

## GEOMORPHOLOGY, SOILS AND VEGETATION DIFFERENTIATION IN A TROPICAL RAIN FOREST ENVIRONMENT IN SURINAME<sup>1</sup>

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### ABSTRACT

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A landscape model of a tropical rain forest environment is described. The main events of the geomorphological evolution of the study area since the late Tertiary comprise the development of a planation surface during the Miocene followed by deposition of Pliocene continental Upper Coesewijne sediments and subsequent dissection during Quaternary times. Parent material and geomorphology led to the development of Entisols and Ultisols. The occurrence of various subgroups of these orders is closely related to the distribution of the main vegetation formation types, mesophytic semideciduous forest, xeromorphic formations like walaba forest and savanna forest, and mixed mesophytic and walaba forest.

Differences in chemical properties of four representative soils which are all very poor, appear to be small and it is suggested that they cannot be regarded as main causes of the vegetation differentiation in the study area.

Differences in soil physical properties are more pronounced resulting in distinct variations of soil water retention characteristics. Under the given climatic conditions a comparison is made of the water balance of the representative soils. Results suggest that the mean monthly plant-available soil moisture is a major variable in vegetation differentiation, whereas the length of the edaphically dry period is of lesser importance. In relation to the implementation of the Kabalebo storage lakes project these findings imply the necessity for research into the risks of savannisation and increased sediment production.

### INTRODUCTION

A multidisciplinary survey was carried out in the Dalbana-Upper Kabalebo drainage basins in connection with the Kabalebo-project in West Suriname. Without adequate environmental management implementation of the Kabalebo project will produce adverse environmental effects. The basic information, essential for such management is generally provided by a landscape model that describes the relations between landscape components, relief, soils, vegetation and water. In earlier publications (RIEZEBOS & NACHENIUS, 1981; RIEZEBOS ET AL., 1982) parts of the landscape model were described. In the present paper an attempt is made to extend the model and to relate the geomorphology and soil properties to the occurrence of different vegetation formations.

The area under study here is only part of the region that was surveyed in 1980 and 1981 and forms the water-divide be-

tween Dalbana Creek and Corantijn River (Fig. 1). For the major part the water-divide consists of gently undulating plateaus which, mainly on their east flank, have strongly been dissected. The plateaus are formed by continental Pliocene sediments of the Upper Coesewijne Formation. The sediments are underlain by the weathering mantle of Precambrian rocks (mainly granites and granodiorites) which is exposed wherever the Upper Coesewijne Formation is absent (e.g. on lower hills and on slopes).

The climate is seasonal with a mean annual rainfall of about 1800 mm. Mean monthly temperatures range from 26°C in January to 28.5°C in October. According to the Köppen standards the climate is classified as 'Am'.

### GEOMORPHOLOGICAL EVOLUTION

The Precambrian basement in Suriname is part of the Guiana Shield. It is geomorphologically characterized by a cyclic occurrence of planation and dissection (KING ET AL., 1964;

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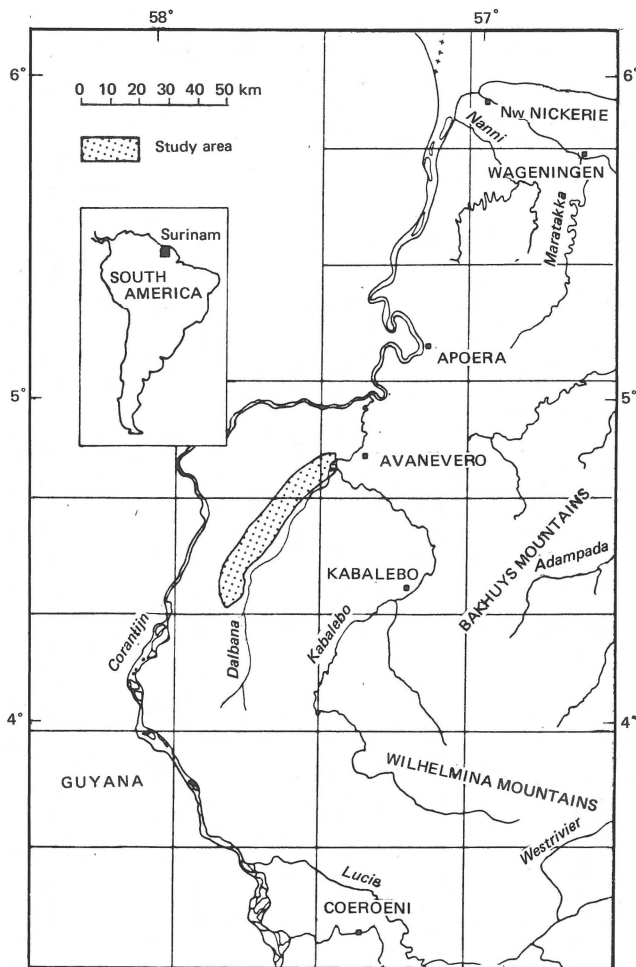


