Runoff and erosion before and after clearing depending on the type of crop in western Africa

E.J. ROOSE

1. INTRODUCTION

In spite of the international efforts to increase production, demand for food has grossly lagged behind its production in the tropics. In addition to the semiarid and arid regions, malnutrition and hunger are also common in the humid tropics.

In West African regions of sparse population, the development programs are concerned less with increasing the yields from existing farms than with extending arable land area through mechanized operations of clearing and cultivation. Very aggressive climatic conditions that prevail in this region cause rapid mineralization of organic matter and result in the degradation of the physical properties, soil erosion and leaching of nutrients (Harroy, 1944; Charreau, 1972; Roose, 1973 to 1980). In addition, the soils of the arid regions are degraded by a long dry season ranging from two to six months per year (Chauvel, 1977; Humbel, 1974). Soil equilibrium, therefore, is fragile, both from chemical and structural point of view. This equilibrium is, however, preserved under natural conditions of the integrated biological system. Once the equilibrium is disturbed, the soil and edaphic environments are easily degraded (Roose, 1980).

What are the implications of land clearing and cultivation? The potential fertility of tropical soils is often overestimated because of the apparent lush vegetation growth. In fact, the forest feeds on its own debris and reuses the nutrients which are concentrated on the soil surface by various biological activities. Once the storage of organic matter have been mineralized, the ferrallitic soil cover is no more than a weathered skeleton devoid of nutrient reserves. As soon as the forest disappears, the carbon contents in soil decrease, nutrients weakly held by kaolinitic clays are leached, biological activities are reduced, macroporosity declines and soil structure is degraded (Nye and Greenland, 1964; Fauck *et al.*, 1969; Charreau and Fauck, 1970; Siband, 1972, 1974; Roose, 1973 to 1980). Therefore, the clearing and cultivation of virgin soils raise critical problems of soil conservation. This report compares runoff and soil erosion from the natural vegetation cover of the forest or savanna with different types of perennial or annual crops. Erosion and runoff are used as criteria of imbalance between the physical environment and the land use to assess the risks of land degradation.

Table 1. Ecological characteristics of the experimental sites.

	Adiopodoume	Anguedegou	Azaguie	Divo	Bouake	Korhogo	Saria	Gonse
Climate	← Sub-equatorial (two rainfall seasons) →					Transitional tropical	pure tropical	
rainfall (mm)	2,150	2,100	1,750	1,550	1,200	1,350	830	860
PET* (mm)	1,250	1,300	1,314	1,280	1,300	1,660	1,885	1,905
rainfall erosivity index (Wischmeier, 1962)	1,260	1,000	885	825	512	676	450	430
temperature (°C)	26.2	26.2	26.2	26.0	26.1	27.0	28.0	28.1
Greencover	← wet dense forest →				wooded savannah		bush savannah	
	evergreen			semi-deciduous	Guinean	Soudanian	Soudano-Sahelian	
Landforms	strongly incised plateau		narrow hills	wide hills	wide hills	residual relief and long piedmont slopes	residual relief and very long piedmont slopes	
grade of slope (%)	<65	<39	14	10	4	3	0.7	0.5
length slope (m)	20–500	100–500	180	300	700	750–1,000	2,000	3,000
Soils	strongly desaturated ferrallitic			medium desaturated ferrallitic			tropical ferruginous	
Bedrock	argillaceous sand upper Tertiary		chloritic schists	granites	granites (pegmatite lodes)	granites (quartz lodes)	granites	
			← Precambrian →					

*PET=potential evapotranspiration.

2. METHODS AND CHARACTERIZATION OF THE ENVIRONMENT

Many researchers have studied the dynamics of tropical soils under clearing and cultivation (Fauck *et al.*, 1969; Charreau and Fauck, 1970; Siband, 1972; Blic, 1976; Roose, 1980; Blic and Moreau, 1979). Results presented here are from a series of experiments conducted on erosion plots and from some field observations made on large plantations in Ivory Coast. The soils of the experimental sites are ferrallitic derived from tertiary sand clay sediments (ORSTOM station at Adiopodoumé, IRCA plantation at Anguededou), chlorite schists (IRFA station at Azaguié) or granitic-gneiss (IFCC station at Divo, IRAT station at Bouake ORSTOM basin at Korhogo) (Fig. 1). The runoff and erosion collection systems have been described elsewhere (Roose, 1973 to 1980). These humid tropical regions are characterized by an aggressive climate (Table 1). The rainfall erosivity factor R ranges from 450 to 1200 and increases with the annual rainfall amount and with the frequency of rainstorm events. The relief is not very steep, and slopes exceeding 20 percent are rare.

