XXXIII

Tropical Ecology 40(2): 177-190, 1999

ISSN 0564-3295

Vegetation characteristics of fallow plots and soil erosion in south-western Nigeria

S.O. OKE[†], A.O. ISICHEI[†] & P.O. AINA[‡]

[†] *Department of Botany,* [‡]*Department of Soil Science, Obafemi Awolowo University, Ile-Ife*

Abstract: A study was carried out to find out the magnitude of runoff and sediment yield and various vegetation parameters in Ile-Ife area of south western Nigeria. Seven 50 x 50 m sample plots in Ile-Ife area, Nigeria were selected; one plot in a relatively undisturbed secondary forest and six other plots in disturbed areas with ages ranging from one year to five years old. Results showed that plots in younger fallows had fewer woody species and individuals than the older plot. A comparison of the bare and vegetated plots clearly showed that development of vegetation affects physical and chemical soil characteristics. The bare plot produced the highest values of both runoff and sediment yield followed distantly by the natural forest plot while the disturbed young plots with lesser tree densities had the lowest runoff and sediment yield.

Resumen: Este estudio se llevó a cabo para determinar la magnitud de la escorrentía y la producción de sedimento y varios parámetros de la vegetación, en el área Ile-Ife del suroeste de Nigeria. Se seleccionaron siete parcelas de muestreo de 50 x 50 m; una de ellas en un bosque secundario relativamente poco perturbado, y las otras seis en áreas perturbadas con edades que variaban de uno a cinco años de edad. Los resultados mostraron que las parcelas con los barbechos más jóvenes, tuvieron menos especies leñosas e individuos con respecto a las parcelas más viejas. Una comparación entre las parcelas sin y con vegetación, mostró claramente que el desarrollo de la vegetación afecta las características físicas y químicas del suelo. La parcela desnuda produjo los valores más altos de escorrentía y producción de sedimento, seguida distantemente por las parcelas en el bosque natural, mientras que las parcelas perturbadas más jóvenes con menos densidad de árboles tuvieron la escorrentía y la producción de sedimentos más bajas.

Resumo: Este estudo foi realizado na região de Ile-Ife, no sudoeste da Nigéria com o objectivo de encontrar a magnitude do escorrimento e dos sedimentos e os vários parâmetros da vegetação. Sete parcelas amostra de 50 x 50 m na região de Ile-Ife foram seleccionadas; uma parcela numa floresta secundária relativamente intacta e as outras seis em zonas disturbadas com idades variando entre o ano e os cinco anos. Os resultados mostraram que as parcelas nos pousios jovens têm menos espécies lenhosas do que as de idade mais avançada. Uma comparação entre as parcelas despidas de vegetação, com as revestidas, mostraram, claramente, os efeitos da vegetação nas caracteríticas físicas e químicas do solo. O solo nu gerou os maiores valores de escorrimento e de sedimentos seguidos a grande distância pela parcela de floresta natural, enquanto que as parcelas jovens disturbadas com menores densidades de revestimento arbóreo apresentaram o menor escorrimento e a menor produção de sedimentos.

Key words: Fallow plots, runoff, sediment, soil erosion, southwestern Nigeria, vegetation characteristics.

All correspondence should be addressed to Dr. S.O. Oke.

Introduction

Vegetation characteristics have relevance to land use planning and vegetation management (Sanford 1982) and is very useful in separating such large categories of vegetation as forest, grassland, desert, savanna and others. The typical mature vegetation in southwestern Nigeria is lowland rainforest (Keay 1959) or semi-deciduous moist forest (Charter (1969). White (1983) has classified the vegetation of southwestern Nigeria as Guinea-Congolian rainforest of the drier type.

Forest land can be cleared or disturbed in a number of ways, each characterised by a certain degree of soil disturbance. Rotational bush fallow has been identified as the single most important reason for loss of tropical forest before the 1980's (Lanly 1982). Also felling and extraction of large trees may produce so much damage to the surrounding vegetation that regrowth may be too slow for further profitable exploitation (Burgess 1971; De Graaf 1986).

Erosion and subsequent sedimentation can result from above-mentioned deforestation processes such as clearing for agriculture, timber extraction, road making and harvest, or from the suppression of protective ground vegetation by trees (Leeks & Roberts 1987). Each time land is cleared of its vegetation without the necessary soil conservation measures, the land is exposed to erosion. Specifically, degradation of the protective cover given by vegetation could intensify the erosive processes and the structural breakdown of soil (Andreu *et al.* 1994) because of the progressive decrease in soil organic matter and the lack of soil protection against raindrop impact, splash and sediment removal (Fullen 1991). The presence or absence of a good vegetation cover or soil conservation measures are strong determinants of amount of sediment generated by surface erosion.

There has been little evidence for soil erosion under forests as there have been only a few quantitative studies (Moffat 1988). Vegetation is the major factor controlling the conservation of soil and water (Fu Bojie 1989). The vegetation canopy and litter effectively intercept the force of rain drops and thereby minimizes soil dispersion by raindrop impact (Lal 1974). Some of the precipitation intercepted by the forest canopy will drip from leaves or flow down tree trunks or is evaporated. Raindrops intercepted by the tall large leaved canopy coalesce to form large drops which are more erosive when they fall from considerable height of teak canopy with great impact with which they strike the soil surface (Okali *et al.* 1987).

Natural tropical forests in their normal undisturbed forms are not seriously affected by erosion (Andreu *et al.* 1994), but due to man's desire to develop, a lot of pressure is brought onto the land which was previously thickly vegetated (Jeje 1987). The removal of this vegetation cover greatly increases the hazard (Lal 1974). The magnitude of erosion caused by the removal of protective vegetation cover depends on soil, land form and rainfall characteristics and on the management system adopted. Studies of sediment yield are valuable for several reasons. Values of sediment yields in an environment can be used as a measure of the extent of vegetation degradation, because the amount of material transported in a runoff is an index of the rate of erosion. In essence, sediment production is a useful index with which to assess the effect of deforestation on the soil environment.

The present study attempts to identify the elements and structure of fallow Plots in Ile-Ife area and to examine the relationship between the vegetation physiognomy and water erosion sediment yield in Ile-Ife area of southwestern Nigeria.

Materials and methods

The study was carried out in seven Plots located in Ile-Ife area of southwestern Nigeria between latitude 7°31′N and 7°33′N and longitude 4°31′E and 4°34′E. The seven representative Plots of 50 x 50 m each were designated as Plots 1, 2... and 7.

The study area is underlain by metamorphic rocks of the Precambrian Basement Complex. These rocks show great variation in structure, mineral composition and grain size (Smyth & Montgomery 1962). The soils of the area are moderately to strongly leached and have low to medium humus content, weakly acid to neutral surface layers and moderately to strongly acid sub-soils (Smyth & Montgomery 1962). The climate of the area is humid tropical, with distinct dry and wet seasons. The wet season starts from around mid March to late October, and rainfall pattern is bimodal with peak periods in July and September.

One Plot (Plot 7) in a relatively undisturbed secondary regrowth forest and six other Plots in disturbed area were established. Plots 1 and 2 were one year old fallow, Plot 3 was a two years old fallow, Plo

4 and 5 were three years old fallows, Plot 6 was a five years old fallow, while Plot 7 was a forested Plot.

Tree density was estimated in each of the seven Plots by complete enumeration. Every woody plants (trees and shrubs) $\geq$1m within each Plot was tagged with a number, counted and identified to species level. Indices of diversity and similarity were calculated based on the enumerations to know the species diversity in each Plot and the similarities of the Plots to each other.

The girths of the $\geq$ 3 m high woody plants were measured at breast height (GBH) and at mid-point for those less than 3 m high. The girth measurement were used to calculate the basal area for each species. The height of each individual tree was measured using an Haga altimeter. Tree crown area was measured by taking two diameters at right angles to each other across the canopy of the plants, one of which was the maximum diameter for the plant and the other minimum. The average of these two measurement represented the crown diameter. The crown area of each plant canopy was calculated from the following formula:

$$A = D^2/4$$

where, D is the average crown diameter.

