THE INFLUENCE OF DEFORESTATION ON THE HYDRIC BALANCE OF SOILS IN THE LUBUMBASHI ENVIRONMENT (SHABA, ZAÏRE) (1)

BY

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ABSTRACT. — At the Luiswishi site, in the surroundings of Lubumbashi (Zaïre), on a red ochre zonal soil, three vegetation types are found, belonging to the same succession. Soil moisture was followed during a 15-months period. Comparison of soil water reserves indicated that the substitution of the dry evergreen forest, the ecosystem frequently admitted to be the climax of Upper Shaba, by the woodland produces a clear decrease (64 mm or 5.0% of the mean annual rainfall) for the upper two metres. Moreover this modification is reinforced by the reduction of *Macrotermes* activity, inducing a greater number of abandoned termitaria, a more xeric milieu. Protection of soil by the forest canopy thus appears to outweigh any higher rate of transpiration which might be expected to occur in the dry evergreen forest.

The next step in environmental degradation, the savanization of the biotope, has less impact on soil water reserves but, nevertheless, should be avoided regarding other ecological consequences. Progression of the deforested area around the Upper Shaba mining towns by charcoal and firewood production — today the woodland, for 70 km around Lubumbashi, is threatened with destruction, whilst an area of 30 km radius has already been completely cleared-out — has alarming consequences, notably decrease of biomass production, rise of the mean annual temperature and of the mean daily amplitude.

RÉSUMÉ. — *Influence du déboisement sur le régime hydrique des sols dans la région de Lubumbashi (Shaba, Zaïre).* — Au site de la Luiswishi, dans les environs de Lubumbashi (Zaïre), sur un sol zonal rouge ocre, s'observent trois formations végétales appartenant à la même série évolutive. L'humidité du sol y a été suivie pendant quinze mois. La comparaison des réserves hydriques du sol montre que la substitution de la forêt dense sèche, l'écosystème fréquemment considéré comme le climax du Shaba méridional, par la forêt claire amène une diminution nette (64 mm ou 5,0% des précipitations moyennes annuelles) pour les deux mètres supérieurs. De plus, ce changement se voit renforcé par la diminution d'activité des *Macrotermes*, entraînant un nombre plus élevé de termitières abandonnées, un milieu également plus xérique. La protection du sol par le couvert forestier compense donc le taux plus élevé de transpiration que l'on peut attendre en forêt dense sèche.

(1) Note 57 of the Contribution to the study of the Miombo woodland ecosystem.

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Bull. Soc. Roy. Bot. Belg. **119** : 161-178 (1987). — Communication présentée à la séance du 8 octobre 1986 ; manuscrit déposé le 8 octobre 1986.

L'étape suivante dans la dégradation de l'environnement, la savanisation du milieu, a moins d'impact sur les réserves en eau du sol, mais, néanmoins, est à éviter compte tenu d'autres conséquences écologiques. La progression de la zone déboisée autour des villes minières du Shaba méridional suite à la production de charbon de bois et de bois de feu – aujourd'hui la forêt claire est menacée de destruction sur un territoire s'étendant jusqu'à 70 km de Lubumbashi, tandis qu'une surface d'un rayon de 30 km est déjà totalement déboisée – amène des conséquences alarmantes, notamment une diminution de la biomasse produite et une augmentation de la température moyenne annuelle et de l'amplitude moyenne journalière.

INTRODUCTION

In comparison with other components of the ecosystem, such as leaves, stems (trunks, branches, twigs), roots, litter and animals, the soil and the atmosphere are easily the two main sources of water reserves in land ecosystems.

This is why soil moisture and soil water content have been studied in detail in numerous ecosystems relating from biomes differing as widely as northern coniferous forests, deciduous forests in temperate regions, the Mediterranean sclerophyllous forests, etc. There are fewer studies for tropical regions. We should nonetheless note the research work on rain forests (Mc Ginnis *et al.* 1962, Hill 1972, Huttel 1972, Chaicharus & Chunkao 1973), on woodlands (Strang 1969, Alexandre & Nzengu 1974) and on savannas (Strang 1969, Babalola & Samie 1972, De Villiers 1978, Bate *et al.* 1982).

The woodlands, which cover 2,864,650 km^2 or 9.1% of Africa in the Zambezian region alone, according to the A.E.T.F.A.T. map (White 1981), are found in no less than 8 countries (Angola, Zambia, Mozambique, Tanzania, Zaïre, Zimbabwe, Malawi and Burundi). In the Zambezian Region four main types of woodlands may be recognized, namely:

	area (km^2)	% age of the Zambezian region
Wetter Zambezian miombo woodland	1,239,975	33.35
Drier Zambezian miombo woodland	730,875	19.66
Colophospermum mopane woodland	354,900	9.54
Undifferentiated woodland	538,900	14.49
North Zambezian	(247,500)	(6.65)
South Zambezian	(136,575)	(2.89)

In a general way, woodlands have been little studied.

However, in addition to preliminary remarks on the importance of the water factor in the Lubumbashi area in Upper Shaba (Misson 1950), we do possess a study on the water regime of three soils situated respectively in woodland, in periodically flooded and dried steppe savanna ("dambo") and in the transition zone of these two vegetation types (Alexandre & Nzengu 1974) and a study of the water balance in woodland (Alexandre 1977) but none of these works develops the theme of the extent to which the vegetation cover influences soil water reserves. Such a subject is important for a region in which deforestation is rapidly developing, the radius of peri-urban deforestation increasing by nearly one kilometer per year (Malaisse *et al.* 1980), and already exceeding 30 km. It is moreover a factor in the study and understanding of the regressive evolution of the vegetation cover under human influence in the dry evergreen forest – woodland – wooded savanna succession. The existence of such a succession is a rare occurrence which seems to be exceptional if not absent in other savanna dominated regions (WALKER 1981) and never proceeding beyond a dry thicket physiognomy in Southern African arid savannas (HUNTLEY 1982). In Shaba, nevertheless it is frequently admitted (SCHMITZ 1962, MALAISSE 1982).