Fig. 1  
Location of the study area in West Suriname.

ZONNEVELD, 1969; 1982). In Suriname three Tertiary planation cycles are recognized. For the present study area the youngest planation level is relevant. The surface is known as the 'Second Late Tertiary Level' (hereafter called LT-2).

Its formation started by the end of the Middle Miocene after regression of the sea. According to KROOK (1979) the main stage of the LT-2 level consisted originally of a surface formed by a system of wide pediments, developed in the intensively weathered regoliths of the Precambrian basement. Locally lateritic duricrusts were formed, remnants of which may still be found. During the Late Miocene the LT-2 surface was eroded and correlative sediments were deposited on the outer shelf (KROOK, 1979). In the Early Pliocene a transgression occurred, followed by a regression and the start of a new erosion phase. The rather coarse (sandy) erosion products were transported over only short distances by braided rivers and deposited as alluvial fans to form the Upper Coesewijne Formation. The continental origin of the Upper Coesewijne sands was already suggested by ZONNEVELD (1951) and confirmed by later observations (VAN DER EYK, 1957; MONTAGNE,

1964; KROOK & MULDER, 1971). The surface on which the Upper Coesewijne Formation was deposited must have been rather flat with a gentle northerly dip (KROOK & MULDER, 1971). The origin of the extensive surface which was formed in the weathering mantle of the Precambrian basement, is still obscure. Quaternary dissection and denudation of the Late Pliocene landscape reduced the extension of the Upper Coesewijne deposits, leaving an east-west running zone of about 70 km wide (in West Suriname). To the south the sediments wedge out against the Basal Complex and in the north they may attain a thickness of 80 m.

In the study area the Upper Coesewijne sediments are mainly present on the Dalbana-Corantijn water-divide and on its western flank, where a lowland relief exists at about 90-120 m a.s.l. The inner parts of plateaus are slightly undulating with a low to very low relief, in contrast to their fringes where the relief increases and slopes steepen. River incision and slope processes stripped the sedimentary cover and exposed the regoliths of the Precambrian basement.

The Upper Coesewijne Formation comprises white sands as well as yellowish brown coloured loamy sands and sandy clay loams. The regoliths of the Precambrian granites consist of reddish to reddish yellow sandy clays and clay loams.

The white and yellowish brown Upper Coesewijne sediments are pedologically related. HEYLIGERS (1963) and KROOK & MULDER (1971) stated that the white sands originated from the more heavy textured yellowish brown deposits through the loss of sesquioxides and clay. The transition between the two is generally less than a few metres wide, the boundary extending almost vertically. SCHULZ (1960) and HEYLIGERS (1963) assume that the distinct vertical boundary is related to an initially only minor textural difference that resulted in vegetation differentiation.

On the lighter textured soils an open stand vegetation, which produces raw humus, may have favoured the leaching of sesquioxides and fine soil particles (clay and silt). Eventually, prolonged leaching accentuated the initial textural difference and the bleached sands were formed.

