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Mineral nutrient flow from an inselberg in south-western Nigeria

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ABSTRACT. In a study carried out to find out if inselbergs enrich their surroundings with nutrients via drainage, amounts of total nitrogen, nitrate-nitrogen and potassium in rainfall, drainage from bare rock patches and vegetation mats on an inselberg in south-western Nigeria were measured over one year. 43.3 kg ha^{-1} total nitrogen, 4.8 kg ha^{-1} nitrate-nitrogen and 10.7 kg ha^{-1} potassium were recorded in rainfall for the year of study. The amount of total nitrogen in drainage from bare rock was 79% of that in rainfall whilst that in drainage from vegetation mats was 29% of the rainfall amount. The respective values for nitrate-nitrogen were 57% and 13%; for potassium they were 90% and 38%.

It was assumed that the loss of nutrients as water drains through vegetation mats and over bare patches was due to absorption by plants and soil in the mats and lichens in the bare patches. It was therefore concluded that there was no net enrichment of rainwater with nutrrients as it flows over inselberg slopes. There is, however, a funelling of water along with contained nutrients from the inselberg to the surrounding areas. This funnelling is additional to the nutrients and rainfall incident on these surrounding areas and may account for the vegetation around inselbergs being more lush than vegetation in the same area but further away from the inselbergs.

A simple modelling approach was used to assess potential nutrient outflow from inselbergs. The model shows that discharge of nutrients from the edges of inselbergs increases linearly with inselberg diameter. The model further shows that if nutrient funnelling only affects an area near to the edge of the inselberg then nutrient addition is several times higher than would be expected from rainfall deposition alone.

KEY WORDS: enrichment, inselberg, nutrients, flow simulation, south-western Nigeria, runoff.

INTRODUCTION

In south-western Nigeria there is a chain of moderate height pre-Cambrian age, basement complex metamorphic rock inselbergs. The inselbergs consist mainly of fine-grained biotite gneisses and schists. Where the slopes on the inselbergs are not too steep, vegetation mats develop. The typical inselberg surface is usually a mosaic of 'bare' patches and vegetation mats, both of varying size and shape. These 'bare' surfaces provide a variety of micro-habitats which are colonized by lichens and cyanobacteria (blue-green algae) (Hambler 1964).

In most of the vegetation mats on these inselbergs, *Cyanotis* D. Don. spp. and *Afrotrilepis pilosa* (Boeck.) J. Raynal are typical of the perennial drought-enduring plants found. Richards (1957) documents the species found at the Idanre Hills, at the southern tip of the inselberg chain, whilst Isichei & Longe

(1984) report on the composition of mats at Ile-Ife and Hambler (1964) on the composition of mats and 'bare' patches from the Iseyin area, further to the north-west.

The vegetation immediately adjacent to inselbergs is usually more lush than in the surrounding areas, giving an impression that there is some improvement of the edaphic environment around inselbergs, and Hambler (1964) attributes this to an improved water regime.

Other evidence from the literature suggests that the soils around inselbergs might contain more than average levels of nutrients. Wild (1971) reported that soils derived from basement complex parent materials in Nigerian savanna contained relatively more total potassium than those derived from sandstone, alluvium or amphibolite. Awodoyin (1986) working at the base of one of the inselbergs at Ile-Ife reported exchangeable potassium levels of between 0.45 and 0.49 milli-equivalents per 100 g soil, values which are slightly higher than the 0.11 to 0.45 range for soils in the general area reported by Okeya (1977). Muoghalu & Isichei (1987) reported a mean exchangeable potassium value of 0.21 meq/100 g soil for inselberg mat soils but obtained a mean total nitrogen level of 0.55% in these mat soils. This nitrogen level is nearly twice the value reported for soils of dry lowland rain forest in that zone (Agboola 1979).

The present study aims to evaluate the nutrient contribution of inselbergs and their associated organisms to their immediate surroundings through drainage from the inselbergs. It was not possible to deal with all nutrients at the same time so those that are considered important in the sense that they are often limiting to plant growth were studied. Nitrogen, phosphorus and potassium have often been cited as limiting in most West African soils (Bromfield 1969, Heathcote & Stockinger 1970, Jones & Wild 1975). Potassium and nitrogen were studied because the former is a significant component of inselberg rocks and the latter could be fixed by plants living on the inselbergs. A modelling approach is used to assess the magnitude of discharge of drainage water and nutrients to surrounding soils with varying inselberg size and inselberg surface plant cover.

