other hand decomposition of humus will proceed at an increased rate because of an increased soil temperature.

Leaching losses may become important now because absence of a transpiring vegetative cover gives rise to an increase in leaching by rain water, because the concentration of anions in the soil solution increases as a result of a more rapid mineralization of organic matter and because root uptake of ions has stopped practically. Besides burning adds large amounts of mineral salts to the soil; as far as they are soluble these salts will be transported readily through the profile during the first heavy rains. Finally if the soil is not very permeable and if the area in which the plot is situated has a slight relief there will be also considerable losses of nutrients by erosion of ash.

However the ash is a very important source of nutrients for the crops grown in shifting cultivation because natural fertility of the soils in question is low. In this respect nitrogen and also sulphate nutrition of the crops take in a special position. Because all nitrogen and sulphate stored in the forest is lost in the burn on clearing it is only soil nitrogen and sulphate that can be used by crops. As a rule nitrogen nutrition is satisfactory because of a rapid mineralization of humus. Sulphate might be deficient in many cases.

Harvesting the crops certain amounts of nutrients are removed from the plot. Besides, decomposition of organic matter and leaching cause impoverishment of the top soil. Depending on general level of soil fertility this impoverishment limits cropping to a more or less short time. As a rule soil fertility in shifting cultivation is short-lived indeed.

If long enough the fallow which comes after the occupation period will restore soil fertility. This restoration proceeds along different lines. In contrast to annual crops the fallow vegetation is able to take up nutrients from the subsoil by its deep root system. These nutrients are stored partly in the vegetative biomass itself, partly in the top soil. Increment of the soil nitrogen comes from microbiological fixation both in the soil and in the phyllosphere (RUINEN, 1965) and in the rhizosphere.

The rate of nutrient immobilization in the forest fallow varies with the age of the fallow. BARTHOLOMEW et al. (NYE & GREENLAND, 1960) found out in Yangambi, Congo, that with exception of P after five years the same amounts of element had been immobilized as half of the amounts accumulated after eightteen years. On an average of the first five years following amounts were immobilized per annum per ha: 111 kg N, 6.1 kg P, 88 kg K and 82 kg Ca+Mg; on an average of the first eightteen years these figures were: 38 kg N, 5.8 kg P, 33 kg K and 45 Kg Ca+Mg.

The effective accumulation, aiming at the quantity which can be liberated from the vegetation by burning will be at its maximum after about twenty years (LAUDELOUT, 1961).

Increasing the age of the fallow increases the immobilization of nutrients but this is mostly due to the weight increase of larger woody parts.

Next to the restoration of chemical soil fertility an improvement of the physical constitution of the soil occurs at the same time during the fallow period. Although in forest regions deterioration of soil structure is not striking as a rule because intensive tillage is absent, a little more compact surface layer leads rapidly to a strong decrease of the infiltration rate and to subsequent losses of ash by increased run-off. Therefore an improvement of the soil constitution by a forest fallow is favourable for mineral nutrition of the crops grown after burning.

The present study will discuss some changes in soil characters as a result of shifting cultivation against the background of the above broadly sketched processes.

A preliminary report has been published in report no. 96 (in Dutch) of the Centre for Agricultural Research in Surinam (CELOS). This report also contains comprehensive agronomic information about the shifting cultivation system used by Bushnegroes in the Brokopondo-district, Surinam.

2. METHODS AND MATERIALS

2.1. FIELD RESEARCH

The research was carried out on the terrace soils of the Surinam-river in the Brokopondo-district near the village Dreipade.

To allow for a comparison to be made between some important stages in land use soil samples were collected from seven different sites. These samples came from profile pits with sampling depths: 0-2.5 cm, 1-3.5, 2.5-5, 3.5-6, 5-7.5, 6-8.5, 7.5-10, 10-12.5, 17.5-20, 25-27.5, 32.5-35, 45-47.5, 57.5-60, 70-72.5, 87.5-90, 105-107.5, 125-127.5, 147.5-150 and 170-172.5 cm.

Because sampling depths within the 0-10 cm layer are overlapping the samples in this layer had to be taken next to each other. Therefore the first seven samples do not refer exactly to the same soil column, the samples below 10 cm however do.

All samples were taken with 50 cc aluminium tubes of 2.5 cm height to know volumina exactly. For each thin layer four cores of 50 cc were collected and they were mixed to a sample of 200 cc which was used for analysing.

Apart from the samples taken from the profile pits samples were collected at five different places lying all round the pit in a circle with diameter of about 5 m. They come from the depths 0-5 cm and 5-10 cm. For this purpose aluminium tubes of 100 cc and 5 cm height were used. These samples give an idea of local variations in the top soil.

For micromorphological analysis undisturbed soil samples were collected by means of small metal boxes.

2.2. LABORATORY RESEARCH*

The following methods were used for analysing.

Bulkdensity	: determination after drying during 24 hours at 105°C.
Percentage fine earth	: the sample passing through a 2 mm sieve.

* Texture and nitrate were analysed in the laboratory of the Experimental Station for Agriculture in Paramaribo; all other chemical analyses were carried out in the laboratory of the CELOS.

Organic carbon	: wet oxidation according to Walkley & Black; the obtained values are multiplicated uniformly with a factor 1.15 for conversion into elementary carbon; in fact this multiplication factor varies somewhat with depth and time (ANON., 1974).
Total nitrogen	: destruction with H_2SO_4 according to Micro-Kjehldahl.
pH-KCl and pH-H_2O	: shaking during an hour; measuring directly in suspension.
CEC	: percolating with NH_4OAc at pH 7.
Exchangeable K, Ca and Na	: flame fotometric determination in NH_4OAc percolated solution.
Water soluble K, Ca and Na	: percolating with distilled water in the same ratio as used for determination of CEC.
Water soluble organic carbon	: oxidation with an overmeasure of $KMnO_4$ and backtitration with oxalic acid (ANON., 1965).
Phosphate	: a) Bray I: standard method. b) P-H_2O : measuring in water percolated solution.
Nitrate	: determination by cadmium-copper reduction to nitrite; nitrite is then determined by means of a diazotization method (WOOD et al., 1967).
Chloride	: determination according to Mohr.
Bicarbonate	: titration with NaOH and phenolphtalein, and HCl and methyl-orange for CO_2 (HOFSTEE and FIEN, 1971).
Texture	: pipette method according to Robinson, using H_2O_2, HCl and sodium pyro-phosphate for fractions below 53 mu; for fractions above 53 mu using sieves.

More detailed information about standard methods can be found in JANSSEN and TJON ENG SOE-MONSANTO (1973).

Thin sections for micromorphological study were made according to the method described by JONGERIUS & HEINTZBERGEN (1963). The size of the slides equals circa 8x15 cm. For a micromorphological description a Leitz-Orthoplan polarizing microscope was used.
The thin sections are described with the terminology proposed by BREWER (1964).

A point counting method is used to determine the amounts of clay skins. With this method an imaginary net of points is put on the slide. At every point it is observed whether a clay skin occurs or not. Counting a lot of points in this way one gets an estimation of volume percentage of clay skins in a certain soil layer.

Pore size distribution is measured in a similar way. For this purpose imaginary lines are drawn across the slide. Of all pores, cracks and channels which are crossed by these lines the diameter is noted. The different diameters together give an idea of the pore size distribution.

For determination of the total amount of pores in an area unit all pores with a diameter less than 500 micron are counted in eight narrow bands of 400 micron width. The total area in which pores are counted varies between 1.5 and 2 cm^2 in each slide.
The observations for the three above mentioned counting methods are carried out using a magnification of 125x.

3. GENERAL DATA ON THE SOILS NEAR DREIPADE

In the following section the geomorphology, geology and general soil conditions of the river terrace landscape near Dreipade will be briefly discussed.

Figure 3 shows a geomorphological section of this landscape south of the village Dreipade. On the geomorphological map (Fig. 4) the right position of the section has been marked.

Low-, medium- and highlevel terrace are situated between the residual schist hills in the west and the most recent river valley in the east.

The genesis of the old terrace landscape took place in the Pleistocena era. The residual schist hill landscape in which the terraces have developed forms part of the basal complex of the great Guyanese shield. This shield dates back to Precambrium time. It consists of many different kinds of rock but in the Brokopondo-area schist dominates. The recent river valley is probably of Holocene age. Leevee and basin can be distinguished easily.

The topography of the old terrace landscape is weakly undulating to undulating. The terraces are intersected by creeks and gullies. From a hydrological point of view the main watercourses are the Tapoeripa creek in the south and the Compagnie-creek in the west. Between them less important drainage systems exist, all running to the Suriname-river.

The heights of the various geomorphological structures near Dreipade are given below:

low-level terrace	: 10-12 m N.S.P.
medium-level terrace	: 14-20 " "
high-level terrace	: 26-34 " "
leevee	: 7- 8 " "
basin	: 6- 7 " "
schist hills	: 34-60 " "

Geomorphology makes a distinction between erosional terraces and depositional terraces. In respect to soil properties the most important difference between them is a different texture. The schist of the residual landscape also provides for the parent material of the erosional terraces. Soils developing from this material have a clayey texture, while generally spoken the alluvial deposits of the depositional terraces gave rise to a loamy texture. Besides the residual parent material contains more iron than the alluvial parent material.

Drainage of the terrace soils is in general moderately good to good because of their location.

But even though the physiographical situation can be the same, texture causes a difference in drainage: the loamy soils of the plateaux are essentially well drained but the presence of residual clay in the subsoil can change this good drainage into a moderately good one.

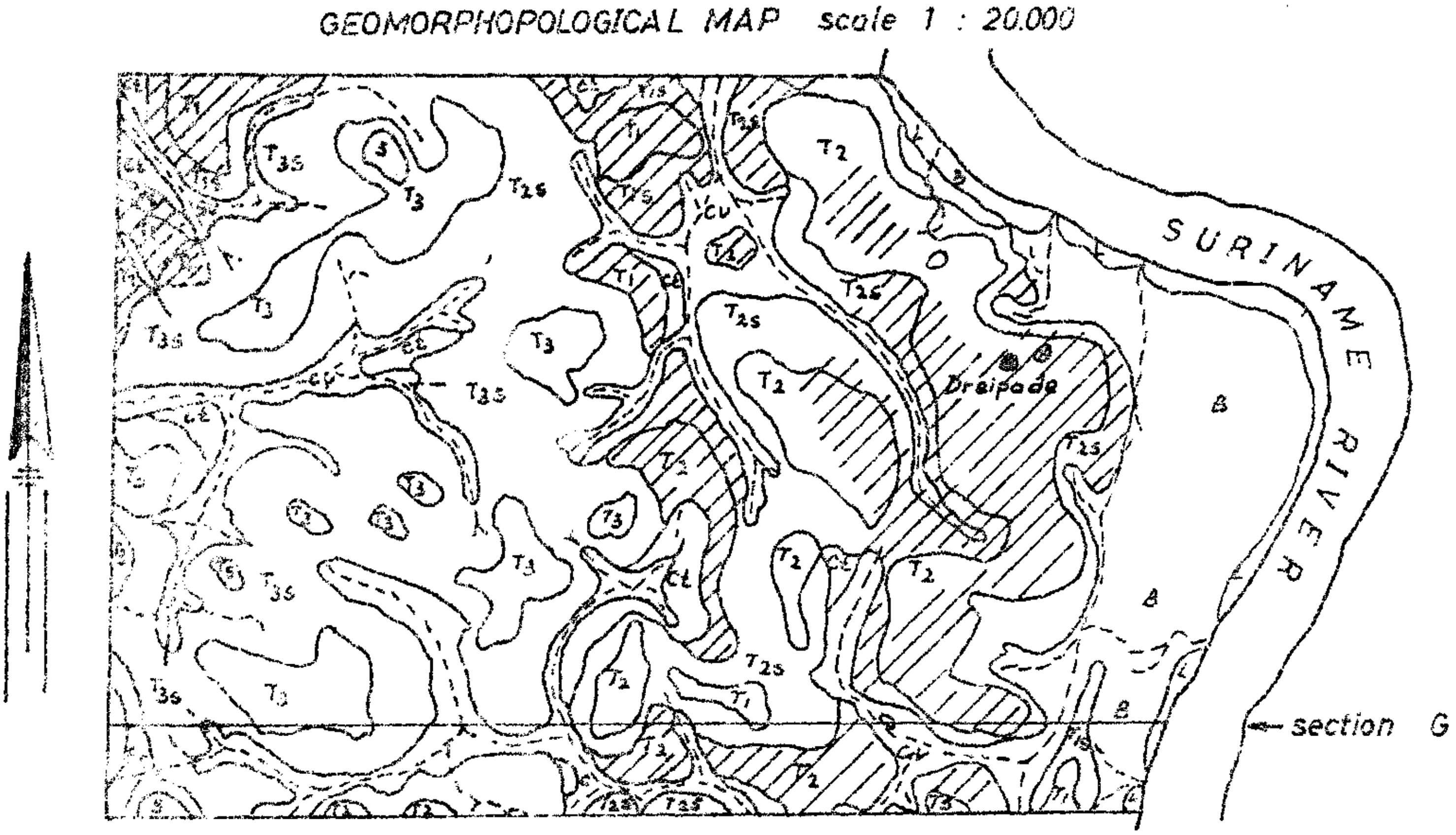


Fig. 3. Geomorphological section of the terrace landscape south of the village Dreipada (from MULDERS, 1973).

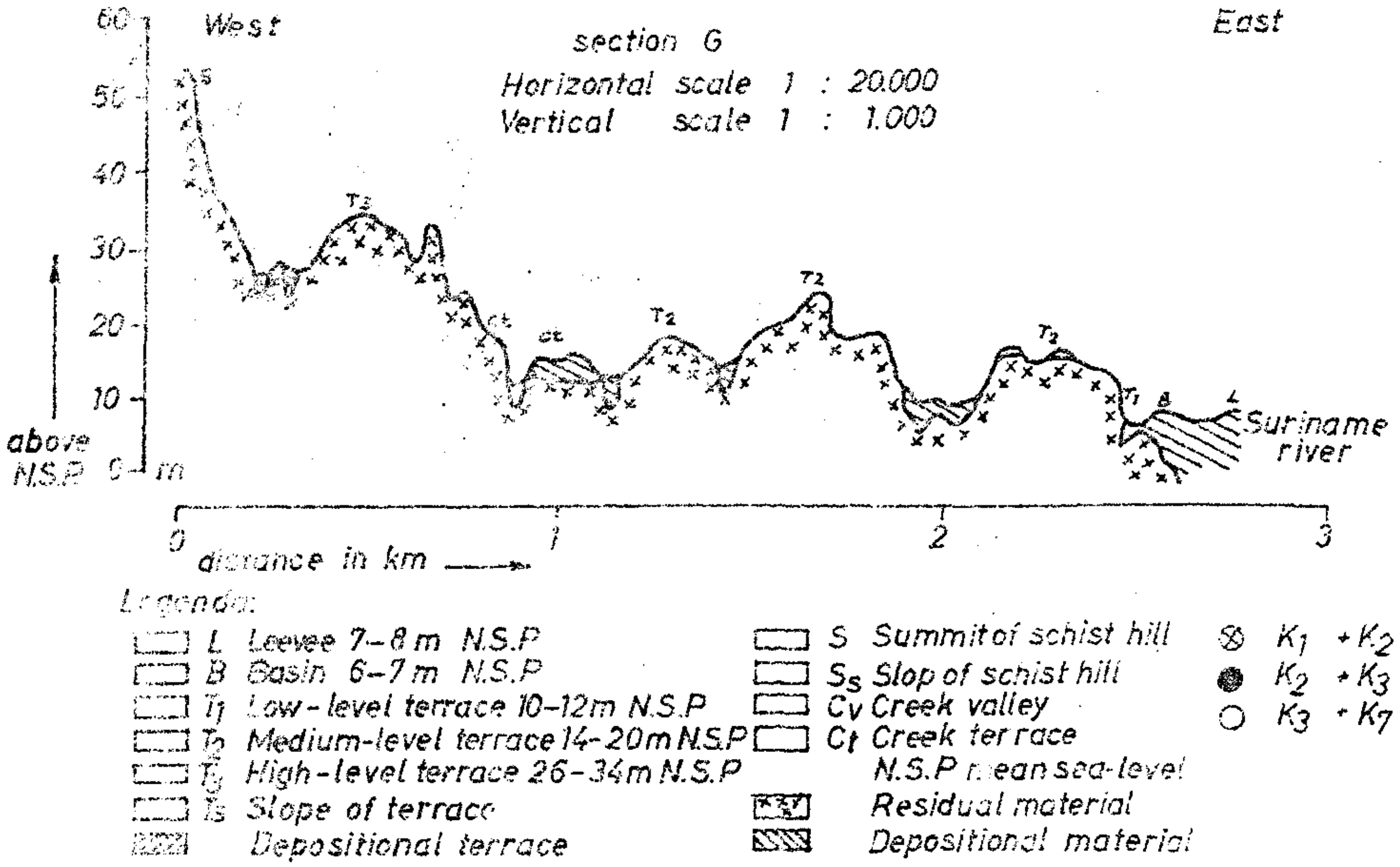


Fig. 4. Geomorphological map of the Dreipada area (from MULDERS, 1973) with the situation of the profile pits K1, K2, K3, K4, K5 and K7.

Therefore the main division of the terrace soils for soil mapping purposes (MULDERS, 1973) depends upon the situation of the soils, whether they are situated on the plateaux or on the terrace slopes. With this distinction differences in texture, moisture class, depth of homogenization and color of mottles are correlated.

For a long time the terrace soils have been preferred by Bushnegroes for their shifting cultivation because of their location and their good physical properties. This is the reason that these soils nowadays are covered largely by secondary forest of various age. Aerial photographs of the area show the typical mosaic-like vegetation pattern as a result of shifting cultivation.

4. CHOICE OF THE PROFILE PITS

The most important consideration for the choice of the sampled sites was the wish to create a homogeneous group of profiles, that is to say the profiles ought to be homogeneous with regard to texture, good drainage and absence of iron concretions. Differences in texture and drainage influence strongly the organic carbon content and so they restrict mutual comparability of the profiles. The presence of iron concretions makes it difficult to use aluminium tubes to obtain reliable data about bulkdensities.

Besides only a very limited number of different stages in land use could be sampled within the scope of the present study.

Eventually the following sites have been chosen:

Code	Stage	History
K_6	sec.forest,more than 100 years old	?
K_1	2 months after burning	sec.forest,about 100 years old
K_5	sec.forest, about 7 years old	old secondary forest
K_2	2 months after burning	sec.forest, about 7 years old
K_7	sec.forest, about 3 years old	sec.forest, about 7 years old
K_4	sec.forest, about 15 years old	?
K_3	over one year after burning	sec.forest, about 15 years old

The position of the pits is shown in Fig. 3 with exception of K_6. Pit K_6 is situated 2 km north-east from Dreipade on low-level terrace.

The best reference for determination of changes in soil characters caused by human activity is certainly the soil under virgin forest. However virgin forest could not be found on the terrace soils in these surroundings. Although the forest near pit K_6 was very old (with trees of 1-2.5 m in diameter at breast height) and although it was similar to virgin forest in physiognomy, the soil profile showed evidence of human activity. The charcoal in it points to a very old occupation period.

Another more serious disadvantage of profile K6 forms its lighter texture in relation to all other profiles which also show minor differences in texture. Therefore texture has complicated the interpretation of most analyses.

Texture itself is analysed for the profiles K_2, K_3, K_4 and K_6. Texture and texture profile of K_1 is similar to that of K_4; the same applies to K_7 and K_3, and K_5 and K_2.

For all stages of land use samples were collected from profile pits. Besides samples of the top soil were taken from five different places near each pit. Latter samples will be indicated in the tables as A_1, A_2, A_3, A_4 and A_5. Two soil samples indicated with M refer to mixed samples composed of five cores. These cores come from five different places distributed over about 0.25 ha of the plots K_1 and K_2.

Finally ten undisturbed soil samples for micromorphological analysis were taken from the pits K_2, K_3, K_5, K_6 and K_7. One small box contained a sample of the 0.5-15.5 cm layer, the other contained a sample of the 15.5-30.5 layer.

5. PROFILE DESCRIPTIONS

5.1. REMARKS

In the following some important profile characteristics will be explained. In 5.2 complete descriptions are given.

Division in horizons

All forest profiles have a thin litter layer (O_1) consisting of organic material of which the original structure can be recognized. The O_2-horizon consisting of humus is very thin. Therefore the boundary between O-horizon and the mineral soil is sharp. They are mutually connected by a system of fine roots. When the forest is cleared and burnt the organic material of the O-horizon is lost by burning.

The mineral soil consists of an A_1-horizon with accumulation of humus and a B-horizon. Between A_1 and B the A_3- and AB-horizons form transitional horizons. All profiles show characteristics of a textural B-horizon.

Color

All profiles are characterized by a very gradual change of color with depth.

In profile K_2 the influence of the charcoal addition could be observed clearly. The charcoal is incorporated into the soil by soil tillage and animal activity. Finely distributed it causes darker colcrs as is shown by following data.

	K_5 secondary forest	K_2 after burning
A_1 :	10 YR 3/3 dark yellowish	10 YR 3/2 very dark yellowish brown
A_3 :	10 YR 4/4: 75% dark yellowish brown 10 YR 5/6: 25% yellowish brown	10 YR 3/3: 75% dark brown 10 YR 5/4: 25% yellowish brown

The addition of organic matter to the subsoil can also give rise to local changes of color (see K3). The yellow colors along the filled up root channels are a result of a change in the iron compounds of the soil. This change coheres with a change of the redox potential consequent to the supply with organic material.

Structure .

In the top soil the grade of structure is weak. Biological activity causes rounded elements of all size classes. In the subsoil the structure is more pronounced; it consists of compound angular elements which can be easily divided into smaller particles.

Biological activity

In all profiles activity of ants has been observed but in most cases also termites and worm casts have been seen. Pore space is especially high but not only in the top soil. The greater number of pores have a diameter less than 1 mm.

Consistency

The top soil has a crumb structure and because of its loamy texture it is slightly sticky and slightly plastic. A possible destruction of the crumb structure caused by shifting cultivation is clearly demonstrated by the top soil of K.; after sowing of the rice the soil surface was silting up quickly.

Rooting

The layer of 0-50 cm contains the bulk of the roots. The quantity of thick roots is very small in the profiles under young secondary vegetation. On the other hand there are many old root channels in these profiles originating from thick roots of the previous forest. These channels are filled up with humous material mixed with charcoal. Pore space in it is very high. Besides there is a clear accumulation of fresh roots in these channels. It is difficult to assess to which extent this humous material may enrich the subsoil absolutely with organic matter. But it is clear that this kind of channels locally disturb the organic matter profile seriously.

Clay elements, clay skins, concretions

The origin of the solid clay elements in the AB- and B-horizon is unknown.

In the field the presence of clay skins can not always be determined without doubt but the micromorphological study . revealed their real existence. Their origin will be discussed in 7.2.

Soft nodules in the subsoil are pieces of weathered schist; they indicate the presence of residual parent material.

Texture

Data about texture are given in 6.1.

Classification of the profiles

In view of the rather strong increase of clay content with depth and the presence of clay skins in the top soil (see 7.2) all profiles may be classified as Ultisols (Typic Paleudults) according to the 7th Approximation of the American soil taxonomy.

5.2. DESCRIPTIONS

The profiles are described according to the "Guidelines for Soil Description" prepared by the FAO.

Profile K_1

GENERAL DATA

Mapping unit: B. 1.1.2. (MULDERS, 1973)
Area and location: Dreipade, 30 m.W.
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 882.2 --- E: 378.4
Elevation: + 16 m NSP
Aerial photo no.: R 20 0.5058, 5059
Date of description: 1-2-1974
Described by: Van Vuure, Kruisinga, Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: end of the short rainy season; in past 14 days before description rainfall exceeded evapotranspiration
Geomorphological unit: medium-level terrace
Parent material: pleistocene river deposits
Physiography: plateau
Relief: subnormal
Slope: single, almost flat
Hydrology:
- a) soil drainage: well drained
- b) groundwater table:
  - presumed highest: > 1.60 m below the soil surface
  - presumed lowest : > 1.60 m below the soil surface
  - actual : > 1.60 m below the soil surface
- c) flooding: never

Moistness: surface soil moist, subsoil moist
Biological activity:
- a) depth of undisturbed soil: > 1.60 m
- b) other features: many worm casts and ants in 0-30 cm layer

Land use: first year of occupation; cultivated with rice, maize, cassava, okra, Xanthosoma spp. in shifting cultivation; cleared: August-September 1973, virgin or old secondary forest;
burnt: midst of November 1973
Notes on soil samples: date of sampling: 28-12-1973.