The regolith of the Precambrian basement is several metres deep. The main weathering process that formed the profiles is desilication. Cations and silica, mobilized by hydrolysis were leached and kandite clay minerals and sesquioxides originated. Desilication results in an absolute impoverishment of silica, alkali and alkaline earth metals and in the residual accumulation of stable weathering products (MOHR ET AL., 1972).

## SOILS

The Upper Coesewijne Formation and the Precambrian Basement soils were both described, sampled and analyzed. Complete data are given by NACHENIUS & RIEZEBOS (1982). For the present study area four representative soil profiles were selected. Their properties are summarized in Table I. Pedon 2

Table 1  
Summary of field and analytical data of four representative soils. (pedon numbers refer to soil profiles in Fig. 2).

	pedon 1			pedon 2			pedon 5			pedon 7			
	0-32	32-100	100-180	0-12	12-100	100-190	0-30	30-55	55-130	0-42	42-62	62-89	89-155
classification	Typic Paleudult			Typic Quartzipsamment			Typic Paleudult			Typic Hapludult			
slope	0°			0°			6°			3°			
drainage	well drained			excessively drained			imperfectly drained			well drained			
colour	10YR <sup>5</sup> /3	10YR <sup>5</sup> /6	10YR <sup>5</sup> /8	10YR <sup>3</sup> /2	10YR <sup>7</sup> /1	7.5Y <sup>8</sup> /1	10YR <sup>5</sup> /3	7.5YR <sup>6</sup> /6	5YR <sup>5</sup> /6	10YR <sup>4</sup> /3	5YR <sup>6</sup> /4	7.5YR <sup>7</sup> /4	10 R <sup>6</sup> /8
colour mottling	-	-	-	-	-	-	-	-	7.5YR <sup>8</sup> /2	-	2.5YR <sup>5</sup> /8	2.5YR <sup>5</sup> /8	10YR <sup>8</sup> /8
particle size distribution (weight %)													
200-2000 μm	59.8	47.6	36.8	86.8	81.7	81.7	51.6	37.8	22.5	41.8	27.9	22.7	26.0
50-200 μm	25.0	24.7	17.3	12.7	17.3	17.3	27.8	23.1	24.4	10.5	6.4	4.1	4.0
20-50 μm	1.3	4.6	10.2	0.1	0.7	0.8	4.9	2.8	10.5	15.0	10.7	11.3	10.0
2-20 μm	0.6	1.5	7.6	0.2	0.2	0.2	2.1	2.4	5.4	12.6	17.2	24.1	30.4
< 2 μm	13.2	21.5	28.1	0.1	0.0	0.0	13.5	33.8	37.2	20.1	37.7	37.8	29.5
pH-H <sub>2</sub> O	4.5	4.5	4.9	4.1	4.2	5.1	4.8	4.7	4.8	4.6	4.1	4.5	4.8
pH KCl	4.4	4.5	4.8	2.9	3.2	5.1	4.2	4.2	4.1	4.4	3.8	3.8	3.7
% C	1.24	0.43	0.26	3.20	0.47	0.11	0.81	0.36	0.21	0.76	0.57	0.45	0.17
% N	0.07	0.02	0.01	0.05	0.01	0.00	0.04	0.02	0.01	0.03	0.04	0.02	0.00
meq.CEC/100g.f.e.	4.00	2.37	2.98	6.72	0.20	0.00	3.07	2.98	3.24	4.28	5.59	6.46	4.80
% Base Saturation	6.0	6.3	6.0	n.a.	n.a.	n.a.	5.4	5.7	4.6	4.7	5.9	6.3	5.8
Exch. Potassium meq./100g.f.e.	0.04	0.03	0.03	n.a.	n.a.	n.a.	0.04	0.04	0.00	0.03	0.04	0.02	0.02

developed in the bleached Upper Coesewijne sands whereas pedon 1 is characteristic for the non-bleached, yellowish brown Upper Coesewijne sandy (clay) loams.

Pedons 5 and 7 developed in the regoliths of Precambrian granite. In the study area the regoliths are exposed where the Upper Coesewijne sediments have been removed as on (moderately) steep hill slopes and some interfluvies.