The percentage cover of grasses or forbs was estimated both as basal and aerial cover. Percentage basal cover was estimated by dropping a pointed metal rod (Greig-Smith 1983) perpendicularly and consistently on the same side of a 50 m central line transect at every metre point and noting whether it hits the base of a herb, grass or forb.

Erosion Plots, each measuring 25 x 4 m were constructed on a 10% slope in each of the seven 50 x 50 m Plots. A 25 x 4 m Plot that was kept bare all the time was also located outside the experimental Plots as control.

Sediment yield was measured in the seven erosion Plots for two years (1989 and 1990). Two manual rainguages were installed close to each erosion Plot. Runoff from each Plot was collected in plastic water tanks. The volume of runoff was measured after each shower after which it was stirred vigorously and samples taken for laboratory analysis to determine pH, electrical conductivity, suspended solid and solute sediment loads using filtration methods. The rest of the runoff was discarded and the tanks rinsed and put back in place.

To avoid overflow of collection tanks, the channel was divided into three parts by a multi-slot divisor so that only 1/3 of the runoff was channelled into the collection tank. Whatever runoff value obtained from the tank was multiplied by three. The collecting channels and the troughs were covered with galvanized iron sheets to ensure that only the runoff from the Plots entered the tanks and to prevent evaporation of the runoff water.

Rainfall Parameters

Gross rainfall

Each Plot was equipped with two British Standard rainguages. The gauges were inspected every morning and the rain water measured and recorded against the previous day. The rainguage measurements were used to produce daily, weekly, monthly and annual rainfall for each Plot.

Throughfall

Rainguages were also randomly installed under various tree canopies and herbaceous canopies in each Plot to determine the percent throughfall, throughfall being that portion of the rainfall which reaches the ground directly through gaps in the canopy and as drip from leaves and stems (Leyton *et al.* 1968). These throughfall values were compared to the rain received as free fall on a bare ground surface.

Stem flow

The portion of the rainfall which reaches ground by running down the stem as stem flow (Leyton *et al.* 1968). A spiral galvanized iron sheet about 20 cm in width was appressed to each bole with half-inch nails. The other end was folded into a funnel-shaped snout and directed into a mounted 2 litre container to collect stem flow during rainfall. Four such containers were randomly set in each Plot. The upper surface of the spiral iron sheets were covered with polythene to exclude rainfall through the canopy. The stem flow was collected at the end of every rainfall and its volume was measured.

Soil sample collection

Five 50 m line transects were laid randomly within each 50 x 50 m Plot. Soil samples were collected systematically at every fifth metre point along the slope from 0-5 cm and 5-10 cm depth using a soil auger. The samples were air dried and sieved through a 2 mm sieve and stored for chemical analysis.

Twenth-five soil samples were also collected along the same transects using 85 cm^3 core samplers to take undisturbed soil samples for bulk density determination. Such soil samples were then placed in air tight containers. In the laboratory, the soil sample was placed in an oven at 105°C and dried to a constant weight. The bulk density was determined by dividing the weight by the sample volume.

Soil particle size distribution was determined by the hydrometer method (Bouyocous 1961), using 0.2 m sodium hydroxide as the dispersing agent. The soil was separated into percentage sand, clay and silt. The soil pH was measured in 1:2 KCl solution, with pH meter. The soil organic matter content was determined by the chromic acid digestion method (Black 1965).

Statistical analysis

Variation in soil properties, runoff sediment yield, stem flow, rainfall percentage interception, pH and electrical conductivity of the runoff among Plots were statistically analyzed by analysis of variance. Relationship between vegetation factors and runoff and sediment yield were assessed using correlation analysis.

Results

Table 1 indicates some of the soil properties at 0-5 cm and 5-10 cm soil depths in the study areas. The pH of the soils of all the Plots showed that they were slightly acidic (6.3 - 6.9). There was no significant difference between the pH values of the upper and lower soil layers or among the different Plots.

Particle size distribution

Plot 5 had the highest sand content at both 0-5 and 5-10 cm depths 75.1% and 77% respectively while Plot 4 had the lowest sand (38.1% and 33.2%) and highest clay and silt contents with the value from other Plots intermediate (Table 1). There was significantly ($P \leq 0.001$) more sand fraction than either clay or silt in all Plots except in Plot 4.

The sand/clay ratio was lowest in Plot 4 while that of Plot 5 was the highest. With the exception of Plot 5, the clay content in the upper layer was consistently higher than that in the lower layer while difference in the sand and silt contents between the two layers was slight in all Plots. This difference in particle size distribution between soils in the upper and lower layer was, however, not statistically significant when analysis of variance was applied. Also the difference in particle size distribution between soil among the Plots was not statistically significant.

Organic matter

Soil organic matter content in the upper layer (0-5 cm) was significantly higher than in the lower (5-10 cm) layer ($P \leq 0.05$) in all the Plots. Plot 6 had the highest organic matter in the upper layer while Plot 1 had the lowest with others of intermediate value. Plot 4 had the highest organic matter in the (5-10 cm) lower layer while Plot 1 had the lowest organic matter closely followed by Plot 7. Other Plots were intermediate. This difference in the organic matter content among the Plots was not statistically significant.

Bulk density

The bulk density of the soils ranged from 1.19 g cm^{-3} in Plot 3 to 1.35 g cm^{-3} in Plot 4 in the 0-5 cm layer and from 1.29 g cm^{-3} in Plot 2 to 1.55g cm^{-3} in Plot 4 in the 5-10 cm layer. The bulk density of the upper layer was lower than that in the lower layer in all Plots.

Plot 3 had the lowest bulk density in the upper layer while Plot 2 had the lowest in the lower layer and other Plots had intermediate values. This difference in bulk density between upper layer and lower layer was statistically significant at $P<0.05$. The difference in the bulk density among the different Plots was, however, not statistically significant.

Vegetation parameters

Some species (woody and herbaceous) are common to most of the Plots in varying frequencies. Sorensen's index of similarity (IS) between the Plots shows that Plots 1 and 2 to be most similar. The least similarity was found between the youngs Plots (Plots 1 and 2) and the forest Plot (IS = 9.32% and 7.89%) while others similarities were intermediate (Table 2). The Shannon-Wiener species diversity index was found to be high in Plots 5 and 7 H' = 2.711 and 2.538); low in Plots 1 and 2 (1.835 and 1.445) and intermediate in the remaining Plots (Table 2).

The total density, total mean basal area, total mean crown horizontal area of woody species are also shown in Table 2. Plot 7 with the highest number of

Table 1. Mean value ± 95% Confidence Interval of soil properties at 0-5 cm and 5-10 cm soil depth in seven study plots in Ile-Ife Area of Southwestern Nigeria.