DESCRIPTION OF SOIL HORIZONS

A_1 0-11 cm: dark brown (10 YR 3/3); medium-coarse sandy loam; weak fine-coarse subangular blocky; friable, plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; many very fine, common fine, common medium and common coarse roots; much charcoal on surface; clear and smooth on:

A_3 11-23 cm: dark yellowish brown (10 YR 4/4), 75%, and yellowish brown (10 YR 5/6), 25%; medium-coarse sandy loam; weak fine-coarse subangular blocky; friable, plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; many very fine, common fine, common medium and few coarse roots; gradual on:

AB 23-40 cm: yellowish brown (10 YR 5/6); medium coarse sandy clay loam; weak fine-coarse, subangular blocky-angular blocky; friable, plastic and sticky; many very fine, few fine, few medium and few coarse pores; few very fine, few fine, few medium and few coarse roots; gradual on:

B_1 40-62 cm: brownish yellow (10 YR 6/6); medium-coarse sandy clay loam; weak fine-coarse, angular blocky-sub-angular blocky; friable-firm, plastic and sticky; many very fine, few fine, few medium and few coarse pores; few very fine, few fine, very few medium and very few coarse roots; clay cutans, thin and patchy; solid clay elements, few cubic, 1x2 cm; diffuse on:

B_{21} 62-82 cm: strong brown (7.5 YR 5/8); clay; weak moderate, compound angular blocky; friable-firm, plastic and sticky; many very fine, few fine, few medium and few coarse pores; very few very fine, very few fine, very few medium and very few coarse roots; clay cutans, thin and patchy; solid clay elements, few and cubic, 1x2 cm; diffuse on:

B_{22} 82-160 cm: strong brown (7.5 YR 5/8) to yellowish red (5 YR 5/8); clay; moderate, compound angular blocky; firm, plastic and sticky; many very fine, few fine, few medium and few coarse pores; very few very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, many and subangular blocky, 0.3x0.3 cm; few fine faint yellowish brown (10 YR 5/8) mottles and few fine distinct dark red (2.5 YR 3/6) soft nodules of rotten rock.

Profile K_2

GENERAL DATA

Mapping unit: B. 1.1.2. (MULDERS, 1973)
Area and location: Dreipade, 120 m.W.
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 882.2 --- E: 378.2
Elevation: + 16 m NSP
Aerial photo no.: R 20 0 5058, 5059
Date of description: 10-4-1974
Described by: Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: end of the short dry season; in past 14 days before description rainfall exceeded evapotranspiration
Geomorphological unit: medium level terrace
Parent material: pleistocene river deposits
Physiography: plateau
Relief: subnormal
Slope: single, almost flat
Hydrology:
a) soil drainage: moderately well - well drained
b) groundwater table:
presumed highest: > 1.70 m below the soil surface
presumed lowest : > 1.70 m below the soil surface
actual : > 1.70 m below the soil surface
c) flooding: never

Moistness: surface soil moist, subsoil moist
Biological activity:
a) depth of the undisturbed soil: > 1.70 m
b) other features: many worm casts, ants and termites in 0-30 cm layer

Land use: first year of occupation; cultivated with rice, maize, cassava, okra, Xanthosoma spp., Dioscorea spp. in shifting cultivation;
cleared: August-September 1973, secondary forest 7 years old;
burnt: midst of November 1973

Notes on soil samples: date of sampling: January 1974.

DESCRIPTION OF SOIL HORIZONS

A_1 0-11 cm: very dark grayish brown (10 YR 3/2); medium-coarse sandy loam; weak fine-coarse subangular blocky; friable, plastic and slightly sticky; many very fine, many fine, few medium and few coarse pores; many very fine, many fine, many medium and common coarse roots; much charcoal, also on surface; clear and smooth on:

A_3 11-21 cm: dark brown (10 YR 3/3), 75%, and yellowish brown (10 YR 5/4), 25%; medium-coarse sandy loam; weak fine-coarse subangular blocky; friable, plastic and sticky; many very fine, many fine, few medium and few coarse pores; common very fine, many fine, many medium and few coarse roots; gradual on:

AB 21-39 cm: yellowish brown (10 YR 5/6); medium-coarse sandy clay loam; weak moderate fine-coarse subangular blocky; friable, plastic and sticky; many very fine, many fine, few medium and few coarse pores; common very fine, common fine, few medium and very few coarse roots; diffuse on:

B_1 39-75 cm: strong brown (7.5 YR 5/6); medium-coarse sandy clay loam; moderate compound angular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; few very fine, fine and medium, very few coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky 1x2 cm; diffuse on:

B_{21} 75-110 cm: strong brown (7.5 YR 5/8); clay; moderate compound angular blocky; firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; very few very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x2 cm; few fine faint brownish yellow (10 YR 6/6) mottles and few fine distinct dark red (2.5 YR 3/6) soft nodules of rotten rock; diffuse on:

B_{22} 110-160 cm: reddish yellow (7.5 YR 6/8), 50%, and reddish yellow (5 YR 6/8), 50%; clay; moderate compound angular blocky; firm, plastic and sticky; common very fine, many fine, few medium and few coarse pores; very few very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x2 cm; common fine faint brownish yellow

(10 YR 6/6) and common fine faint red
(2.5 YR 5/8) mottles; few fine distinct dark red
(2.5 YR 3/6) soft nodules of rotten rock.

Profile K_3

GENERAL DATA

Mapping unit: B. 1.1.3. (MULDERS, 1973)
Area and location: Dreipade, 400 m.NW
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 882.6 --- E: 377.0
Elevation: + 16 m NSP
Aerial photo no.: R 20 0 5058, 5059
Date of description: 16-4-1974
Described by: Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: end of the short dry season; in past 14 days before description rainfall exceeded evapotranspiration
Geomorphological unit: medium-level terrace
Parent material: schist (residual)
Physiography: plateau
Relief: subnormal
Slope: single, almost flat
Hydrology:
a) soil drainage: moderately well drained
b) groundwater table:
presumed highest: > 1.60 m below the soil surface
presumed lowest : > 1.60 m below the soil surface
actual : > 1.60 m below the soil surface
c) flooding: never
Moistness: surface soil moist, subsoil moist
Biological activity:
a) depth of undisturbed soil: > 1.60 m
b) other features: many ants in surface soil
Land use: end of one year shifting cultivation: fallow vegetation with Solanum subinerme, S. jamaicense, S. rugosum, S. asperum, Trema micrantha, Cecropia obtusa, C. sciadophylla, Vismia spp. a.o.; mean height: 2-3 m
Notes on soil samples: date of sampling: 19-2-1974.

DESCRIPTION OF SOIL HORIZONS

(01 1-0 cm: locally a little litter on surface)

A_1 0-10 cm: dark brown (10 YR 3/3); medium-coarse sandy clay loam; weak-moderate fine-coarse subangular blocky; friable, plastic and slightly sticky; many very fine, many fine, few medium and few coarse pores; many very fine, many fine, common medium and common coarse roots; common charcoal, also on surface; clear and smooth-wavy*) on:

* Boundary locally broken in soil pits: humus accumulation in tongues (root channels) up to a depth of 100 cm; in it also accumulation of fresh roots, many medium and common coarse pores, common charcoal and reduction colours alongside (brownish yellow: 10 YR 6/6-6/8).

A_3 10-21 cm: yellowish brown (10 YR 5/4, 60%, and 10 YR 5/6, 40%); medium-coarse sandy clay loam; moderate compound subangular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; common very fine, common fine, few medium and few coarse roots; little charcoal; clear and smooth on:

AB 21-40 cm: yellowish brown (10 YR 5/6); clay; moderate compound angular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; common very fine, common fine, few medium and few coarse roots; solid clay elements, few subangular blocky, 1x1 cm - 1x2 cm; gradual on:

B_1 40-79 cm: strong brown (7.5 YR 5/8); clay; moderate compound angular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; few very fine, few fine, very few medium and very few coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x2 cm; few fine faint red (2.5 YR 5/8) mottles; diffuse on:

B_{21} 79-160 cm: strong brown (7.5 YR 8/8) - yellowish red (5 YR 5/8); clay; moderate compound angular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; very few very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x1 cm; few fine distinct dark red - dark reddish brown (2.5 YR 3/6-3/4) soft nodules; few fine faint brownish yellow (10 YR 6/8) mottles.

Profile K_4

GENERAL DATA

Mapping unit: B. 1.1.2. (MULDERS, 1973)
Area and location: Dreipade, 50 m.W.
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 882.2 --- E: 378.4
Elevation: + 16 m NSP
Aerial photo no.: R 20 0 5058, 5059
Date of description: 9-4-1974
Described by: Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: end of the short dry season; in past 14 days before description rainfall exceeded evapotranspiration
Geomorphological unit: medium-level terrace
Parent material: pleistocene river deposits
Physiography: plateau
Relief: subnormal
Slope: single, almost flat

Hydrology:
a) soil drainage: well drained
b) groundwater table:
presumed highest: > 1.70 m below the soil surface
presumed lowest : > 1.70 m below the soil surface
actual : > 1.70 m below the soil surface
c) flooding: never
Moistness: surface soil moist, subsoil moist
Biological activity:
a) depth of undisturbed soil: > 1.70 m
b) other features: worm casts, ants and termites in 0-30 cm layer
Land use: forest fallow, about 15 years old
Notes on soil samples: date of sampling: 15-3-1974.

DESCRIPTION OF SOIL HORIZONS

O_1 2-0 cm: organic material; between O_1 and A_1 surface mat of mainly fine roots; abrupt and wavy on:

A_1 0-12 cm: dark brown (10 YR 3/3); medium-coarse sandy loam; weak fine-coarse subangular blocky; friable-very friable, plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; many very fine, common fine, medium and coarse roots; much charcoal, mainly at a depth of about 10 cm; clear and smooth on:

A_3 12-22 cm: dark brown (10 YR 4/3), 75%, and yellowish brown (10 YR 5/6), 25%; medium-coarse sandy loam; weak fine-coarse subangular blocky; friable, plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; common very fine, fine and medium, very few coarse roots; little charcoal; gradual on:

AB 22-40 cm: yellowish brown (10 YR 5/6); medium-coarse sandy clay loam; weak fine-coarse subangular blocky; friable, plastic and sticky; many very fine, common fine, few medium and few coarse pores; common very fine, common fine, few medium and very few coarse roots; gradual on:

B_1 40-65 cm: yellowish brown (10 YR 5/8); medium-coarse sandy clay loam; weak-moderate compound subangular blocky-angular blocky; friable, plastic and sticky; many very fine, few fine, medium and coarse pores; common very fine, common fine, few medium and very few coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky 1x2 cm; diffuse on:

B_{21} 65-90 cm: strong brown (7.5 YR 5/6); clay; moderate compound angular blocky; firm, plastic and sticky; many very fine, few fine, medium and coarse pores; few very fine, few fine, very few medium and coarse roots; clay cutans, thin and patchy; solid clay elements few subangular blocky, 1x1 cm; diffuse on:

B_{22} 90-140 cm: strong brown (7.5 YR 5/6-5/8); clay; moderate compound angular blocky; firm, plastic and sticky; many very fine, few fine, medium and coarse pores; very few, very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x1 cm; few fine distinct red (2.5 YR 5/8) mottles; diffuse on:

B_{23} 140-170 cm: reddish yellow (7.5 YR 6/8, 50% and 5 YR 6/8, 50%); clay; moderate compound angular blocky; firm, plastic and sticky; many very fine, few fine, medium and coarse pores; very few very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x1 cm; few fine distinct red (2.5 YR 5/8) mottles.

Profile K_5

GENERAL DATA

Mapping unit: B. 1.1.2. (MULDERS, 1973)
Area and location: Dreipade 130 m.W, 15 m NW of K_2
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 882.2 --- E: 378.2
Elevation: + 16 m NSP
Aerial photo no.: R 20 0 5058, 5059
Date of description: 12-4-1974
Described by: Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: end of the short dry season; in past 14 days before description rainfall exceeded evapotranspiration
Geomorphological unit: medium-level terrace
Parent material: pleistocene river deposits
Physiography: plateau
Relief: subnormal
Slope: single, almost flat
Hydrology:
a) soil drainage: moderately well - well drained
b) groundwater table:
presumed highest: > 1.60 m below the soil surface
presumed lowest : > 1.60 m below the soil surface
actual : > 1.60 m below the soil surface
c) flooding: never
Moistness: surface soil moist, subsoil moist
Biological activity:
a) depth of undisturbed soil: > 1.60 m
b) other features: worm casts, ants, termites in 0-30 cm layer
Land use: forest fallow, about 7 years old
Notes on soil samples: date of sampling: 16-3-1974.

DESCRIPTION OF SOIL HORIZONS

O_1 2-0 cm: organic material; between O_1 and A_1 surface mat of mainly fine roots; abrupt and wavy on:

A_1 0-13 cm: dark yellowish brown (10 YR 3/4); medium-coarse sandy loam; weak fine-coarse subangular blocky; friable, plastic and slightly sticky; many very fine, many fine, few medium and few coarse pores; many very fine, fine and medium, common coarse roots; common charcoal, much of it at a depth of 10-15 cm; clear and smooth on:

A_3 13-24 cm: dark yellowish brown (10 YR 4/4), 75%, and yellowish brown (10 YR 5/6), 25%; medium-coarse sandy loam; weak fine-coarse subangular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; common very fine, many fine, many medium and few coarse roots; little charcoal; gradual on:

AB 24-41 cm: yellowish brown (10 YR 5/6); medium-coarse sandy clay loam; moderate fine-coarse subangular blocky; friable-firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; common very fine, common fine, few medium and few coarse roots; gradual on:

B_1 41-70 cm: strong brown (7.5 YR 5/6); medium-coarse sandy clay loam; moderate compound angular blocky; firm, plastic and sticky; many very fine, many fine, few medium and few coarse pores; few very fine, few fine, very few medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x2 cm; diffuse on:

B_{21} 70-105 cm: strong brown (7.5 YR 5/8); clay; moderate compound angular blocky; firm, plastic and sticky; many very fine, many fine, few medium and coarse pores; few very fine, few fine, very few medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x1 cm; few fine faint brownish yellow (10 YR 6/6) mottles; few fine distinct red (2.5 YR 5/8) mottles; diffuse on:

B_{22} 105-160 cm: strong brown-reddish yellow (7.5 YR 5/8-6/8); clay; moderate compound angular blocky; firm, plastic and sticky; many very fine, common fine, few medium and coarse pores; very few very fine, fine, medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular blocky, 1x1 cm; common fine faint red (2.5 YR 5/8) and brownish yellow (10 YR 6/6) mottles; few fine-medium distinct dark red (2.5 YR 3/6) soft nodules of rotten rock.

Profile K_6

GENERAL DATA

Mapping unit: B. 3.1. (SARO, 1968)
Area and location: Dreipade, 2 km NW
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 884.0 --- E: 377.2
Elevation: + 11 m NSP
Aerial photo no.: R 20 0 5058, 5059
Date of description: 7-6-1974
Described by: Van Vuure, Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: beginning of the long rainy season; in past 14 days before description rainfall exceeded evapotranspiration
Geomorphological unit: low-level terrace
Parent material: pleistocene river deposits
Physiography: plateau
Relief: subnormal
Slope: single, almost flat
Hydrology:
- a) soil drainage: moderately well drained
- b) groundwater table:
  - presumed highest: > 1.70 m below the soil surface
  - presumed lowest : > 1.70 m below the soil surface
  - actual : > 1.70 m below the soil surface
- c) flooding: never

Moistness: surface soil moist, subsoil moist
Biological activity:
- a) depth of undisturbed soil: > 1.70 m
- b) other features: many ants in surface soil

Land use: secondary forest > 100 years old; some trees of 1-2.5 m diameter at a height of 1.5 m present
Notes on soil samples: date of sampling: 22-5-1974.

DESCRIPTION OF SOIL HORIZONS

O_1+O_2 2-0 cm: organic material; between 0 and A_1 surface mat of mainly fine roots; abrupt and smooth on:

A_1 0-13 cm: dark brown (10 YR 4/3); sandy loam; very weak fine-medium subangular blocky; very friable, slightly plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; many very fine, many fine, many medium and common coarse roots; little charcoal, clear and smooth on:

A_3 13-49 cm: yellowish brown (10 YR 5/6); sandy clay loam; very weak fine-medium subangular - angular blocky; very friable, plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; many very fine, many fine, few medium and few coarse roots; few fine faint strong brown (7.5 YR 5/6) mottles; few charcoal; gradual on:

B_1 49-67 cm: strong brown (7.5 YR 5/6); sandy clay loam; very weak fine-medium angular blocky; very friable, plastic and slightly sticky; many very fine, common fine, few medium and few coarse pores; few very fine, fine, medium and coarse roots; few fine faint strong brown (7.5 YR 5/8) mottles; gradual on:

B_2 67-96 cm: strong brown (7.5 YR 5/6-5/8); sandy clay; very weak fine-medium angular blocky; very friable, plastic and sticky; many very fine, few fine, few medium and few coarse pores; very few very fine, fine, medium and coarse roots; few fine-medium distinct red (2.5 YR 5/8) mottles; gradual on:

B_3 96-140 cm: brownish yellow (10 YR 6/6); sandy clay; very weak fine-medium angular blocky; very friable, plastic and sticky; many very fine, few fine, few medium and few coarse pores; very few very fine, fine, medium and coarse roots; many coarse prominent red (2.5 YR 5/8) mottles; common quartz, fine medium and blocks (-10 cm diameter), angular and also rounded; abrupt on:

IIC 140-170 cm: yellow (10 YR 7/6); clay; sticky and plastic many coarse prominent light red (2.5 YR 6/6) and few medium faint white (10 YR 8/2) mottles; residual subsoil.

Profile K_7

GENERAL DATA

Mapping unit: B. 1.1.3. (MULDERS, 1973)
Area and location: Dreipade, 500 m NW
Coordinates: Topographical map of Surinam, scale 1:40.000 (1972)
sheet: 22d; N: 882.6 --- E: 377.0
Elevation: + 16 m NSP
Aerial photo no.: R 20 0 5058, 5059
Date of description: 15-5-1974
Described by: Ketelaars.

SOIL SITE CHARACTERISTICS

Weather: end of the short dry season; in past 14 days before description evapotranspiration exceeded rainfall
Geomorphological unit: medium-level terrace
Parent material: schist (residual)
Physiography: plateau
Relief: subnormal
Slope: single, almost flat
Hydrology:
- a) soil drainage: moderately well drained
- b) groundwater table:
  - presumed highest: > 1.60 m below the soil surface
  - presumed lowest : > 1.60 m below the soil surface
  - actual : > 1.60 m below the soil surface
- c) flooding: never

Moistness: surface soil moist, subsoil moist
Biological activity:
- a) depth of undisturbed soil: > 1.60 m
- b) other features: ants in surface soil

Land use: third year of fallow; vegetation dominated by Cassia multijuga, regenerating from last secondary wood (ca. 7 years old); height of vegetation: 5 m, but spots with only low herbs are also present: Rolandra fruticosa, Paspalum conjugatum, Panicum rudgei, a.o.
Notes on soil samples: date of sampling: 9-5-1974.

DESCRIPTION OF SOIL HORIZONS

O_1 2-0 cm: litter, locally distributed and mainly consisting of dead leaves of Cassia multijuga.

A_1 0-9 cm: dark brown (10 YR 3/3); medium-coarse sandy clay loam; weak fine-coarse subangular blocky; friable, slightly sticky and slightly plastic; many very fine, common fine, few medium and few coarse pores; many very fine, many fine, common medium and few coarse roots; common charcoal in few and nearly horizontal layers; clear and smooth on:

A_3 9-16 cm: dark brown (10 YR 4/3), 80% and yellowish brown (10 YR 5/4), 20%; medium-coarse sandy clay loam; weak fine-coarse subangular blocky; friable, slightly sticky and slightly plastic; many very fine, common fine, few medium and few coarse pores; many very fine, many fine, common medium and few coarse roots; little charcoal; clear and wavy on:

AB 16-37 cm: yellowish brown (10 YR 5/6); clay; moderate compound subangular-angular blocky; friable, sticky and plastic; many very fine, common fine, few medium and few coarse pores; many very fine and fine, few medium and coarse roots; little charcoal; clear and wavy, locally irregular (see note) on:

B_1 37-70 cm: strong brown (7.5 YR 5/8); clay; moderate compound angular blocky; friable-firm, sticky and plastic; many very fine and few fine, medium and coarse pores; common very fine and fine, very few medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular-angular blocky, 1x1 cm; gradual on:

B_{21} 70-110 cm: yellowish red (5 YR 5/); clay; moderate compound angular blocky; friable-firm, sticky and plastic; many very fine, few fine, medium and coarse pores; few very fine and fine, very few medium and coarse roots; clay cutans, thin and patchy; solid clay elements, few subangular-angular blocky, 1x1 cm; few fine distinct brownish yellow (10 YR 6/6) mottles; few fine distinct red (2.5 YR 4/8) and dark red (2.5 YR 3/6) soft nodules; diffuse on:

B_{22} 110-160 cm: yellowish red (5 YR 5/6); coarse sandy clay; moderate compound angular blocky; friable-firm sticky and plastic; many very fine and few fine, medium and coarse pores; few very fine and fine, very few medium and coarse roots; clay cutans, thin and patchy; solid clay elements with coarse sand incorporated, few angular blocky, 1x1 cm; common medium-coarse distinct, yellow (10 YR 7/8) and strong brown (7.5 YR 5/8), red (2.5 YR 4/8) and dark red (2.5 YR 3/6) soft nodules.

Note: boundary locally broken in soil pit; humus accumulation in tongues (root channels) up to a depth of 130 cm; in it also accumulation of fresh roots; many medium and common coarse pores.

6. PHYSICAL AND CHEMICAL SOIL PROPERTIES

6.1. TEXTURE

6.1.1. Results

Texture data are given in Table 1 for the profiles K_2, K_3, K_4 and K_6. Texture of K_1 is similar to that of K_4, texture of K_5 is similar to that of K_2 and the same applies to K_7 and K_3.

6.1.2. Discussion

As is illustrated by Table 1 there are important differences in texture between the sampled sites. Clay content varies strongly both in top soil and in subsoil and within the profile itself.

The influence of texture on other soil properties is extreme. For a better understanding of differences in organic carbon content, bulkdensity and CEC among others this influence must be analysed. For this purpose texture data as a function of depth are graphically intrapolated.

6.2. BULKDENSITY AND PORE SPACE

6.2.1. Results

In Table 2 data about bulkdensity and pore space in all profile pits are recorded. Figure 5 and Figure 6 show a diagram of the bulk-density profiles.

Pore space is calculated from the obtained bulkdensity values on the basis of a specific gravity of 2.65 g/cm^3 for the soil matrix.

Finally Table 3 contains information about bulkdensity and pore space obtained from the top soil samples.

6.2.2. Discussion

6.2.2.1. Bulkdensity and pore space in the top soil

From the data in Table 3 the effects of shifting cultivation on the pore space of the soil can be characterized as follows. Pore space in the layer from 0-10 cm of the heavy terrace soils amounts to 60-70% when under forest. Shifting cultivation causes a decrease of pore space to a minimum of 50%. Restoration of the previous more favourable pore space takes place within seven years in view of the values found for K_5.

The above mentioned figures apply to soils with rather heavy texture of the top soil (loam-clay loam-silty clay). In sandy soils bulk-density values are usually higher partly due to a lower organic matter content in it but probably also due to an effect of the texture itself. However the relationship between bulkdensity and texture and organic matter content can only be observed clearly within a homogeneous group of soils under natural vegetation. On account of this relationship the bulkdensity value in the upper 10 cm of K_6 appears to be relatively high and so pore space relatively low.