Soil formation in the Upper Coesewijne deposits varies with parent material characteristics. On the bleached white sands, soils are excessively drained and show only little evidence of development of pedogenic horizons. Their texture is sand which is composed of quartz for more than 95%. The soils are classified as Typic Quartzipsamments (SOIL SURVEY STAFF, 1975). In the non-bleached deposits the pedogenic development is more pronounced. Soils have a textural B-horizon and are well drained. They are classified as Typic Paleudults.

Soil formation in the sandy clay or clay loam regoliths of the Precambrian granites is related to topographic position. The soils on moderately steep to steep slopes have a clay content that increases with depth and they are classified as Typic Paleudults. Locally soils show characteristics associated with periodical water saturation, as in pedon 5 where water, infiltrated in the Coesewijne sediments, seeps out at the contact with the clayey regoliths. At lower inclinations soils have a textural B-horizon below which the clay content decreases again. In the topsoil plinthite concretions are often abundant, pointing to former laterization processes. The well drained soils are classified as Typic Hapludults.

## VEGETATION

Four main vegetation formation types are present in the study area:

- mesophytic rainforest
- creek forest
- walaba forest
- savanna forest.

LINDEMAN (pers. comm., 1982) found the following dominant species for the semideciduous mesophytic rainforest: *Aspidosperma excelsum*, *Swartzia spp.*, *Astrocaryum sciophilum*, *Oenocarpus bacaba* and *Oenocarpus oligocarpa*.

Where the undergrowth of rainforest is dominated by *Astrocaryum sciophilum*, it is called 'boegroemaka forest' instead of rainforest.

Creek forest is dominated by:

*Euterpe oleracea*, *Attalea maripa*, *Pterocarpus officinalis* and *Tabebuia insignis*, and large herbs (*Monocotyledons*).

The dominant species in walaba forest is: *Eperua falcata*.

Savanna forest is dominated by:

*Catostemma fragrans*, *Swartzia bannia*, *Licania incana*, *Matayba opaca*, *Aspidosperma excelsum*, *Couepia cognata*, *Ocotea schomburgkiana* and *Ormosia costulata*.

## THE LANDSCAPE MODEL

Terrain classification and mapping revealed correlations between geomorphology, soils and vegetation formation types (NACHENIUS & RIEZEBOS, 1983; RIEZEBOS ET AL., 1982). Schematically these relations are depicted in Fig. 2. The four representative pedons (1, 2, 5 and 7) are indicated as well as other

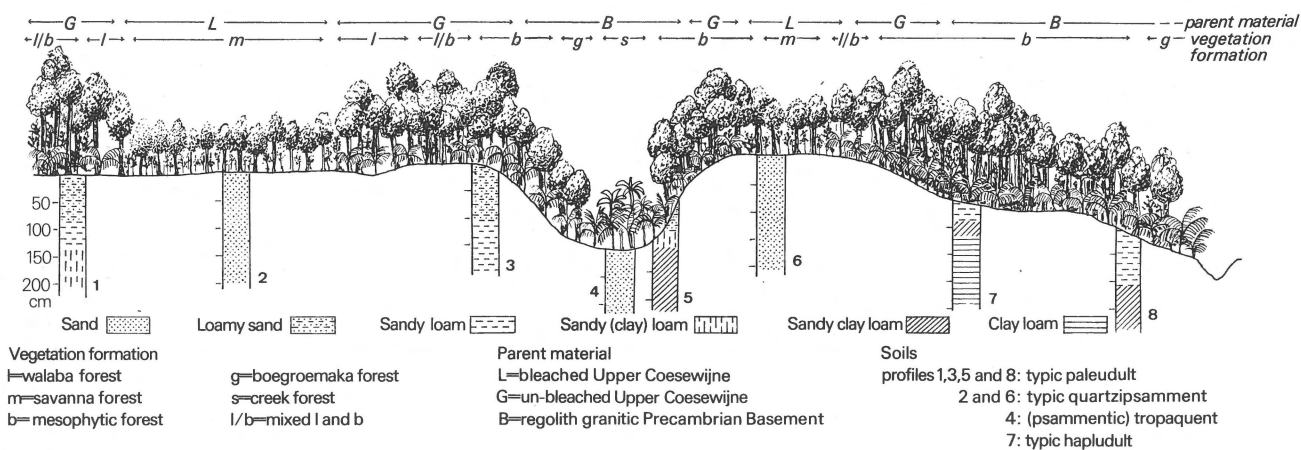


Fig. 2

The landscape model. Outline of generalized relationships between geomorphology, soils and vegetation.

profiles (3, 4, 6 and 8) of which only descriptions and no analytical data were available. Their classification is therefore tentative.