3. RESULTS

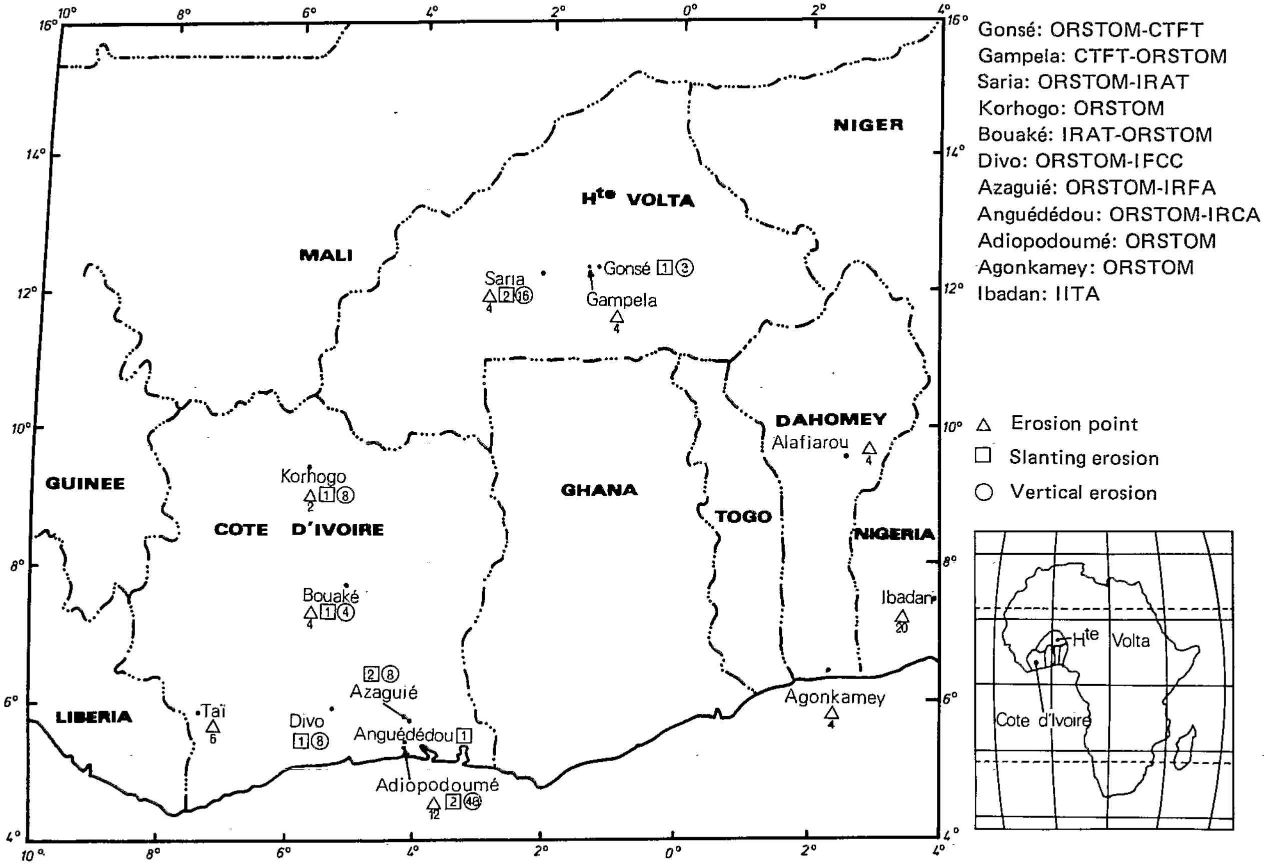
Comparisons are made between the mean annual runoff coefficients (KR_{AM}) expressed as percentage of rainfall, the maximum runoff coefficients during an annual rainfall event (KR_{MAX} in %), total erosion (fine particles in suspension + coarse particles, expressed in t/ha/year), and the ratio of suspended losses to total erosion (S/E in %).

3.1 *Effects of deforestation*

The data in Table 2 present observations made on a plot of 15 m length, of 23 percent slope and covered with secondary dense rainforest of at least ten years. It was cleared on April 25, 1966, and planted to cassava on mounds and to peanut on contours in 1967. Afterwards, it was kept as a bare ploughed soil, free of weeds, and ploughed every year. Even with manual clearing operations, the low runoff coefficients (KR = 0.5 to 3 percent) and erosion (E = 52 kg/ha/year) under natural vegetation cover are rapidly changed to high runoff coefficients (KR = 15 to 50 percent), 25 to 100 times higher, and to considerably higher soil losses (E = 400 to 750 t/ha/year). When the soil is covered with leaf litter under a dense forest vegetation only very fine particles are likely to migrate (S/E = 100 percent). In cultivated soils, on the contrary, erosion is so intense that it erodes the whole humiferous horizon. Erosion is no longer selective (microravinement), and the proportion of fine eroded particles in suspension falls to less than 6 percent of the total erosion. It can also be observed that in the first cropping year, runoff and erosion were considerably lower than in the following years. This may be due to less erosive rainfalls, but mainly due to better soil protection by cassava canopy during the periods of heavy rainstorms (Roose, 1973, 1977).

3.2 *Runoff and erosion from perennial crops*

The data in Table 3 show the results from observations made on a plot located at the IFCC station near Divo in the western region of Ivory Coast. The plot is 38 m long, on



Source: Roose (1980).

Figure 1. Localities of erosion stations in West Africa.

Table 2. Rainfall, runoff and erosion measured in the plot P6 of the ORSTOM Centre at Adiopodoumé before and after clearing. Strongly desaturated ferrallitic soil on tertiary clay sandy sediments. Slope 23 percent.