If drainage water from inselberg slopes enriches surrounding soils with nutrients there are three likely sources of such nutrients. One is the direct weathering of the inselberg rock surface either chemically by rainfall itself or a combination of this with the weathering activities of plants. Carbonic acid produced by the reaction of carbon dioxide from plant respiration with water, and organic acids produced during plant decay both aid chemical weathering. Williams & Rudolph (1974) have observed that because of the weakly acidic proporties of lichen thalli and the metal-complexing ability of their surface hyphae they are able to participate in weathering of rock materials and the decomposition of trapped particles.

The second likely source of nutrients is leaching from lichens, cyanobacteria and higher plants. Some of these lower plants could be nitrogen fixing and leachates from them are likely to contain higher levels of nitrogen than ordinary drainage water. There is also the addition of the nutrients contained in the tissues of these organisms to the surrounding land when these organisms as well as whole vegetation mats are washed down (Richards 1957).

The third likely source is that which is simply transferred to the surrounding area in runoff, but without enrichment from the inselberg surface.

MATERIALS AND METHODS

The study site

The study was carried out on one of three inselbergs located within the Obafemi Awolowo University Campus (7° 32′ N, 4° 31′ E) at Ife in south-western Nigeria with a summit height of about 400 m above sea level.

The University campus and the area around it are underlain by pre-Cambrian age basement complex rocks. The soil is ferruginous and is deep and intensely weathered with few weatherable materials remaining except on inselbergs (Smyth & Montgomery 1962). The soils, which are usually acid, contain less than 10% clay, which is mainly kaolinite, and hence are characterized by low cation exchange capacity and low water holding capacity (Ayodele 1986).

The Ife area usually has an eight month wet season from March to October and a four month dry season from November to February (Figure 1). The annual rainfall is variable and averaged 1413 mm for the period 1969-1973 (Duncan 1974), for example, but in the year of this study, 1985, it was 1950 mm. Temperatures are not very variable; the mean monthly maximum is about

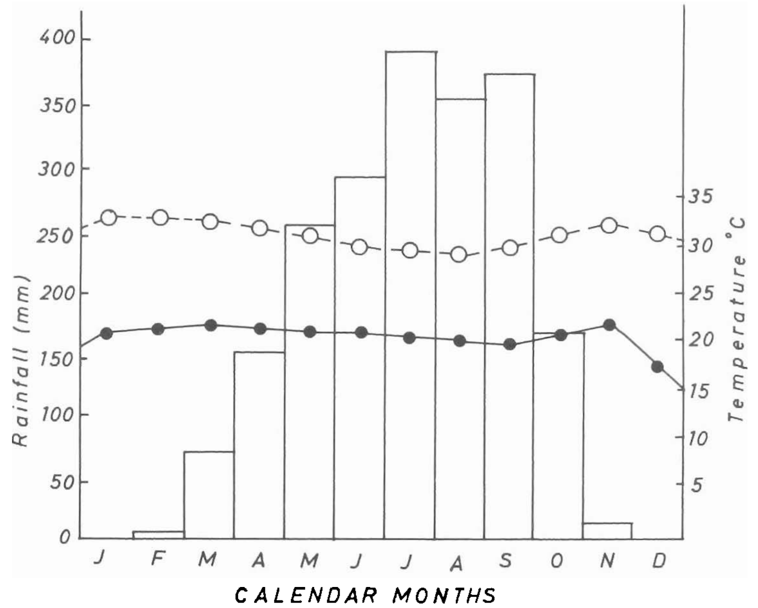

Figure 1. Monthly temperature and rainfall at Ile-Ife, south-western Nigeria, 1985. (Figure used courtesy of the Department of Geography, University of Ife.) Histogram: monthly rainfall, o--o--o: mean monthly maximum temperature; •—•—•; mean monthly minimum temperature.

31°C and the mean monthly minimum 21°C. Relative humidity is high for most of the year; in the wet season it is between 80 and 95% at 10.00 h whereas in the dry season it is between 70 and 80%.

The dome of the inselberg studied covered about 0.25 km^2 of which about half was bare (without soil and vascular plant cover but with lichens) and half was with vegetation on shallow soil. Muoghalu & Isichei (1987) reported, for 15 vegetation mats studied, a mean soil depth of 6.92 cm, soil total nitrogen concentration of 0.55%, exchangeable potassium of 0.21% and a sand:clay ratio of about 8. Lichen cover averaged 65% on the bare patches.