Semi-deciduous mesophytic rainforest is generally present in geomorphological units consisting of undulating, dissected terrain where soils are developed in the weathering mantle of Precambrian granitic rocks. Xeromorphic vegetation formation types (walaba- and savanna forest) occur in geomorphological units where relative relief is low (plateaus and gentle slopes) and soils developed in sediments of the Upper Coesewijne Formation. Assuming that climatological conditions are uniform over the study area, the vegetation differentiation, at least on a geographical scale, is related to geology and the geomorphological evolution as reflected in soil-chemical and -physical properties.

In looking for explanations of the established geomorphology-soil-vegetation relations soil chemical properties of the representative profiles were compared (Table I).

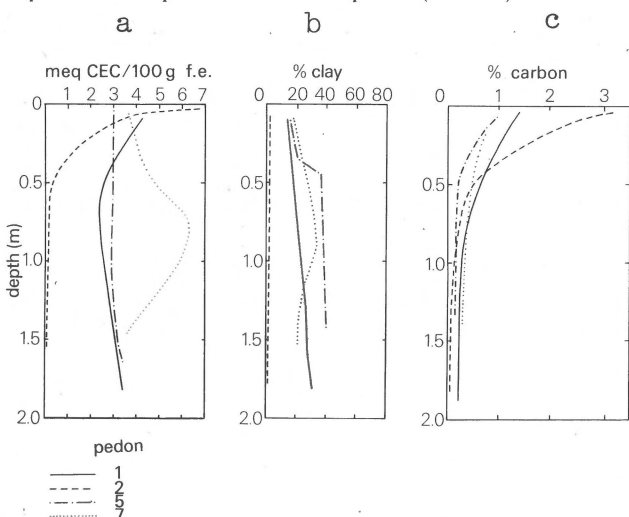


Fig. 3

Cation exchange capacity of the fine earth (f.e), change of clay content, and variation of carbon content, respectively a, b, and c, versus depth in the four representative soils (pedon numbers refer to soil profiles in Fig. 2).

Soil reaction indicated acid conditions for all soils. The pH-values generally increase slightly with depth and differences between profiles are only minor.

CEC-values (Fig. 3a) are low and range from a maximum of almost 7 meq/100 g fine earth in the topsoil (quartzipsamment of profile 2) to zero in the subsoil of the same pedon. In profile 7 a maximum CEC-value is reached in the B-horizon suggesting that contrary to profile 2, CEC in the hapludult is related to clay content (Fig. 3b). In the quartzipsamment clay is nearly absent and the CEC depends on the carbon content (Fig. 3c) which is highest in the topsoil and rapidly decreases with depth.

The values of nitrogen content are extremely low, just like those of exchangeable potassium (Table I). Differences between the profiles regarding nitrogen, potassium and also base saturation are small.

The differentiation between (mesophytic) rain forest and savanna (forest) vegetation has been attributed to the chemical status of soils (LANJOUW, 1936; WAIBEL, 1948). Because of their low fertility soils would not be able to maintain dense rain forest in which case more open and lower savanna forest or even open savanna takes over. SOMBROEK (1966), however, postulated that low natural fertility can be ruled out as a cause of savanna. Most soils under forest have a low base saturation and even soils with extremely low cation exchange capacities often have a rain forest cover. HILLS (1969) stated that whenever nutrient levels are observed which are lower under savanna than under forest, the lower fertility may rather be a result of savanna than a cause.