		1960 Forest	1961	1962	1963	1964	1965 Forest	Median under forest 1956–1965	1966[a] Cassava on mounds	1967[b] Peanut on contour	1968 Bare soil	1969 Bare soil	1970 Bare soil
Rainfall	mm	1898	2289	2773	2434	1647	2300	2321	1496	1673	2084	1951	1655
JSA		–	–	1927	1358	1084	1673	–	614	990	861	989	1251
KR_{AM}	%	0.6	0.4	0.1	0.2	0.5	0.6	0.5	18.3	25.0	24.7	26.1	31.2
KR_{MAX}	%	2.7	3	1	3.4	3.9	7.3	3.2	75	77	65	76	68
Total erosion		0.013	0.021	0.013	0.007	0.052	0.227	0.052	162.4	427.3	622.3	564.2	746.0
T/ha/an S/E	%	100	100	100	100	100	100	100	5.7	1.7	2	2.6	2.7

[a] = Manual clearing carried out on April 25. 1966. Plantation of cassava on mounds.
[b] = Peanuts planted on contour at the end of April.
S/E = Ratio of eroded materials in the form of fine suspensions to total erosion (fine + coarse, say sands and aggregates which can deposit downslope and form colluviums).

Table 3. Rainfall, runoff and erosion measured in the ERLO plot of the IFCC station close to Divo before and after clearing (December 1970). Moderately reworked ferrallitic soil on granite. Slope 10 percent. Lines 4.5 m apart planted with cacao-trees and spacings occupied by forest regrowth.

	Semi-deciduous forest			Cacao-plantation+forest regrowth					Median
	1967	1968	1969	1970	1971	1972	1973	1974	1967–1974
Rainfall (H in mm)	1242	1955	1211	1436	1220	1291	1388	1375	1333
Rusa erosivity index	607	1100	500	848	599	684	795	659	672
KR_{AM} %	0.5	1.4	0.5	1	0.3	0.4	0.4	0.4	0.4
KR_{MAX} %	2.9	6	4.6	6.1	1.2	1.5	2.4	1.7	2.7
Erosion (kg/ha)	503	644	128	191	133	73	58	98	130
S/E %	73	38	23	29	8	22	45	33	24

10 percent slope, and is under high semi-deciduous forest (Roose and Jadin, 1969). After four years of baseline data collection, this forest was cleared with a chain saw and lightly burnt. Trunks were cut into pieces and placed in between the rows of cacao trees planted on contour. There was no weeding and the forest regrowth in between rows was used as shading for cacao seedlings.

Because the soil was never exposed, the rate of mineralization of the organic matter was reduced. The build up of organic matter was as good as in the forest cover. There were also no alterations in the drainage patterns or in biological activities, particularly that of earthworms. Soil bulk densities were also similar to those under forest cover or in cacao plantations (even on the surface), and the infiltration rates measured were higher than the intensity of regular rainfalls. Runoff losses were generally insignificant with this type of land use, despite high rainfall erosivity ($R_{median} = 672$). Cacao trees developed a full canopy cover within four years.

Similar results of low erosion and runoff were also observed in the IRCA rubber plantation at Anguededou (Table 4), established on a slope of 30 percent on a ferrallitic soil (Roose *et al.*, 1970; Tran Than Canh, 1972). These data indicate that these soils can be effectively utilized with the appropriate management.

3.3 *Runoff and erosion from arable land*

The data in Table 4 show some results from measurements made concurrently on plots under natural vegetation cover and on an adjacent plot with bare or cultivated soil. Under natural conditions of forest or non-degraded savanna, runoff ($KR_{AM} = 0.1$ to 5.5 percent) and erosion (E = 10 to 500 kg/ha/year) were low even on steep slopes of up to 65 percent and for highly erosive rains (R factor of 600 to 1200). Soil erosion, however, increased dramatically on bare soils. Runoff from bare soil was as much as 15 to 50 percent of annual rainfall and was even more than 80 percent for some storms. Soil losses increased rapidly to 50 to 600 t/ha/year for slopes ranging from 3 to 20 percent. The decrease in soil erosion by the canopy cover depended on cultural practices, percent vegetal cover and the structural stability of the surface soil. The data in Table 5 show the effects of different crop covers on soil loss in comparison with the bare plot (C factor).

In addition to the natural vegetation, forage crops, banana plantations, tree crops

Table 4. Runoff and erosion from various natural and cultivated plots in West Africa.