Collection, treatment and chemical analyses of water samples

Six runoff plots were established by building low concrete walls to channel runoff to six collecting points from three bare areas whose horizontal areas were 3.26 m^2, 12.15 m^2 and 14.09 m^2 respectively, and from three vegetated areas of sizes 3.06 m^2, 11.18 m^2 and 33.66 m^2. Each catchment was assumed to be a sector with the collecting point as the angle of the sector and the concrete dams as the two sides. The total area of the catchment (A) was estimated accordingly using the equation: $A = \pi r^2 \theta/360$, where θ is the angle between the two dams at the collecting point, and r the radius of the assumed sector.

Slope was measured in each catchment using a clinometer (SILVA, Type 15T) and the slope data were used to correct the measured catchment areas to horizontal areas when calculating water and nutrient flows. The collecting points were equipped with polythene collecting cans fed by polythene funnels which were fitted to the collecting points. Pieces of aluminium gauze were fixed to the mouths of the funnels to hold back litter. Collecting of drainage water started from 11 March 1985 and continued until 15 October 1985 at the end of the rainy season.

Collection of rainfall was in three rain gauges which were randomly positioned on the inselberg. Drainage water and free-fall rainwater were collected and their volumes measured after each shower. Collections from night showers were made before 09.00 h the following morning. To prevent accumulation of micro-organisms, collectors were rinsed with hydrochloric acid after each collection. In the laboratory, 2 ml chloroform were added to the water samples to suppress any microbial growth and they were stored in the freezer when immediate analysis was not possible.

The water samples were analysed for potassium, nitrate-nitrogen and total nitrogen. Samples were filtered through a Whatman No. 1 filter paper prior to analysis. The early showers in March were analysed singly (except for total nitrogen because of the large volume required), but monthly samples were bulked thereafter. Potassium concentration was measured with an atomic absorption spectrophotometer (Perkin Elmer 305B) using an air-acetylene flame. Samples for total nitrogen analysis were first digested following Allen *et al.* (1974) before colorimetric determination of ammonia in the digest in an autoanalyser at the International Institute of Tropical Agriculture (IITA), Ibadan (Tel & Rao 1982). Nitrate nitrogen was determined without digestion, also at IITA.

Formulation of the model for nutrient flow from an inselberg to surrounding areas

For the purposes of modelling, an inselberg is envisaged as a circle of diameter, D, and area, A.

The amount of nutrient coming down the inselberg slopes depends on the amount of the nutrient in rainfall and how much it is increased or decreased when rain water drains from bare rock or a vegetation mat.

The proportion of an inselberg which is devoid of vegetation mats is denoted by p. Thus, the total area covered by bare patches and vegetation mats is pA $(1 - p)$ A m^2 respectively.

The amount of a particular nutrient falling in rainfall is denoted by R g m^{-2} y^{-1} and the proportion running off from bare patches and vegetation mats is denoted by b and v respectively.

Thus, the total amount of a nutrient draining from an inselberg is given by:

$$[bRp + vR(1 - p)]\ A\ g$$

and the amount discharged per metre of circumference (DIS) is:

$$[bRp + vR(1 - p)]\ A/C$$

and as $A = \pi D^2/4$, and $C = \pi D$,

$$DIS = 1/4\ [bRp + vR(1 - p)]\ D\ g\ m^{-1}$$

This formulation was run as a Pascal computer program RUNOFF, in which inselberg diameter was varied from 100 to 1000 m and bare patch proportion (and therefore vegetation mat cover) between 0.0 and 1.0 of inselberg area. Values for R, b and v were obtained from the data reported in this paper.

RESULTS

Water flow from the inselberg surface

There were 102 showers on the inselberg, amounting to 1932 mm of rain during the study period, 99% of the annual total. Monthly rainfall and temperature patterns for the year of the study are shown in Figure 1. (Data obtained at the University of Ife weather station about 1 km from the inselberg).