Another important issue of the soil chemical status in humid tropical regions is that rain forests as well as savanna forests generally depend on a closed nutrient cycle. Mineral cycling follows biotic pathways in which organic soil horizons are most important and mineral soil is largely bypassed. Therefore the available data on soil chemical properties of the representative soils do not permit final conclusions about their explicative relevance. It may, however, be suggested that as far as mineral soil is concerned, the small differences in chemical properties cannot be regarded as main causes of

vegetation differentiation. For comparable areas in northern Suriname SCHULZ (1960) and HEYLIGERS (1963) arrived at similar conclusions.

The soil physical properties that were compared comprise those that are related to soil moisture conditions. Water retention curves of the upper 100 cm zone of the four representative soils were presented by RIEZEBOS ET AL. (1982) and are given in Fig. 4. The soil water capacity and the plant-available soil water differ considerably. The quartzipsamment (profile 2) represents the least favourable soil with a water capacity of only 7% whereas the hapludult of profile 7 has a soil water capacity of 37%.

In the calculations only the upper 100 cm of the profiles is considered, assuming that this depth coincides with the root zone. Furthermore it is assumed that excess soil water is freely drained under the force of gravity until field capacity is attained at  $pF = 2$  and that the wilting point is reached at  $pF = 4.2$ . In addition, the soils are assumed to be in level topographic oppositions, without lateral supply or loss of soil water.

Under these assumptions the potential amount of plant-available soil moisture ranges from 5% by volume for profile 2 to 21% by volume in profile 7 (for 100 cm soil these percentages equal 50 mm and 210 mm water respectively).

An estimate of the mean monthly potential evapotranspiration together with soil water retention characteristics permitted the calculation of the mean monthly water balance (THORNTHWAITE & MATHER, 1957) for the representative soils. All soils were supposed to bear the same hypothetical vegetation cover.

It was shown (RIEZEBOS ET AL., 1982) that in the months February-March and September-December the potential evapotranspiration (PET) exceeds the rainfall (P) and the

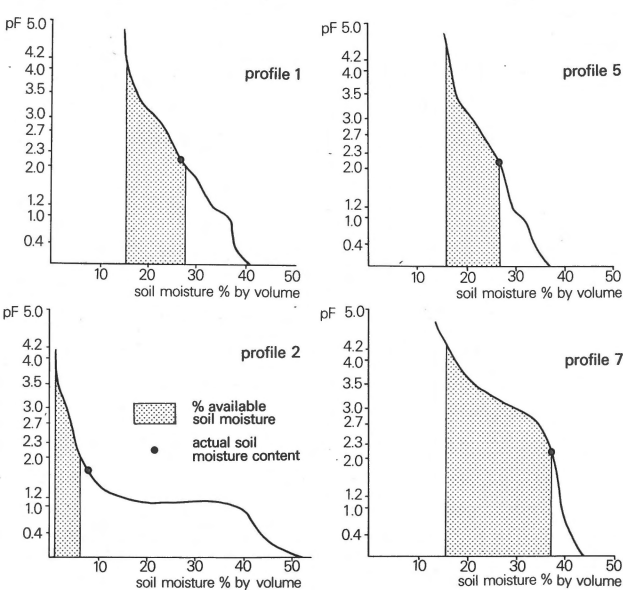


Fig. 4 Water retention characteristics of the four representative soils. (profile numbers refer to Fig. 2).