Stations	Slope	Annual Runoff % (KR_{AM})			Daily Max. Rate of Runoff (KR_{MAX})			Erosion (t/ha/year)			
	%	natural cover	bare plot	cropped plot	natural cover	bare plot	cropped plot	natural cover	bare plot	cropped plot	Sources
Adiopodoumé : ORSTOM,											
1954-75	4.5	–	35	–	–	98	–	–	60	–	Roose 73-79
Secondary rainforest	7	0.1	33	0.5 to 30	0.7	95	60-87	0.017	138	0.1–100	
Rain = 2100 mm in 4 seasons	11	0.3	–	–	1.3	–	–	0.034	–	–	
Ferrallitic soil on III sand.	20	0.5	24	–	3.2	76	–	0.052	570	–	
	65	1.2	–	hevea	12	–	hevea	0.455		hevea	
Anguededou: IRCA-ORSTOM, 1966-74	29	–	–	0.3 to 1			2 to 4			0.06 to 3	Roose 1970
Terraced Rubbertree plantation				Md = 0.5			Md = 2.2			Md = 0.2	
Azaguié: IRFA-ORSTOM, 1966-74				banana		–	banana		–	banana	Roose
Rain forest	14	0.4 to 5.5	–	5.5 to 12	3 to 39		25 to 74	0.05–1.4		0.7–4.5	Godefroy 1977
Rain = 1750 mm in 4 seasons		Md = 2	–	Md = 9	Md = 14		Md = 60	Md = 0.15		Md = 1.8	
Ferrallitic Soil on schist Banana plantation											
Divo: IFCC-ORSTOM, 1967-74				cocoa			cocoa			cocoa	Roose, Jadin
Semi-deciduous dense forest	10	0.5 to 1.4	–	0.3 to 0.4	3 to 6	–	1 to 2.4	0.1 to 0.6	–	0.06–0.1	1970-79
Rain = 1450 mm in 4 seasons Ferrallitic soil on granite Cocoa plantation.											
Bouaké: IRAT-ORSTOM, 1960-73											Kalms 1975
Dense bush savannah		Pro. 0.03	15–49	0.1 to 26	Pro. 0.2	40 to 70	5 to 65	Pro 0.001	11 to 52	0.1 to 26	Bertrand 1967
Rain = 1200 mm in 4 seasons	4	FP. 0.23			FP. 1			PF. 0.050			Roose et B.
Ferrallitic soil on granite.											1972
Korhogo: ORSTOM, 1967-74											
Clear bush savannah	3	FP 1 to 5	25–40		8 to 30	67 to 89	–	0.01–0.160	3 to 9	–	Roose
Rain = 1400 mm in 2 seasons		Md = 3.0		Md = 33	Md = 19			Md = 0.110	Md = 4	–	1975-79
Ferrallitic Soil on granite.											
Saria: IRAT-ORSTOM, 1971-74											
Soudano-sahelian bush savannah	0.7	Pro. 5-8	35 to 43	10 to 37	Pro. 20–30	69–71	40 to 65	Pro. 0.2-0.7	14–35	3–14	Arnvets 73
Rain = 850 mm in 2 seasons	1.7	Pat. 10			Pat. 41			Pat. 0.17	Mo = 20	Mo = 7.3	Roose et al. 1974-79
Superficial ferruginous soil on iron crust on granite.		Pro. 0.4			Pro. 1 to 8			Pro. 0.10			
Gonsé/Gampela: CIFT-ORSTOM, 67/74		Pro. 0.2			Pro. 1			Pro. 0.02-0.05			Roose,
Soudano-sahelian savannah	0.4	FP. 2.5			FP. 8-10			FP. 0.05-0.15			Birot, 70
Rain = 800 mm in 2 seasons		FT. 15			FT. 50-70			FT. 0.41			
Leached ferruginous soil on granite.	0.8							–	–	–	Roose 78
			–	2 to 45	–	–	50-70	–	10 to 21	0.6-10	CTFT, 72
Séfa (Sénégal): IRAT-ORSTOM, 54/63		Pro. 0.1-1.2						Pro. 0.02-0.2			Roose, 67
Clear woodland	1 to 2	FP 0.3-1.5	25 to 55	8 to 10	–	–	–	FP. 0.02-0.5	30 to 55	2 to 20	Charreau, 1972
Rain = 1300 mm in 2 seasons Leached ferruginous soil on granite.											
Agonkamey (Bénin): ORSTOM, 64/69			after clearing						17 to 28		Verney Volkoff
Dense thicket	4.4	0.1 to 0.9	17	20 to 35	2.5	69	70-80	0.3 to 1.2	after clearing	10 to 85	
Rain = 1300 mm in 4 seasons Ferrallitic soil on III sand											Wilaime, 67 Roose, 73, 76
Ibadan (Nigeria): IITA, 1972-73	1		31-58	0.1-15	–	70-89	20-40		5-10	01.6	
Dense bush savannah	5		38-62	3.2-36	–	70-100	40-50		43-156	0.1-11	Lal, 1975
Rain = 1200 mm in 4 seasons	10		36-57	3.4-26	–	80-94	40-70		59-233	0.1-7	
Ferrallitic soil on granite.	15		30-57	2.9-25	–	70-88	30-60		116-229	0.1-43	

Pro = total protection; FP : early burned; FT = late burned; Md = median; Mo = arithmetic average; Pat = extensive grazing.

with live mulches and crops mulched with residue also reduced erosion to tolerable levels ($C \leqslant 0.01$). In comparison, the C factor for most seasonal food crops ranged from 0.2 to 0.8.

4. DISCUSSION

4.1 *Land clearing and soil degradation*

Soil is in equilibrium with its environment under the natural vegetation cover (Roose,