The volume of rainwater collected in the 5-inch diameter rain gauge was converted to volume m^{-2} and the relationship between the volume of rain and water flow m^{-2} from the vegetation mats and bare patches is shown in Figure 2. For the months March to October, an average of 234.35 l of rain m^{-2} $month^{-1}$ was collected in the rain gauge whilst an average of 128.08 and 44.96 l m^{-2} flowed from the bare patches and vegetation mats respectively. In other words,

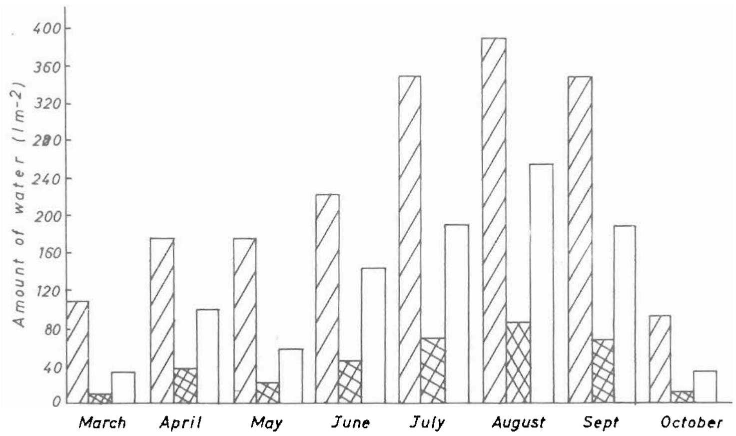

Figure 2. Amounts of rainfall collected in rain gauges and as drainage through bare rock patches and vegetation mats on an inselberg in south-western Nigeria during the 1985 rainy season. ▨ Rain gauge collection; □ bare patch drainage; ⊠ vegetation mat drainage.

flow from the bare patches was about 55% of the rain gauge and that from the mats was about 19%. It is assumed that the differences in flow are accounted for by evaporation from the inselberg surface and evapotranspiration from the vegetation mats.

Nutrients in rainwater and drainage water

Potassium concentrations in the three types of collection show a very similar pattern (Figure 3) with a high concentration in the first month of the rainy season and a sharp drop and levelling off later in the season. Vegetation mats show the highest concentration whilst rainwater has the lowest.

Rainwater had the highest nitrate-nitrogen concentration in March (Figure 3), about four times the concentration in drainage from mats and eight times that in drainage from bare patches. From April, the second month of the rainy season, however, the patterns of concentration in the three collections were similar to but much less consistent than the potassium concentration patterns.

Total nitrogen concentration remained more or less the same in rainwater throughout the season but in drainage from vegetation mats and bare patches the concentration fluctuated at the beginning of the season and steadily declined to the level in the rainwater towards the end of the season.

A Wilcoxon matched pairs, signed-rank test showed that rainfall nitrate-nitrogen concentrations were not significantly different from either bare patch or mat drainage concentration. In the case of potassium and total nitrogen however, mat and bare patch drainage concentrations were significantly higher ($P<0.05$) than rainfall. Amounts (kg ha^{-1} y^{-1}) of potassium, nitrate-nitrogen and total nitrogen in rainfall, bare patch and mat drainage (Table 1) were highest in rainfall followed by bare patch drainage whilst those in mat drainage were the lowest.