THE ENVIRONMENT

The Lubumbashi surroundings are an intermediate plateau of the fold arch of Upper Shaba, varying in altitude between 1,200 and 1,350 metres. The climate is tropical, of the Cw type according to Köppen. It is characterized by a rainy season (November to March), a dry season (May to September) and two transition months (October and April). The dry season lasts an average of 186 days and only receives 35 mm rain ; average rainfall reaches 1,270 mm, but large between year differences occur (716 to 1758 mm) (MALAISSE 1978b). Rainfall, rain variability and daily precipitation regime have been studied in detail (MALAISSE *et al.* 1978, HARJOABA & MALAISSE 1978, KALOMBO 1979, SOYER & NTOMBI 1982). Half the daily precipitations are less than 5 mm, but these represent less than 10 per cent of the total volume of rainfall ; heavy rainfalls over 50 mm represent only 7.8%, the 15-20 mm class being the mode. The average temperature is around 20°C. The lowest temperatures, around 4°C, occur at the beginning of the dry season, i.e. from May to mid July. The months of October and sometimes November are the hottest, with a maximum daily temperature reaching 31 to 33°C.

Samples were taken at two sites in the surrounding of Lubumbashi, notably Kasapa (11° 36' 38" S, 27° 28' 47" E, alt. 1245 m) and Luiswishi (11° 29' 05" S, 27° 36' 10" E, alt. 1208 m). At Luiswishi site, on a red ochre zonal soil of clay texture belonging to the Kaponda series (SYS & SCHMITZ 1959) three vegetation types are found. These belong to the same evolutive series representing the results of increasing anthropic pressure and being those of dry evergreen forest-woodland-wooded savanna. The dry evergreen forest is closed, dense, multilayered, most of the trees in the upper layer loosing their leaves briefly. The period of defoliation does not coincide for the various deciduous species. The undergrowth is evergreen and the grass layer almost entirely composed of seedlings. The basal area is around 33 $m^2.ha^{-1}$ and the leaf area index (L.A.I.) varies from 5.0 (mid December) to 2.6 (beginning of October) (MALAISSE & COLONVAL-ELENKOV 1981a, MALAISSE 1984). The woodland, which today covers 85% of the region surrounding Lubumbashi is of mixed formation type, with a grass layer surmounted by a tree stratum with nearly interlocking foliage, mainly umbrella types, with light covering, the whole being open and airy. The basal area is around 19 $m^2.ha^{-1}$ and the L.A.I. varies from 3.2 (beginning of December) to 0.8 (beginning of September) (MALAISSE 1986). The wooded savanna forms a continuous dense grass layer at the end of the rainy season, dominated by *Loudetia simplex.* It is overshadowed locally by trees and shrubs whose basal area is around 3.5 $m^2.ha^{-1}$. These three ecosystems of the same regressive series show sharp differences in their main ecological characteristics : air and soil temperatures, relative humidity of the air, basal area, L.A.I. of the woody and grass layers, biomass and species composition, etc. (FRESON *et al.* 1974, MALAISSE 1973, 1982, 1986).

The Kasapa site is a woodland dominated by *Julbernardia paniculata, Brachystegia spiciformis* and *B. boehmii*; hence it is a "miombo". High termitaria which may reach 6-7 metres in height are scattered through the area at a density of 4 per hectare. The vegetation of the termite mounds has been described in detail elsewhere (Malaisse 1978a, Malaisse & Anastassiou-Socquet 1983). Data taken at Kasapa deal with these high termitaria and the soil between them in woodland. We attempt to distinguish the main features of these two sub-ecosystems. The soil is deep, drained, generally gritty, red clay. The subfoundation is made up of carbonate rocks (Alexandre & Nzengu 1974).

METHODS

Soil granulometry

Soil samples are oven dried at 105°C. They are then sifted under water through a 50 µm mesh screen. Those equal or superior to 5 µm, undergo dry sifting by shaking for 10 minutes. Those less than 5 µm undergo sedimentation in an Atterberg column. Each value is the mean of three samplings.

Soil density

Soil density was established by using Kubiena boxes (Kubiena 1953) and taking the sample from the profile wall at selected depths.

Soil moisture

Soil moisture (w) was determined by the traditional thermogravimetric method after oven drying at 105°C for 72 hours (Rawlins 1976). It is expressed as a percentage of dry soil weight. Samples weighing an average of 150 g were taken by drilling at depths of 10, 25, 50, 75, 100, 125, 150, 175 and 200 cm in Luiswishi site, and at 25, 50, 75 and 100 cm in Kasapa site. Since no previous studies were available, the problem of sample frequency and density was arbitrarily solved in the following manner : drilling every week (Kasapa) or every month (Luiswishi) in a circular area of approximately 75 m^2 or half way up a single high termite mound perpendicularly to the slope. The results are the mean of two samplings ; they are set out in a hydric diagram : ordinate depths, time on the x-axis and humidity in isoplethes from interpolation. Furthermore, observations on soil humidity in the upper 5 centimetres were made in woodland at Kasapa from the end of November to the end of April, i.e. during virtually the entire rainy season and the onset of the dry season. Five samples were taken everyday, always between 9 and 10 o'clock.