Table 1. The texture of the horizons of profile K_2, K_3, K_4 and K_6

profile	horizon	layer (cm)	clay (2 mu)	silt (2-53 mu)	sand (53 mu)
K_2	A_1	0-11	23.1	14.2	62.7
	A_3	11-21	28.2	13.4	58.4
	AB	21-39	43.7	13.4	42.9
	B_1	39-75	65.0	11.9	23.1
	B_{21}	75-110	66.6	13.1	20.3
	B_{22}	110-160	69.9	17.4	12.7
K_3	A_1	0-10	43.2	19.1	37.7
	A_3	10-21	48.0	23.0	29.0
	AB	21-40	69.9	16.2	13.9
	B_1	40-79	77.7	15.9	6.4
	B_2	79-160	64.6	23.7	11.7
K_4	A_1	0-12	33.3	10.5	56.2
	A_3	12-22	41.1	13.7	45.2
	AB	22-40	41.7	30.7	27.6
	B_1	40-65	68.2	13.8	18.0
	B_{21}	65-90	72.1	13.2	14.7
	B_{22}	90-140	70.0	16.4	13.6
	B_{23}	140-170	72.3	21.7	6.0
K_6	A_1	0-13	11.8	12.4	75.8
	A_3	13-49	18.5	11.5	70.0
	B_1	49-67	23.9	11.8	64.3
	B_2	67-96	38.3	13.8	47.9
	B_3	96-140	32.7	21.2	46.1
	IIC	140-170	30.0	38.8	31.2

Table 2. Bulkdensity and pore space as a function of depth; profiles K_1 up to K_7

depth (cm)	K_1		K_2		K_3		K_4		K_5		K_6		K_7	
	*)	**)												
0-2.5	97.5	64	109	59	79	69	89	67	85	68	96.5	64	97.5	64
1-3.5	105	61	99.5	63	91	66	100.5	63	99	63	108.5	60	114.5	57
2.5-5	115	57	116	57	93	65	115.5	57	108	60	124.5	54	118.5	56
3.5-6	117.5	56	124	54	100	63	120.5	55	127.5	52	123.5	54	123	54
5-7.5	118	56	127.5	52	102	62	126.5	53	133.5	50	129.5	52	125	53
6-8.5	118	56	132.5	50	107	60	124.5	54	137	49	140.5	47	131	51
7.5-10	116.5	57	135	50	120	55	127.5	52	137	49	147.5	45	134	50
10-12.5	124.5	54	133	50	124	54	130.5	51	144	46	151.5	43	135	50
17.5-20	137	49	150.5	44	136	49	133	50	150.5	44	162.5	39	142	47
25-27.5	145	46	154.5	42	141	47	145	46	153.5	43	163.5	39	146	45
32.5-35	150	44	153.5	43	136	49	147.5	45	157	41	164	39	148	45
45-47.5	146	45	146.5	45	130	51	136.5	49	144	46	160	40	137	49
57.5-60	143	47	144	46	128	52	133	50	147	45	154.5	42	130.5	51
70-72.5	141.5	47	142.5	47	134	50	137.5	49	147	45	152.5	43	131	51
87.5-90	145.5	46	146	45	136	49	134	50	138	48	154.5	42	131	51
105-107.5	143	47	149.5	44	138	48	145	46	139.5	48	160	40	139.5	52
125-127.5	144	46	144	46	136	49	143.5	46	139.5	48	167	37	146	52
147.5-150	139	48	141	47	137	49	143	47	143	47	157	41	144.5	54
170-172.5			141.5	47	137	49	138	48	138.5	48	158	41	146	55

*) bulkdensity: g/100 cm^3

**) pore space : %

Table 3. Bulkdensity in g/100 cm^3 (a) and pore space in % (b) for plots K_1 up to K_7; A_1 up to A_5 are data from 5 samples of 100 cm^3 each with a mean: $\bar{A}$; M comes from a compound sample of 5 cores of 100 cm^3 each; at the right in the table mesh bulkdensity and pore space figures are given for a depth of 0–10 cm; last figures are calculated from A_1 up to A_5 indicated as $\bar{A}_1$ and from A_1 up to A_5 plus M indicated as $\overline{(A+M)}$

depth (cm)	A_1		A_2		A_3		A_4		A_5		M		$\bar{A}$		$\bar{A}$ *)		$\overline{(A+M)}$ *)	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
K_1 0–5	107	60	105	61	108	60	107	60	102	62	108	60	106	60	114	57	112	58
5–10	126	53	120	55	123	54	122	54	118	56	113	58	122	54				
K_2 0–5	129	52	126	53	122	54	123	54	122	54	132	51	124	54	131	51	134	50
5–10	137	49	137	49	140	48	133	50	137	49	144	46	137	49				
K_5 0–5	72	73	76	72	81	70	91	66	101	62			84	69	98	64		
5–10	108	60	89	67	105	61	128	52	123	54			111	59				
K_4 0–5	90	67	82	70	78	71	100	63	76	72			85	68	98	64		
5–10	100	63	117	56	118	56	108	60	106	60			110	59				
K_3 0–5	102	62	89	67	99	63	95	65	103	62			98	64	106	60		
5–10	105	61	116	57	114	57	117	56	116	57			114	57				
K_7 0–5	116	57	96	64	99	63	96	64	87	68			99	63	114	57		
5–10	124	54	127	53	131	51	128	52	129	52			128	52				
K_6 0–5	105	61	128	52	92	66	94	65	115	57			107	60	117	56		
5–10	136	49	134	50	102	62	133	50	124	54			126	53				

*) 0–10 cm

The structure of the top soil under forest is very loose. Towards the soil surface pore space increases to 70% or even more. Besides numberless micro pores there are also many meso pores and macro pores in the upper centimetres. The root mat which develops between litter-layer and mineral soil attributes to a spongy structure. The infiltration capacity and rate for rain water are high and during heavy rainfall much water can be stored temporarily in the top soil. Since there is a continuous production of vegetative material animal activity will never stop and will help maintain this favourable soil constitution.

After burning the soil lies unprotected against rainfall. Especially the surface layer is very fragile. Plot K_2, used again for shifting cultivation after seven years fallow had to be cleared of weeds before rice was sown rather lately. Only a slight soil tillage with a hoe was needed for this weeding but it had striking consequences which could be observed after a few rain showers: the soil surface was silting up rapidly resulting in run-off and probably loss of ash.

A minor disturbance of the soil surface gives rise readily to a process of soil degradation under the prevailing climatological conditions. Compaction of the top soil decreases pore space with 10-20% (Table 3). This decrease itself means already a loss of water storing capacity of 10-20 mm rainfall. But compaction decreases mainly the number of macro pores. Now macro pores determine largely the infiltration capacity. This is illustrated by data from VAN DER WEERT & LENSELINK (1972). They compared the permeability of compacted and non-compacted sandy loam and observed changes of pore size distribution.

Table 4 shows a total loss of macro pores by compaction accompanied with a decrease in pore space from 49 to 33% and a strong decrease of the water permeability. Thus soil compaction will increase run-off and so the danger of erosion. Subsequently effective rainfall, i.e. the proportion that can be used by crops will decrease.

Table 4. Pore size distribution and permeability of compacted and non-compacted soil samples (from VAN DER WEERT & LENSELINK, 1972)

	micro pores	meso pores (volume %)	macro pores	K*
non compacted	25.6	12.6	11.2	8.7
compacted	24.6	8.3	0.0	0.4

* K = permeability expressed as meters/day; data are mean values of nine cores.

However in normal shifting cultivation practices changes in soil structure are limited by the absence of soil tillage, the rapid development of a protective ground cover of crops and wild plants and the fact there is only one cropping season. This is illustrated by observations from plot K_1. Here soil tillage was restricted to making plant holes and covering seed. Silting up of the soil surface did not take place and compaction was limited.

If the same soils are cleared mechanically the loss of a good surface structure is inevitable. Though serious compaction probably may be prevented by scheduling clearing operations accurately to rainfall and soil type, pore space in the top soil will always decrease. LENSELINK & PARSAN (1970) measured bulkdensity and pore space in a terrace soil under a young citrus plantation at Baboenhol. The soil was covered by kudzu for several years. Texture varied between sand and sandy clay loam. Pore space in the upper 10 cm varied mainly between 40 and 43%. Data from VAN DER WEERT & LENSELINK (1973) show that pore space may be somewhat larger in soils with a clayey texture.

However local variations of pore space are high as a result of differences of moisture percentage during clearing and differences of pressure put on the soil. Thus the soil near windrows is less compacted than between them.

6.2.2.2. The bulkdensity profile

Considering bulkdensity versus depth (Figures 5 & 6) it is notable that all profiles show a similar picture. From the surface to a depth of about 30 cm pore space decreases strongly where as below this depth pore space increases slowly. From a depth of 60-70 cm a decrease of pore space can be observed again.

From these data one would think the top soil has been compacted to a certain depth. However it seems unlikely shifting cultivation can cause such a compaction. If it could cause compaction one should conclude the compaction is unrestorable because profile K6 (under forest for over 100 years) shows the same picture. It is interesting that other investigators also have found a compacted layer in mechanically cleared terrace soils at the same depth. They attributed this phenomenon to the clearing with heavy machinery. In Table 5 some data from a young oil-palm plantation with a kudzu ground cover are presented. Irrespective of soil type all profiles show a minimum pore space between 20 and 30 cm. Although it is reasonable to assume an important influence of mechanical clearing on the bulkdensity profile special profile characters may explain the shape of the bulkdensity profile under shifting cultivation as the original shape.

Studying bulkdensity and pore space in relation to other profile data some factors appear to be important, viz. organic carbon content, texture and use or use history. Since these factors are mutually dependent variants it is very difficult to establish the contribution of each factor apart in a certain case. However an explanation of the present bulkdensity profiles may be the following.

For the strong decrease of pore space in the upper 25 cm the nearly exponential decrease in organic matter content may be responsible. This is illustrated by Figure 8 and by many data from the literature which sometimes gives a very good correlation between both factors if profiles under natural vegetation are studied (see for instance CURTIS & POST, 1964).

Between 25 cm and 70 cm pore space increases slowly. Just between these depths texture data show a strong rise in clay content. Thus the increase of pore space below 25 cm may be a result of an increasing clay content. However clear evidence for this causal relationship lacks in this study because the influence of texture could not be analysed independently from the influence of organic matter content.

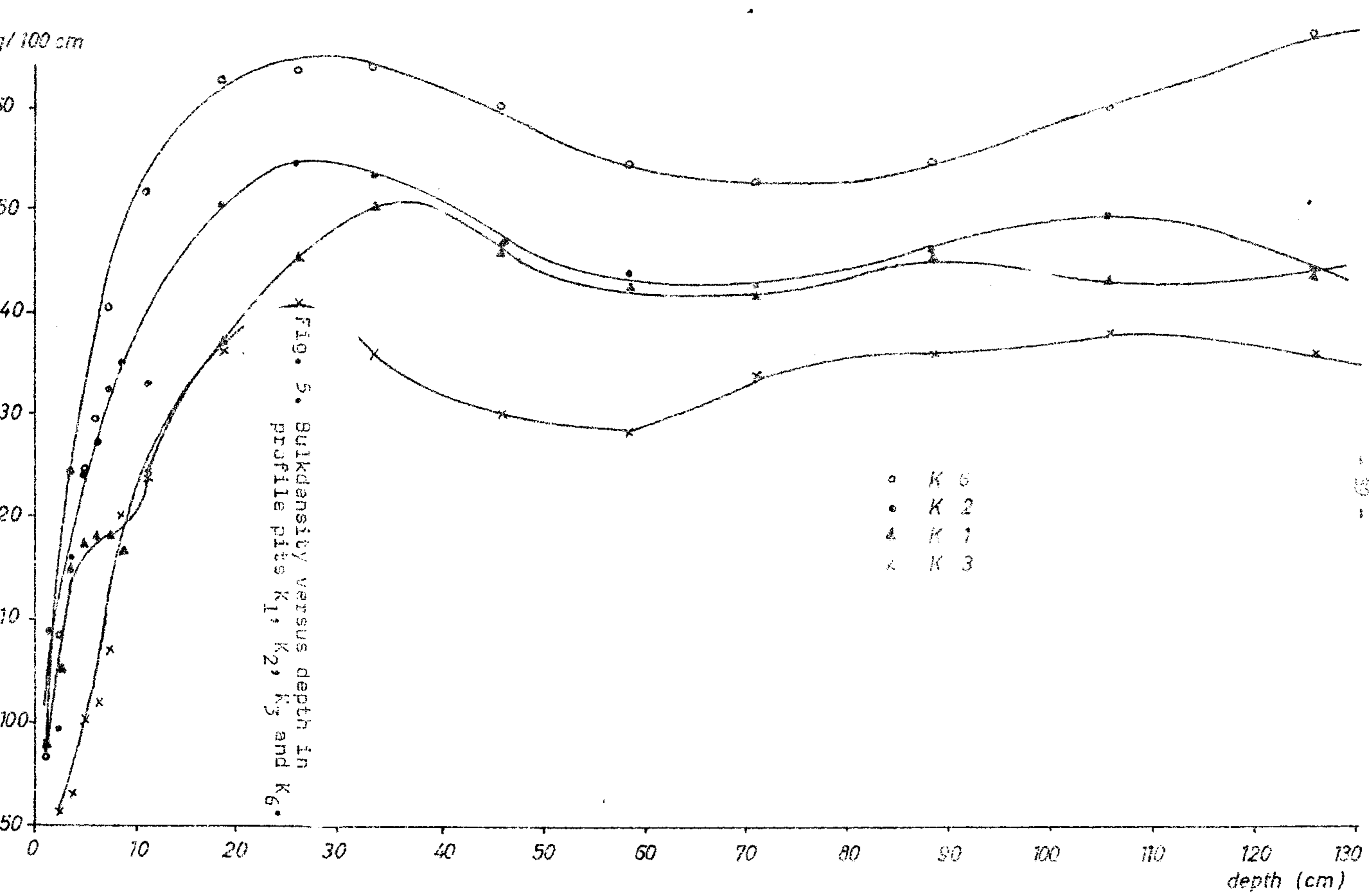


Fig. 5. Bulkdensity versus depth in profile pits K_1, K_2, K_3 and K_6.

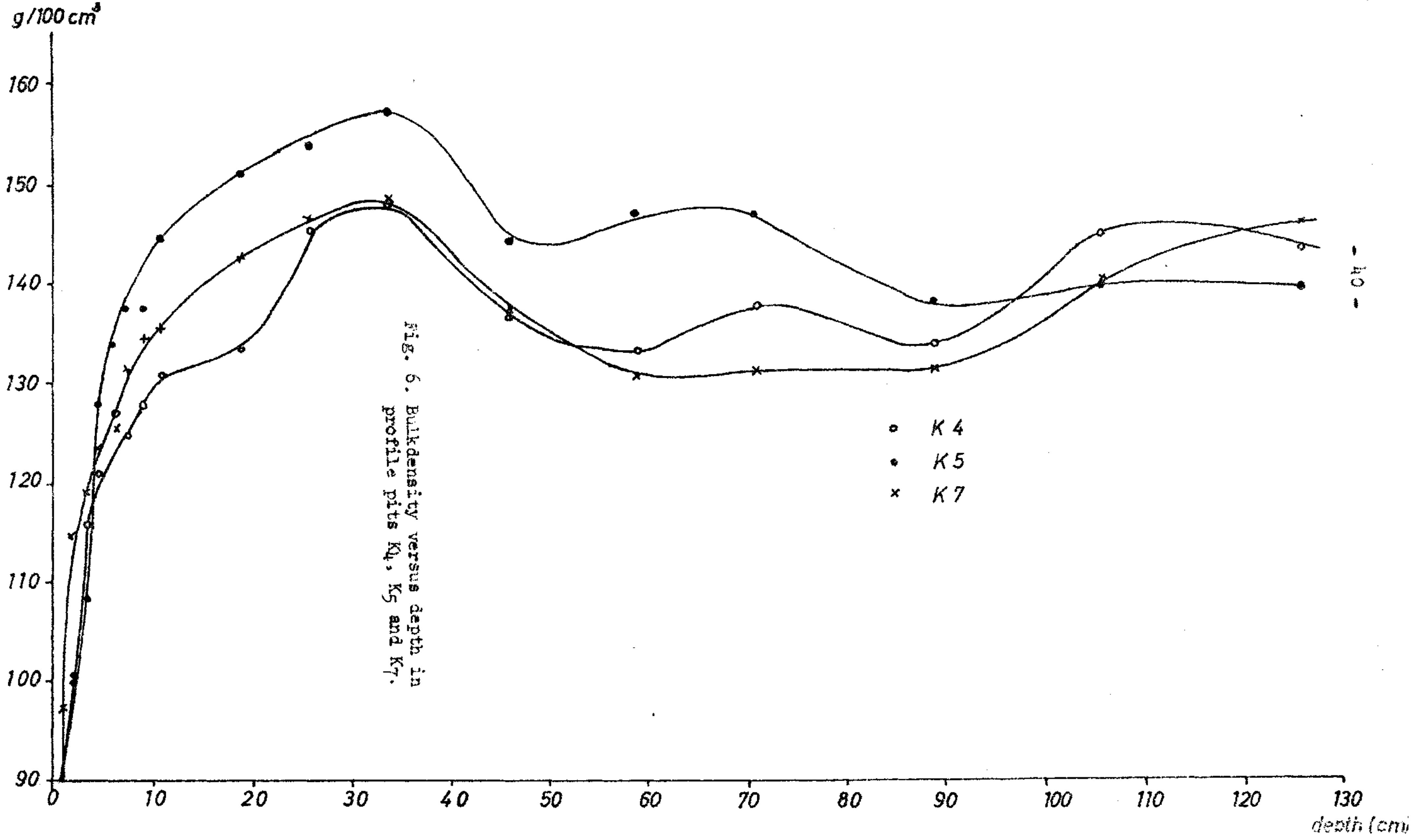


Fig. 6. Bulkdensity versus depth in profile pits K_4, K_5 and K_7.

Table 5. Bulkdensity and pore space of soils under a young oilpalm plantation at Victoria (from JANSSEN, 1973)

soil type	depth (cm)	bulkdensity ($g/100\ cm^3$)	pore space (%)
heavy terrace soil	5-10	142	46.4
	25-30	154	41.8
	60-65	145	45.3
light terrace soil	4-9	152	42.6
	25-30	160	39.6
	70-75	152	42.6
light terrace soil	3-8	149	43.8
	20-25	170	35.8
	30-35	148	44.2
	70-75	159	40.0
heavy basin soil	5-10	132	50.2
	20-25	141	46.8
	60-65	134	49.4

Below 70 cm texture does not change much and probably a decreasing organic matter content may bring about a decreasing pore space again.

So the shape of the bulkdensity profile in the soil under shifting cultivation may be explained by a characteristic texture profile and the organic carbon profile. With this explanation the question about the total influence of mechanical clearing on the terrace soils still goes unanswered. A compaction of the top soil has already been discussed. But it seems likely the influence of mechanical clearing extends to a greater depth. In sandy to sandy loamy soils of the Zanderij-formation VAN DER WEERT & LENSELINK (1972) found a maximal compaction between 10 and 20 cm but the total influence extended to 70 cm at least.

The fact that in terrace soils a "compacted" layer between 25 and 35 cm already appears to be present under natural conditions emphasizes the importance of taking care of optimum soil and weather conditions during mechanical clearing. The presence of a sandy or loamy top soil on a clayey subsoil is a very common feature of terrace soils. Since loamy soil material is compacted more easily than clay in this case compaction by heavy machinery will maybe be concentrated for a greater part in the top soil where pore space already shows a minimum.

Finally Figure 7 from VAN DER WEERT & LENSELINK (1972) may illustrate the fragile character of the terrace soils as a habitat for crops. The authors studied bulkdensity and root intensity of a terrace soil in the experimental citrus garden at Baboenhol. The bulkdensity

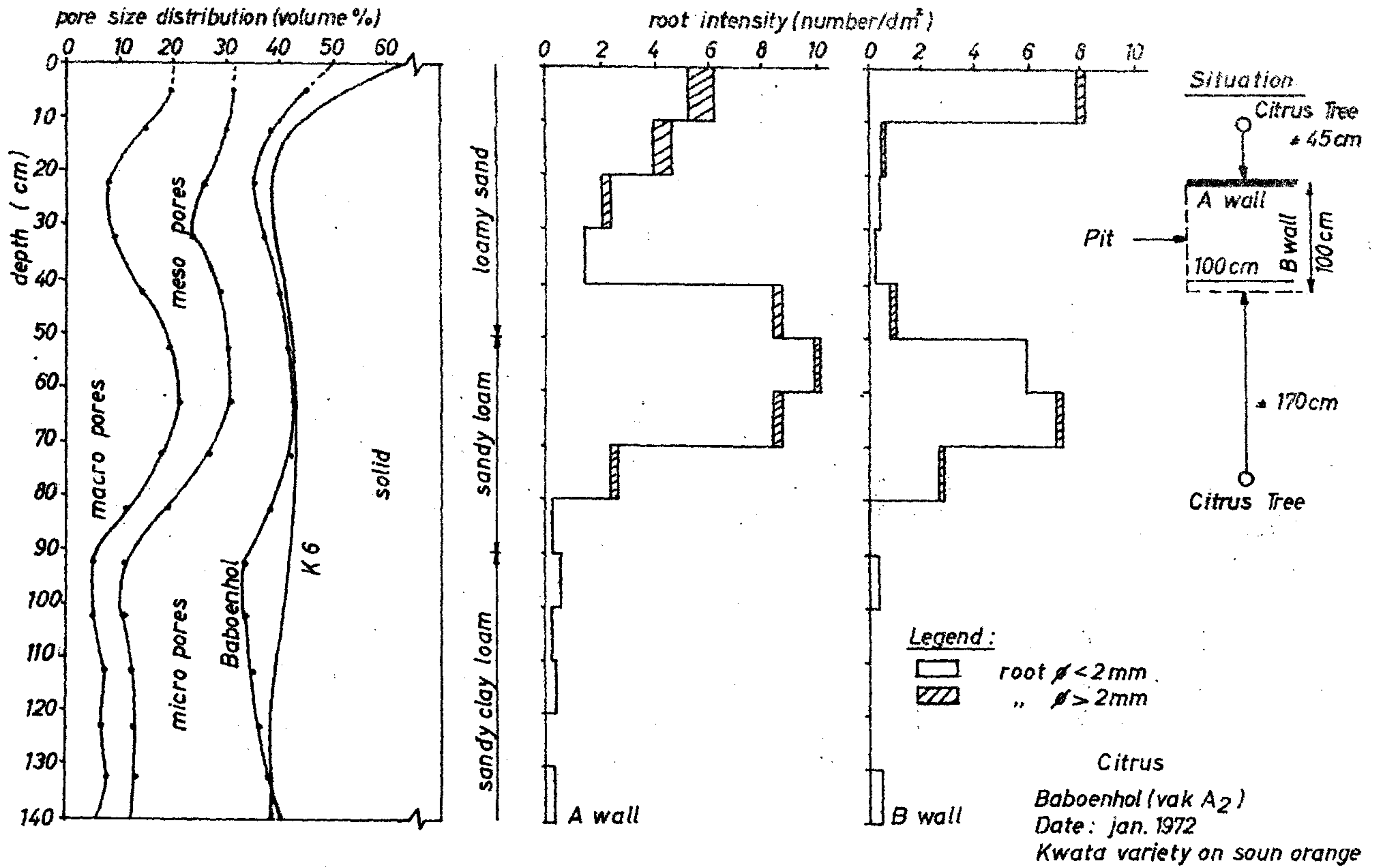


Fig. 7. Pore size distribution (points are averages of 4 core samples of appr. 400 cm^3 each) and root distribution of a citrus tree at Baboenhol compared with pore space of profile K_6.

profile is compared with that of profile K_6. Texture of both profiles are very similar. It can be seen that the rootability of the mechanical cleared soil for citrus is limited strongly by compact soil layers between 10 and 40 cm and below 80 cm.

The authors give following critical values for rootability: a pore space of 45% (bulkdensity circa 148 g/100 cm^3) will impede rooting a pore space of 34% (bulkdensity circa 175 g/100 cm^3) will make rooting impossible. These values apply to soils with a sandy texture, in clay soils they may be somewhat lower. Comparing these critical values with the minimum pore space between 25 and 35 cm in the profiles under shifting cultivation (in loamy top soils 41-47 volume %; in a sandy top soil (K_6) 39%) the fragile character of these soils becomes obvious. Only a slight compaction will reduce rooting possibilities for crops seriously.

6.2.3. Conclusions

The effects of shifting cultivation on the physical properties of the soil can be characterized as follows. Pore space for the first 10 cm of the heavy terrace soils was found to be 60-70% when under forest, decreasing to 50-60% when used for shifting cultivation; the pore space is restored within 7 years.

The bulkdensity profiles showed a typical shape. In the upper 25 cm bulkdensity increased strongly whereas from 25 to 70 cm it decreased slightly. Below 70 cm bulkdensity increased again. Thus the soil profiles showed a minimum pore space between 25 and 35 cm; for heavy terrace soils this minimum lay between 41 and 47%, for light ones below 40%.

The typical shape of the bulkdensity profiles might be explained by an exponential decrease of the organic matter content with depth and a strong increase in clay content between 25 and 70 cm.

The compact layer in the top soil may impede root growth of crops in shifting cultivation but certainly it will after further compaction as a result of mechanical clearing.

6.3. ORGANIC CARBON

6.3.1. Results

The organic carbon contents as a function of depth are plotted on double logarithmic paper according to the method proposed by BENNEMA (1973). The same is done with data on total nitrogen, CEC, potassium, calcium and phosphate. Some peculiarities and problems of the plotting of profiles on double logarithmic paper are discussed below.

The organic carbon contents of the top soil samples are presented in Table 6. From these data total amounts per hectare in the upper 10 cm are calculated.

Table 6. Organic carbon in the top soil; see Table 3 for code explanation

depth (cm)		A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$	$\bar{A}'$	$\overline{(A+M)}$
K_1	0-5	2.92*	2.90	3.00	3.19	3.45	3.19	3.09	27**	27
	5-10	2.23	2.51	2.14	2.17	2.62	2.19	2.33		
K_2	0-5	2.60	2.89	2.47	2.59	2.33	3.07	2.58	23	25
	5-10	2.01	2.00	1.85	1.93	1.91	2.40	1.94		
K_5	0-5	2.91	2.68	2.33	2.46	2.56		2.59	23	
	5-10	(4.42)	1.93	1.85	2.00	2.02		1.95		
K_4	0-5	3.09	2.59	(4.99)	2.67	2.71		2.77	25	
	5-10	2.06	2.12	2.55	1.92	(3.45)		2.16		
K_3	0-5	3.58	3.57	3.48	3.24	3.47		3.47	31	
	5-10	2.78	2.84	2.63	2.81	2.81		2.77		
K_7	0-5	2.52	2.79	3.15	2.65	2.77		2.78	25	
	5-10	1.91	2.17	2.47	1.91	(3.27)		2.12		
K_6	0-5	2.26	2.13	2.90	2.28	2.70		2.45	21	
	5-10	1.65	1.44	2.12	1.71	1.87		1.75		

*) organic carbon content in $g/100\ cm^3$

**) amount in kg/ha

6.3.2. Discussion

In the introduction the cycle of organic matter in the ecosystem of the tropical rain forest is briefly discussed. The organic matter in the soil forms an important element of this cycle. In ferrallitic soils it plays a major role in the nutrition of the vegetation and also of crops if the land is used for agriculture.