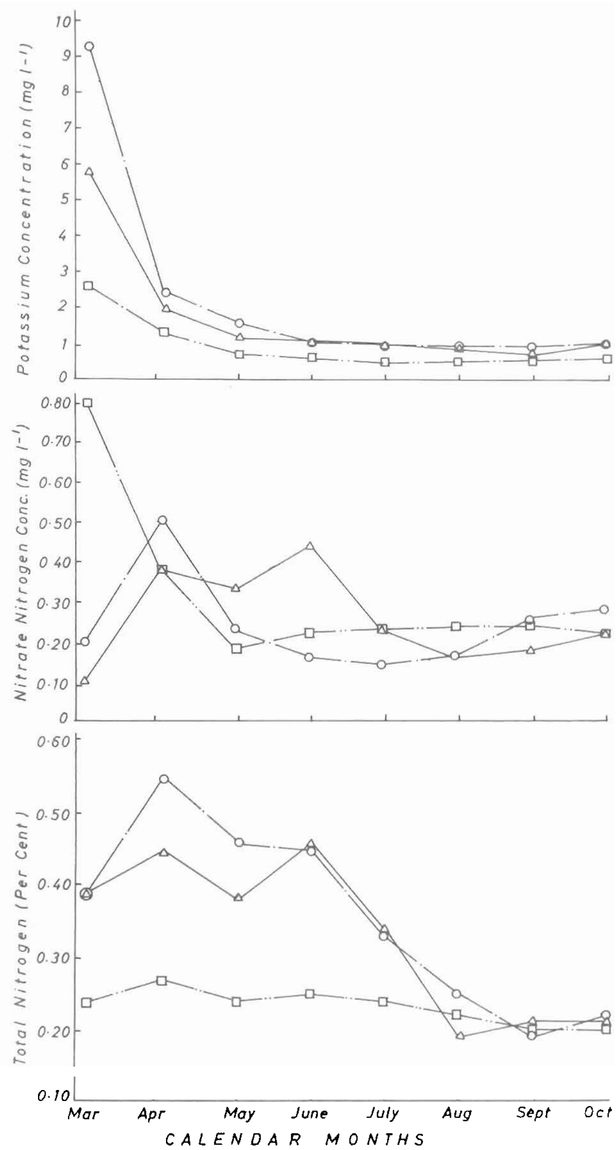

Figure 3. Concentrations of total nitrogen, nitrate-nitrogen and potassium in rainfall collected in rain gauges, as drainage through bare rock patches and as drainage through vegetation mats on an inselberg in south-western Nigeria, 1985. □—··—□ Rain gauge collection; △——△ bare patch drainage; ○—·—○ vegetation mat drainage.

Potassium amount in rainwater (Figure 4) is highest at the beginning of the rainy season in March and falls sharply the next month, only to rise again moderately during the period of heavy rains in July, August and September. The amount in drainage from bare patches is significantly much lower than in rainwater in March; there was an increase in April and then a decrease in May. In the months of July, August and September the amounts in drainage from

Table 1. Amounts of potassium, nitrate-nitrogen and total nitrogen in rainfall, drainage from bare patches and drainage from vegetation mats on an inselberg in south-western Nigeria in 1985. (Figures in brackets represent drainage nutrient amount as a proportion of rainfall amount).

	Amount (kg ha^{-1} y^{-1})		
Nutrient	Rainfall	Bare patch	Vegetation mat
Potassium	10.7	9.6 (0.90)	4.0 (0.38)
Nitrate-nitrogen	4.8	2.7 (0.57)	0.6 (0.13)
Total nitrogen	43.3	34.1 (0.79)	12.6 (0.29)

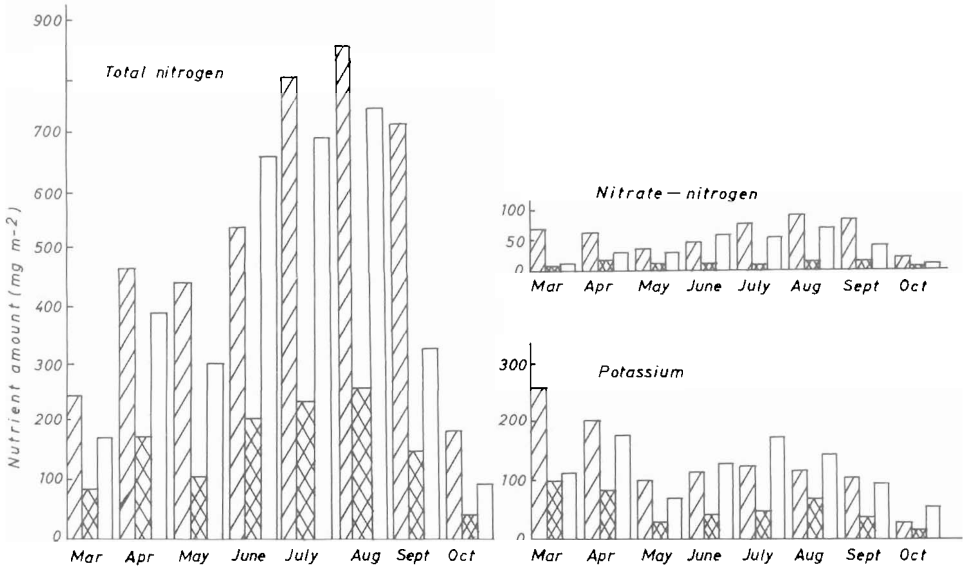

Figure 4. Amounts of total nitrogen, nitrate-nitrogen and potassium in rainfall, drainage through bare patches and vegetation mats on an inselberg in south-western Nigeria during the rainy season, 1985. Rain gauge collection; vegetation mat drainage; bare patch drainage.

bare patches exceeded those in rainwater but the differences are not statistically significant. Drainage of potassium from vegetation mats has a seasonal pattern similar to that of rainwater but the amount is much lower at all times during the season. A month by month comparison using the Wilcoxon signed-rank test showed that potassium amounts in rainfall were greater than amounts in drainage from vegetation mats ($P<0.05$) but not significantly higher than amounts in drainage from bare patches. Bare patch amounts were significantly higher than vegetation amounts ($P<0.05$).