RESULTS

Figure 1 summarizes original data obtained regarding soil granulometry in Kasapa site, and results already published by Goffinet (1975) for Luiswishi site. Table 1 reports the different soil densities noted. Values varied from 1.11 to 1.47. These values correspond to those published by Alexandre & Nzengu (1974), which, for three soil types in the

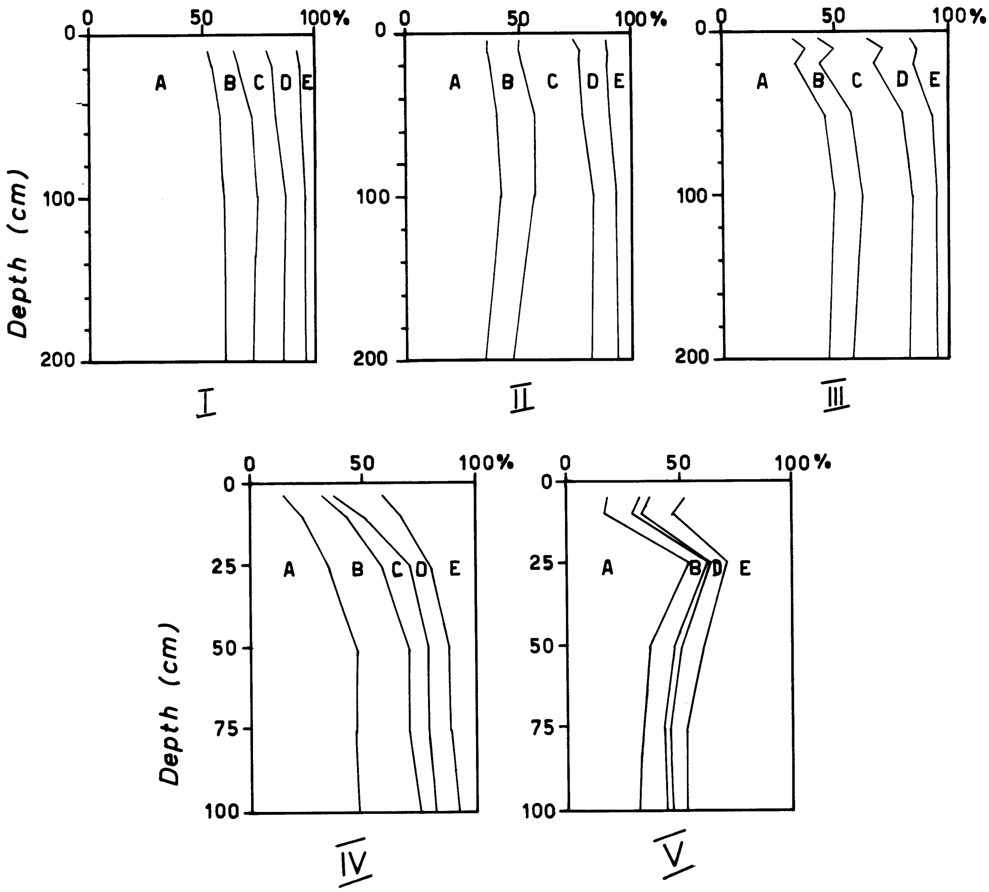


FIG. 1. — Soil texture at Luiswishi site (I. — Dry evergreen forest, II. — Woodland, III. — Wooded savanna) and at Kasapa site (IV. — Woodland, V. — High termite hill). Values in percentage, A : clay (< 2 µm), B : fine silt (2 to 20 µm), C : coarse silt (20 to 50 µm), D : fine sand (50 to 250 µm) and E : coarse sand (0.25 to 2 mm). Data for Luiswishi site are after Goffinet (1975), for Kasapa site original.

TABLE 1

Soil density at diverse depths at the studied sites

Kasapa site								
Depth (cm)	- 10	- 25	- 50	- 75	- 100			
Woodland	1.299	1.216	1.234	1.206	1.111			
Termite mound	1.158	1.312	1.426	1.387	1.158			
Luiswishi site								
Depth (cm)	- 10	- 25	- 50	- 75	- 100	- 125	- 150	- 175
Vegetation type								
Dry evergreen forest	1.138	1.199	1.412	1.226	1.278	1.321	1.236	1.373
Woodland	1.251	1.255	1.395	1.327	1.445	1.428	1.354	1.265
Wooded savanna	1.284	1.250	1.466	1.253	1.375	1.282	1.279	1.244

Lubumbashi environment, gave results between 1.22 and 1.33. For termite mounds, ALONI *et al.* (1981) noted values between 1.38 and 1.72. Our value of 1.29 is slightly lower. The soil density of termite mounds increases with depth, the filled in layers having the highest density (ALONI *et al.* 1981).

Figure 2 and 4 show hydric diagrams obtained in the Kasapa and Luiswishi sites. In both sites and at the 5 stations studied, the upper layer hydration (0-10 cm at Luiswishi, 0-25 cm