	Soil Depth	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
% Sand	0-5 cm	71.5 ± 2.0	65.2 ± 2.7	67.6 ± 3.7	38.1 ± 2.9	75.1 ± 3.7	70.4 ± 4.8	70.5 ± 4.6	71.6 ± 0.4
	5-10 cm	72.1 ± 1.9	66.2 ± 1.1	73.2 ± 3.0	33.2 ± 3.0	77.0 ± 3.0	71.6 ± 5.2	70.2 ± 3.7	71.9 ± 3.0
% Silt	0-5 cm	11.5 ± 1.3	11.8 ± 1.6	13.7 ± 2.5	18.2 ± 1.9	10.0 ± 4.6	7.8 ± 2.0	9.5 ± 1.7	10.2 ± 4.4
	5-10 cm	11.4 ± 0.8	11.4 ± 0.8	9.8 ± 2.2	19.4 ± 1.3	8.8 ± 2.2	8.3 ± 1.5	10.7 ± 1.6	9.7 ± 2.3
% Clay	0-5 cm	17.0 ± 1.2	23.0 ± 1.9	18.7 ± 4.2	43.7 ± 3.2	14.9 ± 1.5	21.8 ± 3.6	20.0 ± 2.9	18.2 ± 2.4
	5-10 cm	16.5 ± 1.5	22.4 ± 1.9	17.0 ± 1.6	47.4 ± 3.2	14.2 ± 2.2	20.1 ± 4.3	19.1 ± 2.7	18.4 ± 2.4
Sand/clay ratio	0-5 cm	4.2 ± 0.4	2.9 ± 0.4	3.8 ± 0.8	0.9 ± 0.1	5.3 ± 0.5	3.5 ± 0.7	3.9 ± 0.9	3.9 ± 0.9
	5-10 cm	4.4 ± 0.4	3.0 ± 0.3	4.3 ± 0.6	0.7 ± 0.1	5.4 ± 0.9	3.9 ± 0.9	3.9 ± 0.9	3.9 ± 0.8
pH (cacls)	0-5 cm	6.3 ± 0.2	5.8 ± 0.2	5.9 ± 0.2	6.2 ± 0.1	6.1 ± 0.1	5.7 ± 0.2	6.1 ± 0.1	6.2 ± 0.1
	5-10 cm	6.2 ± 0.2	5.6 ± 0.2	5.9 ± 0.2	5.9 ± 0.2	5.9 ± 0.3	5.5 ± 0.3	5.9 ± 0.2	6.0 ± 0.3
pH (H_2O)	0-5 cm	6.9 ± 0.2	6.5 ± 0.2	6.7 ± 0.2	6.7 ± 0.1	6.6 ± 0.3	6.4 ± 0.2	6.7 ± 0.1	6.5 ± 0.2
	5-10 cm	6.9 ± 0.2	6.4 ± 0.3	6.6 ± 0.1	6.5 ± 0.2	6.7 ± 0.2	6.3 ± 0.0	6.6 ± 0.2	6.5 ± 0.2
% Organic matter	0-5 cm	2.66 ± 0.67	2.89 ± 0.5	3.97 ± 0.83	4.01 ± 0.67	3.99 ± 0.70	4.44 ± 0.39	3.95 ± 0.69	2.34 ± 0.71
	5-10 cm	2.34 ± 0.44	2.70 ± 0.36	2.74 ± 0.45	3.55 ± 0.21	2.64 ± 0.12	2.41 ± 0.88	2.38 ± 0.30	2.13 ± 0.44
Bulk density (g cm^{-3})	0-5 cm	1.32 ± 0.10	1.20 ± 0.13	1.19 ± 0.09	1.35 ± 0.22	1.30 ± 0.11	1.32 ± 0.11	1.22 ± 0.13	1.59 ± 0.11
	5-10 cm	1.50 ± 0.10	1.29 ± 0.12	1.37 ± 0.11	1.55 ± 0.11	1.39 ± 0.06	1.53 ± 0.11	1.45 ± 0.15	1.62 ± 0.11

Table 2. Vegetation characteristics of the seven study plots in Ile-Ife area of Southwestern Nigeria.

Plots	Age (yr)	No. of woody species	Density of woody species (no. ha^{-1})	Basal area of woody species (m^2 ha^{-1})	Total crown horizontal area (m^2 ha^{-1})	Cover of herb (%)		Density (no. ha^{-1}) of woody species in three height classes			Sorensen index of similarity (IS)	Shannon-Wiener species diversity index (H′)
						Aerial	Basal	3m	3-7m	7m		
1 (TC)	1	11	216	2.10 ± 0.21	878 ± 51	708 ± 164	41.30	60	96	60	TA = 55.55% TB = 32.26% R7 = 21.62% PH = 33.33% AG = 22.86% FR = 09.52%	1.835
2 (TA)	1	7	176	0.04 ± 0.00	176 ± 17	823 ± 132	39.14	48	128	0	TB = 22.22% R7 = 34.78% PH = 25.00% AG = 09.52% FR = 07.89%	1.445
3 (TB)	2	20	224	1.23 ± 0.05	1001 ± 33	825 ± 115	15.85	68	116	56	R7 = 16.67% PH = 44.44% AG = 23.53% FR = 39.22%	2.349
4 (R7)	3	16	401	0.29 ± 0.01	227 ± 9	778 ± 135	13.44	180	236	9	PH=43.90% AG = 46.67%	2.226
5 (PH)	3	25	392	1.56 ± 0.10	657 ± 11	745 ± 150	10.46	136	140	64	FR = 17.02% AG = 41.03%	2.711
6(AG)	5	15	192	4.00 ± 0.17	226 ± 78	828 ± 137	6.21	36	140	64	FR = 28.57%	2.093
7 (FR)	25	31	732	9.04 ± 0.23	7796 ± 91	–	–	48	50	184	FR = 40.00%	

species (31) also had the highest total plant density (732) while Plot 2 with the lowest number of species (7) also had the lowest plant density (176). Plot 7 had the highest mean basal area, 9.040 ± 0.237 m^2ha^{-1} and it had the highest woody density 732 trees ha^{-1} while Plot 2 had the lowest mean basal area 0.04 ± 0.002 m^2ha^{-1} and it also had the lowest woody density 176 trees ha^{-1}.

Plot 7 had the highest mean total crown area (7796.328 ± 91.127 m^2) followed by Plot 6 > Plot 1> Plot 5> Plot 3> Plot 4> Plot 2 (Table 2). The ground area covered by total crown horizontal area in Plot 7 (forest Plot) was greater than one hectare while others were less. This was mainly due to the vertical packing of some species. Plot 7 had a greater number of trees in the height class 7m (184 trees ha^{-1}) than other Plots while Plot 2 had none in that height class. All the Plots had more of the trees in the height class, 3-7 m, than any other height class. All the Plots except Plot 7 had the least number of trees in height class >7 m.

The mean aerial cover of herbaceous plant was more than 100% every month in all the Plots except Plot 7 (forest Plot) where there was no herbaceous plant at all (Table 2). This amount of cover was as a result of the overlapping foliage arrangement of the plants. The mean aerial cover of Plot 6 which was fully dominated by *Chromolaena odorata* and the oldest of the fallow Plots had the highest mean annual aerial cover of 828.25 ± 137.98% and closely followed by Plot 3 825.63 ± 114.21% while Plot 1 had the lowest mean annual aerial cover of 708.13 ± 164.65% and except Plot 7 (forest Plot) which had none and others had intermediate value (Table 2).

Rainfall and runoff

The rainfall amount was highest in September and closely followed by July in all the seven sites