It can store plant nutrients partly incorporated in the organic compounds and partly adsorbed in exchangeable form to the organic matter. This property is more important in ferrallitic soils as these soils have practically no mineral reserves of plant nutrients; besides the mineral part of the soil has a low storage capacity (CEC) for K, Ca and Mg (see 6.5) and often a high fixing power for phosphorus. Furthermore organic matter determines to some degree the water storage capacity and the structure stability of the soil. Finally organic matter has a strong influence on pore space and so on rooting possibilities as is clear from 6.2.

In view of the foregoing special attention should be paid to the amounts of organic matter in ferrallitic soils under different conditions.

A first look at the data in Table 6 shows that organic carbon content in the top soil of all plots is low. The percentage of organic carbon in the top soil under evergreen rain forest is often between 2 and 4% (BENNEMA, 1973) which corresponds with 40 to 80 g C per dm^2 to a depth of 20 cm. Data from Table 6 show that in the terrace soils the carbon content often drops below 2% within the upper 10 cm. Using data from the profile pits an amount varying between 30 and 50 g C per dm^2 in the upper 20 cm can be calculated. Maybe these low values are characteristic for the prevailing environmental conditions with regard to humus building and decomposition, but it may also be due in whole or in part to the method of analysis and calculation (see 2.2).

Table 6 also shows that local variations in carbon content through the top soil are an important factor when interpreting single data from profile pits. Differences in carbon content between the various plots will be discussed further on.

Plotting of the carbon content as a function of depth on double logarithmic paper the carbon profiles show a straight line between certain depths, see Fig. 9-15. The equation of this line can be written as: $\log c = \log a + b \log p$ or $c = ap^b$ in which a and b are constants and p is the soil depth. The function is valid between some centimetres from the soil surface (3-10 cm) up to 90-170 cm, depending on the profile.

Although other functions can be used to describe the relation of the carbon content with depth the logarithmic function has the adventage that it can be visualized on logarithmic paper. However to be able to use the formula $c = ap^b$ some problems have to be solved.

Concerning depth in the formula a correction (indicated as p_o) is needed equal to the depth at which the carbon content reaches its maximum. If the carbon content would be expressed as a percentage of the mineral soil the correction for depth could be found at p = 50%. But in this study the carbon content is expressed as weight per volume because this expression has the advantage that real quantities (e.g. per ha in a certain soil layer) can be calculated, added up or subtracted. Adding up is used if the equation $c = ap^b$ between depth p1 and p2 is integrated to know the organic matter content of this layer.

The maximum carbon content as weight per volume can not directly be derived from the carbon contents of the collected samples, but STEWART e.a. (1970) proposed a method to calculate the value from the relation between bulkdensity and organic carbon content. According to data he collected there would be a linear relationship between the volume of mineral components and the volume of organic components taken from samples with a constant bulk volume. Extrapolating this linear relationship to zero volume of the mineral components he found an amount of 25 g organic matter per 100 cm^3.
He called this value the self-packing density of organic matter which is identical to the maximum organic matter content.

Plotting of the carbon contents and bulkdensity data of the upper 35 cm of all profiles in the way STEWART e.a. proposed an approximately linear relationship can be established within the range of the obtained values (Fig. 8). The relationship is certainly obscured by many interfering factors as differences in texture, land use and use history. To find the self-packing density of organic matter the line has to be extrapolated with the large risk of making great errors. Extrapolating would furnish a value of 11 g organic matter (= 5.5 g organic carbon) per 100 cm^3. This value appears to be rather low in comparison with the values found by STEWART e.a. and some other investigators. From the regression function between bulkdensity and organic carbon content which CURTIS & POST (1964) give for Vermont forest soils a value of 16 g organic matter/100 cm^3 can be calculated. Using data from VAN WISSEN (1974) who studied carbon profiles under grassland and agriculture in Kenya a value of 20 g organic matter is found. Finally data from SANCHIT (1974) who studied carbon profiles under virgin forest in Surinam indicate for some profiles rather low values of about 16 and for other profiles rather high values of about 40 g organic matter per 100 cm^3.

Though a self-packing density of 11 g organic matter per 100 cm^3 seems to be rather low and its calculation being a disputable point it is applied in constructing the carbon profiles because it appeared to fit the data very well.

Now the correction for depth (p_o) can be found as follows. As stated by BENNEMA (1973) a correction for depth will practically not effect the log values of depth for the deeper layers, because a small interval in log values represents already a considerable interval in depth. So a first approximation of the line which represents the function of carbon content with depth can therefore be based on the samples deeper in the profile. Thus using profile K6 as an example it appears that carbon expressed as weight per volume can be described as:

$$c = 17\ p^{-1.00}$$

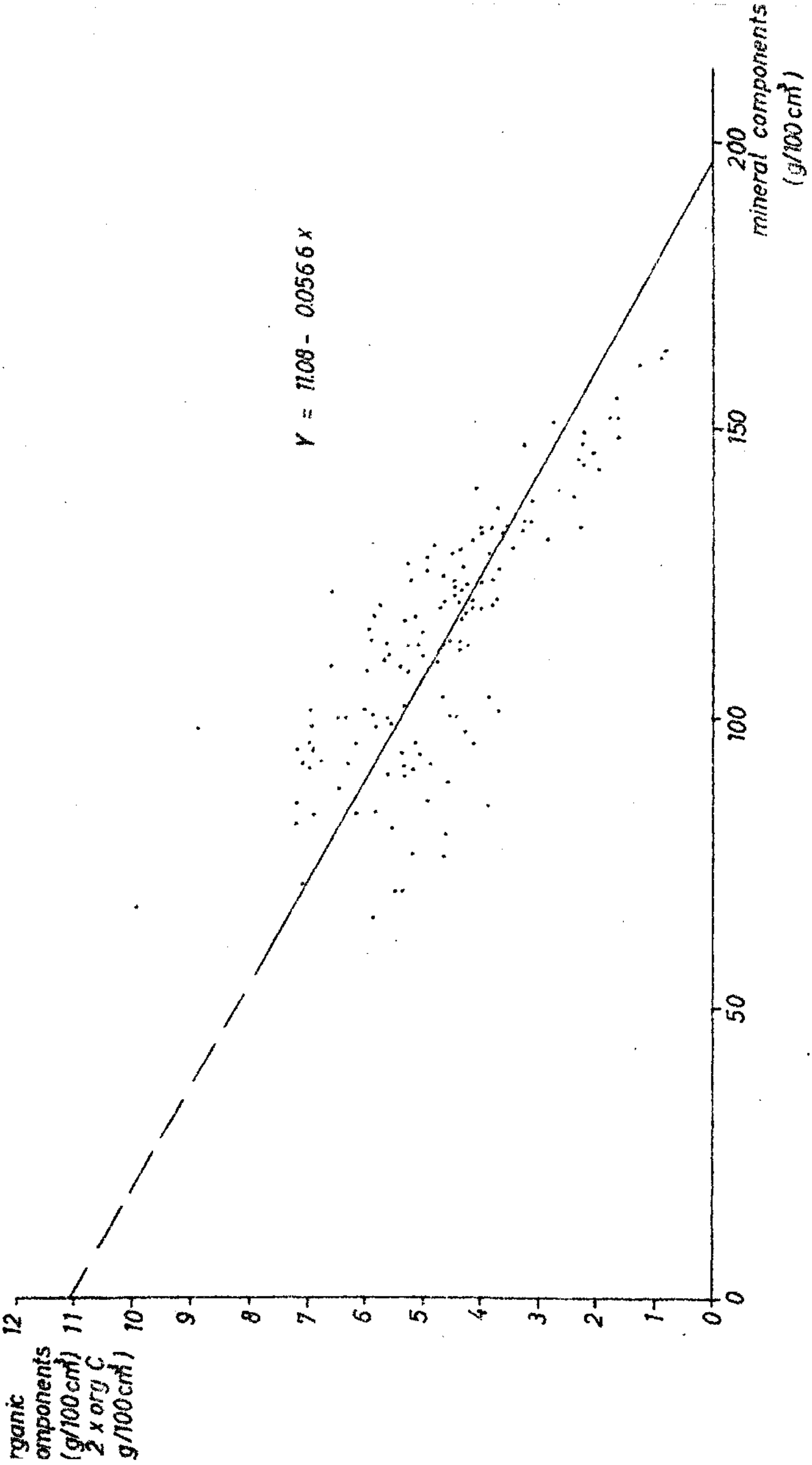
The correction for depth is then:

$$5.5 = 17\ p^{-1.00}$$
$$p_o = 3.0 \text{ cm}$$

Because the corrections for depths are rather large sometimes the calculations have to be repeated on base of the corrected data.

Another difficulty is met in plotting the carbon content. The data are mean contents of layers. It is however not exactly known at what depth this mean carbon content occurs. This unknown depth, which is called the representative depth is the depth at which the sample should be plotted. Especially in the upper centimetres which have a

Fig. 8. Relation weight of organic components and weight of mineral components in samples of 100 cm³; only data from the upper 35 cm of the soil are plotted.



strong increase of the carbon content to the surface this representative depth will differ from the mean depth. The representative depth then can be calculated as follows (cf. BENNEMA, 1973):

$$ap^{b}_{repr.} = \frac{\int_{p1}^{p2} ap^{b}\,dp}{p2 - p1} \qquad \text{or}$$

if b = -1 $$p_{repr.} = \left\{\frac{p2^{(b+1)} - p1^{(b+1)}}{(b+1)\ (p2 - p1)}\right\}^{1/b}$$

and in the case b = -1 $$p_{repr.} = \frac{p2 - p1}{\ln p2 - \ln p1}$$

The representative depth has been calculated for the samples from the upper 5 centimetres. Below this depth this difference between representative depth and mean depth is negligible.

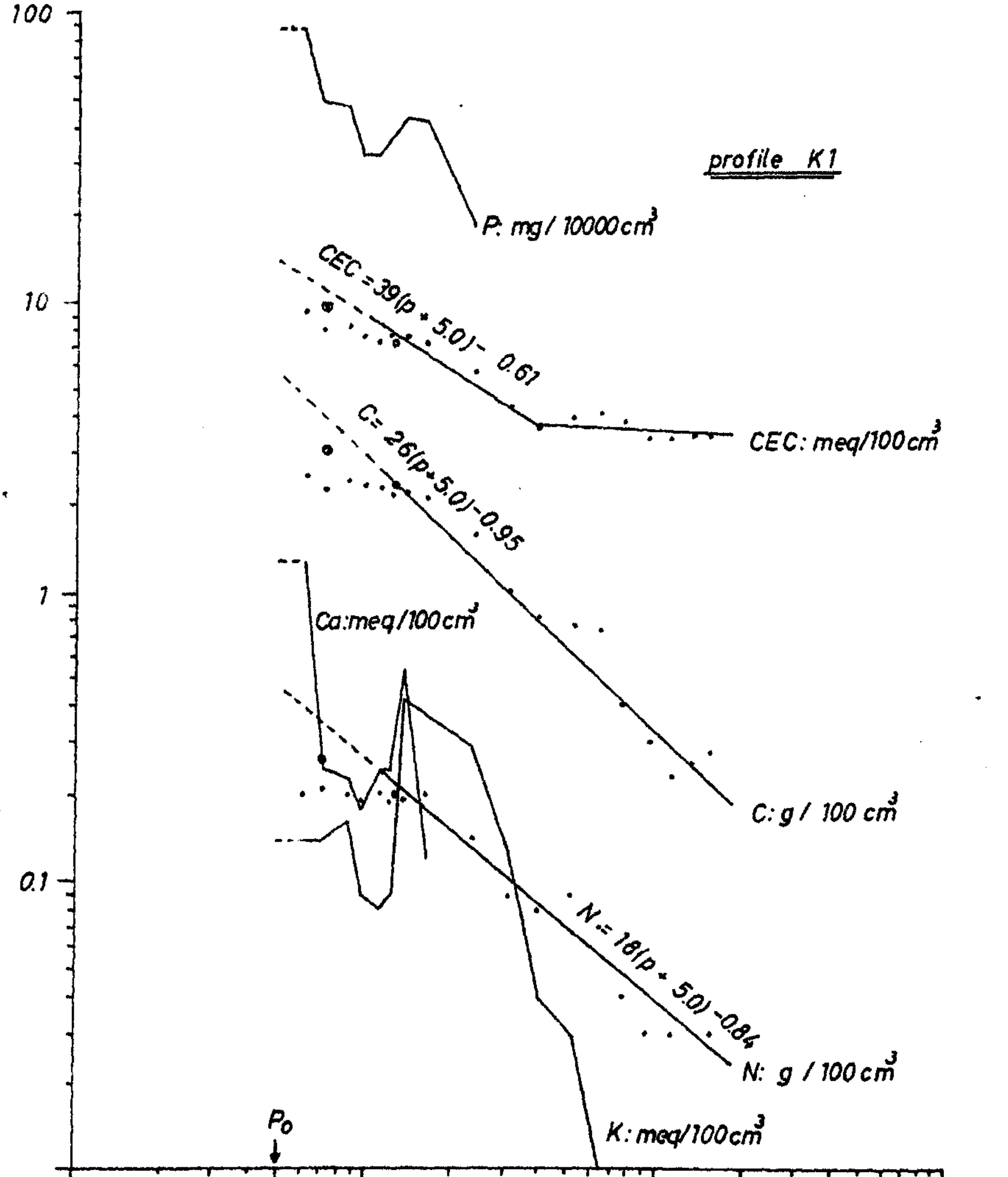
After having calculated the correction for depth and the representative depth of the surface soil samples the fitting of the formula $c = ap^b$ to carbon data can be studied from the graphs on double logarithmic paper.

Concerning the carbon profile of K_6 which may be nearly equal to the carbon profile under virgin forest the equation $c = (p+3.0)^{-1.00}$ appears to describe the function of carbon content versus depth fairly well. Only in the upper 3 cm the real carbon content is lower than the formula indicates. Below this depth the equation is valid up to 170 cm at least, although the values of some deeper samples are somewhat divergent probably due to random variation of small samples. Other profiles show similar deviations between 90 and 170 cm probably also corresponding to a certain depth of the solum.

The carbon profile of K_6 is comparable with the carbon profiles of oxisols under virgin forest regarded by BENNEMA (1973) as the modal ones. It is also similar to some carbon profiles of residual ferrallitic soils under forest in Surinam (Patamaka region and Tibiti region) studied by SANCHIT (1974). The carbon contents of these profiles are plotted in Fig. 16 in a somewhat modified way. Since the corrections for depth could not be calculated they are estimated from the values of the deeper samples. As shown by Fig. 16 a p_o equal to 2 cm fits the carbon data of profile PAT A16 and PAT B21 very well, and a p_o equal to 1.5 cm for profile TIK 11. Some other carbon profiles from the same regions also studied by SANCHIT show a different shape but the data are partly unreliable due to analysis errors. From the profiles in Fig. 16 the difference in maximum carbon content at p = 0 is notable. Because a systematic deviation due to different laboratory methods is excluded in this case the carbon content at p = 0 seems to vary largely with local soil conditions. In this respect it might be of special ecological interest to study differences of this value but it is very difficult to obtain comparable data.

Apart from K_6 all other profiles of this study are used more or less recently for shifting cultivation. So it is to be expected that these profiles are lower in carbon content, at least in the top soil. Therefore the carbon profile will differ from the original one under virgin or old secondary forest which shows a straight line on double logarithmic paper from some centimetres below the soil surface to 90-170 cm depth. Now a particular advantage of the carbon profile is that it can be used very well to determine changes in organic carbon

Fig. 9. Profile K_1; C, N, CEC, P-Bray I, and exchangeable K and Ca as a function of depth; . samples from profile pits, o mean values of samples A_1 (0-5 cm) and A_2 (5-10 cm).



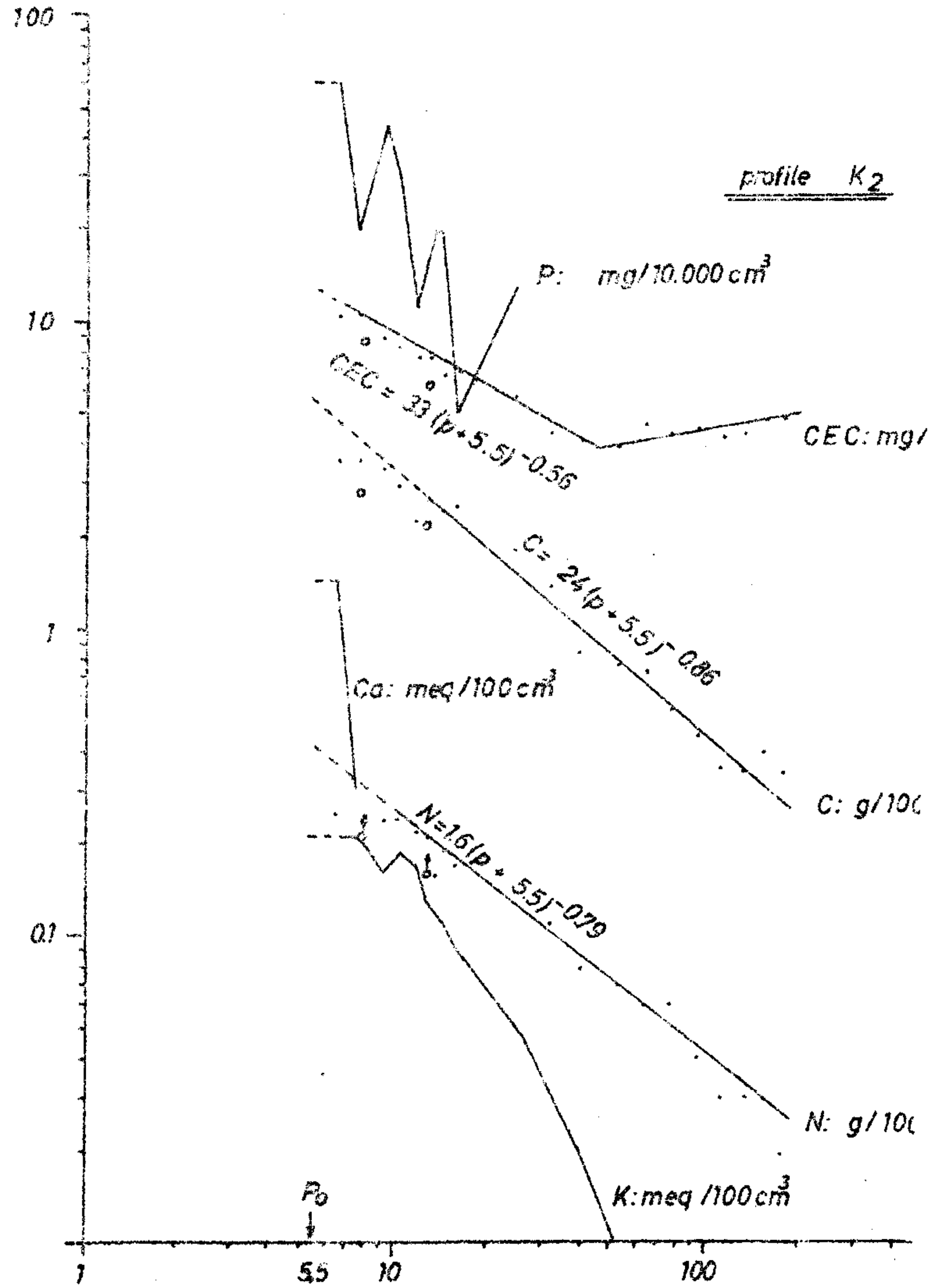


Fig. 10. Profile K_2; C, N, CEC, P-Bray I, and exchangeable K and function of depth; . samples from profile pits, o mean of samples A_1 (0-5 cm) and A_2 (5-10 cm).

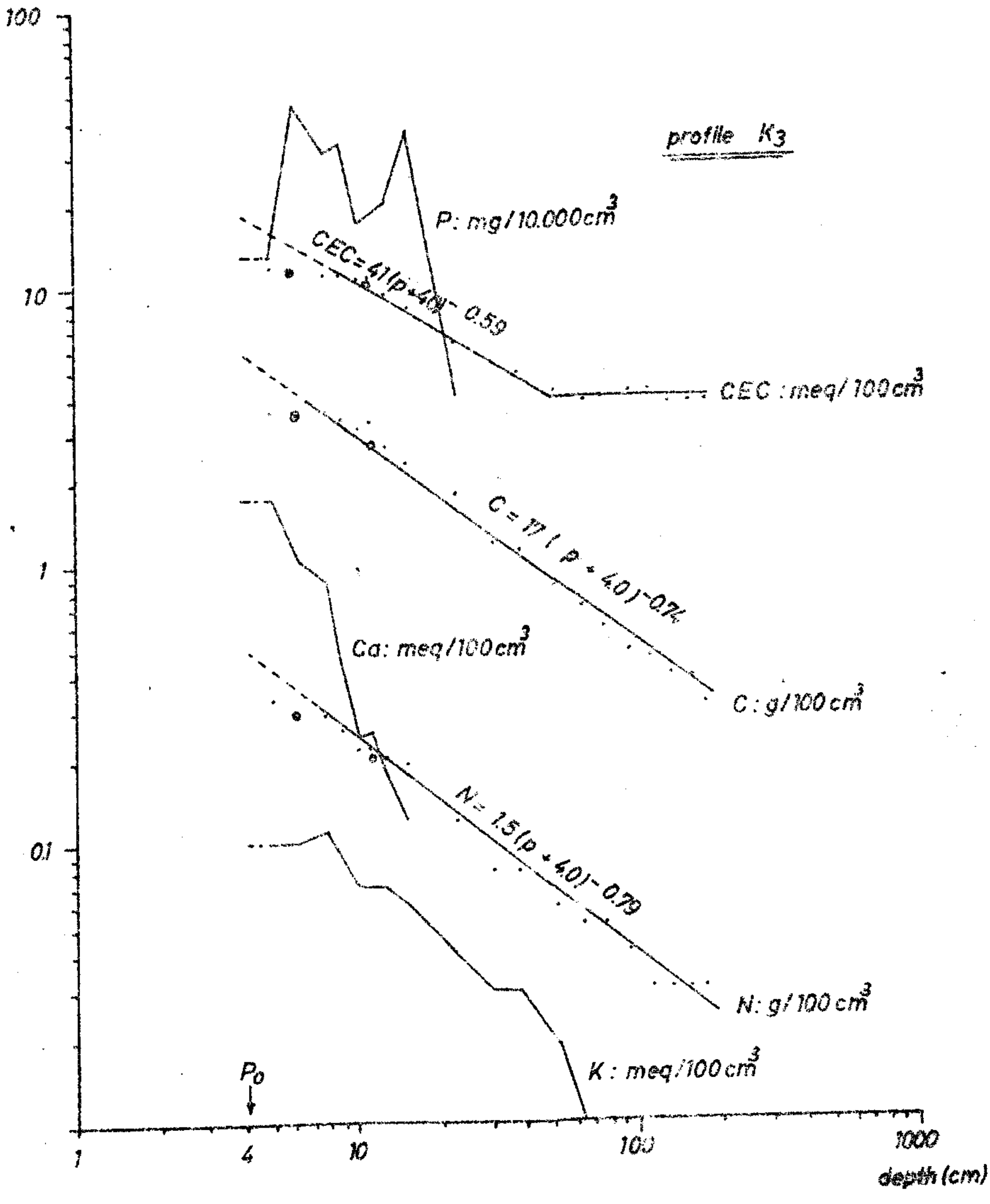


Fig. 11. Profile K_3; C, N, CEC, P-Bray I, and exchangeable K and Ca as a function of depth; . samples from profile pits, o mean values of samples A_1 (0-5 cm) and A_2 (5-10).