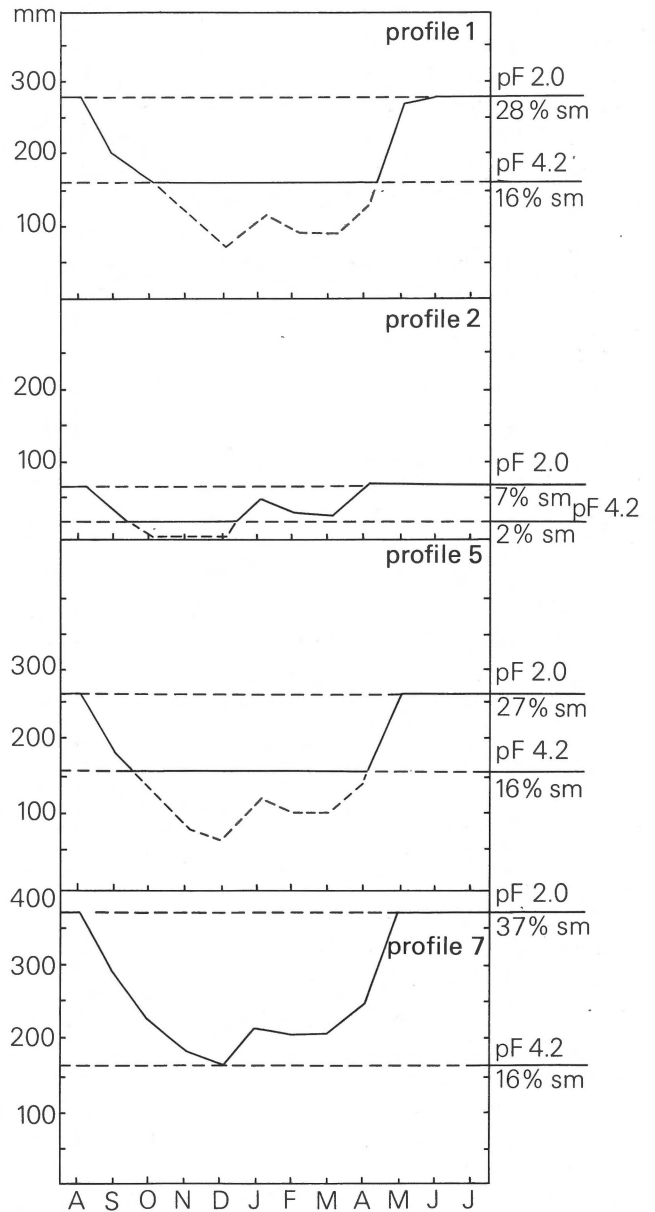


Fig. 5 Mean monthly plant available soil moisture (sm) in the upper 1 cm of the representative soils. (profile numbers refer to Fig. 2).

actual evapotranspiration (AET) is determined by the rainfall and the soil moisture content. During the wet months (January and April-August) the AET equals the PET.

In the dry months the withdrawal of soil water by evapotranspiration (soil moisture utilisation) is different for each of the soils. The outcome of soil moisture utilisation regarding soil water content was calculated for each month, starting at the end of the longest wet season (August) when soils are assumed to be at field capacity. Results are given in Fig. 5.

The most striking difference is between profiles 2 and 7. In profile 2 there is only 50 mm plant-available water in the upper 100 cm in August. This amount is consumed early between September and October. Between December and

January soil water becomes available again, though in small amounts. Under the same climatic and assumed vegetation conditions there is 210 mm water available in profile 7. As soon as this amount has been used (December) the soil is recharged and wilting point is hardly reached. In view of the differences between the profiles regarding the availability and the amounts of soil water it is argued that on soils like the hapludult of profile 7 a relatively denser and more water-consuming vegetation can be sustained than on quartzipsamments like profile 2 (rain forest and savanna forest respectively).

Profiles 1 and 5 appear to be very much alike. In profile 1 the plant-available moisture of 120 mm in August is consumed in October, leaving the soil dry until April. In profile 5 there is initially 110 mm water available which is consumed a little sooner whereas equally until April there is no water available. Yet, the paleudult of profile 1 bears another vegetation type (mixed xeromorphic Walaba forest and rainforest) than the paleudult of profile 5 (rainforest).

The similarity between profiles 1 and 5 regarding moisture availability, however, is deceptive. It is the result of reducing the complex ecological reality to mean monthly available soil water. A reduction like that calls for simplifications and assumptions. One of the assumptions indicated above regarded lateral movement of soil water. A comparison between profile 1, which is in a topographically high and level position, and profile 5, situated on a slope, indicates that profile 5 is likely to have additional lateral water supply. Actually, the field description (Table I) indicates that below 55 cm alternations of oxidation and reduction occur, witness the hydromorphic features (pinkish white mottles in a yellowish red matrix). The additional supply may be considerable in sites like that of profile 5 since it is just below the contact between the highly permeable bleached Upper Coesewijne sands and the less permeable regolith of the Basal complex.