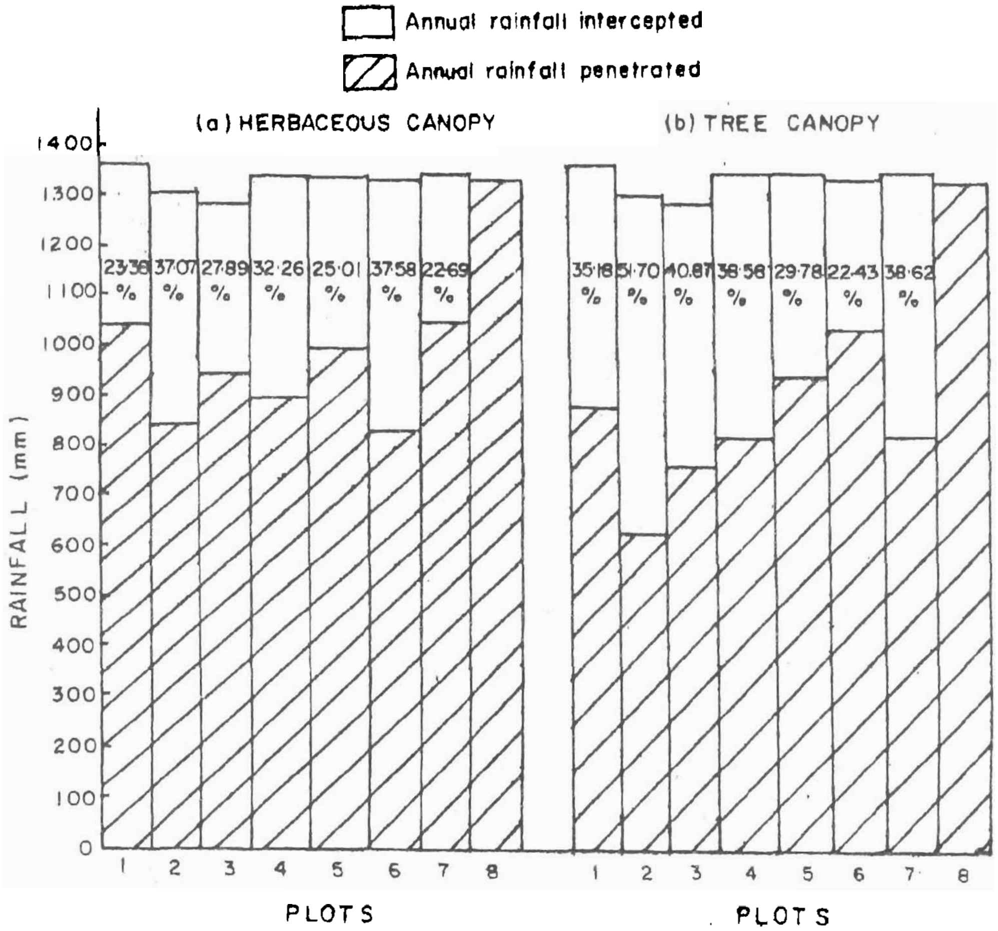

Fig. 1. Mean annual rainfall intercepted and penetrated (mm) in seven study plots in Ile-Ife area of Southwestern Nigeria.

(Table 3). The rainfall amount did not vary much among the Plots and the difference in the amount of rainfall was not significant. However, mean monthly rainfall within each Plot was significantly different at P<0.001 which indicated that mean rainfall amount in September was significantly higher than that of other months.

As expected, mean runoff was consistently higher from the bare Plot (Plot 8) than from the others, and was followed by Plot 7 (forest Plot) and Plot 2 produced the lowest mean runoff except in October and November when Plots 3 and 1 produced the lowest mean runoff respectively (Table 3). This difference in the monthly runoff produced in the different Plots was statistically significant at (P<0.01). Similarly the monthly mean runoff produced within each Plot was statistically significant at P<0.001.

Rainfall interception

The percent rainfall interception of herbaceous and the tree canopy increased from April to November in all the Plots (Fig. 1). The mean annual herbaceous percent rainfall interception was highest in Plot 6 (37.58%) and closely followed by Plot 2 (37.07%). The percent rainfall interception was lowest in Plot 7 (22.69%) and closely followed by Plot 1 (23.38%) while other Plots had intermediate values. There was significant difference in the amount of rainfall penetrating the herbeceous canopy among the different Plots (P<0.001) and among the months (Fig. 1).

The proportion of rainfall intercepted by the tree canopy was highest in Plot 2 (51.7%) and lowest in Plot 6 (22.43%) while others had intermediate values. There was a significant difference in the amount of rainfall penetrating the tree canopy among the different Plots at P<0.001 and among the different months (P<0.001).

Stem flow

The mean stem flow was closely related to stem size (r = 0.84). The mean stem flow was highest in Plot 7 (forest Plot) with a mean annual stem flow of 115 ± 8.9 litres per tree while Plot 2 had the lowest mean annual stem flow of 7.40 ± 0.66 litres per tree. It was observed that Plots with the highest mean basal area (Plot 7; 9.04 m^2 ha^{-1}) also had the highest mean stem flow (Table 4). It was also found that a positive significant correlation (r = 0.74) exists between stem flow and mean basal area. There was a significant difference in the stem flow among the Plots (P<0.01) and among the different months (P<0.01).

Sediment yield

The monthly pattern of sediment yield varies a great deal. The highest total sediment yield occurred in September in Plots 3, 7, and 8 and in April in Plots 1 and 2 while it occurred in July in Plots 4, 5 and 6. The lowest value was obtained in August when the rainfall was minimum in Plots 1-6 while it occurred in April in Plots 7 and 8 (Table 5).

Total sediment yield from all the Plots except Plots 7 was very high in April, the beginning of the rainy season when the herbaceous cover was low. On annual basis the highest amount of total sediment yield was from bare Plot (Plot 8, 201.8 kg ha^{-1}) as excepted while the lowest was from Plot 2 (20 kg ha^{-1}) (Table 5). Comparing the sediment yield among the Plots covered with vegetation, the sediment yield was unexpectedly highest in Plot 7 (100 kg ha^{-1}) and closely followed by Plot 1 (88.66 kg ha^{-1}) > Plot 6 (83 kg ha^{-1}) > Plot 4 (56 kg ha^{-1}) > Plot 5 (44.53 kg ha^{-1}) > Plot 3 (38.52 kg ha^{-1}) > Plot 2 (20 kg ha^{-1}) (Table 5).

The difference in the total sediment yield among these Plots was significant at P<0.001 and the total sediment yield monthly was also significantly different at P<0.001.

The relationship between suspended and dissolved sediments varied from Plot to Plot; the ratio ranged between 1:1 to 4:1 (Table 5). While suspended sediment was higher than dissolved in all the Plots except Plot 7 (forest Plot) where dissolved was consistently higher than suspended sediment constitutes 70.1% in Plot 1: 61.7% in Plot 2; 59.7% in Plot 3; 67.6% in Plot 4: 53.5% in Plot 5, 58.8% in Plot 8. There was also significant difference in the amount of suspended sediment generated among the Plots at P<0.001.

A consideration of the amount of suspended sediment generated within each Plot, it was observed that its values were higher than half of the total sediment in young Plots while it was less than half in Plot 7 (forest Plot). Similarly a look at the monthly sediment yield showed that sediment yield varied seasonally with rainfall amount in all the Plots. However, variation was less in Plot 7 (forest Plot) where there was not much variation in the vegetation cover.

(Table 3). The rainfall amount did not vary much among the Plots and the difference in the amount of rainfall was not significant. However, mean monthly rainfall within each Plot was significantly different at $P<0.001$ which indicated that mean rainfall amount in September was significantly higher than that of other months.

As expected, mean runoff was consistently higher from the bare Plot (Plot 8) than from the others, and was followed by Plot 7 (forest Plot) and Plot 2 produced the lowest mean runoff except in October and November when Plots 3 and 1 produced the lowest mean runoff respectively (Table 3). This difference in the monthly runoff produced in the different Plots was statistically significant at ($P<0.01$). Similarly the monthly mean runoff produced within each Plot was statistically significant at $P<0.001$.

Rainfall interception

The percent rainfall interception of herbaceous and the tree canopy increased from April to November in all the Plots (Fig. 1). The mean annual herbaceous percent rainfall interception was highest in Plot 6 (37.58%) and closely followed by Plot 2 (37.07%). The percent rainfall interception was lowest in Plot 7 (22.69%) and closely followed by Plot 1 (23.38%) while other Plots had intermediate values. There was significant difference in the amount of rainfall penetrating the herbeceous canopy among the different Plots ($P<0.001$) and among the months (Fig. 1).

The proportion of rainfall intercepted by the tree canopy was highest in Plot 2 (51.7%) and lowest in Plot 6 (22.43%) while others had intermediate values. There was a significant difference in the amount of rainfall penetrating the tree canopy among the different Plots at $P<0.001$ and among the different months ($P<0.001$).

Stem flow

The mean stem flow was closely related to stem size ($r = 0.84$). The mean stem flow was highest in Plot 7 (forest Plot) with a mean annual stem flow of 115 ± 8.9 litres per tree while Plot 2 had the lowest mean annual stem flow of 7.40 ± 0.66 litres per tree. It was observed that Plots with the highest mean basal area (Plot 7; 9.04 $m^2\ ha^{-1}$) also had the highest mean stem flow (Table 4). It was also found that a positive significant correlation ($r = 0.74$) exists between stem flow and mean basal area. There was a significant difference in the stem flow among the Plots ($P<0.01$) and among the different months ($P<0.01$).

Sediment yield

The monthly pattern of sediment yield varies a great deal. The highest total sediment yield occurred in September in Plots 3, 7, and 8 and in April in Plots 1 and 2 while it occurred in July in Plots 4, 5 and 6. The lowest value was obtained in August when the rainfall was minimum in Plots 1-6 while it occurred in April in Plots 7 and 8 (Table 5).