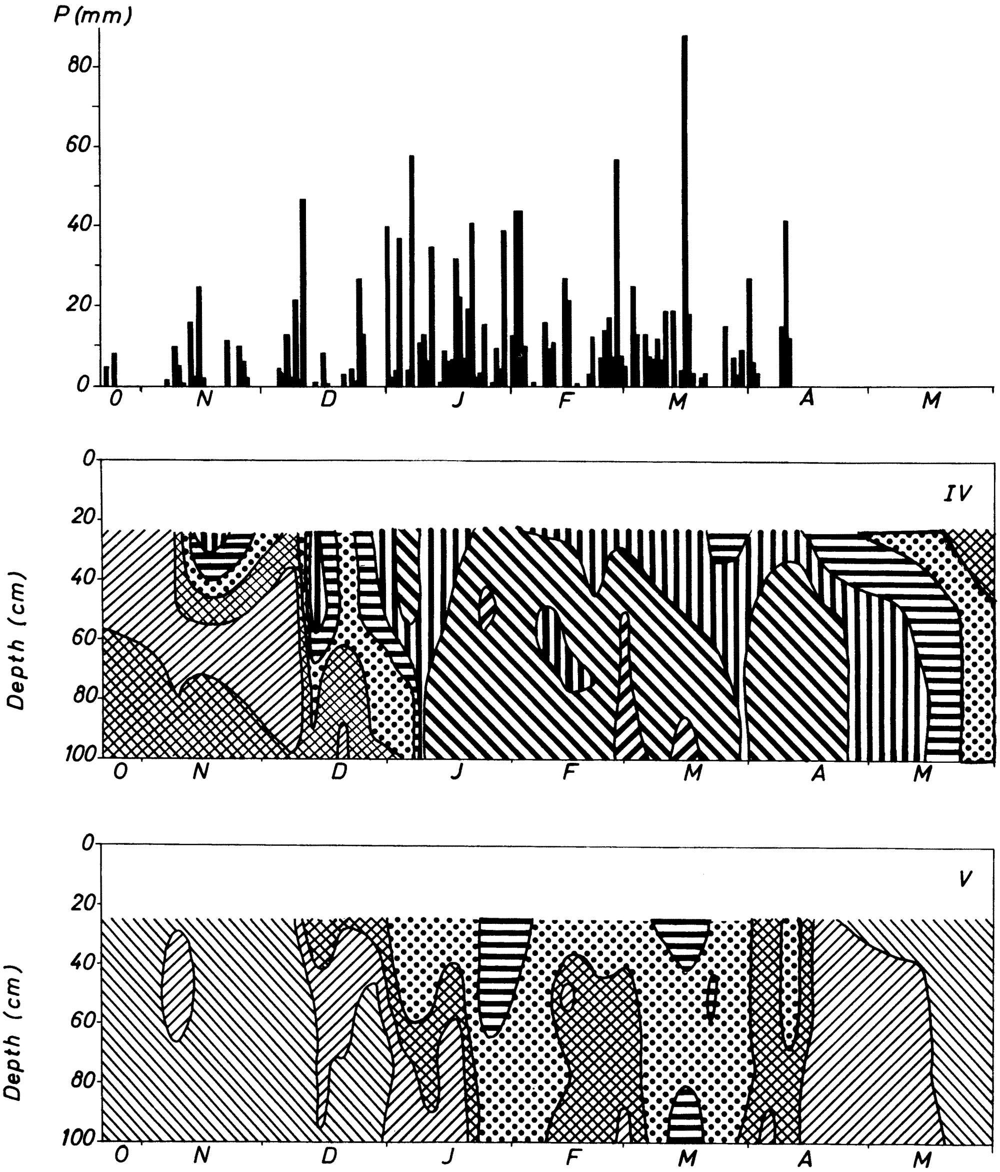


FIG. 2. — Daily precipitations (mm) and soil moisture (%) of two soils in a "miombo" type woodland at Kasapa site (period 20.10.1976 to 31.5.1977). The two soils are : IV. — Site situated between high termitaria, V. — High termite hill.

at Kasapa) is not noted. Observations on soil hydration in the top 5 centimetres (Fig. 3) show that the hydration of the upper soil layer may vary considerably from day to day. A heavy rainfall causes a brutal rise in hydration whilst several hours of sunshine promote soil drying both through evaporation and percolation. Daily variations of 15% are not exceptional. For this reason the upper layer hydration has not been noted in the graphs.

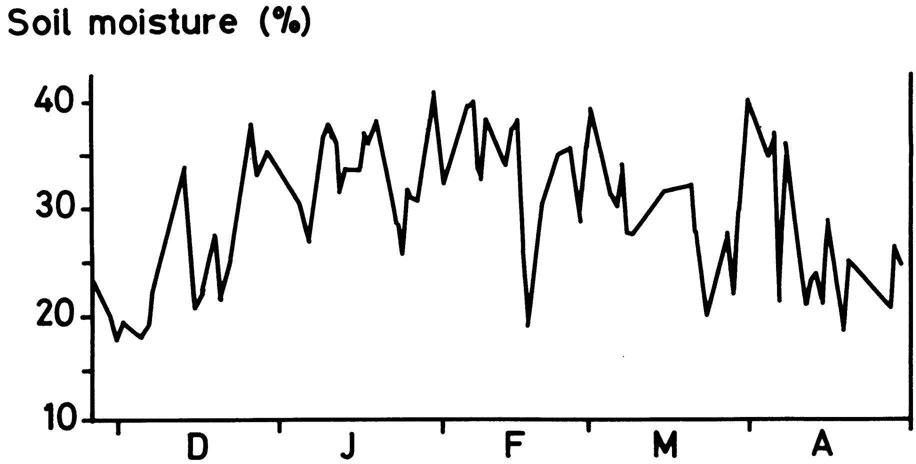


FIG. 3. – Daily variation of surface soil moisture (0-5 cm depth) in woodland at Kasapa site (period from 26.11.1976 to 29.04.1977).

In general, figures 2 and 4 show variations similar to those already noted by ALEXANDRE & NZENGU (1974) for soils in Shaba, viz.: progressive drying out beginning mostly in April, and relatively rapid wetting in November-December, followed by a humid period with many fluctuations. The comparison of different stations on the same site allow other deductions to be made.

At Luiswishi, the dry evergreen forest diagram differs sharply from those of the other two vegetation types. Hence the upper part of the cross-section shows high hydration all year round. For example in the upper 25 cm, rainy season hydration varies between 32.5 and 40%, and even in the dry season it is still greater than 15%, whereas in woodland and wooded savanna it borders on or is less than 10%. Deeper these differences still exist but are less pronounced. At 175 cm depth, for example, annual hydration averages are 22.0, 18.5 and 20.8% respectively for dry evergreen forest, woodland and wooded savanna.

As far as the woodland and the wooded savanna are concerned, the two hydric diagrams are almost identical, except below 150 depth, where the savanna shows values of around 2.5% higher than the woodland.

At Kasapa, in woodland, high termitaria soil is always dryer than that between the mounds. Differences during the rainy season are around 6.4% for the cross-section as a whole. They rise with increase in depth, from 4.7% at 25 cm depth to 7.4% at 100 cm. This would seem to prove that high termitaria are a more xeric environment than the surrounding woodland.