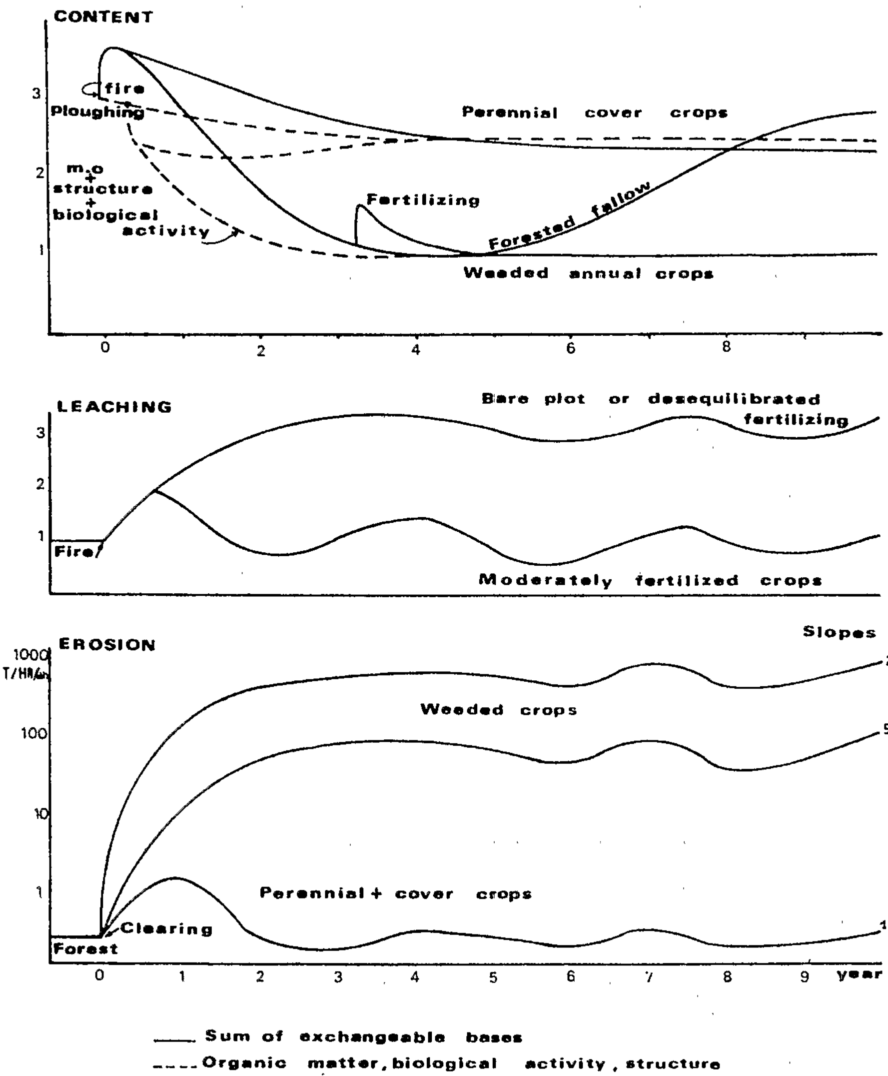


Figure 2. Diagram of ferrallitic soils evolution after clearing and cropping.

1980). Therefore, the losses by erosion and leaching are low and are compensated by inputs from rainfalls, dusts and, mainly, biological activity. Forest fallow restores the fertility of surface horizon (Landelout and Van Bladel, 1967). The rapid turnover and biological activities increase nutrient concentration in the surface horizon. In addition, physical properties are favorable with high total porosity of up to 60 percent. Land clearing creates an imbalance, causes a rapid mineralization of organic matter and decreases biological activity. The magnitude of these alterations depends on land clearing methods (Fig. 2).

Traditional or manual clearing. Traditional clearing followed by light burning can

Table 5. The vegetal cover factor (C Factor) for different crops in West Africa.

Cultural techniques		Annual average C Factor
Bare continuously fallowed		1
Forest or dense shrub, high mulched crops		0.001
Savannah, prairie in good condition		0.01
Over-grazed savannah or prairie		0.1
Crop cover of slow development or late planting–first year		0.3 to 0.8
Crop cover of rapid development or early planting–first year		0.01 to 0.1
Crop cover of slow development or late planting–second year		0.01 to 0.1
Corn, sorghum, millet (as a function of yield)		0.4 to 0.9
Rice (intensive fertilization)		0.1 to 0.2
Cotton, tobacco (second cycle)		0.5 to 0.7
Peanuts (as a function of yield and the date of planting)		0.4 to 0.8
1st year cassava and yam (as a function of the date of planting)		0.2 to 0.8
Palm tree, rubber-tree, coffee, cocoa with cover crop		0.1 to 0.3
	burned residue	0.2 to 0.5
Pineapple on contour (as a function of slope)	buried residue	0.1 to 0.3
	surface residue	0.01
Pineapple and tied-ridging (slope 7%)		0.1

improve soil fertility and, by preserving the root system, enhance structural stability of the surface horizons (Moreau, 1982). The practice of mixed cropping also provides a continuous ground cover throughout the year. Under these conditions, soil degradation, if any, is less and gradual and is observed only three to five years later when the root system decays. Any decline in crop yield with traditional farming is more due to a build up of weeds and parasites than to decline in chemical fertility (Jurion and Henry, 1967).

Semi-mechanized clearing. The use of chain saw or of selective mechanization to establish perennial tree crops can also preserve soil fertility and structural stability if clearing is done in the dry season and soil is immediately sown to cover crops. The root system and soil structure are preserved. Soil degradation is less, and favorable growth of tree crops is achieved even with the low rates of fertilizer application. Among successful examples of these plantations are the IFCC cacao and coffee plantations at Divo and the IRCA plantations of rubber-trees in lower Ivory Coast (Tran Than Canh, 1972; Roose, 1980).

Mechanized clearing for perennial crops. If mechanized clearing is done with heavy machines (200 to 300 hp) in the dry season for establishing perennial crops, soil degradation can be reduced provided the soil is immediately seeded to leguminous covers (*Pueraria, Centrosema* or *Flemingia*). With an effectively established cover, soil degradation, observed in localized places, if any, and the adverse effects of compaction and of structural breakdown disappear within a few years. Experiments conducted at IRCA plantation at Anguededou on ferrallitic soil showed no differences in physical properties among plots cleared manually or by mechanical means. On the other hand, the results of a survey conducted in the IRHO palm-tree plantation at la Mé (lower

Ivory Coast) showed that the fertility of top 30 cm layer decreased rapidly after a two-year temporary improvement following burning. The chemical fertility finally stabilized fourteen years later with organic matter content at 60 percent of that under forest, nitrogen at 75 percent and basic cations at 90 percent. An application of potash ranging from 80 to 180 kg/ha/year was found to be sufficient to attain a new equilibrium favorable to the production of palm trees (Ollagnier *et al.*, 1978).