Total sediment yield from all the Plots except Plots 7 was very high in April, the beginning of the rainy season when the herbaceous cover was low. On annual basis the highest amount of total sediment yield was from bare Plot (Plot 8, 201.8 $kg\ ha^{-1}$) as excepted while the lowest was from Plot 2 (20 $kg\ ha^{-1}$) (Table 5). Comparing the sediment yield among the Plots covered with vegetation, the sediment yield was unexpectedly highest in Plot 7 (100 $kg\ ha^{-1}$) and closely followed by Plot 1 (88.66 $kg\ ha^{-1}$) > Plot 6 (83 $kg\ ha^{-1}$) > Plot 4 (56 $kg\ ha^{-1}$) > Plot 5 (44.53 $kg\ ha^{-1}$) > Plot 3 (38.52 $kg\ ha^{-1}$) > Plot 2 (20 $kg\ ha^{-1}$) (Table 5).

The difference in the total sediment yield among these Plots was significant at $P<0.001$ and the total sediment yield monthly was also significantly different at $P<0.001$.

The relationship between suspended and dissolved sediments varied from Plot to Plot; the ratio ranged between 1:1 to 4:1 (Table 5). While suspended sediment was higher than dissolved in all the Plots except Plot 7 (forest Plot) where dissolved was consistently higher than suspended sediment constitutes 70.1% in Plot 1: 61.7% in Plot 2; 59.7% in Plot 3; 67.6% in Plot 4: 53.5% in Plot 5, 58.8% in Plot 8. There was also significant difference in the amount of suspended sediment generated among the Plots at $P<0.001$.

A consideration of the amount of suspended sediment generated within each Plot, it was observed that its values were higher than half of the total sediment in young Plots while it was less than half in Plot 7 (forest Plot). Similarly a look at the monthly sediment yield showed that sediment yield varied seasonally with rainfall amount in all the Plots. However, variation was less in Plot 7 (forest Plot) where there was not much variation in the vegetation cover.

species (31) also had the highest total plant density (732) while Plot 2 with the lowest number of species (7) also had the lowest plant density (176). Plot 7 had the highest mean basal area, 9.040 ± 0.237 m^2ha^{-1} and it had the highest woody density 732 trees ha^{-1} while Plot 2 had the lowest mean basal area 0.04 ± 0.002 m^2ha^{-1} and it also had the lowest woody density 176 trees ha^{-1}.

Plot 7 had the highest mean total crown area (7796.328 ± 91.127 m^2) followed by Plot 6 > Plot 1> Plot 5> Plot 3> Plot 4> Plot 2 (Table 2). The ground area covered by total crown horizontal area in Plot 7 (forest Plot) was greater than one hectare while others were less. This was mainly due to the vertical packing of some species. Plot 7 had a greater number of trees in the height class 7m (184 trees ha^{-1}) than other Plots while Plot 2 had none in that height class. All the Plots had more of the trees in the height class, 3-7 m, than any other height class. All the Plots except Plot 7 had the least number of trees in height class >7 m.

The mean aerial cover of herbaceous plant was more than 100% every month in all the Plots except Plot 7 (forest Plot) where there was no herbaceous plant at all (Table 2). This amount of cover was as a result of the overlapping foliage arrangement of the plants. The mean aerial cover of Plot 6 which was fully dominated by *Chromolaena odorata* and the oldest of the fallow Plots had the highest mean annual aerial cover of 828.25 ± 137.98% and closely followed by Plot 3 825.63 ± 114.21% while Plot 1 had the lowest mean annual aerial cover of 708.13 ± 164.65% and except Plot 7 (forest Plot) which had none and others had intermediate value (Table 2).

Rainfall and runoff

The rainfall amount was highest in September and closely followed by July in all the seven sites

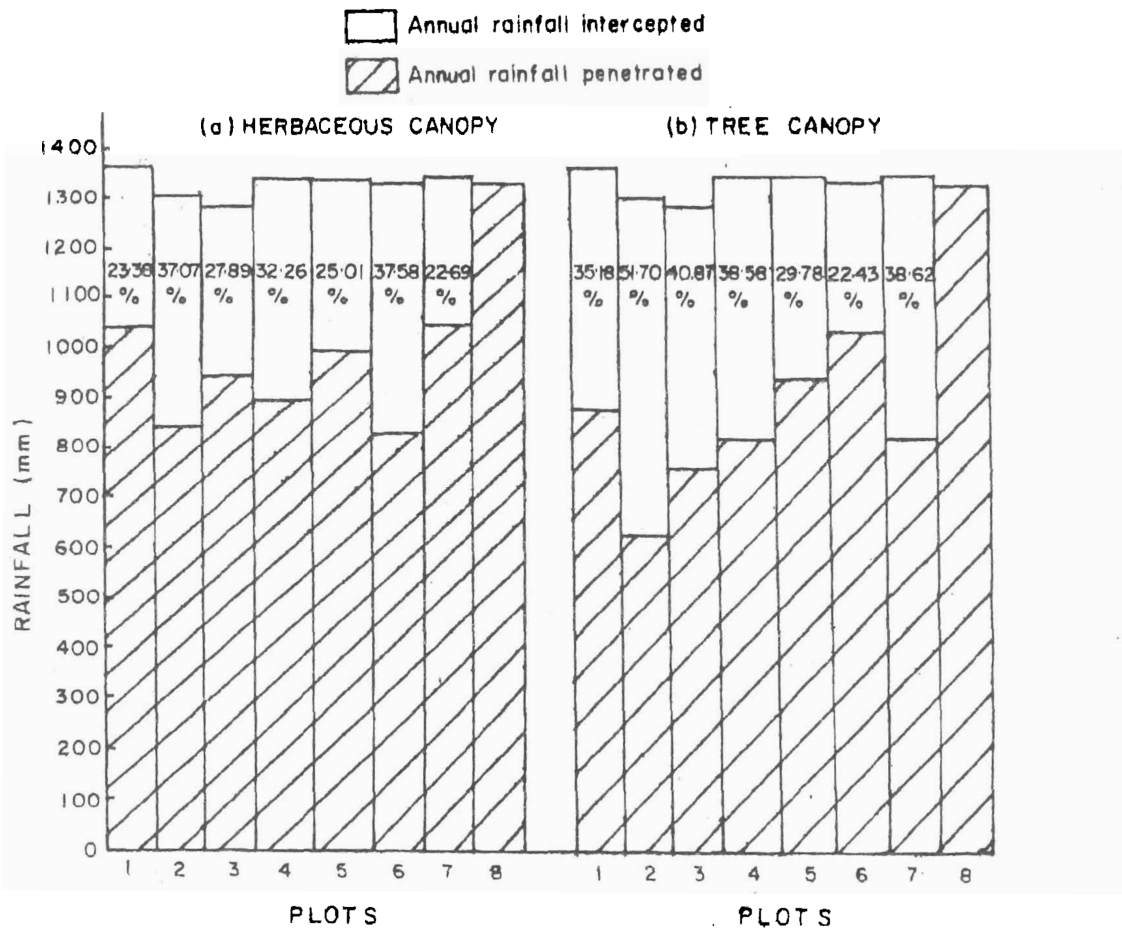

Fig. 1. Mean annual rainfall intercepted and penetrated (mm) in seven study plots in Ile-Ife area of Southwestern Nigeria.

Table 3. Monthly mean rainfall and mean runoff in seven study plots in Ile-Ife area of Southwestern Nigeria (1989 and 1990).