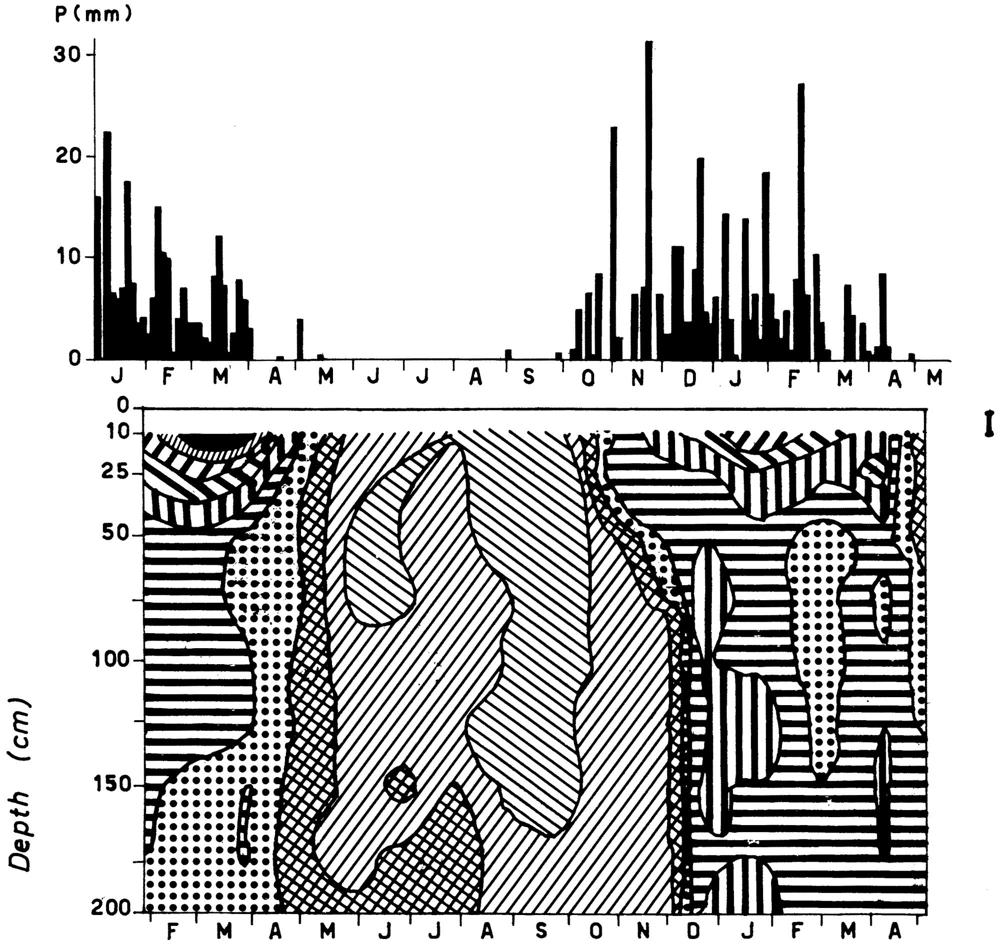
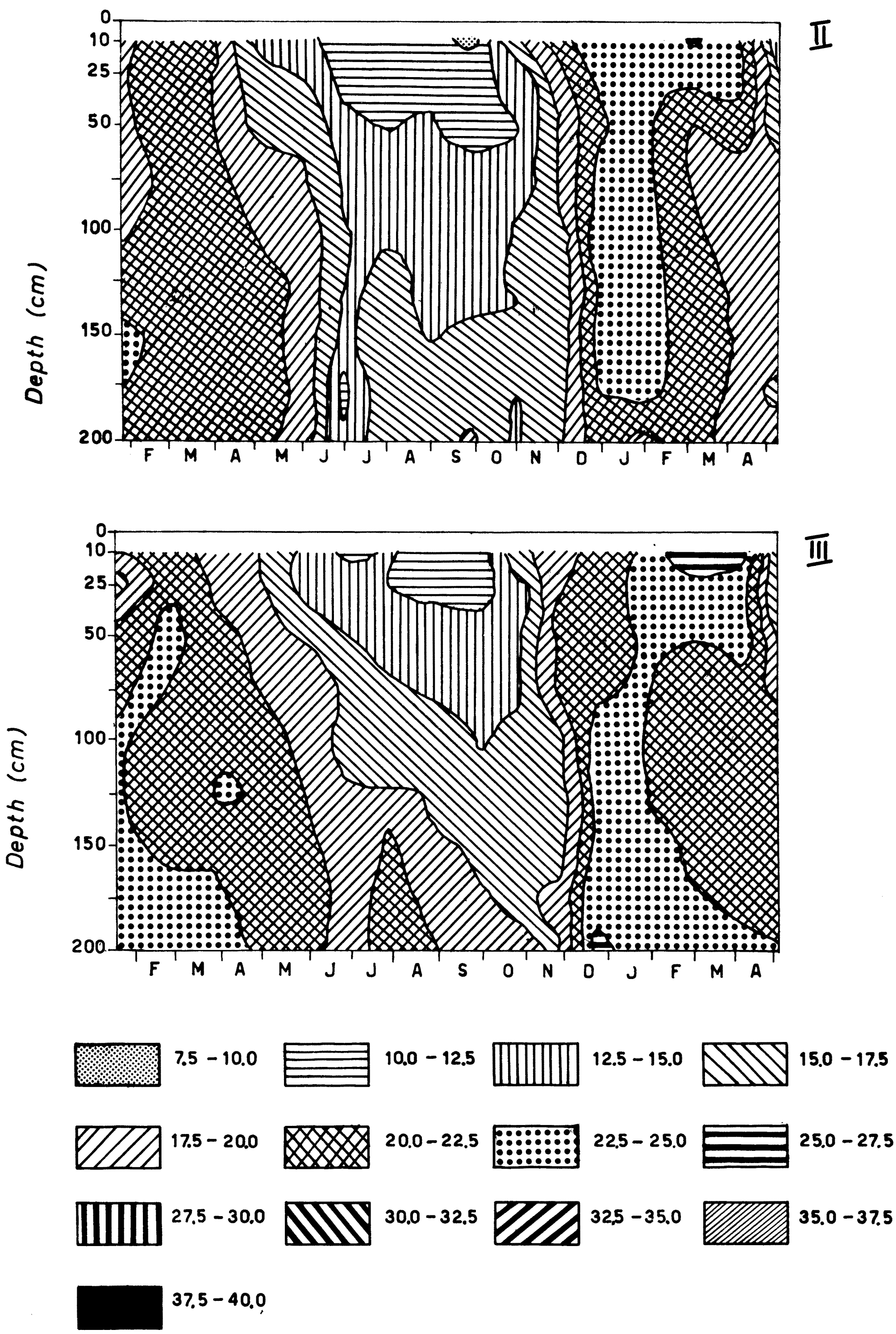