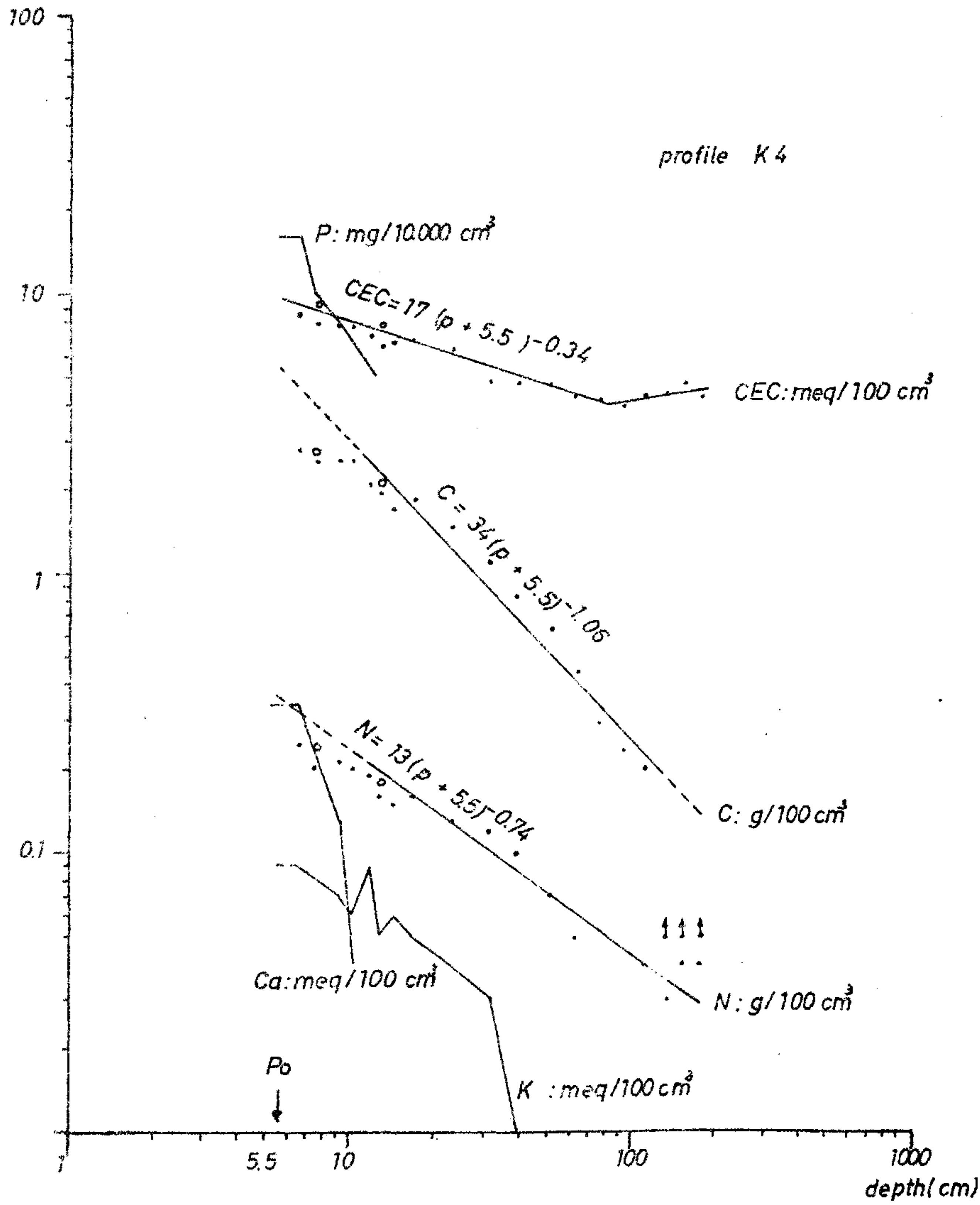


Fig. 12. Profile K_4; C, N, CEC, P-Bray I, and exchangeable K and Ca as a function of depth; . samples from profile pits, o mean values of samples A_1 (0-5 cm) and A_2 (5-10 cm).

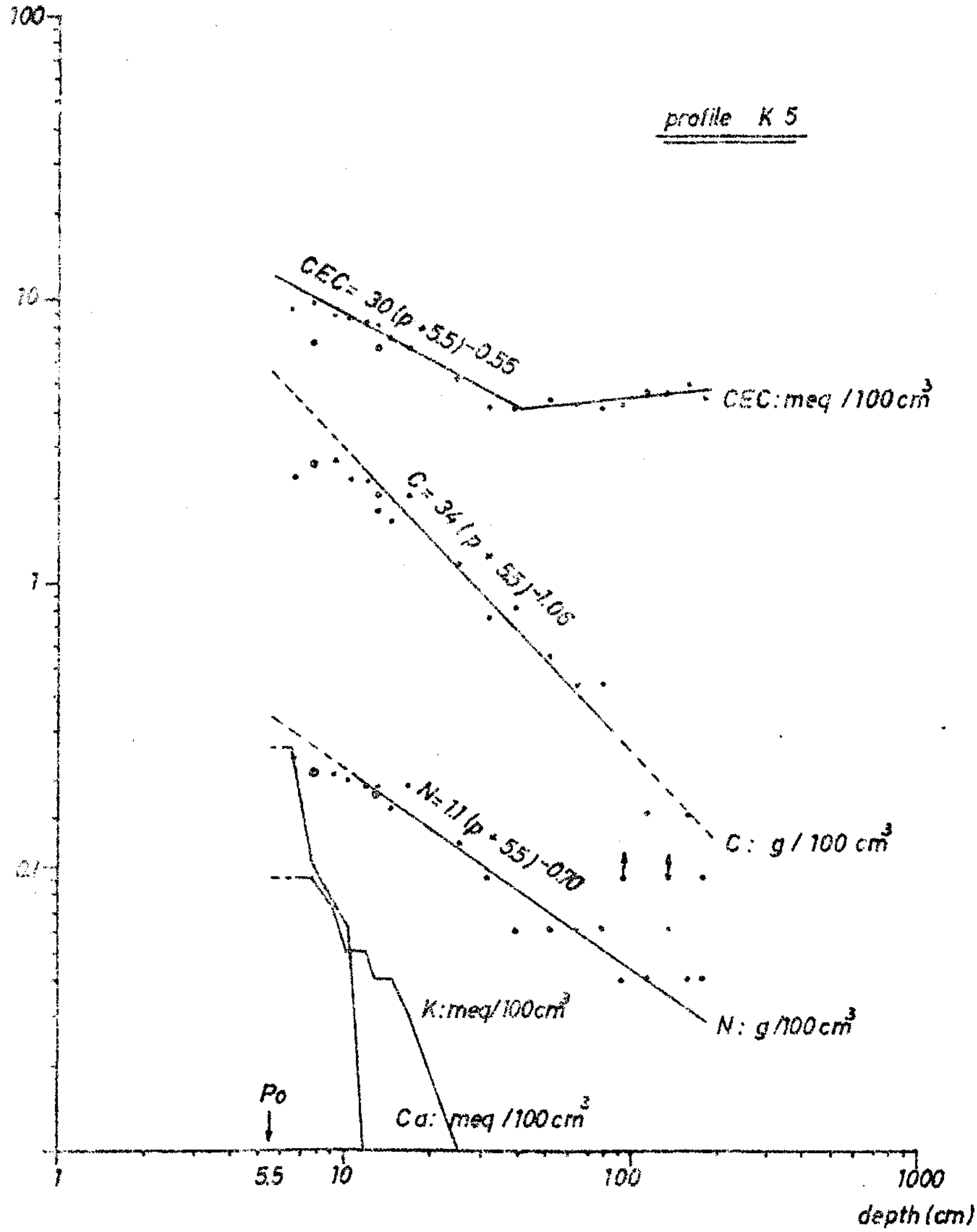


Fig. 13. Profile K_5; C, N, CEC, and exchangeable K and Ca as a function of depth; . samples from profile pits, o mean values of samples A_1 (0-5 cm) and A_2 (5-10 cm).

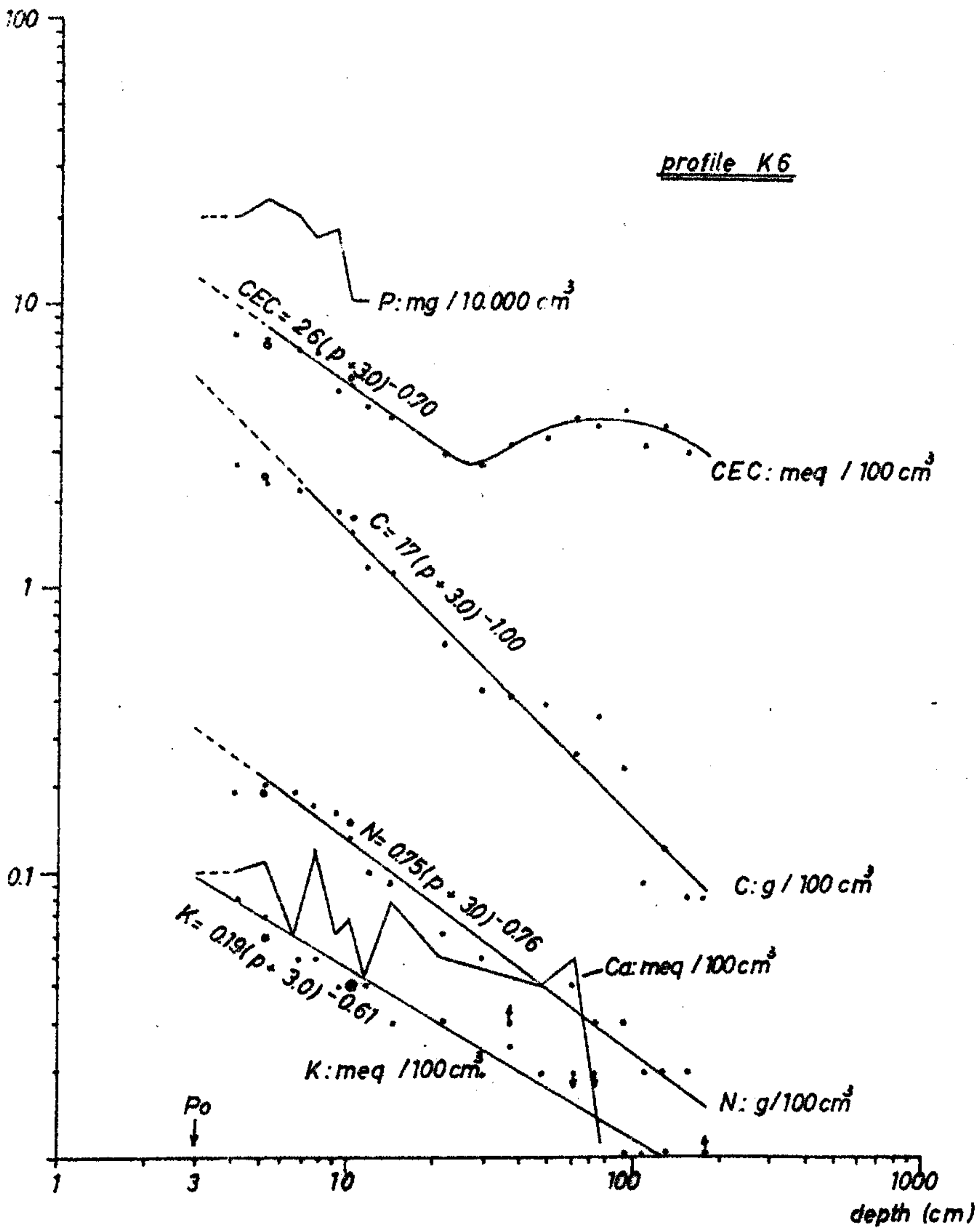


Fig. 14. Profile K_6; C, N, CEC, P-Bray I, and exchangeable K and Ca as a function of depth; . samples from profile pits, o mean values of samples A_1 (0-5 cm) and A_2 (5-10 cm).

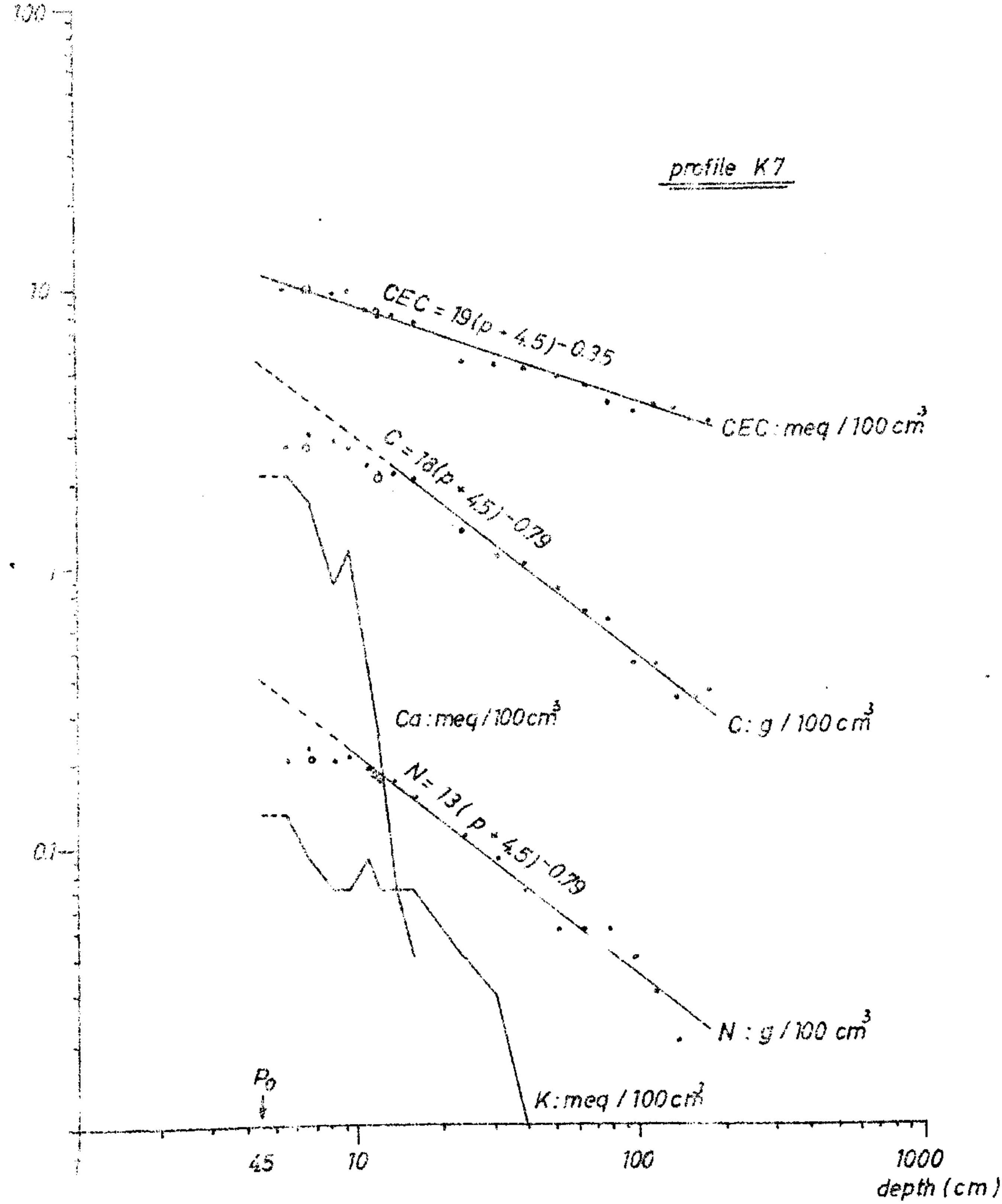


Fig. 15. Profile K_7; C, N, CEC, and exchangeable K and Ca as a function of depth; . samples from profile pits, o mean values of samples A_1 (0-5 cm) and A_2 (5-10 cm).

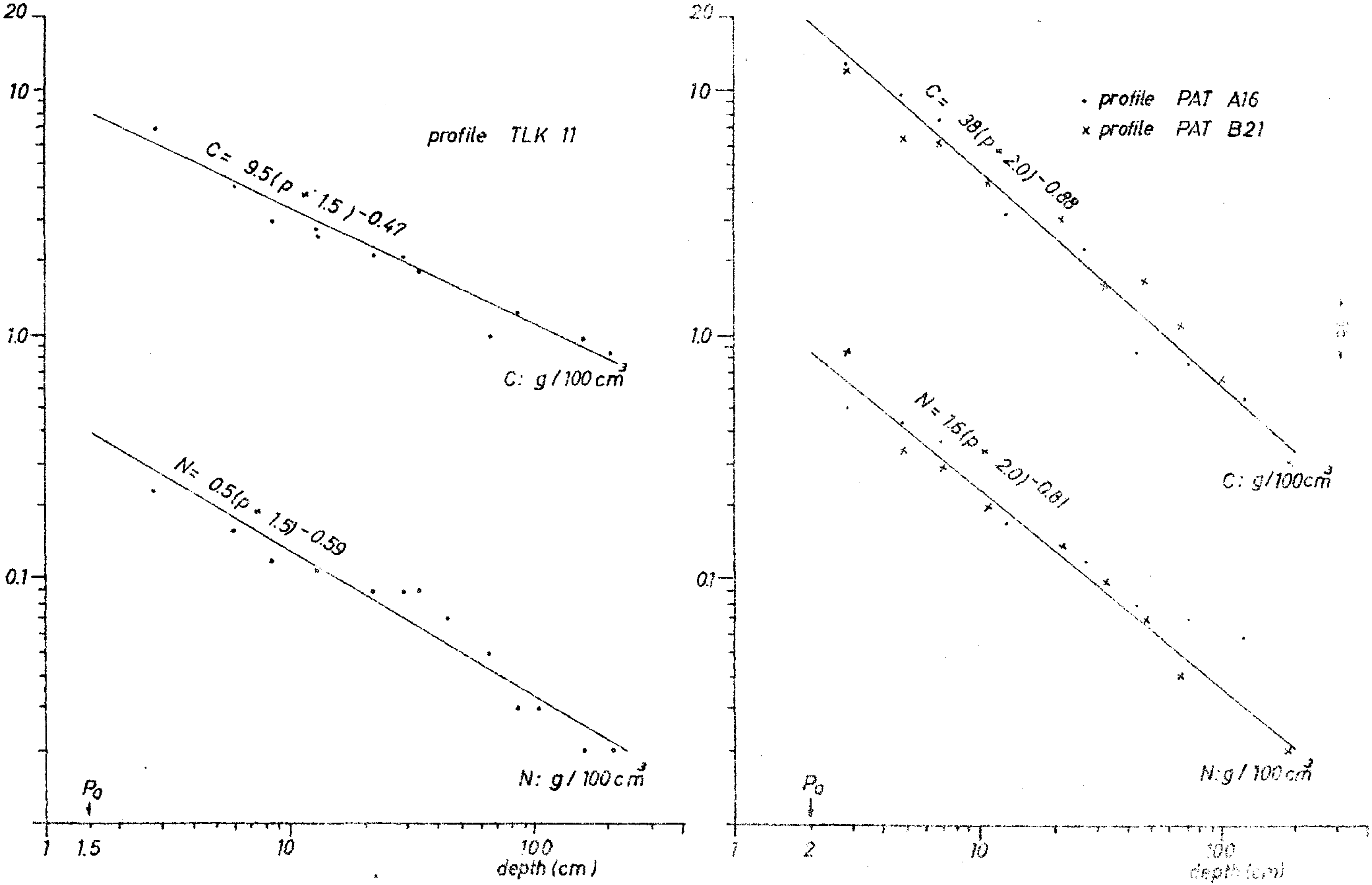


Fig. 16. The carbon and nitrogen profiles of two ferralitic soils under virgin forest in Surinam (modified from SANCHIT, 1974).

content of the top soil due to agricultural use after deforestation. The lower part of the organic carbon profile will change only very slowly because of a low rate of humus increment and humus decay. Comparison of the top soil (which did change) with the lower part (which did not change much) makes it possible to determine the changes in organic matter content that occurred in the top soil. Determination of changes in this way is not influenced by differences in organic carbon content between plots which are a result of a different texture or other interfering factors.

Studying the carbon profiles of K_1, K_2, K_3, K_4, K_5 and K_7 in relation to the carbon profile of K_6 it can be seen that changes in carbon content are limited to the upper 10 cm of the profiles. A quantitative approach of the changes in this layer has been made as follows. The original amount of carbon in the upper 10 cm of every profile has been calculated by integrating the function $c = ap^b$ between $p = 0$ and $p = 20$ cm. This original amount has been compared with the average amount in the top soil samples (A-samples). The results are presented in Table 7.

Table 7. The amounts of organic carbon in the upper 10 cm of profiles K_1 up to K_7; X: amount calculated by integrating $c = ap^b$, Y: average amount of A-samples

profile	carbon content (c) as weight per volume versus depth (p)	X g/100 cm^2	Y g/100 cm^2	Y expressed as % of X
K_1	$c=26(p+5.0)^{-0.95}$	32	27	84
K_2	$c=24(p+5.5)^{-0.86}$	34	24	71
K_3	$c=17(p+4.0)^{-0.74}$	36	31	86
K_4	$c=34(p+5.5)^{-1.06}$	31	25	81
K_5	$c=34(p+5.5)^{-1.06}$	31	23	74
K_6	$c=17(p+3.0)^{-1.00}$	25	21	84
K_7	$c=18(p+4.5)^{-0.79}$	33	25	75

A disadvantage of this method is the fact that an average value of several samples distributed over a certain area is compared with a value based on the carbon contents of only one soil column. The representative value of the last figure is unknown because knowledge about the local variation of organic carbon content in deeper soil layers is not available. For a full statistical analysis of changes in carbon content much more data should be collected to get a good idea of the variation of this parameter through the whole soil profile.

Another difficulty is met in interpreting the data in Table 7 because it is not known exactly to which depth the function $c = ap^b$ of a certain profile under virgin forest would have been valid, whether this is 3 cm, as indicated by K_6 or not. This will influence the way the percentages in Table 7 may be compared.

6.3.3. Conclusions

After all a tentative conclusion with regard to changes in organic carbon content may be the following. Changes in organic carbon content due to normal shifting cultivation practises are limited to the upper 10 cm. The fact changes are limited to this soil layer may be the result of the absence of intensive soil tillage and the very short cultivation period (only one cropping season).

Considering a profile under old secundary forest (K_6) as a reference the amount of organic carbon in the upper 10 cm decreased about 15% after a second use of the profile for shifting cultivation within 7 years (K_5, K_2, K_3).

The original carbon content in the upper 10 cm of the profile may have been restored after a fallow period of 15 years (K_4).

6.4. TOTAL NITROGEN

6.4.1. Results

Diagrams of the nitrogen profiles are found in the Figures 9 up to 15. Nitrogen amounts in the samples from the top soil are recorded in Table 8 (see next page).
From these values amounts of nitrogen expressed as kg per ha for the 0-10 cm layer are calculated. Latter figures together with those of Table 6 are used for determination of C/N ratios (Table 9).

Table 9. C/N ratios in the top soil of plots K_1 up to K_7

depth	K_1	K_2	K_3	K_4	K_5	K_6	K_7
0-10 cm	11.8	12.9	13.0	11.8	11.6	12.4	12.9

6.4.2. Discussion

Gaseous nitrogen not taken into account, soil nitrogen practically entirely forms part of the organic matter. A small percentage consists of free and adsorbed ammonium ions. Nitrate seems to be absent in the soil solution of the studied soils, maybe due to the method of analysis.

Figures 9 up to 15 already demonstrate the relationship between total nitrogen and organic carbon. Nitrogen profiles much resemble carbon profiles. The nitrogen proportion of organic matter is given by the C/N ratios in Table 9. This ratio varies between 11.6 and 13.0, which values agree with those mentioned in the literature as normal for organic matter in ferrallitic forest soils.

In accordance with the differences in organic carbon content the differences in total nitrogen amounts of the top soil can not be explained in a simple way. High organic matter contents also mean high amounts of nitrogen or in other words an increase in organic matter will be accompanied with an increase in nitrogen supply; the reverse applies to decomposition of organic matter in the soil. As Table 8 illustrates absolute amounts of fixed nitrogen in the soil are extremely high. Only in the upper 10 cm of the soil an average of 2000 kg N per ha is incorporated. Such amounts are higher than those incorporated in a mature forest vegetation.

Table 8. Total nitrogen in the top soil; see Table 3 for code explanation

	depth (cm)	A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$	$\bar{A}$ '	$\overline{(A+M)}$
K_1	0–5	0.26*)	0.25	0.24	0.26	0.29	0.25	0.26	2300**)	2300
	5–10	0.20	0.19	0.20	0.18	0.22	0.20	0.20		
K_2	0–5	0.19	0.21	0.19	0.21	0.17	0.22	0.19	1750	1800
	5–10	0.18	0.16	0.15	0.17	0.15	0.16	0.16		
K_5	0–5	0.20	0.23	0.19	0.20	0.22		0.21	1950	
	5–10	0.16	0.15	0.16	0.24	0.18		0.18		
K_4	0–5	0.26	0.23	0.23	0.23	0.23		0.24	2100	
	5–10	0.18	0.18	0.20	0.17	0.17		0.18		
K_3	0–5	0.28	0.28	0.28	0.28	0.26		0.28	2400	
	5–10	0.20	0.19	0.19	0.21	0.19		0.20		
K_7	0–5	0.16	0.19	0.24	0.20	0.21		0.20	1900	
	5–10	0.15	0.18	0.21	0.15	0.21		0.18		
K_6	0–5	0.17	0.18	0.20	0.19	0.19		0.19	1700	
	5–10	0.15	0.12	0.18	0.13	0.16		0.15		

*) nitrogen content in $g/100\ cm^3$
**) amount in kg/ha

From the view point of plant production in shifting cultivation the soil nitrogen supply is very important because nitrogen from the vegetation is lost by burning. Decomposition of organic matter in the soil provides a source for nitrogen nutrition of the crops. Assuming a humus decomposition rate of 2-5% per year - as GREENLAND & NYE (1959) calculated for forest soils in West Africa - 40-100 kg N per ha per year would be released in this way. Taking into account an even more rapid decomposition after burning the forest, it will be clear crops as a rule do not suffer from nitrogen deficiency. Observations in the field could not discover any symptoms of nitrogen deficiency.
In a summary about fertilizer trials NYE & GREENLAND (1960) conclude responses of nitrogen fertilization are low on such soils if the fallow period is long enough. In case of increasing intensity of land use (i.e. continuing the cropping season) responses also increase.