Mechanized clearing for annual crops. This causes rapid soil degradation because the vegetal cover is removed to windrows 50 to 150 meters apart, soil is compacted, roots are removed, subsoil is mixed with the organic layer and a fine seedbed is mechanically prepared. These operations usually result in land failure, and degraded soils are usually abandoned within two or three years' after cultivation. The soil is deprived of the organic and mineral reserves tied in the biomass, and the nutrient rich surface soil is scraped off. The soil is exposed to intense radiation and tropical rains. Once the root system is removed, the surface soil is mixed with the infertile subsoil. A new equilibrium achieved later renders a degraded soil of low fertility to decline further with the accelerated erosion.

Mechanised clearing with heavy equipment results in degradation of soil structure and in accelerated soil erosion. For instance, all regions cleared and cultivated mechanically for the pineapple plantations of the Ono region have serious problems of erosion. It is even difficult to perform mechanical operations because of deep gullies. Streams are often flooded and reservoirs have been silted up. In neighboring plots of small holders where the cultivation is done by the manual methods, erosion is effectively curtailed.

This degradation, however, is not irreversible. For instance, an exceptional rainfall event (234 mm in 24 hours) occurred in the young oil palm plantation of Dabou and led to a dramatic erosion. Establishment of a *Pueraria* cover improved biological activity and nutrient supply, and the soil was improved to its initial level within four years.

4.2 *The reasons for soil degradation after clearing*

Degradation of chemical and physical properties following land clearing is usually attributed to the aggressive climatic conditions, soil fragility and the rapid mineralization of organic matter which increase losses by erosion and drainage. These cause-effect relationships, however, have rarely been quantified. The rate of degradation is rapid in the first years until the soil attains a new equilibrium within five to fifteen years depending on the land use adopted.

1. Erosion accelerates soon after the soil is exposed and continues even when the land is taken out of production. Erosion is less, however, under perennial than annual crops.
2. Leaching losses of plant nutrients from cultivated soils are severe only when there occurs a nutrient imbalance (Roose, 1977 to 1980).

The high rate of soil degradation observed after land clearing is not, therefore, caused only by the accelerated erosion and leaching losses of plant nutrients. In this regard, the importance of biological activity in maintaining a dynamic equilibrium between losses and gains should not be underestimated. Land clearing removes biomass and leaf litter and exposes the soil. Denudation and burning hasten the mineralization of soil organic matter. A rapid mineralization of humus, roots and surface plant debris continues even for a few years after clearing. This decline in organic matter content results in a decrease in the activities of mesofauna and microflora. It is this decline in biological activity that impedes improvements in soil structure and the nutrient status of the surface horizons. The new soil equilibrium attained with the impeded biological activity depends on the quality and quantity of organic matter supplied by the new cropping systems and the control of its losses. Agronomists and pedologists (Harroy, 1944; Van Den Abeele and Vandenput, 1956; Aubert, 1959; Cunningham, 1963;Jurion and Henry, 1967) often recommend that soil be continuously covered to protect it from the direct solar radiation and from the kinetic energy of raindrops (Dabin and Leneuf, 1958; Fournier, 1967; Roose, 1967 to 1980). When the soil is covered, erosion is eliminated (Tables 3, 4 and 5). In spite of erosion control, soil degradation can still occur if biological activity is not restored (Ollagnier *et al.*, 1978; Cunningham, 1963; Moulo, 1974; Tran Thanh Canh, 1972). Improved cropping systems adopted must ensure a high level of biological activity if soil degradation is to be prevented.

5. CONCLUSIONS

There is no simple method of a rapid development for mechanized intensive farming of food crop production in the humid tropics. Climatic conditions are aggressive, and the soil chemical and physical properties are drastically influenced by its organic matter content. The latter is rapidly mineralized and declines even more rapidly with the accelerated soil erosion.

The transition from forest to cultivation causes degradation of the physical, chemical and biological environments. The complex forest ecosystem is very effective in reducing the losses of nutrients and in concentrating the nutrient reserves in the surface horizon. The rate of soil degraded can be decreased by the following methods:

- By using gradual and low-energy land clearing methods, e.g., manual or chain saw clearing, burning *in situ*, maintenance of the surface horizon along with its root system and reduction or elimination of soil tillage;
- By growing tree crops with legume covers which are an effective substitute of a forest environment; and
- By protecting the field area allocated to food crops with anti-erosive systems such as a continuous soil cover with appropriate rotations, by forage fallows and by the liberal use of crop residue mulch.

SUMMARY

The fertility of ferrallitic soils in humid tropical regions of Africa depends largely on their organic matter reserves. The latter is rapidly mineralized in warm and aggressive climates. Soil structure degrades rapidly after land clearing. These problems raise some important questions regarding the management of these soils for sustained productivity.