FIG. 4. — Average precipitation per 3 day period at Lubumbashi (mm. day^{-1}), soil moisture (%) at Luiswishi site (period 28.1.1972 to 7.5.1973). The three types studied are : I. — Dry evergreen forest, II. — Woodland, III. — Wooded savanna.

DISCUSSION

In a single phytogeographical area, environmental factors control the distribution of the different vegetation types or rather of the different ecosystems. In this respect soil properties such as nutrient status, pH, salinity and texture play an essential role, but the overwhelmingly important factor determining the special distribution of forest, savanna and grassland in Southern Africa is soil moisture balance (TINLEY 1982). Unfortunately data on the water factor in general, and on the soil water reserves have rarely been established over a whole year of observation ; studies dealing with the soil water reserves of the various vegetation types in the same area are even rarer. From this point of view the work of AVENARD (1967) made in


II
Depth (cm)
0
10
25
50
100
150
200
F M A M J J A S O N D J F M A
III
Depth (cm)
0
10
25
50
100
150
200
F M A M J J A S O N D J F M A
7.5 – 10.0
10.0 – 12.5
12.5 – 15.0
15.0 – 17.5
17.5 – 20.0
20.0 – 22.5
22.5 – 25.0
25.0 – 27.5
27.5 – 30.0
30.0 – 32.5
32.5 – 35.0
35.0 – 37.5
37.5 – 40.0

the forest-savanna contact zone of the Ivory Coast is particularly instructive. He singles out three main types of hydric graph, which he defines as follows :

a. more or less constant humidity through the year according to depth (bands of equal humidity parallel to the soil surface) ;
b. vertical variation of humidity through the year, i.e. frequent variations at the same depth (bands of equal humidity perpendicular to the soil surface) ;
c. irregular variation in time and depth, humid patches being randomly scattered throughout the section.

The same author considers that these types are mainly linked to the soil texture, sandy soils giving type b. In clay soils he recognises a trend towards type b in savanna and towards types a and c in semi-deciduous dense forest. These conclusions show that, in the same phytogeographical territory, different vegetation types either correspond to or induce different soil humidity patterns.

In Central Mozambique, miombo savanna occurs on excessively drained soils, of less than 50 cm depth, while, on deeper soils, the miombo is invaded by thickets of forest components (Tinley 1982). In South-Central Africa, the woodlands dominated by *Brachystegia, Isoberlinia* and *Julbernardia* trees occupy the plateaux which are virtually coincident with the Tertiary planation surfaces and are characterized by ferrallitic soils ; differences in their composition are related to differences of soil and drainage (Cole 1982).

At Luiswishi, the seasonal differences in soil water reserves for the three vegetation types studied are the result of various, sometimes conflicting tendencies, which distinguish these ecosystems. In fact, the only common factor the three Luiswishi ecosystems possess is the same input of water in the form of rainfall. Even at this stage, they are differentiated by the rainfall interception by tree and grass layers. Tree and shrub layers interception diminishes from the most woody ecosystem to the more open wooded savanna (Freson *et al.* 1974). But these differences are partially compensated by the grass layer interception for which measures are being calculated, and which is virtually nil in dense evergreen forest and maximal in wooded savanna. The varying importance of the litter also causes different interception ; litter reduces or at least retards the surface drainage, a widely recognized benefit (Doley 1981). At Luiswishi, litter is practically non-existent in savanna, reaches its maximum values in woodland after fire passage (in September) and in dense evergreen forest just after the beginning of the rainy season (October). These maximum values are of 9.8, 217.1 and 333.5 $g.m^{-2}$ dry weight (Malaisse unpubl. data) for wooded savanna, woodland and dry evergreen forest respectively. Water input at soil level thus varies greatly according to vegetation type. At this level, water losses are due to evaporation from the soil, transpiration, deep percolation beyond the reach of plants and the depth of the water table. Let us review some of these various components of the water balance-sheet.

Some estimations of interception in woodlands are available. De Villiers (1978) reported canopy interception to be 17-21% of the rainfall in *Burkea africana* wooded savanna at Nysvley (South Africa). Malaisse (1978b) for a miombo woodland at Kasapa (Zaïre) observed values of 19.0% for tree and shrub canopy interception, Freson *et al.* (1974) 21.2% for a *Marquesia* woodland at Luiswishi ; whilst in dry evergreen forest this reaches 42.3%.

Where dense forest cover develops, the water content of the soil is often high throughout the year, and reduction of water content, during short dry periods, is more uniform with depth

(Avenard 1971, Hill 1972, Chaicharus & Chunkao 1973, Fournier 1979). On the other hand, for many vegetation types which develop under lower rainfall, changes in water content near the soil surface are very rapid after cessation of rain (Medina 1982), particularly where direct solar radiation reaches the ground. This was observed repeatedly in a subequatorial evergreen forest of the Ivory Coast (Bernhardt-Reversat *et al.* 1972), in a tropical dry forest of Costa Rica (Reich & Borchert 1984), in a mixed conifer forest of California (Arkley 1981) and in a short-grass steppe of Colorado (Sala *et al.* 1981). Woodland and wooded savanna figures agree perfectly with this typical hydric behaviour of tropical climates soil with a long dry season.