6.4.3. Conclusions

The amounts of nitrogen in the soil are related to the amounts of organic carbon by the C/N ratio. This ratio varied from 11.6 to 13.0 in the studied soils.

Soil nitrogen supply is high in a well balanced shifting cultivation system. Nitrogen nutrition of the crops is satisfactory as long as a high organic matter content is maintained i.e. in the case the fallow period is long enough.

6.5. CATION EXCHANGE CAPACITY CEC

6.5.1. Results

In the same way as applied to the carbon and nitrogen profiles a graphic representation of the CEC profiles is given in the Figures 9 up to 15. Data about the samples from the top soil are found in Table 10.

Table 10. Cation exchange capacity (CEC) in meq/100 cm^3 of the top soil; see Table 3 for code explanation

	depth (cm)	A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$
K_1	0-5	9.05	9.42	8.82	9.74	10.20	9.41	9.45
	5-10	6.98	7.99	6.54	6.70	8.05	7.59	7.25
K_2	0-5	8.10	7.61	7.27	6.52	6.53	10.23	7.21
	5-10	6.47	5.18	5.70	6.64	7.06	6.38	6.01
K_5	0-5	5.67	5.10	7.71	7.23	8.05		6.75
	5-10	6.72	5.92	6.48	6.32	7.28		6.54
K_4	0-5	9.75	8.91	9.27	9.48	9.27		9.34
	5-10	7.54	8.28	8.58	7.13	7.87		7.88
K_3	0-5	12.07	12.20	11.49	11.08	8.96		11.16
	5-10	10.40	9.63	10.75	10.10	9.82		10.14
K_7	0-5	7.88	10.39	13.37	8.89	9.27		9.96
	5-10	6.81	7.48	9.30	7.24	10.69		8.30
K_6	0-5	6.44	6.39	7.51	6.59	8.44		7.07
	5-10	5.21	4.58	6.37	5.33	5.69		5.40

Concerning the method of determination of the CEC it is worth-while to observe the pH of the ammonium acetate solution for percolation. This pH value amounts to seven which figure is much higher than that of the soil solution. Determination of the CEC at the pH of the soil solution would produce lower values. Especially the CEC of organic matter and to a minor degree the CEC of kaolinite also depends on the pH.

6.5.2. Discussion

In soils with mainly kaolinitic clay minerals the capacity to adsorb cations in exchangeable form depends to a high degree on the organic matter content of the soil. In some measure this is illustrated by the shape of the carbon profiles and the CEC profiles (see Fig. 9-15). Apart from the subsoil the diagrams of both kinds of profiles show a similar shape. In the subsoil CEC values are relatively high due to an increasing clay content i.e. an increasing contribution of the clay to total CEC.

The different degree to which both clay and organic matter contribute to total CEC can be calculated via the method described below (see BENNEMA, 1966). The method refered to is based on the assumptions that

1) the cation exchange capacity of the soil in question is practically all located in the clay fraction and the organic matter,
2) one gram of clay has in the same profile approximately the same cation exchange capacity through-out the solum and
3) one gram of carbon has in the same profile approximately the same exchange capacity through-out the solum.

The data from the samples of one profile are the basis for calculating. For each sample $\frac{100}{\text{clay}}$ CEC and $\frac{100}{\text{clay}}$ carbon in which CEC is the cation exchange capacity of the sample determined in the laboratory, clay is the percentage of clay and carbon is the percentage of carbon can be calculated. The values are different for the different samples of one profile, so these terms are the variables and could be called X_1 and X_2. The relationship between X_1 and X_2 can be expressed as follows:

$X_1 = CEC_{100} + CEC_{1c}X_2$, in which CEC_{100} is the cation exchange capacity of 100 grams clay and CEC_{1c} is the cation exchange capacity of one gram carbon. This equation can be solved statistically or approximately graphically. Figure 17 represents an example. Complete data of the calculation of CEC_{100} by means of linear regression analysis are given in Table 11, as is the case with CEC_{1c}. Since exact texture data were known only for profiles K_2, K_3, K_4 and K_6 the calculation is restricted to these profiles.

As shown by Table 11 the CEC of organic matter varies between 2.6 and 3.1 meq per gram carbon; CEC_{100} amounts to 2.2-5.5 meq per 100 gram clay. Taking into account a loamy texture for the top soil of the studied terrace soils with a percentage of clay less than 40% it can be seen that the mineral part of these soils contribute less to a well balanced and regular provision of the vegetation with mineral plant nutrients than the organic matter. This is not only important under natural conditions but also if fertilizers are applied in an agricultural use of these soils.

Concerning the saturation of the exchange complex aluminium is the most important metal ion in terrace soils under forest (JANSSEN, 1973) if amounts are expressed as milli-equivalents.

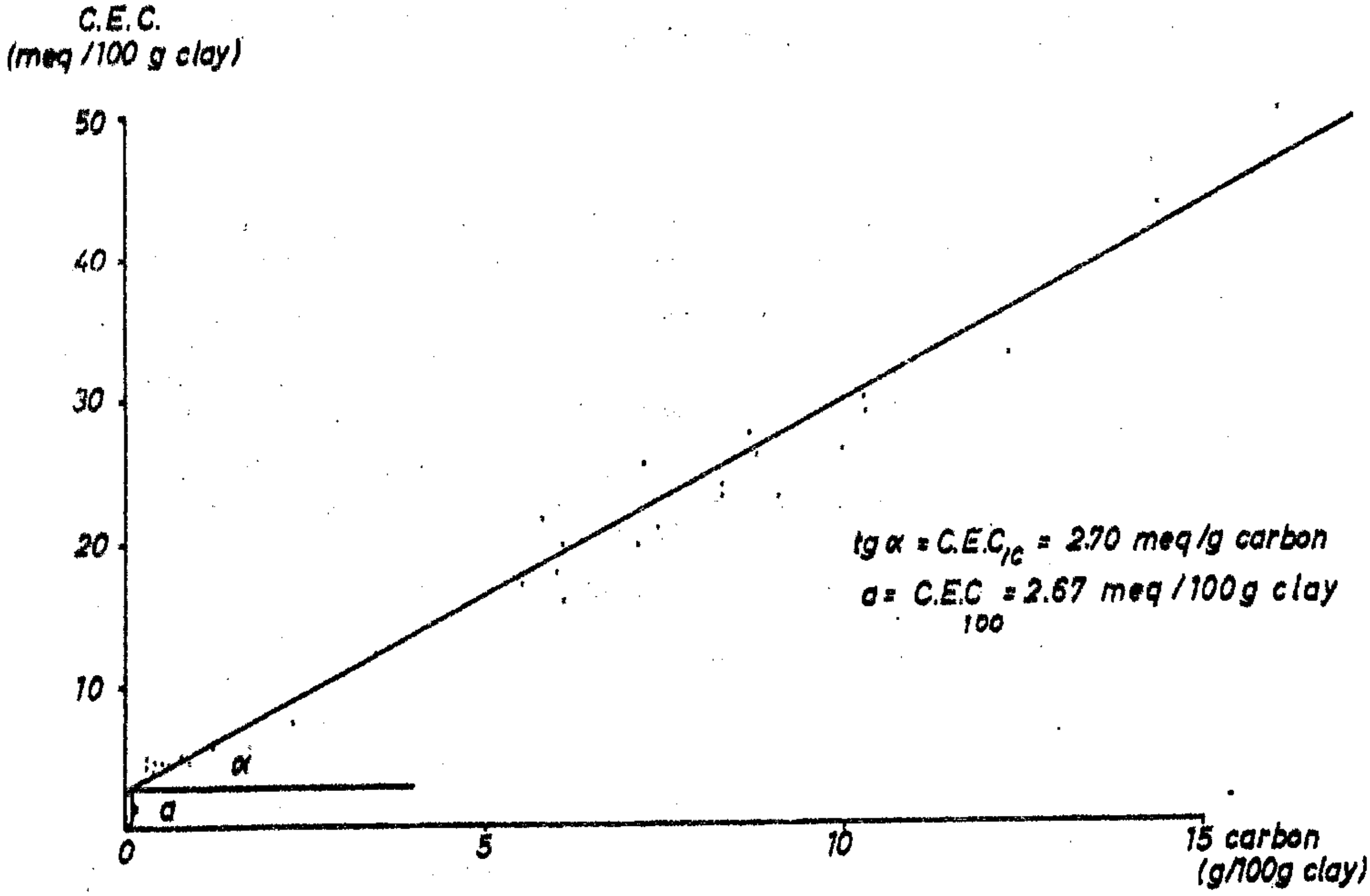


Fig. 17. Relation cation exchange capacity and grams carbon with presence of 100 grams clay; profile K_2.

Table 11. Values for CEC of 100 grams clay and CEC of one gram carbon obtained by linear regression analysis of cation exchange capacity (Y) on grams carbon (X) with presence of 100 grams clay; r^2 is the coefficient of determination

profile	regression function	r^2	CEC_{100} meq/100 g clay	CEC_{1c} meq/g carbon	standard error of CEC_{100}	standard error of CEC_{1c}	standard error of estimate of Y on X
K_2	$Y=CEC_{100}+CEC_{1c}.X$	0.99	2.67	2.70	0.57	0.08	1.79
K_3	$Y=CEC_{100}+CEC_{1c}.X$	0.99	2.15	3.07	0.28	0.06	0.86
K_4	$Y=CEC_{100}+CEC_{1c}.X$	0.99	3.90	2.60	0.26	0.06	0.81
K_6	$Y=CEC_{100}+CEC_{1c}.X$	0.99	5.52	2.72	0.64	0.06	1.98

The contribution of K, Ca and Na is very small in such conditions. It amounts 5% at most and it decreases with depth. Among Ca, K, Na and Mg the first one is more important.

Addition of ash to the soil will increase base saturation. For this purpose exchange of ions is necessary. The process of exchange as a rule proceeds very rapidly. However an increased amount of a certain ion adsorbed to the complex will be maintained only for the time the concentration of the ion in question in the soil solution is also maintained at an increased level. In the case of mobile ions as potassium ions their concentration in the soil solution can change rapidly due to percolating rain water. As a result changes in the amount of potassium at the exchange complex will be of short duration.

6.5.3. Conclusions

In the studied soils the contribution of the clay to total CEC appeared to amount to 2.2-5.5 meq per 100 grams clay. These figures are low due to the fact kaolinite was dominant in the clay fraction. The contribution of organic matter amounted to 2.6-3.1 meq per gram carbon.

From a viewpoint of a regular and well balanced provision of both natural vegetation and crops with plant nutrients the actual and potential contribution of organic matter to total CEC is of special interest compared to the contribution of the clay in terrace soils.

6.6. POTASSIUM

6.6.1. Results

The diagrams of the potassium profiles are represented in Figures 9 up to 15. The amounts of potassium in the top soil are found in Table 12.

Table 12. Exchangeable potassium in the top soil; see Table 3 for code explanation

	depth (cm)	A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$	$\bar{A}'$	$\overline{(A+M)}$
K_1	0-5 5-10	0.14*) 0.14	0.16 0.12	0.17 0.15	0.14 0.10	0.18 0.14	0.13 0.10	0.16 0.13	57**)	45**)
K_2	0-5 5-20	0.15 0.11	0.19 0.08	0.22 0.11	0.17 0.12	0.15 0.11	0.28 0.16	0.18 0.11	57	86
K_5	0-5 5-10	0.07 0.05	0.04 0.06	0.08 0.05	0.07 0.05	0.07 0.05		0.07 0.05	23	
K_4	0-5 5-10	0.11 0.06	0.07 0.08	0.09 0.07	0.09 0.04	0.07 0.05		0.09 0.06	29	
K_3	0-5 5-10	0.09 0.06	0.13 0.07	0.12 0.08	0.16 0.07	0.08 0.04		0.12 0.07	37	
K_7	0-5 5-10	0.13 0.09	0.09 0.06	0.10 0.07	0.09 0.08	0.10 0.08		0.10 0.08	35	
K_6	0-5 5-10	0.05 0.04	0.05 0.04	0.06 0.05	0.07 0.04	0.07 0.04		0.06 0.04	20	

*) potassium content in meq/100 cm^3
**) potassium amount in kg/ha

6.6.2. Discussion

6.6.2.1. The distribution of potassium through the profile

Both in biotic and abiotic environment the element potassium is often present in the form of free or adsorbed ions. Potassium salts are very soluble in water. Because of these properties the rate of turnover of potassium in the nutrient cycle is very high as already mentioned in the introduction.
Some aspects of this rapid turnover are also demonstrated by the data of the present investigations and these will be discussed in the following.

The potassium profile under forest (see Fig. 14) shows a gradual decrease with depth. This decrease in K content of the soil runs parallel to a decrease in exchangeable capacity. The upper 10 cm of the profile contains 13-27 kg K/ha (profile K_4, K_5 and K_6) corresponding with a potassium saturation of the complex of less than 1%.

During the burning of the forest potassium from the vegetation is spread upon the soil surface in the form of carbonates, silicates and phosphates. During the first rains which follow K is readily released from these salts and it is washed together with anions into the profile. Translocation of K through the profile is a rapid process. Comparing K_1 and K_2 sampled only two months after burning with the other profiles the top soil already appears to be enriched with K to a depth of 30 cm. Estimating this enrichment, an amount of about 100 kg K/ha for K_2 and about 200 kg K/ha for K_1 is found.

Besides the K-profiles one or three years after burning (K_3 and K_7) appear to differ only a little from the profiles after seven or fifteen years (Table 13), taking into account differences in total CEC. K_6 under mature forest show a rather low K content through the entire profile due to a rather low total CEC. Obviously the increase of readily available K is of short duration. However it is not clear yet what will happen with the potassium after being washed into the soil and translocated to a certain depth.

Table 13. Vertical distribution of potassium through the profiles K_1 up to K_7 in kg/ha

depth (cm)	K_1	K_2	K_3	K_4	K_5	K_6	K_7
0- 10	78	66	33	27	24	13	35
10- 50	217	51	50	42	19	13	40
50-100	11	20	17	18	0	10	19
0-100	306	137	100	87	43	36	94

6.6.2.2. Leaching of nutrients

Confronted with the data of the potassium determination of profiles K_1 and K_2 against those of the other profiles it was thought worth-while to investigate the mobility of potassium and other cations in these profiles. For this purpose samples were percolated with distilled water in the same ratio as usual for determination of the CEC. In the percolated solution the concentration of K, Ca en Na were measured.
In order to establish what kind of anions provide compensating negative charges phosphate, nitrate, chloride, bicarbonate and organic carbon also were determined. Organic carbon might play a role in the form of simple carbonic acid anions. The results of the analyses are recorded in Tables 14, 15 and 16.

In all three profiles the total amount of potassium soluble in water is 50-60% of the amount determined with ammonium acetate percolation here called exchangeable or available K. So irrespective of profile, whether under young secondary forest (K_5) or under cropping (K_1 and K_2) this percentage is high. Under forest it seems to be connected with a rapid mineralization and with a high rate of leaching out of the leaves.

The high percentage of water soluble potassium in profiles K_1 and K_2 means that a large part of the potassium from the ash comes directly into the soil solution and remains dissolved. So this fraction is extremely mobile and depending on the quantity of leaching rainfall immediately after burning it will move to deeper soil layers more or less rapidly.

The amounts of water soluble calcium are relatively small but the elements sodium is mobile like potassium. The quantity of water soluble sodium expressed as a percentage of the total quantity determined with NH_4OAc percolation shows an increase after burning from 35 to 70% (K_5 compared with K_1 and K_2).

NYE & GREENLAND (1960) consider nitrate and bicarbonate to be most frequent anions in the soil solution of ferrallitic soils. However in the analysed samples the presence of nitrate could not be established. The soil solution seemed to contain nitrogen only in the form of ammonium.
As a matter of course the role of phosphate and chloride in the soil solution is negligible. Sulphate was not determined but presumably the concentration of this anion also may be low.

The most important anion which provides compensating negative charges for translocation of cations is probably the bicarbonate ion. Its concentration in the percolated solution (see Tables 15 and 16) appears to equal the concentration of all cations together. Next to bicarbonate maybe organic anions play a more or less important role. Supposing that all organic carbon in the percolated solution comes from formic acid, HCOOH, or acetic acid, CH_3COOH, there are organic anions enough to balance all positive charges. This supposition is partly based on the fact the organic carbon must belong to water soluble compounds, and partly on data from the literature. In a summary about the occurrence of organic compounds in the soil FLAIG (1971) mentions acetic acid and formic acid in a concentration of 0.5-1.0 meq per 100 grams soil each. These figures are of a similar range as which can be calculated from the organic carbon contents in Tables 15 and 16.

Table 14. Amounts of K, Ca, Na, P, NH_4 and Cl in samples from profile K1 determined in different ways
a) determined with NH_4OAc percolation
b) determined with H_2O percolation
c) determined after extracting with NH_4F+HCl according to Bray I
d) determined in H_2O percolated solution according to Micro-Kjeldahl without previous destruction

depth (cm)	K meq/100 g		Ca meq/100 g		Na meq/100 g		P ppm		NH_4 meq/100 g	Cl meq/100 g
	a	b	a	b	a	b	c	b	d	b
0–2.5	0.14	0.08	1.29	0.05	0.05	0.05	8.9	0.05	0.1	
1–3.5	0.13	0.08	0.24	0.05	0.02	0.06	4.8	0	0.1	
2.5–5	0.14	0.09	0.20	0.03	0.04	0.05	4.1	0	0.1	
3.5–6	0.08	0.06	0.15	0.03	0	0.01	2.7	0	0.1	
5–7.5	0.07	0.06	0.20	0.02	0.03	0.02	2.7	0	0.1	
6–8.5	0.08	–	0.20	–	0.03	–	3.1	–	–	
7.5–10	0.36	0.17	0.46	0.02	0.11	0.04	3.7	0	0.2	T
10–12.5	0.30	0.19	0.10	0.01	0.05	0.05	3.3	0	0.1	R
17.5–20	0.21	0.09	0	0	0.01	0.01	1.3	0	0	A
25–27.5	0.09	0.04	0	0	0.02	0.04	0	0	0	C
32.5–35	0.03	0.02	0	0	0.04	0.04	0	0	0	E
45–47.5	0.02	0.01	0	0	0.07	0.06	0	0	0	S
57.5–60	0.01	0	0	0	0.07	0.02	0	0	0	
70–72.5	0	0	0	0	0.04	0.02	0.6	0	0	
87.5–90	0	0	0	0	0.01	0	0	0	0	
105–107.5	0.01	0	0	0	0.02	0	0	0	0	
125–127.5	0	0	0	0	0.01	0	0	0	0	
147.5–150	0	0	0	0	0.01	0	0	0	0	
170–172.5	0	0	0	0	0.01	0	0	0	0	

Table 15. Amounts of K, Ca, Na, NO_3, HCO_3 and C in samples from profile K_2 determined in different ways:
a) determined with NH_4OAc percolation
b) determined with H_2O percolation

depth (cm)	K meq/100 g a	K meq/100 g b	Ca meq/100 g a	Ca meq/100 g b	Na meq/100 g a	Na meq/100 g b	NO_3 meq/100 g b	HCO_3 meq/100 g b	C mmol/100 g b
0-2.5	0.19	0.10	1.31		0.09	0.11		0.33	0.65
1-3.5	0.21	0.09	0.30		0.09	0.08		0.24	0.74
2.5-5	0.14	0.07	0		0.06	0.08		0.18	0.76
3.5-6	0.15	0.07	0		0.07	0.04		0.17	0.52
5-7.5	0.13	0.07	0		0.14	0.06		0.16	0.52
6-8.5	0.10	0.05	0		0.06	0.04		0.09	0.47
7.5-10	0.08	0.04	0	T	0.03	0.03	A	0.09	0.70
10-12.5	0.07	0.04	0	R	0.03	0.02	B	0.12	0.44
17.5-20	0.03	0.01	0	A	0.06	0.04	S	-	0.20
25-27.5	0.02	0	0	C	0.04	0.03	E	-	0.16
32.5-35	0.01	0.01	0	E	0.04	0.04	N	0	0.16
45-47.5	0.01	0	0	S	0.07	0.05	T	-	0.11
57.5-60	0.01	0.01	0		0.04	0.03		0	0.08
70-72.5	0.01	0.01	0		0.04	0.02		-	0.07
87.5-90	0.01	0	0		0.06	0.01		0	0.06
105-107.5	0.01	0.01	0		0.04	0.01		-	0.01
125-127.5	0.01	0	0		0.03	0		0	0.08
147.5-150	0.01	0	0		0.03	0		-	0.01
170-172.5	0.01	0	0		0.01	0		0	0.08

Table 16, Amounts of K, Ca, Na, P, HCO_3 and C in samples from profile K_5
determined in different ways:
a) determined with NH_4OAc percolation
b) determined with H_2O percolation

depth (cm)	K meq/100 g a	K meq/100 g b	Ca meq/100 g a	Ca meq/100 g b	Na meq/100 g a	Na meq/100 g b	P ppm b	HCO_3 meq/100 g b	C mmol/100 g b
0-2.5	0.11	0.05	0.31		0.11	0.11		0.33	0.81
1-3.5	0.09	0.04	0.10		0.07	0.07		0.16	0.78
2.5-5	0.07	0.04	0		0.08	0.08		0.14	0.76
3.5-6	0.04	0.03	0.05		0.06	0.04		0.14	0.76
5-7.5	0.04	0.03	0		0.04	0.02		0.14	0.66
6-8.5	0.03	0.02	0		0.05	0.01		0.07	0.64
7.5-10	0.03	0.02	0.01	T	0.05	0	T	0.08	0.57
10-12.5	0.02	0.02	0	R	0.06	0	R	0.08	0.50
17.5-20	0.01	0.01	0	A	0.03	0	A	0.11	0.36
25-27.5	0.01	0.01	0	C	0.04	0.01	C	0.05	0.25
32.5-35	0.01	0.01	0	E	0.04	0.01	E	0.07	0.15
45-47.5	0.01	0	0	S	0.03	0	S	0.04	0
57.5-60	0	0	0		0.04	0		0.05	0.01
70-72.5	0	0	0		0.07	0		0.04	0
87.5-90	0	0	0		0.05	0		0.04	0
105-107.5	0	0	0		0.05	0.01		0.01	0
125-127.5	0	0	0		0.06	0		0.04	0
147.5-150	0.01	0	0		0.06	0		0.06	0
170-172.5	0.01	0	0		0.06	0		0.12	0

However it is not clear to which environmental conditions the data of FLAIG apply.

Between the amounts of water soluble organic carbon and the total amounts of organic carbon a linear relationship exist applicable to at least the upper 30 cm of the soil. The water soluble part is a percentage of about 0.4 of total carbon for K_5 (before burning) and about 0.2 for K_2 (after burning).

Considering the above-mentioned results as an indication for a rapid translocation of potassium from the ash through the profile the question whether this leaching process gives rise to real losses of K from the profile still goes unanswered. Concerning shallow rooting annual crops a certain fraction may soon be beyond their reach. Maybe absolute leaching losses are prohibited by a developing fallow vegetation which will root deeper and take up leached nutrients from the subsoil.

Apart from possible losses due to leaching there are of course losses as a result of harvesting crops. The amounts of potassium removed from the field during harvesting are relatively high for starch crops compared with other crops; cassava, yams and bananas 30-60 kg K per 10.000 kg fresh weight per ha, rice and maize about 3 kg per 1000 kg seed weight per ha.

Losses from the ecosystem can only be replenished by potassium released from little soluble fractions. However these fractions are not large and besides replenishment from this source is a slow process. For twelve forest profiles in Ivory Coast NYE & GREENLAND (1960) give the following proportion between non-exchangeable and exchangeable amounts of element in the upper 20 cm: K: 2.2-10.4, Ca: 1.2-3.7 and Mg: 2.0-8.4. According to data from Liberia, Ghana and Congo a more favourable figure would apply to phosphate, viz. 20-100.

6.6.3. Conclusions

Potassium is very mobile in the soil; over half of the amount determined by ammonium acetate percolation in profile K_1, K_2 and K_5 was water soluble. A large part of the potassium from the ash comes into the soil solution so that it is rapidly translocated through the profile. Enrichment with K from the ash was found up to a depth of 30 cm after two months (profiles K_1 and K_2). Profile K_1 was estimated to be enriched at a rate of 200 kg/ha, profile K_2 at a rate of 100 kg/ha. Changes of the amounts of available potassium after burning were of short duration; they had disappeared after a year.

Compensating negative charges necessary for the translocation of potassium and other cations (particularly ammonium and sodium) were provided by bicarbonate and probably also by organic ions.