Many researchers have attempted to quantify the factors responsible for rapid decline in crop productivity after clearing. Decline in organic matter, erosion and

leaching of plant nutrients are some of the important factors. In addition to erosion, soil degradation is also caused by leaching. The use of perennial crops grown in association with cover crops provides a useful cropping system for the humid environments because it decreases the rate of soil degradation.

The rate of soil degradation can be reduced by adopting manual methods of clearing and burning. This method protects the humiferous horizon and the root system. Cropping systems that cover the soil perfectly (for instance, tree crops grown in association with cover crops) are better suited to these physical environments. Cultural practices developed for cultivation of seasonal food crops should also consider the socioeconomic and logistic constraints in the humid tropics.

ACKNOWLEDGEMENT

The author is grateful to ORSTOM and GERDAT for their assistance in preparing this report.

REFERENCES

Aubert, G. (1959), Influence de divers types de végétation sur les caractères de l'évolution des sols en région équatoriale et subéquatoriale. *Sols et végétations des régions tropicales.* UNESCO, Abidjan, pp. 41–45.

Bertrand, R. (1967), Etude de l'érosion hydrique et de la conservation des eaux et du sol en pays Baoulé. *Fertilité des sols tropicaux.*Tananarive no. 106, pp. 1281–1295.

Blic, Ph. de (1976), Le comportement des sols ferrallitiques de Côte d'Ivoire après défrichement et mise en culture mécanisée: rôle des traits hérités du milieu naturel, *Cah. ORSTOM, sér, Pédol.* 14(2) : 113–130.

Blic, Ph. de, and R. Moreau (1979), Structural characteristics of ferrallitic soils under mechanical cultivation in the marginal forest areas of Ivory Coast. *Soil physical properties and crop production in the tropics.* Wiley Interscience Publication, pp. 111–122.

Charreau, C. (1972), Problèmes posés par l'utilisation agricole des sols tropicaux par les cultures annuelles. *Les sols tropicaux.* IITA, Ibadan.

Charreau, C., and R. Fauck (1970), Mise au point sur l'utilisation agricole des sols de la région de SEFA, *Agron.Trop.* 25 (2): 151–191.

Charreau, C., and R. Nicou (1971), L'amélioration du profil cultural dans les sols sableux de la zone tropicale sèche Ouest Africaine, *Agron. Trop.* 26 (9): 903–978; 26 (11): 1183–1247.

Chauvel, A. (1977), *Recherches sur la transformation des sols ferrallitiques dans la zone tropicale à saisons contrastées.* Travaux et Doc. ORSTOM no. 62.

CTFT (1974), *Rapport annuel 1973.* CTFT/ H.V., Ouagadougou.

Cunningham, R.K. (1963), The effect of clearing on tropical forest soil, *J. Soil. Sci.* 14(2): 334–345.

Dabin, B. and N. Leneuf (1958), *Etude de l'érosion et du ruissellement en basse Côte d'Ivoire, mai 1956–58.* ORSTOM, Abidjan.

Fauck, R., C. Moureaux and C. Thomann (1969), Bilan de l'évolution des sols de SEFA (Sénégal) après quinze années de culture continue, *Agron. Trop.* 24(3): 263–301.

Fournier, F. (1967), La recherche en érosion et conservation des sols sur le continent africain, *Sols africans* 12(1): 5–53.

Harroy, J.P. (1944), *Afrique, terre qui meurt. La dégradation des sols africains sous l'influence de la colonisation.* Bruxelles, Hayez.

Humbel, F.X. (1974), La compacité des sols ferrallitiques du Cameroun: Une zonalité dans ce milieu en relation avec la dessication saisonnière. *Cah. ORSTOM, sér. Pédol.* 12(1): 73–101.

Jurion, F. and J. Henry (1967), *De l'agriculture itinérante à l'agriculture intensifiée.* INEAC, Bruxelles.

Kalms, J.M. (1975), *Influence des techniques culturales sur l'érosion et le ruissellement en région centre de Côte d'Ivoire.* IRAT, Bouaké.

Lal, R. (1976), *Soil erosion problems on an alfisoil in western Nigeria and their control.* IITA Monograph 1, Ibadan.

Laudelout, H. and R. Van Bladel (1967), La jachère naturelle en région tropicale humide. *Fertilité des sols tropicaux.* Tananarive no. 9, pp. 1490–1497.