With the onset of the wet season, percolating water produced a clear wet front which penetrated rapidly. Babalola & Samie (1972) observed this penetration to reach 406 cm depth beneath *Isoberlinia doka* woodland in the northern Guinea savanna zone of Nigeria. At Luiswishi, this penetration reaches two metres depth in a few weeks. Thus the more superficial horizons are the most sensitive ones, wetting and drying quickly at the beginning and end of the rainy season as underlined by San José & Medina (1975) for a lowland savanna ("llanos") at Calabozo, Venezuela.

It is generally admitted that the extraction patterns of soil moisture by different vegetation types reflect root distribution (Doley 1981) ; but this last aspect has rarely been studied in detail. Moreover, little information has been published regarding the relative importance of the grass layer and the woody layers evapotranspiration. In Madagascar, in a *Uapaca bojeri* woodland, the shrubby vegetation has a higher evapotranspiration than the grass layer (Cornet 1977). For the Ibadan surroundings, Lal & Cummings (1979) have observed that subsoil horizons have a lower moisture content for a lowland rain forest than in clearings, reflecting moisture extraction by tree roots from deeper layers. At Luiswishi, the woody layers of the woodland dry out the soil at greater depth than the mainly herbaceous vegetation of the wooded savanna (Fig. 5). But evidence suggests that water use by trees extends to depths considerably deeper than the 200 cm sampled, as already noted elsewhere (Arkley 1981). For instance tree and shrub pre-rain development appears to depend on moisture stored at considerable depth. For miombo trees, Savory (1963) and Malaisse (1986) have established that one or several tap-roots may reach far lower than 5 metres depth.

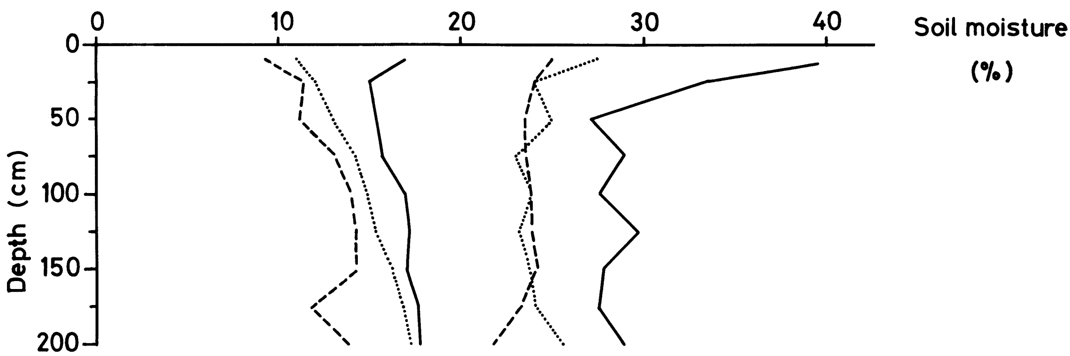


Fig. 5. – Extreme soil moisture (%) observed at different depths at Luiswishi site (dry evergreen forest : –, woodland : ---, wooded savanna : . . .).

At Luiswishi, available soil moistures stored in the upper 2 metres ranged from 429 mm to as high as 699 mm for dry evergreen forest. These extremes are respectively of 372 and 629 mm for woodland and of 386 and 617 mm for wooded savanna. Differences between minimal and maximal soil moisture values on all sites are between 37-41%, but the amount lost decreases from the most woody biotope to the more open ecosystem. Moreover water loss decreases with depth, being for example, 83, 69, 64 and 41 mm respectively for depth slices of 10-50, 50-100, 100-150 and 150-200 cm in the woodland. This agree with RAWITSCHER (1948) observations on a woody savanna ("cerrado") in Emas, state of São Paulo. He found that, during the dry months, the soil moisture variations were dampened and disappear completely at lower levels. BERNHARDT-REVERSAT *et al.* (1972) also noted that in the subequatorial rain forest of the Ivory Coast, water reserves diminish by half in the upper 100 cm during the short dry season and only by 24% at 130-230 cm depth.

Thus dry evergreen forest presents higher soil moisture values than woodland or wooded savanna. HOPKINS (1966) also observed, during the dry season, higher values under moist semi-deciduous forest than under derived savanna woodland in the Olokemeji Forest Reserve of Nigeria. Similarly GHOSH & SUBBARAO (1979) and GUPTA (1980) have reported from India that soil moisture remains at a higher level under forest than under grass. Protection of soil moisture by the forest canopy thus appears to outweigh any higher rate of transpiration which might be expected to occur from the forest community (HOPKINS 1966).

Dry evergreen forest also contrasts with woodland in the large number of perennial shrubs and trees requiring a continuous supply of water for survival. Therefore dry evergreen forest should be associated with locations where soil depth and texture permit water accumulation in the profile and its availability to plants roots all year round.

The hydric diagrams of the Luiswishi woodland and that of the savanna are almost identical. This is easily explained. In both types, the upper 50 cm soil layer contains virtually the entire root system of the grass layer. The above-ground biomass of the savanna grass layer is greater than that of the woodland, for example 417 as against 148 $g.m^{-2}$ dry weight in March at the end of the rainy season, but the mainly horizontal root systems of woodland trees complement the rootlets of the grass layer in such a way that the resulting hydration is similar. On the other hand, in depth, the higher tree density in woodland – 3 to 5 times the number of stems – brings about higher water depletion through the main vertical roots that may reach several metres in depth. ASKEW *et al.* (1971) have also noted that the woody savanna ("cerrado") presents more marked desiccation that the grassy savanna ("campo") during the dry season in the Serra do Roncador (Mato Grosso, Brazil). Likewise observations carried out by SARMIENTO & VERA (1977) in the variation in the water content of the soils of four savannas and two tropical forests in the region of the llanos of Barinas (Venezuela) indicates that the semi-deciduous forest dries out the soil at greater depth that the neighbouring savanna of Boconoito (SARMIENTO 1984).