Because of leaching part of the potassium fraction from the ash may soon be beyond the reach of shallow rooting annual crops.

The total amount of available potassium in the upper 100 cm of the soil under forest had been estimated at 100 kg/ha at the most.

6.7. CALCIUM

6.7.1. Results

The calcium profiles are represented in Figures 9 up to 15. The amounts of calcium in the top soil are given in Table 17.

Table 17. Calcium in the top soil; see Table 3 for code explanation

	depth (cm)	A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$	$\bar{A}'$	$\overline{(A+M)}$
K_1	0–5	1.12 *)	0.55	1.00	0.21	0.42	0.95	0.66	66**)	102**)
	5–10	0	0	0	0	0	0.07	0		
K_2	0–5	1.38	1.79	2.42	0.05	1.30	2.94	1.39	142	300
	5–10	0.04	0.01	0.03	0.01	0.04	0.06	0.03		
K_5	0–5	0.21	0.09	0.14	0.18	0.09		0.14	24	
	5–10	0.10	0.08	0.09	0.08	0.14		0.10		
K_4	0–5	0	0.09	0.44	0.03	0.23		0.16	16	
	5–10	0	0	0	0	0		0		
K_3	0–5	0.73	1.00	1.55	2.66	(7.77)		1.49	189	
	5–10	0.18	0.22	0.43	0.39	0.78		0.40		
K_7	0–5	0.82	2.54	2.93	1.29	1.71		1.86	241	
	5–10	0.12	0.77	0.39	0.29	1.20		0.55		
K_6	0–5	0.11	0.06	0.14	0.22	0.23		0.15	26	
	5–10	0.07	0.07	0.15	0.07	0.21		0.11		

*) calcium content in $g/100\ cm^3$
**) calcium amount in kg/ha

6.7.2. Discussion

In comparison with potassium calcium is much less mobile. Calcium salts are often little soluble in water and in the soil this element is adsorbed more strongly to the complex than potassium. Besides calcium uptake and immobilization by a vegetation is a more gradual process as compared to potassium.

Under a vegetation of secondary forest the Ca profile shows a gradual decrease with depth (see Fig. 14). Burning the forest, calcium from the vegetative biomass comes to the soil in the form of salts. Then it is washed into the soil but translocation through the profile is very slow. Much of the calcium from the ash remains concentrated in the upper 10 cm as the profiles K_1, K_2 and K_3 show (see Table 17 and Fig. 9, 10 and 11). After three years the surface soil still appears to be enriched with calcium, but after seven years this enrichment has disappeared. Maybe in a young fallow the available calcium contents in the soil will fall even below the equilibrium status of mature forest as applies to phosphate (see 6.10). An estimation of the amount of calcium released during burning is exact to a small degree on the basis of the data in Table 17. LAUDELOUT (1961) found an amount of 280 kg per ha for a thirty years old fallow. Considering the data in Table 17 this figure may indicate at least the order of magnitude for the situation here studied. For Kade, Ghana an amount of about 1400 kg Ca per ha was found when a forty years old fallow had been burnt (NYE & GREENLAND, 1960). This quantity seems to be much higher than applies to the conditions prevailing in the present situation. In this connection the rise of pH in the top soil after the burning is much lower for the terrace soils than the one which is reported for the soils of Kade.

In 6.6.2.2 the low mobility of calcium in the soil has been discussed. Leaching of this element is not intensive. Therefore losses of calcium on permeable soils will be brought about mainly by crop removal. But these amounts are not large viz. less than 1 kg per ha for 1000 kg rice or maize, or 10.000 kg fresh weight of yams or bananas. For cassava this quantity is probably somewhat larger.

Although the calcium content of the soil during cropping appears to be rather low this element is much less deficient for crop growth than phosphate (see 6.10) as it was proved by fertilizer trials of JANSSEN (1973).

6.7.3. Conclusions

Calcium is rather immobile in the soil. The calcium added with the ash gave rise to an enriched top soil for a number of years. Losses due to leaching and to crop removal are small. The amounts of calcium released during the burning of the vegetation have been estimated at some hundreds of kilograms per hectare provided the period of fallow was long enough. The amounts of calcium present in the soil after burning are not strongly limiting for crop growth during a few years.

6.8. SODIUM

6.8.1. Results

The sodium profiles are not represented diagrammatically. The contents of the samples from the profile pits are given in Table 18. The amounts in the top soil samples are shown in Table 19.

The flame-fotometric determination of sodium in the laboratory has been readily disturbed. As a result of it the obtained data sometimes seem to be rather irregular and unreliable.

6.8.2. Discussion and conclusions

Sodium is not an essential element for plant growth but it is taken up by the vegetation and so it is present in the nutrient cycle. The sodium saturation of the complex in the upper 10 cm of the soil under forest amounts to circa 1%.

The solubility of sodium salts in water is high. In this respect the behaviour of the element bears a certain resemblance to the behaviour of potassium. The total amount of water soluble sodium expressed as a percentage of the total quantity determined with ammonium acetate percolation increased after burning from 35% (K_5) to 70% (K_1 and K_2).

6.9. pH-H_2O AND pH-KCl

6.9.1. Results

The pH values of the samples from the profile pits are shown in Table 20. For profile K_1 also a graphic representation of the pH as a function of depth is given in Fig. 18. The pH values of the top soil samples are present in Table 21.

6.9.2. Discussion

The pH profile in the soil under forest shows a regular increase of the pH values with increasing depth. The pH-H_2O rises from about 4.0 to 5.5, the pH-KCl from about 3.5 to 4.2. So the change of the potential acidity is smaller than the change of the actual acidity.

After burning, the pH of the top soil increases in some measure, viz. in the upper 5 cm 0.4-1.1 unit for pH-H_2O and 0.1-0.5 for pH-KCl.

Table 18. Exchangeable sodium content (meq/100 cm^3) in samples from profile pits K_1 up to K_7

depth (cm)	K_1	K_2	K_3	K_4	K_5	K_6	K_7
0–2.5	0.05	0.10	0.05	0.02	0.09	0.12	0.03
1–3.5	0.02	0.09	0.04	0.23	0.07	0.13	0.01
2.5–5	0.05	0.07	0.02	0.13	0.09	0.11	0
3.5–6	0	0.09	0.02	0.30	0.08	0.09	0
5–7.5	0.05	0.18	0	0.16	0.05	0.06	0
6–8.5	0.05	0.08	0	0.06	0.07	0.07	0
7.5–10	0.13	0.04	0	0.03	0.07	0.09	0
10–12.5	0.06	0.04	0.01	0.03	0.09	0.09	0.01
17.5–20	0.01	0.09	0	0	0.04	0.06	0
25–27.5	0.03	0.06	0	0.06	0.06	0.05	0
32.5–35	0.06	0.06	0	0	0.06	0.08	0
45–47.5	0.10	0.10	0	0.03	0.04	0.04	0
57.5–60	0.10	0.06	0	0.01	0.06	0.03	0
70–72.5	0.06	0.06	0	0	0.10	0.02	0
87.5–90	0.01	0.09	0.01	0.07	0.07	0.02	0
105–107.5	0.03	0.06	0.04	0	0.07	0	0
125–127.5	0.01	0.04	0.07	0.13	0.08	0	0
147.5–150	0.01	0.04	0.01	0	0.09	0.02	0
170–172.5		0.01	0.01	0	0.08	0	0

So the addition of salts from the ash to the soil clearly brings about a lower concentration of free hydrogen ions, whereas the total amount of hydrogen ions changes only a little.

The extent to which the pH will increase after burning is determined by the amounts of cations added to the soil. This is illustrated by Figures 18 and 19. Both the amounts of potassium and the amounts of calcium in the upper 5 cm of the soil after burning are related to pH values. However among the various cations/ions play a more important role because their quantity expressed as milliequivalents is large compared to the amounts of other cations. Besides calcium is not very mobile and so it gives rise to increased pH values during three years at least as appears from Table 21.

/calcium

Table 19. Sodium in the top soil; see Table 3 for code explanation

	depth (cm)	A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$	$\bar{A}$	$\overline{(A+M)}$
K_1	0–5	0.06 *)	0.04	0.06	0.06	0.05	0	0.05	13**)	5**)
	5–10	0.04	0.06	0.07	0.07	0.05	0.04	0.06		
K_2	0–5	0.09	0.13	0.16	0.06	0.10	0.12	0.11	23	24
	5–10	0.08	0.11	0.08	0.09	0.08	0.09	0.09		
K_5	0–5	0.07	0.06	0.12	0.06	0.08		0.08	17	
	5–10	0.12	0.06	0.10	0.06	0.03		0.07		
K_4	0–5	0.06	0.03	0.03	0.05	0.03		0.04	8	
	5–10	0.04	0.03	0.03	0.02	0.03		0.03		
K_3	0–5	0.03	0.04	0.06	0.07	0.04		0.05	9	
	5–10	0.03	0.05	0.03	0.05	0.01		0.03		
K_7	0–5	0.03	0.06	0.03	0.03	0.08		0.05	7	
	5–10	0	0.01	0	0.01	0.03		0.01		
K_6	0–5	0.08	0.06	0.08	0.10	0.14		0.09	20	
	5–10	0.07	0.07	0.09	0.09	0.09		0.08		

*) content in meq/100 cm^3
**) amount in kg/ha

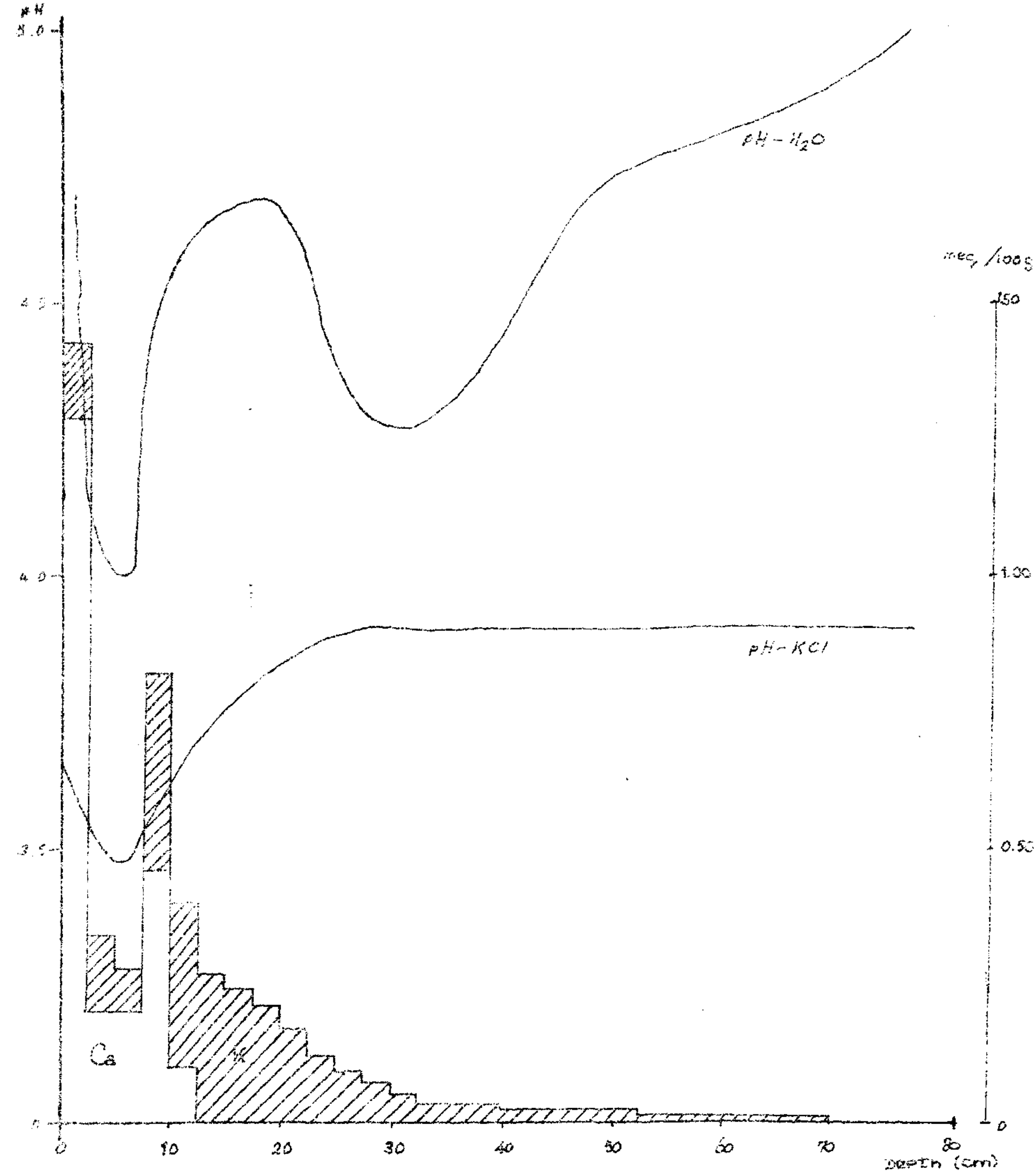


Fig. 18. Profile K_1: pH-H_2O, pH-KCl, K- and Ca-content as a function of depth.

Table 20. pH-values in profile pits K_1 up to K_7; a: pH-H_2O, b: pH-KCl

depth (cm)	K_1 a	K_1 b	K_2 a	K_2 b	K_3 a	K_3 b	K_4 a	K_4 b	K_5 a	K_5 b	K_6 a	K_6 b	K_7 a	K_7 b
0–2.5	4.7	3.6	5.1	4.3	5.1	4.1	4.1	3.5	4.1	3.7	4.2	3.5	5.3	4.3
1–3.5	4.1	3.5	4.9	3.9	4.6	3.8	4.2	3.5	4.3	3.7	4.1	3.5	5.2	4.2
2.5–5	4.1	3.5	5.0	3.9	4.2	3.7	3.9	3.7	3.9	3.9	4.2	3.6	5.1	4.1
3.5–6	4.0	3.5	4.9	4.1	4.5	3.6	4.3	3.7	4.3	3.8	4.3	3.7	5.3	4.1
5–7.5	4.0	3.6	5.0	3.9	4.4	3.6	4.3	3.9	4.2	3.8	4.3	3.7	4.9	4.1
6–8.5	3.9	3.4	4.7	3.9	4.5	3.6	4.3	3.9	4.5	3.9	4.4	3.8	4.9	4.0
7.5–10	4.5	3.7	4.9	4.1	4.3	3.7	4.5	4.1	4.4	3.9	4.5	3.8	4.7	4.0
10–12.5	4.5	3.6	4.7	3.9	4.2	3.7	4.2	3.9	4.2	4.0	4.4	3.8	4.7	4.0
17.5–20	4.7	3.8	4.9	3.9	4.7	3.7	4.5	4.0	4.6	3.9	4.7	3.9	4.8	4.0
25–27.5	4.3	3.9	5.1	4.0	4.7	3.8	4.7	4.1	4.7	4.0	4.8	3.9	4.6	4.0
32.5–35	4.3	3.9	4.9	4.1	4.8	3.9	4.8	4.1	4.8	4.1	4.9	3.9	4.9	4.1
45–47.5	4.7	3.7	5.0	4.1	4.8	3.9	5.0	4.1	4.8	4.1	4.9	3.8	5.1	4.0
57.5–60	4.8	3.9	5.3	4.2	4.7	4.0	5.2	4.1	5.0	4.1	4.9	3.8	5.3	4.1
70–72.5	4.9	3.9	5.5	4.0	4.5	4.0	5.1	4.1	5.2	4.1	5.0	3.8	5.3	4.1
87.5–90	5.3	3.9	5.3	4.2	5.0	4.0	5.1	4.1	5.4	4.1	5.1	3.9	5.3	4.2
105–107.5	5.5	4.0	5.5	4.2	5.1	4.0	5.2	4.1	5.2	4.5	5.2	3.9	5.4	4.3
125–127.5	5.5	4.1	5.7	4.1	5.2	4.1	5.5	4.2	5.3	4.1	5.2	3.8	5.3	4.2
147.5–150	5.3	3.9	5.7	4.1	5.2	4.0	5.5	4.2	5.3	4.1	5.2	3.8	5.3	4.2
170–172.5			5.7	4.0	5.4	4.0	5.3	4.2	5.5	4.2	5.2	3.7	5.3	4.2

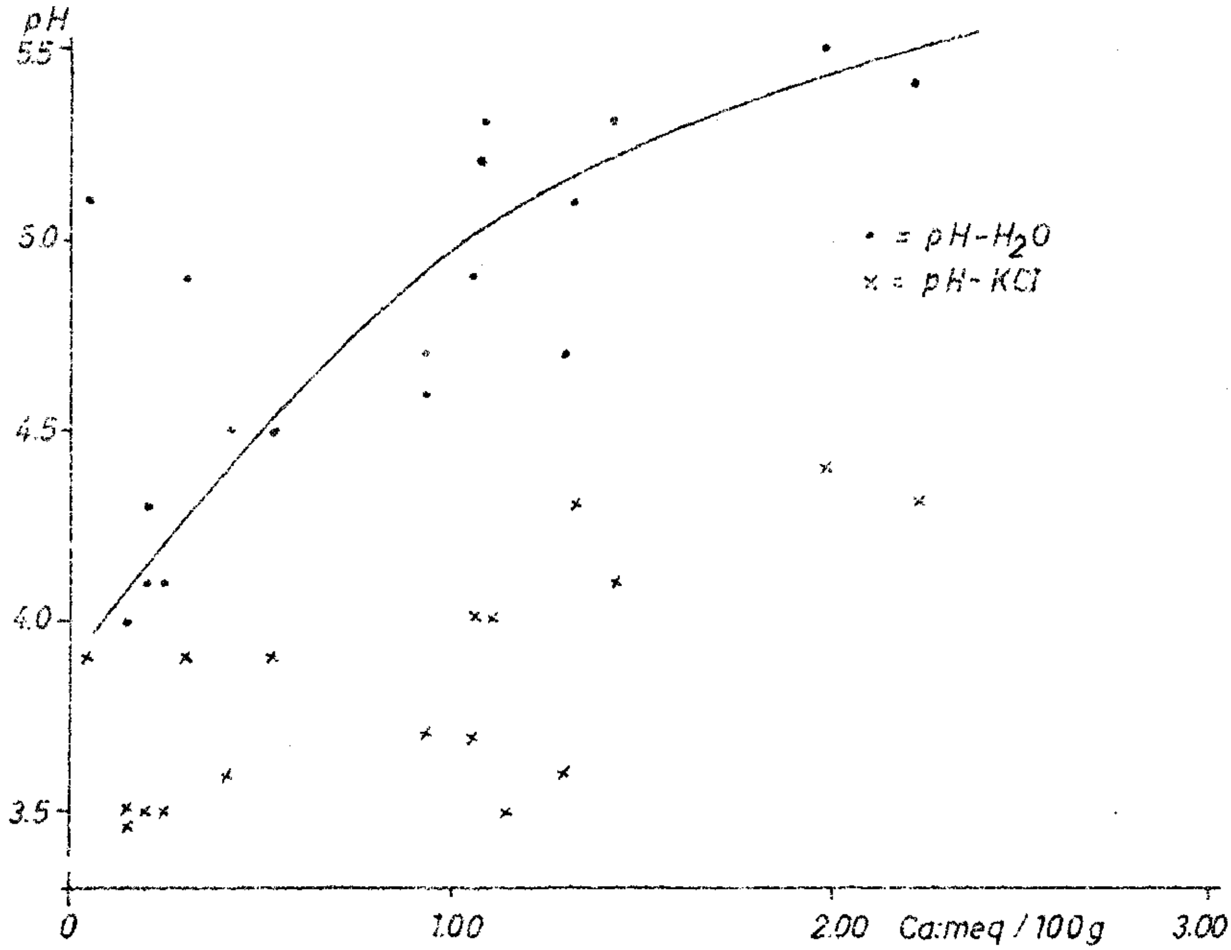


Fig. 19. pH-H_2O and pH-KCl versus calcium content in the upper plots K_1 and K_2.

Table 21. pH-values in the top soil of plots K_1 up to K_7, determined in 5 samples of 100 cm^3 (A_1–A_5) and a mixed sample (M) of 5 x 100 cm^3; a: $pH-H_2O$, b: pH-KCl

	depth (cm)	A_1 a	A_1 b	A_2 a	A_2 b	A_3 a	A_3 b	A_4 a	A_4 b	A_5 a	A_5 b	M a	M b
K_1	0–5	4.9	3.7	4.5	3.9	4.6	3.7	4.3	3.5	4.5	3.6	4.7	3.7
	5–10	4.3	3.7	4.1	3.5	4.2	3.6	4.1	3.6	4.1	3.4	4.1	3.7
K_2	0–5	5.2	4.0	5.3	4.1	5.5	4.4	5.1	3.9	5.3	4.0	5.4	4.3
	5–10	4.9	3.9	4.6	3.8	5.1	3.9	4.7	3.8	4.9	3.8	4.8	3.9
K_5	0–5	4.2	3.5	4.2	3.5	4.1	3.9	4.5	3.8	4.0	3.7		
	5–10	4.2	3.7	4.3	3.7	4.6	3.9	4.5	3.9	4.5	3.7		
K_4	0–5	3.9	3.5	3.9	3.7	4.5	3.9	4.1	3.8	4.2	3.5		
	5–10	4.3	3.7	4.0	3.8	4.3	3.9	4.3	3.9	4.3	3.7		
K_3	0–5	4.5	3.6	4.5	3.5	4.7	3.8	4.9	3.8	6.0	5.0		
	5–10	4.5	3.6	4.4	3.7	4.0	3.7	4.5	3.6	4.6	4.0		
K_7	0–5	5.1	4.1	5.3	4.4	5.4	4.2	5.2	4.1	5.3	4.1		
	5–10	4.9	3.9	5.0	4.0	4.8	4.0	5.0	4.0	5.1	4.0		
K_6	0–5	4.0	3.5	4.2	3.7	4.4	3.7	4.2	3.6	4.2	3.5		
	5–10	4.3	3.8	4.5	3.8	4.5	3.8	4.4	3.8	4.2	3.8		

In the literature also some data about this question can be found. Concerning soils in Kade, Ghana, NYE & GREENLAND (1960) give a pH-H_2O increase of 2.7 units (from 5.2-7.9) in the upper 5 cm and an enrichment of 1400 kg Ca per hectare. In Liberia conditions similar to those of the presently studied area were found: after burning an enrichment of 250 kg Ca per hectare was found accompanied with a pH-H_2O increase of 0.8 unit.

Of course an increase of the pH will influence chemical, physical and microbiological processes in the soil. In the terrace soils one of the results probably is a renewed process of clay illuviation (see chapter 7).

6.9.3. Conclusions

The increased pH after burning, mainly reflecting the actual acidity (pH-H_2O) is chiefly related to the addition of calcium with the ash. The increase amounted to 0.4-1.1 pH unit in the upper 5 cm (i.e. from 4.2-5.3 at most) and was maintained as long as the top soil remained enriched with calcium, viz. about three years.

6.10. PHOSPHATE

6.10.1. Results

The amounts of available phosphate (P-Bray I) in the samples from the profile pits are shown in the Figures 9 up to 15. In the samples from pit K_7 no available phosphate was measured. From profile K_5 only one sample contained available phosphate.

The phosphate contents of the top soil samples are shown in Table 22.

Table 22. Available phosphate in the top soil; see Table 3 for code explanation

	depth (cm)	A_1	A_2	A_3	A_4	A_5	M	$\bar{A}$	$\bar{A}'$	$\overline{(A+M)}$
K_1	0-5	10.4*)	8.6	9.9	5.1	6.3	11.0	8.1	6**)	6**)
	5-10	2.4	3.6	4.1	2.4	4.8	3.1	3.5		
K_2	0-5	0.5	4.6	5.0	1.1	1.3	8.1	2.5	1.5	3
	5-10	0	0	1.2	0	0.5	0.9	0.3		
K_5	0-5	2.2	1.1	0.6	1.0	0		1.0	0.5	
	5-10	0	0	0	0	0		0		
K_4	0-5	1.3	1.9	1.7	0.4	0.8		1.2	1	
	5-10	0.2	3.7	0	0	0		0.8		
K_3	0-5	3.4	3.5	2.7	2.8	4.9		3.5	3	
	5-10	1.3	1.7	2.6	1.0	4.2		2.2		
K_7	0-5	0	0	0	0	0		0	0	
	5-10	0	0	0	0	0		0		
K_6	0-5	3.3	2.7	2.7	2.0	1.9		2.5	2	
	5-10	1.5	0	1.8	1.9	1.0		1.2		

*) content in mg/10.000 cm^3
**) amount in kg/ha

Applying the method "Bray I" the phosphate fraction which is associated with the organic matter is determined. It can form a part of the organic matter or it can be adsorbed to the organic matter.

6.10.2. Discussion

As shown by the phosphate amounts in Tables 22 and 23 the terrace soils are very poor in available phosphate.

Table 23. Distribution of available phosphate through the profiles K_1 up to K_7; amounts expressed as kg per hectare (see also data from the top soil in Table 22)

depth (cm)	K_1	K_2	K_3	K_4	K_5	K_6	K_7
0- 10	5	3.5	3	1	0.1	1.5	0
10- 50	3.5	0	0.5	0	0	0	0
50-100	0	0	0.5	0	0	0	0

The content of the upper 10 cm does not surpass 6 ppm and under forest not even 2 ppm. The total amount of phosphate in the soils may be higher.