	Rainfall (mm)								Run-Off (mm)							
Month	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
April	82.2	92.3	88.0	101.3	108.0	86.5	88.2	83.9	1.67	0.55	0.82	0.72	0.74	1.44	1.83	13.24
May	162.2	169.3	131.0	198.6	179.6	170.2	192.4	164.8	0.32	0.68	1.04	2.91	1.15	2.78	4.42	7.91
June	188.4	191.9	188.3	210.3	214.0	198.8	175.7	171.0	1.78	0.58	1.28	2.37	1.83	3.69	5.09	8.20
July	269.8	266.9	265.1	244.0	265.2	303.6	297.5	281.3	2.71	0.78	2.47	2.65	2.21	4.43	6.12	12.06
August	37.2	38.0	30.2	82.9	72.9	19.4	53.6	92.9	0.36	0.05	–	0.33	0.34	0.09	0.82	3.16
September	361.8	310.0	317.4	266.2	267.5	310.6	310.9	275.6	4.25	1.14	7.30	2.21	1.84	4.82	6.02	10.86
October	197.5	167.6	198.1	181.1	162.9	176.7	169.8	183.9	1.79	0.54	0.48	1.05	0.81	3.43	4.32	4.78
November	64.1	63.2	61.7	60.4	63.5	63.5	63.7	65.1	0.23	0.28	0.28	0.33	0.31	0.38	0.27	1.37
Mean Total	1363.2	1299.3	1279.8	1335.8	1333.6	1329.3	1342.8	1318.5	13.11	4.60	13.67	12.57	9.23	21.06	27.89	61.58

Table 4. Monthly mean stem flow in litres ±95% Confidence interval in seven study plots in Ile-Ife area of Southwestern Nigeria.

Plots	April	May	June	July	August	September	October	November	Mean Total
Plot TC	4.336± 1.518	12.520± 4.507	5.02 ± 1.908	7.996± 2.798	0.216± 0.082	10.060± 3.923	1.728± 0.639	0.560± 0.179	42.436± 3.79
Plot TA	0.759± 0.190	2.191± 0.569	0.875± 0.201	1.399± 0.377	0.038± 0.009	1.761± 0.511	0.302± 0.088	0.114± 0.031	7.439± 0.66
Plot TB	2.590± 0.803	8.630± 2.934	6.166± 2.343	7.936± 2.936	0.224± 0.085	10.462± 3.662	0.630± 0.221	0.196± 0.071	36.744± 3.50
Plot R7	6.196± 2.231	10.560± 4.013	7.350± 3.590	8.260± 2.726	0.220± 0.073	10.492± 4.092	1.798± 0.611	0.600± 0.210	45.476± 3.50
Plot PH	3.711± 1.447	9.978± 3.792	6.110± 3.595	14.937± 5.676	2.880± 1.037	17.220± 6.371	1.824± 0.657	0.711± 0.249	57.282± 5.20
Plot AG	4.024± 1.569	17.430± 7.321	6.110± 2.505	7.904± 3.399	0.192± 0.078	12.060± 4.945	7.640± 3.285	2.744± 1.098	48.258± 4.32
Plot FR	8.890± 1.534	26.500± 13.780	18.025± 9.193	18.290± 9.694	0.635± 0.337	30.020± 16.211	9.190± 4.687	3.450± 1.794	115.000± 8.85

Table 5. Pattern of sediment production in kg/ha in the seven study plots in Ile-Ife area of Southwestern Nigeria (1989 and 1990).

	Plot TC			Plot TA			Plot TB			Plot R7			Plot PH			Plot AG			Plot FR			Plot BK		
Month	TS	SS	DS	TS	SS	DS	TS	SS	DS	TS	SS	DS	TS	SS	DS	TS	SS	DS	TS	SS	DS	TS	SS	DS
April	27.76	26.17	1.58	4.78	3.86	0.92	0.52	0.42	0.10	12.04	11.21	0.83	10.88	8.56	2.32	16.23	12.64	3.58	5.70	1.29	4.41	10.31	8.25	2.06
May	19.68	14.35	5.33	2.93	1.33	1.60	3.83	1.74	2.09	6.55	2.76	3.79	3.99	0.76	3.23	12.20	7.11	5.09	14.23	4.83	9.40	27.11	21.69	5.42
June	6.78	2.80	3.98	1.91	0.58	1.32	2.94	0.92	2.02	9.50	5.07	4.52	8.27	4.11	4.16	8.61	2.83	5.78	14.64	4.94	9.70	29.68	23.74	5.94
July	8.52	4.38	4.14	3.88	3.14	0.74	6.81	3.48	3.33	12.17	8.45	3.72	11.52	6.17	5.35	14.38	7.31	7.07	10.15	2.53	7.62	26.30	21.04	5.26
Aug	3.16	1.85	1.31	0.21	0.18	0.03	0.00	0.00	0.00	3.28	2.60	0.68	1.34	0.48	0.86	1.59	0.96	0.63	10.11	2.99	7.12	18.11	10.87	7.24
Sep	16.22	8.63	7.59	4.40	2.35	2.05	13.84	9.05	4.79	7.81	5.07	2.74	4.70	1.68	3.02	13.99	6.75	7.24	24.40	12.75	11.65	46.88	39.07	7.82
Oct	13.24	8.76	4.48	1.50	0.64	0.86	8.46	5.99	2.47	3.94	2.24	1.70	3.06	1.69	1.37	12.78	8.53	4.25	16.21	9.57	7.64	34.42	26.54	7.88
Nov	3.31	2.20	1.11	0.38	0.24	0.14	2.12	1.41	0.71	0.99	0.69	0.30	0.77	0.39	0.38	3.20	2.14	1.06	4.41	2.00	2.41	8.98	6.39	2.59
	98.66	69.14	29.52	19.99	12.33	7.66	38.52	23.01	15.15	56.37	38.09	18.28	44.53	23.84	20.69	82.98	48.27	34.71	99.85	30.90	59.95	201.80	157.59	44.21

TS : Total sediment yield
SS : Suspended sediment yield
DS : Dissolved sediment yield

Interrelationship between runoff, sediment yield and vegetation parameters

In order to determine the relationship between runoff, sediment yield and vegetation parameter, correlation analysis was carried out between runoff, total sediment yield, suspended sediment yield, and dissolved sediment yield and the following measurements of the vegetation attributes: tree height, tree density, tree basal area, tree canopy, crown horizontal area, herbaceous cover (aerial and basal), litter cover, rainfall interception by tree canopy and herbaceous canopy and stem flow.

Runoff in all the Plots correlates significantly with tree above 7m (0.87**), woody plant basal area in m^2ha^{-1} (0.92**), percentage tree canopy (0.88**), crown area m^2ha^{-1} (0.88**), percentage herbaceous aerial cover (-0.74*), percentage litter cover (0.88**) and stem flow (0.74*) (Table 6).

Total sediment yield in all the Plots correlate significantly with rainfall interception by tree canopy (-0.77*) and stem flow (0.76*). The dissolved sediment yield correlate significantly with woody plant height 3-7 m (-0.77*) and above 7 m (0.93**); woody plant basal area m^2ha^{-1} (0.95**), percentage tree canopy (0.93**), crown area m^2ha^{-1} (0.93**), and percentage herbaceous basal cover (-0.87**) (Table 6).

Discussion

In this study, the bare Plot (Plot 8) produced the highest values of both runoff and sediment yield followed distantly by the forest Plot (Plot 7), while the young Plots had the lowest runoff and sediment yield. The fact that both runoff and sediment yield were highest in the bare Plot (Plot 8) was not unexpected. The effect of vegetation cover on soil protection is clearly reflected in the results obtained. This is in agreement with earlier reports such as Hudson (1971), Stocking and Elwell (1976); Lal (1976); Jeje & Agu (1982); Andreu *et al.* (1994); Andreu *et al.* (1998). On an annual basis 201 kg ha^{-1} yr^{-1} of sediment yield from bare surface (Plot 8) compared fairly well with 180 kg ha^{-1} yr^{-1} obtained from bare Plot by Leow & Ologe (1981) in the savanna of Zaria area of Northern Nigeria, but higher than 157 kg ha^{-1} yr^{-1} obtained by Jeje & Agu (1982) in the bare Plots in the Ile-Ife area of Southwestern Nigeria.