Woodland and wooded savanna are yearly the subject of fire injuries. Fire plays an important role. It markedly reduces soil moisture content (GILLON 1983), as a result of increasing direct solar radiation ; thus the wilting point is reached more rapidly (ATHIAS *et al.* 1975). ALEXANDRE & NZENGU (1974) have observed that fire is followed up by a sudden slow down of the evaporation, whilst other authors consider that undoubtedly fire induces primarily an increasing evapotranspiration resulting from the burnt herbaceous grass layer being stimulated to grow rapidly (West 1971, Troloppe 1982). Comparison of soil moisture made by Gandar (1982) in burnt and unburnt plots of an open grass veld at Nysvley indicates differences only at 30 and 45 cm depth, where the moisture content of soils under the burnt plots was between 5 and 50% lower.

As far as wooded savanna is concerned, our observations suggest several remarks. The grass layer is mainly formed of perennial plants within which should be distinguished tufted grasses from geoxylic suffrutices. Geoxylic suffrutices apparently represent a case of convergent evolution caused by a common driving force which is, however, difficult to be sorted out. Savanna plants grow under pressure of various stress factors all of which may have very strong selective effects : seasonal drought, burning, excessive heat, soil poverty and overgrazing (Medwecka-Kornaś 1980). The root system of the geoxylic suffrutices is mainly horizontal and presents few sinking roots, so that they compete with the tufted grasses for water supply. However White (1977) has pointed out that, in the Zambezian region, geoxylic suffrutices produce shoot growth earlier in the growing season that the grasses, and thereby escape the competition for light and the diminishing water supply. Coutinho (1982) considers that the underground woody organs should not be considered as water reservoir organs but as mineral nutrient storage organs. At Luiswishi, it has been shown that some geoxylic suffrutices possess underground organs which accumulate important water reserves. This is notably the case for most of the Vitaceae, whose tuberous roots contain 700% of water at the end of the dry season versus 1450% in the main rainy season (Malaisse & Colonval-Elenkov 1981b).

Comparison of soil water reserves in high termitaria and in surrounding woodland gives several facts. Firstly the nature of the studied termite mound should be specified, since several classification systems exist (Fanshawe 1969, Ruelle 1969, Aloni 1975, Malaisse & Anastassiou-Socquet 1977). Our observations relate to a high termite mound built by *Macrotermes falciger*, in a secondary active stage (Malaisse & Anastassiou-Socquet 1977), developed in Miombo woodland (Fanshawe 1969), on red-ochre clay soils (Aloni 1975).

Our results indicate that high termitaria are a more xeric milieu than the surrounding woodland. Observations carried out by Watson (1969) on two termite mounds in Zimbabwe indicate that they are subjected to less leaching than the surrounding soils, possibly because run-off from the steeply sloping termitaria is greater than from the land surrounding the mounds. This theory was also supported by Diniz & Aguiar (1972), and explains the existence of a drier cone in the centre of the mound.

It has been noted that in Upper Shaba the whole root system of termitaria vegetation is contained in an exterior envelope one metre thick, most being located in the layer 10 to 20 cm depth ; the outer 40 cm contained about 80 per cent of the dry weight of the roots (Malaisse 1978a) ; whilst Aloni (1975) reported that a study of radial cuttings showed a dense layer of roots with a depth of about 60 cm.

The "secondary active termitaria" stage indicates limited activity by termites other than the construction species and therefore the lack of significant humidity contribution at depth by termites. Moreover, as Schmitz (1971) notes termite mounds have a high evaporation surface. This ensemble of characteristics creates more xeric conditions. In fact several authors (Wild 1952, Duvigneaud 1958, 1960) have noted a xerophilic tendency of the termitaria flora. However, Malaisse (1976) considers that the termitaria flora is composed of a mosaic of ecological groups, among which xerophilic and eutrophic tendencies dominate.

The concentration of water at the base of the stem through stemflow of intercepted precipitation has been reported as an important factor in the water relations of *Balanites aegyptiaca* (GLOVER *et al.* 1962). Even if Glover's observation deals with more dry conditions than Upper Shaba, it should be reminded as this tree is a tropical miombo high termite hill inhabitant.

In conclusion, dry evergreen forest, the ecosystem frequently admitted to be the climax vegetation in Upper Shaba, is the terrestrial ecosystem presenting the best water balance, with relatively important soil water reserves all the year round. With the opening of the canopy by human effects (clearing and annual burning) several modifications occur which all induce more xeric soil conditions : pronounced desiccation of the atmosphere near the soil surface, surface and depth drying up of the soil profile mainly by increasing soil evaporation, reduction of *Macrotermes* activity producing more numerous abandoned termite hills.

Substitution of woodland by wooded savanna is not acting primarily on the soil water reserves, but should be avoided regarding other ecological consequences such as a decrease of biomass production, a rise of the mean annual temperature and of the mean daily amplitude (FRESON *et al.* 1974), increase of fire injuries and lost of nutrients, etc. Thus the progression of the deforested area around the Upper Shaban mining towns which has been reported to be important, produces a savanization of the Upper Shaban environment. This evolution will have long term alarming consequences.

ACKNOWLEDGEMENTS

The authors wish to gratefully acknowledge for their assistance in the field Bulaimu T. (†), Kisimba K. and Muzinga Y. We also thank Ngoy L. for producing the figures for this paper and Umba K. for typing the manuscript.

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