Most of the available phosphate is present in the top soil where also the bulk of the organic matter is concentrated. BRAMS (1973) found a close relationship between P-Bray I and organic carbon content indicating that the available phosphate is indeed associated with the organic matter. Among the present data this relationship only applies more or less to the phosphate and organic carbon contents of K_6, the profile which is least disturbed. The absence of a relationship for the other profiles may be connected with the low values of the P-Bray I determinations and certainly with burning which adds inorganic phosphate to the soil. The contribution of last mentioned phosphate fraction to total available soil phosphate is relatively large as Tables 22 and 23 show.

Although a mosaic-like pattern of ash (i.e. plant nutrients) distribution and therefore large local differences in phosphate content of the soil must be taken into account a tentative interpretation of the laboratory analyses with reference to conditions for crop growth is possible. From the Tables 22 and 23 the following conclusions can be drawn.

At the beginning of the cultivation period on plot K_1 at most 8 kg P/ha was available for crop growth and on plot K_2 at most 5 kg P/ha. These amounts are comparable with those removed with crops. NYE & GREENLAND give following data: with 1000 kg seed weight of maize or rice respectively 2.7 kg and 3.2 kg P is removed, with 10.000 kg fresh weight of cassava 3.0 kg P. Though there will be a certain release of phosphate from decaying roots during the cropping period it is clear that the supply of available phosphate will be exhausted for a greater part after a second or third crop.

On residual soils in the same area with a chemical fertility equalling that of the alluvial terrace soils strong deficiency symptoms of phosphate has been observed when a second crop was grown after a short fallow. Data of a soil fertility research on the terrace soils at Victoria and Baboenhol (JANSSEN, 1973) have also proved that the supply of available phosphate is very limited. From fertilizer trials with maize it appeared that phosphate was the most deficient nutrient.

The available phosphate which is left in the soil after the cropping period is absorbed by the developing fallow vegetation. During its development the contents of available phosphate in the soil decrease to zero (see K_7). The fraction of organic soil phosphate is not restored until the fallow is several years old. As the vegetation grows older it will also take up phosphate from relatively insoluble fractions. Through the vegetation and the litter layer this phosphate finally will come to the organic matter in the top soil.

Losses of phosphate will be brought about chiefly by crop removal. Losses from percolation are negligible because of the low solubility of phosphates (see 6.6.2.2). Besides on these permeable soils little phosphate will be lost as a result of ash being washed away from the soil surface. On less permeable residual soils in the same area indications of large losses by run-off have been found (BUDELMAN & KETELAARS, 1974).

6.10.3. Conclusions

The amount of readily available phosphate in the soil under forest is very small, viz. 1-2 ppm in the upper 10 cm. This amount directly increases with the phosphate during burning, to 8 ppm at most. After two or three crops the quantity of readily available phosphate present at the start of the cultivation period will be exhausted. Therefore phosphate very quickly hampers an extension of the cultivation period.

The available phosphate left in the soil after cropping once is absorbed by the developing fallow vegetation. The fraction of readily available (organic) soil phosphate is not restored until the secondary vegetation is several years old.

7. MICROMORPHOLOGICAL DATA

7.1. RESULTS

Complete descriptions of the slides are added in an appendix (see 7.3). The results of counting pores are summed up in Tables 24 and 25. From both countings the layer from 3-7 cm of profile K_2 which contained much charcoal is excluded. Also in all profiles the attribution of charcoal to total pore space is neglected.

Table 24. Number of pores counted in each class and proportional distribution

	20-50	50-100	100-300	300-500	500-1000	1000-2000	> 2000
K_5-1	812-52	451-29	240-15	31-2	14- 1	7- < 1	2- < 1
K_2-1	745-52	437-30	210-15	29-2	12- 1	3- < 1	3- < 1
K_3-1	673-54	352-28	182-15	34-3	11- <1	3- < 1	0- 0
K_7-1	959-54	522-29	238-13	39-2	15- <1	4- < 1	0- 0

Table 25. Total number of pores with a diameter less than 500 micron per cm^2

	number/cm^2	standard deviation	t_7
K_5-1	1997	225	
			K_5-K_2: 3.24
			K_5-K_3: 3.12
K_2-1	1692	141	
			K_5-K_7: 1.70
			K_2-K_3: 0.90
K_3-1	1588	294	
			K_2-K_7: 1.11
			K_3-K_7: 1.59
K_7-1	1801	237	
			$P(t_7 > 2.37) = 0.05$

The standard deviation in Table 25 is calculated according to the formula:

$$\text{st.dev.} = \frac{x^2 - \frac{(x)^2}{n}}{n-1} = s$$

in which x means: number of pores per cm^2 per counted band, and
n means: number of bands counted (= 8).

Testing of significance is done using the studient-variable with variance

$$\frac{s_1^2 + s_2^2}{n}$$

and with a significant level at 5 percent.

The amounts of clay skins between 15 and 30 cm depth are given in Table 26.

Table 26. Amounts of clay skins between 15 and 30 cm depth in volume % of the soil matrix; profiles K_2, K_3, K_5, K_6 and K_7

profile	clay skins (%)
K_2	1.6 ± 0.9
K_3	3.2 ± 1.3
K_5	1.3 ± 0.8
K_6	traces
K_7	2.7 ± 1.3

7.2. DISCUSSION AND CONCLUSIONS

All profiles are characterized by a high biological activity witness the fact that many biopores are present, i.e. channels, vughs, interconnected vughs and compound packing voids. Especially in the upper 10 cm the soil for a greater part consists of recent animal excrements. Increasing depth decreases this biological activity markedly; this is accompanied with a decrease in organic matter content.

The soil matrix shows the typical portrait of a entirely weathered tropical soil. In a plasma of clay, organic matter and iron almost solely quartz grains occur. These quartz grains are the remains of the original parent material. Unweathered minerals are practically absent. This iron component becomes more and more distinct downwards into the profile as a result of a decreasing organic matter content. There are some phenomena which point to a continuous dissolving and precipitating of the iron compounds in the profile, viz. the desintegration of some ferric nodules and the diffuse boundaries of others and the small amounts of channel neoferrans.

Upwards toward the soil surface these phenomena become less pronounced owing to the fact that the process of homogenization dominates more and more in this direction. Immobilization of iron also takes place in and on charcoal pieces.

Charcoal is present in all profiles distributed over both slides as coarse pieces with a still recognizable wood structure and also finely dispersed through the soil matrix. The highest quantity of charcoal is found in slide K_2-1; this slide shows a charcoal band formed between 3 and 7 cm depth as a result of a superficial soil tillage. This tillage was necessary to remove weeds from the field before cropping.

Clay skins are present in all profiles in certain amounts varying from traces to over 3%. Mainly they are formed in channels below a depth of 15 cm and in the previous xylem vessels of charcoal pieces. These charcoal pieces with clay skins can be found till close to the soil surface.

The mobilization and translocation of clay prior to the forming of clay skins should start just below the soil surface. Besides, this should be a recent or possibly continuous process, since homogenization will fade away old clay skins. The presence of clay skins in charcoal of slide K_2-1 also suggests a translocation of recent data. The charcoal between 3 and 7 cm depth is probably half a year old and at most seven years old. So, one can say clay illuviation is a rapidly proceeding process, in the sense that it gives rise to clearly observable micro-morphological features at short notice. However the amounts of clay involved in the forming of skins may be very small. The total amount of skins in the soil between 15 and 30 cm depth may have been formed during a prolonged period.

On the basis of the studied material nothing can be stated for certain about the origin of the recent clay translocation. However DE BOER (1972) observed the same phenomenon in similar soils in eastern Surinam. From a comparison of profiles under virgin forest and profiles used for shifting cultivation he concluded clay illuviation is an indirect result of clearing and burning the forest. Mobilization of clay antecedent to translocation and illuviation could be caused mechanically viz. by the impact of heavy rainfall on a dry soil; but also chemical changes in soil conditions might play a role viz. an increase of the pH as a result of the addition of ash to the soil.

Among the presently studied profiles a good reference - a profile under virgin forest - to confirm the conclusions of DE BOER is not available. K_6 a profile under secondary forest of more than 100 years old shows clay skins sporadically below 15 cm. The presence of these few skins may be a consequence of a partial destruction of previously greater amounts of skins. This would mean that translocation of clay will stop under a developing secondary forest. But it is also possible that the rate of clay illuviation and forming of skins is less rapid in profile K_6 because of a lighter texture compared with the other profiles. Last mentioned supposition is not backed by data of DE BOER who did not find any relation between texture and amounts of clay skins.

After all it seems likely that shifting cultivation indirectly gives rise to a renewed or accelerated process of clay illuviation in the studied terrace soils. Under virgin forest, i.e. high pH values and alternated wetting and drying of the top soil being absent, this process may have stopped or stabilized at a low rate. Suggesting that shifting cultivation can start clay illuviation in soils which would have been oxisols under virgin forest - as done by DE BOER - seems alien to the concept of oxisols.

Differences in amounts of clay skins between the various profiles can be attributed to a more or less prolonged process of clay illuviation started once or more than once after use of the profile for shifting cultivation.

The conclusions from counting pores are twofold. The proportional distribution of pores with a diameter less than 2 mm appear to be very stable under present land use. On the contrary the total number of pores with a diameter less than 0.5 mm appear to vary between the studied slides. Only differences between K_5 and K_2, and between K_5 and K_3 reach the significance level. These differences stand for a decrease of the number of pores with a diameter less than 0.5 mm in the year following clearing and burning.

This decrease seems to correspond with the decrease in total pore space already concluded from bulkdensity data which are more representative of the plots in question. This compaction of the top soil has been discussed in 6.2.2.1. Although the results of the pore countings suggest that compaction implies a decrease in the number of pores with a diameter less than 0.5 mm probably a decrease in the number of macropores may be more important in this respect. For a slight compaction eliminates these macropores first. Besides changes in the number of macropores volumetrically outweigh changes in the number of pores with a small diameter.

7.3. APPENDIX: MICROMORPHOLOGICAL DESCRIPTIONS OF THE THIN SLIDES

Description of thin section number 75069 (profile K_2, depth 0-15 cm) and number 75070 (profile K_2, 15-30 cm).

Basic structure

Skeleton grains: mainly consisting of quartz with some micas and heavy minerals; most skeleton grains have a low sphericity and an angular to subrounded shape; they occur in a random distribution pattern.

Plasma : consisting of clay, organic matter and iron with an asepic plasmic fabric; the organic matter content decreases with depth.

Voids : biogenetic including channels, vughs, interconnected vughs and compound packing voids.

Special features

Plasma reorientations : skelsepic, glaesepic, channel vosepic and insepic in a weakly striated orientation.

Ferri-argillans: faint ferri-argillans, 5-20(-80) micron in thickness with a sharp outer boundary occur at random from a depth of about 9 cm below the soil surface in channels, but they are also present in the vesicles of charcoal pieces in the layer of 3-7 cm; the quantity between 15-30 cm is $1.6 \pm 0.9\%$ of the soil material.

Matrans : distinct matrans, 5-300 micron in thickness, with a sharp outer boundary are found in charcoal pieces.

Ferrans and neoferrans : few ferrans and neoferrans, 5-20 micron in thickness, with diffuse and irregular boundaries are present in some charcoal pieces.

Papules : derived papules of the above mentioned ferri-argillans occur in a very small quantity.

Pedotubules : few distinct, ortho- and meta-, aggro- and isotubules, 2000-8000 micron in diameter, in a random distribution pattern.

Ferric nodules : few distinct ferric nodules, 20-3000 micron in diameter, subrounded, with a low to high sphericity and sharp boundaries in a random distribution pattern; sometimes they contain quartz grains.

Fecal pellets : common distinct single matric fecal pellets, 50-100 micron in diameter in a clustered distribution pattern common faint welded matric fecal pellets, 50-100 micron on diameter in a clustered distribution pattern distinct single organic fecal pellets, 20-30 micron in diameter, occuring regularly in decaying roots.

Plant remnants :
- fragments of fresh and decaying roots are very common;
- there are many coarse pieces of charcoal mainly in a banded distribution pattern between 3 and 7 cm below the soil surface and much fine grained charcoal is present throughout the 0-30 cm layer.

Description of thin section number 75073 (profile K_5, depth 0-15 cm) and number 75074 (profile K_5, 15-30 cm).

Basic structure

Skeleton grains : mainly consisting of quartz with some micas and heavy minerals; most skeleton grains have a low sphericity and an angular to subrounded shape; they occur in a random distribution pattern.

Plasma : consisting of clay, organic matter and iron with an asepic plasmic fabric; the organic matter content decreases with depth.

Voids : biogenetic including channels, vughs, interconnected vughs and compound packing voids.

Special features

Plasma reorientations : skelsepic, glaesepic, channel vosephic and (in K_5-2) insepic in a weakly striated orientation.

Ferri-argillans : faint to distinct channel ferri-argillans, 5-30 micron in thickness, with a sharp outer boundary; they occur in a random to clustered distribution pattern mainly below a depth of 15 cm; the amount between 15 and 30 cm is $1.3 \pm 0.8\%$ of the soil material; in a minor quantity they are also present in the vesicles of coarse charcoal pieces throughout the 0-30 cm layer.

Matrans : distinct matrans, 30-50 micron in thickness, with a sharp but irregular boundary occur in some charcoal pieces.

Ferrans and neoferrans : few ferrans and neoferrans, 5-50 micron in thickness, with diffuse and irregular boundaries are present in and on coarse charcoal pieces.

Papules : derived papules of the above mentioned ferri-argillans occur in a very small quantity.

Pedotubules : common distinct, ortho- and meta-, aggro- and isotubules, 250-3000 micron in diameter, in a random distribution pattern.

Ferric nodules : common distinct ferric nodules, 20-4000 micron in diameter, subrounded, with a low to high sphericity and sharp boundaries in a random distribution pattern; sometimes they contain quartz grains.

Fecal pellets : many distinct single matric fecal pellets, 20-70 micron in diameter, in a clustered distribution pattern, frequently occuring in channels;
common faint welded matric fecal pellets, 20-100 micron in diameter, in a clustered distribution pattern;
distinct single and welded organic fecal pellets, 20-70 micron in diameter, in a clustered distribution pattern in decaying roots.

Plant remnants : - fragments of fresh and decaying roots are found abundantly throughout both slides;
- coarse pieces of charcoal are scarce and at random distributed, but fine grained charcoal is present in a considerable amount.

Description of thin section number 75071 (profile K_3, depth 0-15 cm) and number 75072 (profile K_3, 15-30 cm).

Basic structure

Skeleton grains : mainly consisting of quartz with some micas and heavy minerals; most skeleton grains have a low sphericity and an angular to subrounded shape; they occur in a random distribution pattern.

Plasma : consisting of clay, organic matter and iron with an asepic plasmic fabric; the organic matter content decreases with depth.

Voids : mainly biogenetic including channels, vughs, interconnected vughs and compound packing voids; craze planes are also found, the quantity becoming larger as depth increases.

Special features

Plasma reorientations : skelsepic, glaesepic, channel vosepic and insepic in a weakly striated orientation.

Ferri-argillans : few faint to distinct ferri-argillans, 5-50 micron in thickness, with a sharp outer boundary, occuring in the vesicles of coarse charcoal pieces in the 0-10 cm layer;
distinct channel ferri-argillans, 10-100 micron in thickness, with a sharp outer boundary, in a random to clustered distribution pattern, mainly present in K_3-2; here the percentage amounts $3.2 \pm 1.3\%$ of the soil material.

Matrans : distinct matrans, 5-70 micron in thickness, with a sharp to faint, irregular boundary occur in most coarse charcoal pieces.

Ferrans and neoferrans : few distinct ferrans and neoferrans, 5-20 micron in thickness, with diffuse and irregular boundaries are found in and on some coarse charcoal pieces.

Papules : derived papules of the above mentioned ferri-argillans are present below 20 cm.

Ferric nodules : common distinct ferric nodules, 20-3000 micron in diameter, subrounded, with a low to high sphericity and sharp boundaries in a random distribution pattern; sometimes they contain quartz grains.

Pedotubules : common distinct, ortho-, aggro- and isotubules, 250-4000 micron in diameter, in a random distribution pattern.

Fecal pellets : distinct single matric fecal pellets, 30-70 micron in diameter, in a clustered distribution pattern, especially abundant in K_3-1;
common welded matric fecal pellets, 30-100 micron in diameter, in a clustered distribution pattern;
distinct single and welded fecal pellets (organic) 20-70 micron in diameter, in a clustered distribution pattern in decaying roots.

Plant remnants :
- fragments of fresh and decaying roots are common in both slides;
- common coarse pieces of charcoal occur mainly in the upper 10 cm with the largest quantity quite near the soil surface;
- much fine grained charcoal is present in K_3-1 and K_3-2.

Description of thin section number 75077 (profile K_7, depth 0-15 cm) and number 75078 (profile K_7, 15-30 cm).

Basic structure

Skeleton grains: mainly consisting of quartz with some micas and heavy minerals; most skeleton grains have a low sphericity and an angular to subrounded shape; they occur in a random distribution pattern.

Plasma : consisting of clay, organic matter and iron with an asepic plasmic fabric; the organic matter content decreases with depth.

Voids : biogenetic including channels, vughs, interconnected vughs and compound packing voids; some craze planes also occur.

Special features

Plasma reorientations : skelsepic, glaesepic, channel vosepic and insepic in a weakly striated orientation.

Ferri-argillans: faint to distinct ferri-argillans, 5-50 micron in thickness, with a sharp to diffuse outer boundary occur regularly in charcoal pieces;
distinct ferri-argillans, 5-100 micron in thickness, with a sharp to diffuse outer boundary, occuring from a depth of 5 cm; the quantity between 15-30 cm is 2.7± 1.3% of the soil material.

Matrans	: distinct matrans, 5-100 micron in thickness, with a sharp to diffuse, irregular boundary, common in charcoal pieces.
Ferrans and neoferrans	: ferrans and neoferrans, 5-20 micron in thickness, with a diffuse boundary are found in and on many charcoal pieces.
Papules	: derived papules on the above mentioned ferri-argillans occur in a small quantity.
Neoferrans and quasi-ferrans	: few channel neoferrans and quasiferrans, 5-30 micron in thickness, with diffuse inner boundaries, in a clustered distribution pattern.
Ferric nodules	: common distinct ferric nodules, 20-4000 micron in diameter, with sharp boundaries, in a random distribution pattern; subrounded, with a low to high sphericity; few distinct ferric nodules, 20-1500 micron in diameter, subrounded, with a low to high sphericity, diffuse boundaries, in a clustered distribution pattern.
Pedotubules	: few distinct, ortho-, aggro- and isotubules, 300-3000 micron in diameter, in a random distribution pattern.
Fecal pellets	: many distinct single matric fecal pellets, 30-50 micron in diameter, in a clustered distribution pattern; common faint welded matric fecal pellets, 30-80 micron in diameter, in a clustered distribution pattern; distinct single and welded organic fecal pellets 30-50 micron in diameter, common in decaying roots.
Plant remnants	: - fragments of fresh and decaying roots are common; - coarse charcoal is present mainly in the upper 10 cm in a random to banded distribution pattern; fine grained charcoal is found throughout both slides in a considerable quantity.

Description of thin section number 75075 (profile K_6, depth 0-15 cm) and number 75076 (profile K_6, 15-30 cm)

<u>Basic structure</u>

Skeleton grains	: mainly consisting of quartz with some micas and heavy minerals; most skeleton grains have a low sphericity and an angular to subrounded shape; they occur in a random distribution pattern.
Plasma	: consisting of clay, organic matter and iron with an asepic plasmic fabric; the organic matter content decreases with depth.
Voids	: biogenetic including channels, vughs, interconnected vughs and compound packing voids.

Special features

Plasma reorientations	: skelsepic, glaesepic, channel vosepic and insepic in a weakly striated orientation.
Ferri-argillans	: distinct ferri-argillans, 10-100 micron in thickness, with a sharp boundary, occur as traces in a clustered distribution pattern below 15 cm.
Ferrans and neoferrans and quasiferrans	: distinct ferrans and neoferrans, 5-200 micron in thickness, with diffuse and irregular boundaries are present in and on charcoal pieces; common distinct channel neoferrans, 5-30 micron in thickness, with a diffuse inner boundary, in a clustered distribution pattern, mainly in K_6-2; few quasiferrans, 5-30 micron in thickness, with a diffuse inner boundary, in a random distribution pattern, mainly in K_6-2.
Papules	: derived papules of the above mentioned ferri-argillans occur in a very small quantity.
Pedotubules	: common faint and distinct, ortho- and meta-, aggro- and isotubules (matric and organic), 400-3000 micron in diameter, in a random distribution pattern.
Ferric nodules	: few distinct ferric nodules, 20-1500 micron in diameter, subrounded, with a low to high sphericity, and sharp boundaries in a random distribution pattern; common distinct ferric nodules, 20-100 micron in diameter, subrounded, with a low to high sphericity, and diffuse boundaries in a random distribution pattern.
Fecal pellets	: common distinct single matric fecal pellets, 30-80 micron in diameter, in a clustered distribution pattern, especially abundant in K_6-1; common faint welded fecal pellets, 30-100 micron in diameter, in a clustered distribution pattern; common distinct single and welded organic fecal pellets, 30-500 micron in diameter, in a clustered distribution pattern.
Plant remnants	: - common fragments of fresh and decaying roots mainly in K_6-1; - very few coarse charcoal pieces but common fine grained charcoal throughout the 0-30 cm layer.

8. SHIFTING CULTIVATION AND PERMANENT AGRICULTURE

Shifting cultivation is an agricultural system with intermittent land use. As a rule a short cultivation period alternates with a prolonged fallow period. During the fallow the original production potential of the ecosystem has to be restored. In permanent agriculture the soil continually provides products which are consumed elsewhere.

To maintain this permanent production a new ecosystem should be formed with the aid of various crops and cultivation methods. The results of a soil fertility research can help to find out an adequate soil use. For this reason some remarks will be made with regard to the agricultural use of the terrace soils.

From the viewpoint of physical soil constitution the use of the terrace soils needs special attention. Under forest a rather good structure can exist but pore space in the top soil between 25 and 35 cm may reach critical values for rootability even under these natural conditions. Therefore these soils appear to be fragile if rooting possibilities of crops after clearing are considered. The pressure of heavy machinery on a moist soil will cause serious compaction in the top soil resulting in a limited root growth of crops, a low infiltration rate, periodically waterlogging, an increased run-off and finally erosion of the top soil. So it is extremely important to carry out mechanical clearing in the right way. If this is neglected the agricultural potential of the soil is lost for many years if not for ever. It is doubtful whether the negative effects of compaction can be removed by soil tillage or the use of crops. VAN DER WEERT & LENSELINK (1973) who studied the influence of mechanical clearing on soil properties and plant growth thoroughly give valuable suggestions about adequate clearing methods:

1) "Clearing operations should be scheduled to rainfall and soil type. Windrowing especially should be done only in the dry season.
2) The windrows should be spaced at a minimum distance, thus reducing the number of passages and hence compaction hazard and top soil removal. For perennials the windrow spacing can be reduced to twice the plantrow distance without seriously affecting the accessibility of the plantation. In that case all plantrows can profitably be situated near windrows because of the better soil structure and nutrient status.
3) Burning should be preferable take place before windrowing. According to MARTIN (1970) the number of motor clock hours per unit area for windrowing reduces significantly when burning takes place before windrowing and when the windrows are spaced at a minimum distance. It is thought that both the better vegetative crop growth and the decrease in operational costs will certainly outweigh the increase in costs for upkeep of the larger number of windrows."

It is self-evident that apart from clearing with heavy machinery other clearing methos should be studied.

From a viewpoint of chemical soil fertility the terrace soils are extremely poor. Especially the available phosphorus content is very low and yiel-limiting. This means that without application of fertilizers permanent agriculture will not be successful. However for an economical use of fertilizers the soil should be able to store plant nutrients temporarily. Now storage capacities depend to a high degree on the content of organic matter in the soil. In the case of fertilizing with phosphorus BRAMS (1973) stated:

"It has been shown that where minimal amounts of inorganic P are used in closely-supervised sites under sustained cultivation, the P associated with organic matter (not necessarily the "organic phosphorus") is relatively inconsequential compared to the contribution of inorganic P from outside sources. It should be carefully noted, however, that much of the positive residual effects of applied inorganic P under sustained cropping are also attributable to the beneficial properties of organic matter; for example, the high ion exchange capacities of this material as well as its chelating properties. These soil parameters are of singular importance to crop production in the leached soils of the humid tropics where exchange capacities are low and P fixation at Al and Fe sesquioxides can be serious yield-limiting factors in many instances."

As the organic carbon content of the terrace soils appears to be rather low it is of special interest to maintain this organic carbon content and if possible to increase it. Since the top soil of the terrace soils has often a light texture organic matter is also important for the water storage capacity. In case of a decreasing organic matter content crops will suffer from drought more frequently.

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