However, very high values of runoff and sediment yield occurred in Plot 7 (forest Plot) which was rather unexpected. This contrasts with the findings of Hewlett & Hibert (1967); Kirby (1969); Whipkey (1969); among others who worked in forested areas in humid temperate regions. However, Pierce

Table 6. Summary of correlation coefficient between various vegetation attributes and runoff and sediment yield in seven study plots 1: Ile-Ife Area of Southwestern Nigeria.

	Correlation of	With			
		Runoff	Total Sediment Load	Suspended sediment Load	Dissolved sediment Load
1.	Woody plant height				
	<3m	−0.34	−0.28	−0.12	−0.34
	3-7 m	0.67	0.41	−0.03	−0.77*
	>7 m	0.87**	0.69	0.28	0.93**
2.	Woody plant density ha^{-1}	0.63	0.42	0.02	0.74
3.	Wood plant basal area $m^2 ha^{-1}$	0.92**	0.66	0.22	0.95**
4.	Percentage tree canopy	0.88**	0.63	0.19	0.93**
5.	Crown area $m^2 ha^{-1}$	0.88**	0.63	0.19	0.93**
6.	Percentage herbaceous aerial cover	−0.74*	−0.58	−0.17	−0.87**
7.	Percentage herbaceous basal cover	−0.69	−0.26	−0.10	−0.56
8.	Percentage litter cover	0.88**	0.48	0.15	0.71
9.	Rainfall interception by herbaceous canopy	−0.30	−0.45	−0.32	−0.47
10.	Rainfall interception by tree canopy	−0.44	−0.77*	−0.52	−0.38
11.	Stem flow	+0.74*	0.76*	0.68	0.63

* = Significant at 0.05
** = Significant at 0.01

(1967); Ruxton (1967); Kessel (1977) and Jeje & Agu (1982) observed overland flow and slope wash in the forested temperate region of the United State; tropical New Guinea; Guyana and Ile-Ife area of Nigeria respectively. On an annual basis the mean sediment yield of 99.85 kg ha^{-1} yr^{-1} from the forest Plot (Plot 7) is fairly close to the 78.9 kg ha^{-1} yr^{-1} from forest Plot by Jeje & Agu (1982) in Ile-Ife Area of Nigeria; but is very much higher than 30 kg ha^{-1} yr^{-1} measured at Abijan, Ivory Coast by Chareau (1982) from a ferralitic soil in an area with total annual rainfall of 210 mm. These observations may be due to the degree of vegetation cover and soil properties and intensity of rainfall. Other values obtained from other vegetated young Plots (1-5 years old Plots) was lower than the 101.6 kg ha^{-1} yr^{-1} obtained by Lal (1976) and 93.8 kg ha^{-1} yr^{-1} obtained by Jeje & Agu (1982) on a similar Plot covered with maize in Ibadan and Ile-Ife Area respectively. This variation may also be due to the degree of vegetation cover, because the younger Plots in this study were covered with dense cover of herbaceous plants and trees than was the case in the maize Plots.

The high volume of runoff and sediment yield observed in Plot 7 (forest Plot) during the study may not be unconnected with absence of herbaceous plant cover including grasses in the inter-tree spaces. Generally runoff was low in the young Plots (Plots 1, 2, 3 etc.) which have herbaceous plants, predominantly grasses in the inter-tree spaces. The role of herbaceous plant cover in preventing erosion has been explained in terms of their rooting pattern which enable them to absorb rainwater and transmit it into the soil at a slow rate. These plants offer resistance to flow of runoff and thereby reduce the rate of their flow. They also act as sieve filtering off suspended matter (Onyekwelu 1987). Onyekwelu (1987) described the herbaceous plant in terms of erosion, as ground cover which produce numerous roots which spread and form a mesh few centimeters below the surface. The numerous roots which spread few centimeters below the soil surface bind the soil particles together, hence some of them are referred to as soil binders. Plots that were effectively covered by ground cover are protected from direct hit of the raindrops.

The high volume of runoff and sediment yield in the forest Plot (Plot 7) and low volume or runoff and sediment yield in the young Plots could also be as a result of stem flow. Results in this study did show that Plot 7 (forest Plot) with more stem in all the girth classes had more stem flow than the young Plots. A related aspect is the erosive power of stem flow and crown drip. Since stem flow represent a concentration of water at the base of the stem, in certain climatic and topographic conditions it may take a dramatic proportion (Herwitz 1986) capable of washing away litter and top soil (Ruxton 1967; Douglas 1971). The stem flow has been estimated at between 5% (Zinke 1967) and 29% (Fraise 1936) of the total precipitation in the rainforest. In this study stem flow was measured volumetrically (Fraise 1936) and the amounts could not be assigned percent in millimeters as expected because of the difficulties associated with the estimation (Frangi & Lugo 1985; Helvey & Patric 1965). Stem flow carries substantial amount of nutrient to the bases of individual trees that are too large to be ignored (Herwitz 1986) and its contribution to dissolved sediment was greater than suspended sediment in Plot 7 (forest Plot) but dissolved less than suspended in other young Plots.

Runoff and sediment yield significantly correlates with trees above 7 m and the role of these tall trees could be explained in terms of increased striking power of raindrops. This is in line with the findings of Chapman (1948) and Okali *et al.* (1987) that the height of the canopy greatly influenced erosion and that the raindrops intercepted by the tall canopy coaleses to form larger drops which are more erosive when they fall from considerable height of canopy. Wiersum (1985), Vis (1986), Brandt (1988) stated that change in drop size was shown to be greater under a multiple canopy than under a single canopy a similar situation to what was observed under Plot 7 (forest Plot) and other young Plots. The result in this study did show that the striking effect of raindrop power was more pronounced in Plot 7 (forest Plot) than other young Plots as a result of more tall trees in the forest Plot. Several workers have shown that plant height is important in determining the amount of soil splash (Screenivas *et al.* 1947; Okali *et al.* 1987). The short erect plant canopy intercepts raindrops so that few raindrops are allowed to reach the soil surface directly. The raindrops reaching the soil surface after interception by short plants are probably those whose kinetic energy have been drastically reduced.

That runoff should exist in the forest Plot (Plot 7) is not surprising because when litter is wet and matted the leaves tightly overlap each other much like shingles on a roof (Kessel 1977; Pierce 1967; Whipkey 1969), water can then flow over the leaves without such infiltration. The significant positive correlation that existed between woody plant basal area and runoff on one hand and sediment yield on the other hand could be explained in terms of relation to total stem flow. Stem flow have been shown to be closely related to stem size (Leyton *et al.* 1968).

However, the percentage tree canopy correlates significantly with runoff and dissolved sediment yield. A light, high tree canopy leads to higher production of herbs, predominantly grasses than dense canopy (Rose Innes & Mansfield 1976; De Leew 1978). It is possible that such dense canopy cannot permit more light to reach the ground surface that will be adequate for photosynthesis. A similar situation of what was observed in this study, among the Plots, with Plot 7 (forest Plot) with dense high canopy which have no herbaceous plant in inter-tree spaces and having high runoff and high dissolved sediment yield than other young Plots with light high tree canopy which encourages production of herbaceous plant in inter-tree position which enable them to reduce the runoff and sediment yield.

The result of this study shows that vegetation cover of trees and non-woody herbaceous species tend to prevent erosion. It revealed further that herbaceous ground vegetation especially grasses is more effective in erosion control and that tree cover alone without sufficient ground vegetation could be considered as not being sufficient in reducing intensity of erosion.

References

Andreu, V., J.L. Rubio & R. Cerni. 1994. Use of a shrub (*Medicago arborea*) to control water erosion on steep slopes. *Soil Use and Management* **10**: 95-99.

Andreu, V., J.L. Rubio & R. Cerni. 1998. Effect of Mediterranean shrub cover on water erosion Valencia, Spain. *Journal of Soil and Water Conservation* **53**: 112-119.

Black, C.A. 1965. *Methods of Soil Analysis*. American Society of Agronomy. Monogram, Madison.

Bouyoucous, C.I. 1961. Hydrometer method improved for making particle size analysis of soil. *Agronomy Journal* **54**: 464-469.

Brandt, J. 1988. The transformation of rainfall energy by a tropical rainforest canopy in relation to soil erosion. *Journal of Biogeography* **15**: 41-48.