The pattern for nitrate-nitrogen amounts (Figure 4) is similar to that of potassium with the amount in the drainage from bare patches and mats being lower than in rainwater at the beginning of the rainy season. The months of July, August and September, however, showed a much higher amount of nitrate-nitrogen falling in rainwater than the early months of March and April, unlike the case of potassium. During these months the amount falling in rain-water was almost double the amount in drainage water. These differences are, however, not statistically significant (Figure 4). Nitrate in bare patch drainage increased from March, rising gradually until June and thereafter declined to the early season level by October. Nitrate in drainage from mats was still the lowest, fluctuating in the early rainy season and being low in the months of May, June and July when the vegetation was actively growing. In this respect, the pattern

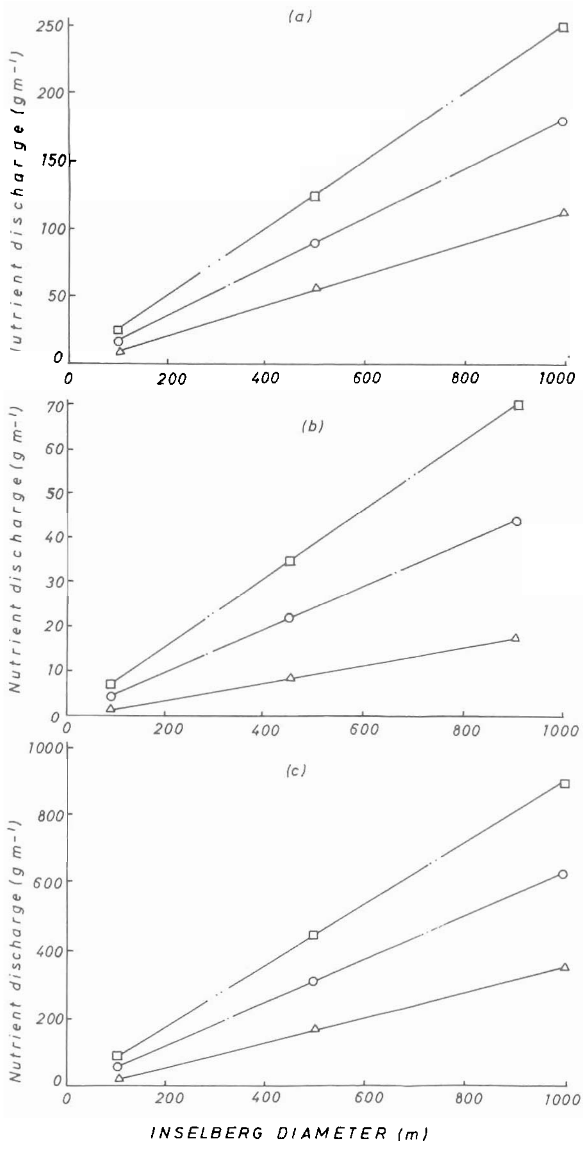

Figure 5. Amounts of potassium (a), total nitrogen (b) and nitrate-nitrogen (c) discharged at the edge of inselbergs in relation to inselberg diameter and the amount of vegetation cover on it as simulated by the model RUNOFF. □—··—□ zero vegetation cover; ○—·—○ 50% vegetation cover; △——△ 100% vegetation cover.

is similar to that shown for potassium. When compared, using the Wilcoxon signed-rank test, nitrate-nitrogen amounts in rainwater were significantly higher ($P<0.05$) than in either bare patch or vegetation mat drainage. Bare patch drainage amounts were higher ($P<0.05$) than vegetation mat drainage.

Total nitrogen amount in rainfall, drainage from bare patches and vegetation mats (Figure 4) showed similar patterns to nitrate-nitrogen, the only difference being the magnitude of the difference in amount in rainfall and drainage from bare patches. Again, the high amount of nitrate seen at the beginning of the season was not reflected in the case of total nitrogen. Total nitrogen amounts were significantly higher, ($P<0.05$) in rainfall than in bare patch drainage which in turn was higher than in drainage from vegetation mats (Wilcoxon signed-rank test).