Le Buanec, B. (1972), Dix ans de culture motorisée sur un bassin versant du centre Côte d'Ivoire. Evolution de la fertilité et de la production, *Agron. Trop.* 27(11): 1191–1211.
Le Buanec B. (1979), Intensification des cultures assolées en Côte d'Ivoire. Milieu physique et stabilité des systèmes de cultures motorisées, *Agron. Trop.* 34 (1): 54–73.
Moreau, R. (1982), Evolution des sols sous différents modes de mise en culture, en Côte d'Ivoire forestiére. *Symposium Land clearing and development, IITA, Ibadan.* ORSTOM, Paris.
Moulo, N. (1974), *Etude comparative des sols sous forêt et sous bananeraie sur schiste à Azaguié d'après deux toposéquences (basse Côte d'Ivoire).* ORSTOM, Abidjan.
Nye, P.H. and D.J. Greenland (1964), Changes in the soils after clearing tropical forest, *Plant and Soil* 21 (1): 101–112.
Ollagnier, M., A. Lauzeral, J. Olivin and R. Ochs (1978), Evolution des sols sous palmeraie après défrichement de la forêt, *Oléagineux* 33(11): 537–544.
Roose, E.J. (1967), Dix années de mesure de l'érosion et du ruissellement au Sénégal, *Agron. Trop.* 22(2): 123–152.
Roose, E.J. (1973), Dix-sept années de mesures expérimentales de l'érosion et du ruissellement sur un sol ferrallitique sableux de basse Côte d'Ivoire. ORSTOM Abidjan, Thèse Doct. Ing. Fac. Sciences Abidjan no. 20.
Roose, E.J. (1976a), *Le probléme de la conservation de l'eau et du sol en République du Bénin. Mise au point en 1976.* FAO/ORSTOM Abidjan.
Roose, E.J. (1976b), *Use of the universal soil loss equation to predict erosion in West Africa.* SSSA., Special Publication no. 21, pp. 60–74.
Roose, E.J. (1977a), Adaptation des méthodes de conservation des sols aux conditions écologiques et socio-économiques de l'Afrique de l'Ouest, *Agron. Trop.* 32(2): 132–140.
Roose, E.J., (1977b) *Erosion et ruissellement en Afrique de l'Ouest. Vingt années de mesures en petites parcelles expérimentales.* Travaux et documents ORSTOM no. 78, Paris.
Roose, E.J. (1978) Pédogenèse actuelle d'un sol ferrugineux complexe issu de granite sous une savane arborescente du Centre Haute-Volta. Gonsé 1968 à 1974. *Cah. ORSTOM, Sér. Pédol.* 16(2): 193–223.
Roose, E.J. (1979), Pédogenése actuelle d'un soil ferrallitique gravillonnaire issu de granite sous culture et sous une savane arbustive soudanienne du Nord de la Côte d'Ivoire : Korhogo 1967–1975, *Cah. ORSTOM, Sér. Pedol.* 17(2): 81–118.
Roose, E.J. (1979–1980), Dynamique actuelle d'un sol ferrallitique très désaturé sur sediments argilo-sableux sous culture et sous forêt dense humide sub-équatoriale du Sud de la Côte d'Ivoire. Adiopodoumé, 1964–1976. I et II. *Cah. ORSTOM*, Sér. *Pédol.* 17(4): 25–47; 18(1): 3–28.
Roose, E.J. (1980), *Dynamique actuelle de sols ferrallitiques et ferrugineux tropicaux d'Afrique Occidentale. Etude expérimentale des transferts hydrologiques et biologiques de matière sous végétations naturelles ou cultivées* Travaux et Documents no. 130. ORSTOM, Paris.
Roose, E.J., *et al.* (1970), *Erosion, ruissellement et drainage oblique sous une plantation d'héveas en basse Côte d'Ivoire.* Rapport ORSTOM - IRCA, Abidjan.
Roose, E.J.I., Arrivets and J. Poulain (1979), *Dynamique actuelle de deux sols ferrugineux tropicaux indurés sur sorgho et sous savane soudano-sahélienne, Saria (Haute-Volta): campagnes 1971–74.* ORSTOM Paris.
Roose, E.J. and J. Godefroy (1977), Pédogenése actuelle comparée d'un sol ferrallitique remanié sur schiste sous forêt et sous une bananeraie fertilisée de basse Côte d'Ivoire : Azaguié 1966 á 1973, *Cah. ORSTOM, Sér. Pédol.* 15(4): 67–94.
Roose, E.J. and P. Jadin (1969), Erosion, ruissellement et drainage oblique sur un sols à cacao en moyenne Côte d'Ivoire. Rapport ORSTOM-IFCC, Abidjan, multigr.
Siband, P. (1972), Etude de l'évolution des sols sous culture traditionnelle en Haute-Casamance, *Agron. Trop.* 27(5): 574–591.
Siband, P. (1974), Evolution des caractères et de la fertilité d'un sol rouge de Casamance, *Agron. Trop.* 29(12): 1228–1248.
Tran-Thanh-Canh (1972), *Etude comparative des sols sous forêt et sous hévéa sur sables tertiaires à l'Anguededous.* ORSTOM, Abidjan.
Van Den Abeele, M. and R. Vandenput (1956), *Les principales cultures du Congo belge.* Publication Ministére Agriculture, Bruxelles.
Verney, R., B. Volkoff and P. Willaime (1967), *Etude de l'érosion sur 'Terres de Basse'.* Rapports ORSTOM Cotonou.
Wischmeier, W.H. and D.D. Smith (1960), An universal soil-loss estimating equation to guide conservation farm planning. *7th Intern. Congress Soil Science*, vol. 1, pp. 418–425.

ABBREVIATIONS USED

ORSTOM: Office Recherche Scientifique et Technique Outre Mer;
GERDAT: Groupement d'Etudes et de Recherches sur le Développement de l'Agriculture Tropicale;
IRCA: Institut de Recherche sur le Caoutchouc en Afrique;
IRFA: Institut de Recherche sur les Fruits et Agrumes;
IFCC: Institut Français du Café et du Cacao;
IRAT: Institut de Recherches en Agronomie Tropicale.

LAND CLEARING AND DEVELOPMENT IN THE TROPICS

Edited by

R.LAL
International Institute of Tropical Agriculture, Ibadan

P.A.SANCHEZ
North Carolina State University, Raleigh

R.W.CUMMINGS, JR
USAID, Bureau for Science & Technology, Washington

OFFPRINT

Roose (Eric)

A.A.BALKEMA / ROTTERDAM / BOSTON / 1986