Burgess, P.F. 1971. The effect of logging hill dipterocarp forests. *Malayan Nature Journal* **24**: 231-237.

Chapman, G. 1948. Size of raindrops and their striking force at the surface in a red plantation. *Trans American Geophys Union* **29**: 664-670.

Charreau, C. 1982. In Meotyppa F. 1973. Soil aspects on the practice of shifting cultivation in Africa and the need for a common approach to soil and land resources evaluation, shifting cultivation, soil conservation. *Food and Agriculture Organisation Soil Bulletin* 24, Rome.

Charter, J.R. 1969. *Map of Ecological Zones of Nigerian Vegetation*. Federal Department of Forestry, Ibadan.

De Graaf, N.R. 1986. *Silvicultural System for Natural Regeneration of Tropical Rainforest in Suriname*, Ph.D. Thesis. Agricultural University Wageningen. 250 pp.

De Leew, P.D. 1978. The primary and secondary productivity of the savanna in the middle belt of Nigeria. Paper presented at *Annual Conference of the Nigerian Society of Animal Production*, Ahmadu Bello University, Zaria, Nigeria.

Douglas, I. 1971. Comments on the determination of fluvial sediment discharge. *Australian Geographical Studies*. **9**: 172-176.

Frangi, J.L. & A.E. Lugo. 1985. Ecosystem dynamics of a subtropical floodplain forest. *Ecological Monographs* **55**: 351-369.

Fraise, F. 1936. Das Bimenklima Van Urwaldern in subtropschen Brasilian. *Petermanns Geographiscene Mitteilurgen* 1936: 301-304.

Fu Bojie 1989. Soil erosion and its control in the Loess Plateau of Ghana. *Soil Use and Management* **5**: 276-282.

Fullen, M.A. 1991. Soil organic matter and erosion processes on arable loamy sand soil in the West Midlands of England. *Soil Technology* **4**: 19-31.

Greig-Smith, P. 1983. *Qualitative Plant Ecology*. 3rd edn. Blackwell Scientific Publication, Oxford.

Helvey, J.D. & J.H. Patric. 1965. Canopy and litter interception of rainfall by hardwoods of Eastern United States. *Water Resources Research* **1**: 193-206.

Herwitz, S.R. 1986. Episodic stem flow in-puts of magnesium and potassium to a tropical forest floor during heavy rainfall events. *Oecologia* **70**: 423-425.

Hewlett, J.D. & A.R. Hibert. 1967. Factors affecting the response of small watersheds to precipitation in humid areas. *In: Proceedings of the International Symposium on Forest Hydrology*, 1965 Penn. State University. Pergamon.

Hudson, N.W. 1971. *Soil Conservation*, Batford London.

Jeje, L.K. 1987. Soil erosion characteristic. Processes and extent in the lowland rainforest areas of southwestern Nigeria. *In:* V.O. Sagua, E.E. Enabor, G.E.K. Ofomata & Oyebande Lekan (eds.) *Ecological Disasters in Nigeria: Soil Erosion*.

Jeje, L.K. & A.N. Agu. 1982. Runoff and soil loss from erosion Plots in Ife Area of Southwester Nigeria *Geo-Eco-Trop* **6**: 161-181.

Keay, R.W.J. 1959. *An Outline of Nigerian Vegetation* (3rd edn). Federal Ministry of Information, Printing Division, Lagos 46 pp + Map.

Kessel, P.H. 1977. Slope, runoff and denudation in the Rapununi. Savanna, Guyana. *Journal of Tropical Geography* **44**: 33-42.

Kirby, M.J. 1969. Infiltration, through-flow and overland flow. *In:* R. Charley (ed.) *Water Earth and Man*, Methuen London.

Lal, R. 1974. Soil erosion and shifting cultivation agriculture. *Food and Ariculture Organisation Soil Bulletin*. 4841.

Lal R. 1976. Soil erosion problems on an Alfisol in Western Nigeria and their control. *International Institute of Tropical Agriculture Monographs*, Ibadan.

Lanly, J.P. 1982. Tropical forest resources. *Food and Agriculture Organisation Forestry Paper No.* 30 106 pp. F.A.O. Rome.

Leeks, G.J.L. & G. Roberts. 1987. The effect of forest and upland stream with special reference to water quality and sediment transport. pp. 9-25 *In*: J. Goode (ed.) *Environmental effect of Plantation Forestry in Wales, Institute of Terrestrial Ecology Symposium* 22, *Institute of Terrestrial Ecology*, Grange-over Sands.

Leow. K.S. & K.O. Ologe. 1981. Rates of soil loss under savanna climate, Zaria, Northern Nigeria. *Geo-Eco-Trop* **5**: 87-98.

Leyton, L., E.R.C. Reynolds & F.B. Thompson 1968. Interception of rainfall by trees and moor land vegetation. *In*: M.E. Solomon & J.W. Wilson (eds.) *Measurement of Environmental Factors in Terrestrial Ecology*. A symposium of British Ecological Society Vol. 8 Reading, 29-31 March 1967. Blackwell Scientific Publications, Oxford and Edinburgh.

Moffat, A.J. 1988. Forestry and soil erosion in Britain. A review. *Soil Use and Management* **4**: 41-44.

Okali, D.U.U., J.C. Okafor & J.N. Anchang. 1987. Forestry practices in erosion prevention and control. *In:* V.O. Saqua, E.E. Enabor, G.E.K. Ofomata & Oyebande Lekan (eds.) *Ecological Disasters in Nigeria: Soil Erosion*.

Onyekwelu, S.S.C. 1987. The effect of ground cover on erosion. *In*: V.O. Saqua, E.E. Enabor, G.E.K. Ofomata & Lekan Oyebande (eds.) *Ecological Disasters in Nigeria Soil Erosion*.

Pierce, R.S. 1967. Evidence of overland flow on forested watersheds pp. 247-253. *In:* W.E. Soper & H.W. Lull (eds.) *International Symposium on Forested Hydrology*. Pergamon Press, London.

Rose Innes, R. & J. Mansfield. 1976. Grass vegetation of the Kaduna Plains. *Land Resources Divisoin, Ministry Overseas Development Report*. Surbiton, U.K.

Ruxton, B.P. 1967. Slope wash under mature primary forest in Northern Papua. *In:* J.N. Jennings & J.A. Mabbutt (eds.) *Land Form Studies from Australia and New Guinea*. University Press, Cambridge.

Sanford, W.W. 1982. Savanna - A general review. pp. 3-23. *In: Nigerian Savanna Selected Papers from State of Knowledge Workshop* W.W. Sanford, H.M. Yesufu & J.S.O. Ayeni (eds.) KLRI New Bussa, Nigeria.

Screenivas, S.L., J.R. Johnston & H.O. Hill. 1947. Some relationship of vegetation and soil detachment in erosion process. *Proceeding of Soil Science Society of America* **12**: 471-478.

Smyth, A.J. & F.R. Montgomery. 1962. *Soil and Land Use in Central Western Nigeria*. The Government of Western Nigeria, Ibadan.

Stocking, M.A. & H.A. Elwell. 1976. Rainfall erostivity over Rhodesia. *Trans. Institution Britain Geography*. **1**: 231-245.

Vis., M. 1986. Interception, drop size dstribution and rainfall kinetic energy in four Colombian forest ecosystem. *Earth Surface Processes and Landforms*. **11**: 519-603.

White, F. 1983. *The Vegetaton of Africa*. A descriptive memoirs to accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa.

Whipkey, R.Z. 1969. Storm runoff from forested catchments by subsurfaces routes. *Publicaiton of International Association of Science Hydrology* **85**: 773-779.

Wiersum, K.F. 1985. *Effect of various vegetation layers in an Acacia anriculiform forest plantation on surface erosion in iava indonesia* pp 79-89.

Zinke, P.J. 1967. Forest interception studies in the U.S. *In:* W.E. Supper, & H.W. Lull (eds.) *International Symposium on Forest Hydrology Pergamon*, Oxford.