Simulations using the model RUNOFF

The predictions from the model RUNOFF show clearly the nature of the linear increase in the amounts of nutrients discharged to inselberg surroundings with increase in inselberg diameter (Figure 5). Further, as vegetation cover on the inselberg increases, the amount of nutrient discharged decreases linearly. Thus, for nitrate-nitrogen there is an average of 16% decrease in discharge for every 10% increase in vegetation mat cover. A maximum of 34% decrease would be observed for a vegetation mat cover increase of from 90 to 100% while an 8% decrease would be observed for a vegetation cover increase of from 0 to 10%. The predicted average for potassium is 9% decrease with a maximum of about 14% and a minimum decrease of 6%. The respective values for total nitrogen are 10%, 17% and 6%.

The model also predicts that an inselberg of 100 m diameter and with 50% vegetation cover, for example, will discharge, per square metre, 16 times more potassium, 13 times more total nitrogen and nine times more nitrate-nitrogen than is present in incident rainfall if the discharge travels no further than 1 m from the inselberg.

DISCUSSION

The amounts of potassium, total nitrogen and nitrate-nitrogen obtained in this study compare well with figures reported from West Africa and other tropical locations (Table 2).

Most of the potassium in rainwater is most likely to have resulted from a washdown of harmattan dust and particulates in the atmosphere (McTainsh & Walker 1982). The northern parts of West Africa receive far more dust than the south, hence the lower value reported here for Ile-Ife than for the more northern locations is to be expected. Total nitrogen amounts reported for West Africa have been widely variable but it is generally agreed that total nitrogen in rainfall increases with increasing annual rainfall amount so that places closer to the coast in West Africa such as Ife are more likely to have more nitrogen deposited in rainfall. Servant *et al.* (1984) obtained nitrate concentrations in

Table 2. Comparison of the amounts of mineral nutrients in rain water collected in Ile-Ife (7° 32′ N, 4° 31′ E) south-western Nigeria, 1985 with figures reported from other West African locations and other tropical areas.

Nutrient	Value obtained from Ile-Ife 1985 (kg ha^{-1})	Values obtained from other locations (kg ha^{-1}) and references
Potassium	10.7	(1) 36.18, Samaru Nigeria. Jones (1960). (2) 17.48, Kade, Ghana. Nye (1961).
Total nitrogen	43.3	(1) 40.42, Gambia. Thornton (1965). (2) 28, average value for rain forest zone of West Africa. Robertson & Rosswall (1986).
Nitrate-nitrogen	4.8	(1) 2.5*, Samaru, Nigeria. Jones & Bromfield (1970). (2) 7.81*, Kade, Ghana. Nye (1961). (3) 3.35*, Cote d'Ivoire. Roose (1974). (4) 4.46*, average value for deciduous forest of West Africa. Robertson & Rosswall (1986). (5) 2.50–12.47, various locations in Venezuela. Sanhueza *et al.* (1988).

* Estimated from reported mineral nitrogen values on the assumption that ammonium: nitrate-nitrogen ratio is 1:1.26.

rainfall ranging from 0.54 to 1.82 mg l^{-1} in Ivory Coast (compared with 0.18–0.80 for this study and 0.16–0.84 obtained by Sanhueza *et al.* 1988). Servant *et al.* have noted the disparity between their figures and the 0.16 mg l^{-1} reported from an earlier Venezuelan study.

The amounts of the nutrient flows reported here are in the order rainwater > bare patches > vegetation mats, the same order as the amounts of water flow. It is apparent that evaporative loss of water was considerable from both the bare patches and, particularly, the vegetation mats. Water loss was more from the mats because they absorb the water and later lose most of it by evapotranspiration. This loss of water has a concentrating effect on the nutrients, resulting in higher concentrations of potassium and total nitrogen in drainage from bare patches and mats. The lower amounts of the elements, however, in the drainage water suggests absorption by the lichens growing in the bare patches and the vegetation community of the mats. This absorption is most easily noticeable with potassium early in the rainy season. On the other hand, very little of the total nitrogen is absorbed throughout the season and the pattern of the amounts of this element follows the seasonal pattern of the amount of water flow. This is not surprising because most of the total nitrogen is usually in complex organic form which is not directly utilized by plants.