Thus, although not evidenced in Fig. 5, the amounts of available soil water will be larger and the period of water availability will be longer in pedons like profile 5 than in the paleudults of the Upper Coesewijne plateaus. The soil water regime of profile 5 may therefore be considered more favourable for maintaining rain forest than the regime of pedon 1 where rain forest is mixed with xeromorphic walaba forest.

Soil water conditions have frequently been discussed in relation to vegetation differentiation in the humid tropics. Especially with regard to the occurrence of savanna vegetation adjacent to rain forest soil water regime has been considered as a main differentiating factor (RICHARDS, 1952; BEARD, 1953; TRICART, 1965; WALTER, 1971). Generally, soil moisture regimes were expressed in qualitative terms (wet soil and dry soil or excessively dry) but SARMIENTO & MONASTERIO (1975) related the distribution of vegetation formations to soil water stress in contrasting seasons. They introduced wilting point, field capacity and saturation, concepts that can be interpreted quantitatively. On this basis they explained the occurrence of eight vegetation formation types under tropical wet and dry

climates in America. For example, semi-deciduous forest would be present in habitats where soil moisture, expressed in pF units, varies between 4.2 and 2 at the end of the dry season. At the end of the wet season soil moisture should be between soil saturation (pF = 0) and a little more than pF = 2 (SARMIENTO & MONASTERIO, 1975). These data are in accordance with those of the present study area and it is concluded that soil moisture regime expressed as the seasonal variation in pF value is a meaningful criterion for explaining vegetation differentiation.

Apart from the variation of soil water retention, another factor should be considered. In profile 2 (Fig. 5) there are only three months that no soil water would be available which is half of the period that there is no water available in profile 1. In view of the vegetation differences between these pedons this suggests that it is the amount of available water which is decisive rather than the duration of water availability. Through human interference in the area (deforestation, formation of storage lakes) soil moisture regimes may be changed. Forest clearing will not necessarily result in a decrease of evapotranspiration and an increase of plant-available moisture, but where this is the case in landscapes of the Upper Coesewijne Formation a shift may be expected in the vegetation to more dense and less xeromorphic forests. An increase of soil moisture in soils of the Precambrian basement could induce mass movements on steeper slopes. If, for instance due to surface sealing or compaction after deforestation, surface runoff increases and available soil moisture decreases, mixed xeromorphic-mesophytic forest may change into savanna forest or eventually into savanna. At the same time increased surface runoff may produce more soil loss and accelerated reservoir sedimentation.

There are indications in the area that vegetation may respond quickly to environmental changes. Aerial photographs from 1948 show extensive surfaces in the Upper Coesewijne Formation which are bare or have only a thin and low shrub-savanna vegetation. On aerial photographs from 1975 the same areas are completely covered by savanna forest.

## CONCLUSIONS

- Differences between representative soils regarding their chemical properties are small in spite of their divergent evolution. The available data suggest that the chemical difference cannot be regarded as a main explicative factor in vegetation differentiation. Future research should pay attention to the role of organic soil horizons in nutrient cycling and vegetation differentiation in the humid tropics.
- Differences between soils regarding physical properties are great and are related to soil moisture retention.
- Quartzipsamments of the Upper Coesewijne Formation have very low water capacities and plant-available moisture. Hapludults, developed in regoliths of the Precambrian base-

ment have the highest water capacity and available moisture. Paleodults take intermediate positions.

– The different vegetation formation types correspond with different soil moisture regimes, expressed as seasonal variations in plant-available moisture. The length of the edaphically dry period is probably less important for vegetation differentiation.

– In cases of human interference in the area (deforestation, formation of storage lakes, etc.) care should be taken to minimize risks of savannisation in certain landscapes. In other landscapes accelerated erosion and possibly mass movements would increase sediment production and hence sedimentation in the reservoirs.

It is strongly advised to establish the extent of these risks through detailed studies.

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