Four lichen genera were found in the bare patches of the study area. Together, they formed a mean cover of 65% of the patches. *Pannaria* sp. Delis. had the greatest cover followed by *Lecidea* sp. Ach., *Haematomma* sp. Massal. and *Cladonia* sp. (Hill) Web. The lichen community and vegetation mats affected nutrient amounts in drainage from them in different ways, the vegetation mats absorbing more of the nutrients in rainfall and the lichens apparently releasing some nutrients at certain times of the year.

The large difference between the amounts of potassium and nitrate-nitrogen in rainfall and the amounts in drainage through mats or bare patches, especially early in the rainy season, indicates a high rate of absorption at this time of year. It could be argued, however, that the lichens are dry or dead and cannot therefore absorb, but Brown (1976) has shown that dead lichen thalli absorb nutrients and that passive uptake of nutrients is more significant than metabolically-linked uptake. Further, Brown observes that monovalent cations are more easily absorbed than divalent or polyvalent ones and that the atmosphere is the major, if not the exclusive source of cations for lichens. Earlier, Syers & Iskander (1973), whilst reviewing the role of lichens in rock break-down, observed that lichens could take up nutrients from flowing water even when the nutrients are at very low levels.

This absorption observed in March does not continue all through the season. In the months of June, July and August the amounts of potassium in drainage from bare patches exceeded those in rainwater indicating that bare patches were releasing more potassium than was being received in rainfall. The higher level of potassium may have arisen from leaching of the lichen surfaces; Brown (1976), for example, observed that about 10% of the recoverable potassium in the lichens in his study was extracellular. Lichens have also been implicated in rock weathering (Syers & Iskander, 1973) so it is possible that potassium weathered from the inselberg rock may be part of the outflow from the bare patches in the rainy season. Grandiorite, a major rock type of the western Nigeria inselbergs has been shown to have a potassium content of 4.36%, whilst coarse granites and fine granites, also inselberg rock constituents, were 4.67 and 4.86% potassium, respectively (O. Ocan, personal communication). The rate of weathering of the western Nigeria inselbergs is, however, unknown. Vegetation mats have many perennials as their constituent plants (Isichei & Longe 1984), so absorption of nutrients is very likely with even the earliest rains. Much of the water stored in mats is delayed to be evaporated later so it is not surprising that there were no indications at all of nutrient release in excess of that in rainfall.

The lower level of nitrate-nitrogen in bare patch drainage in June, July and August indicates its greater use at this time of the year when, with regular rainfall, the lichens are growing. Algal symbionts in lichens utilize nitrate directly and may have accounted for increased absorption in this period of growth.

The low levels of total nitrogen, nitrate-nitrogen and potassium in drainage from the vegetation mats could be explained by high absorption from rainwater by the mat soil. It is likely, however, that drainage from mats and bare patches may carry more nitrogen than observed in this study because large particles and litter which may contain nitrogen and other nutrients were filtered out and not estimated. Such movement of particles and litter may, however, influence the level of nutrients in areas surrounding inselbergs.

It may be concluded from this study that there is no appreciable overall enrichment of nutrients in drainage water from vegetation mats or bare patches. There is, in fact, a significant decrease in drainage from vegetation mats. That does not mean, however, that there is no enrichment of land surrounding the inselberg. There is a funnelling of water along with the nutrients in it down the inselberg slopes. In the present study, this amounted to a total annual flow of 359.65 l m^{-2} of rainwater from vegetation mats and 1024.64 l m^{-2} from bare patches. Thus, the surrounding areas, in addition to the amounts of nutrients they receive through incident rainfall, will also receive the funnelled flow from the inselberg. The amount of nutrient received annually will depend on the relative proportions of the inselberg surface occupied by vegetation mats and bare patches, and the size of the inselberg.

The model RUNOFF gives an insight into the expected levels of nutrient enrichment of soils around inselbergs and together with water enrichment may thus help to account for the more lush vegetation around inselbergs than further away from them. There is, however, some over-simplication in the model which could be corrected by further studies. One is the extent of enrichment away from the inselberg which will be determined by the drainage characteristics of the surrounding soils, a factor not considered in the formulation. There could also be channelling of drainage through very few locations and, in some cases, into streams resulting in a lesser enrichment of immediate surroundings. Levels of actual enrichment could be estimated by direct soil and vegetation analyses and extensive sociological studies to find out if, from the soil fertility point of view, inselbergs affect choice of farmlands and settlements in the areas in which they are found.

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