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Seasonal cycling of nitrogen, phosphorus and potassium in isolated vegetation mats on an inselberg in southwestern Nigeria

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Summary

On the inselbergs at the University of Ife Campus (7°31′N, 4°31′E), southwestern Nigeria are mat communities that are completely isolated from each other and have been shown to behave as real islands in their species–area relationships. The amount of nitrogen, phosphorus and potassium in the vegetation and soil of fifteen of these communities on one inselberg were determined bi-monthly through a growing season. These determinations were carried out by randomly selecting three or four mats at a time, clipping all vegetation and excavating the soil on each mat. The excavated soil was sieved to remove subterranean plant material and, after drying, all plant materials and soil were analysed for three elements, nitrogen, phosphorus and potassium. The clippings and excavations were done in March (beginning of rainy season), May, July and September. The concentration of the three elements in the above-ground plant material was highest in May for nitrogen and potassium and in July for phosphorus, and thereafter the concentrations of the three elements declined. Below ground, nitrogen concentration increased continually, phosphorus increased for some time then dropped while potassium was low in May and later increased. The concentration of nitrogen in the soil increased through the season, phosphorus fluctuated while potassium remained more or less constant. The mats could be valuable in understanding nutrient cycling and the relevance of the results obtained from this study is discussed.

Résumé

Sur les collines du camput de l'Université d'Ife (7°31′N, 4°31′E) au sud-ouest du Nigeria se trouvent des communautés graminéennes complètement isolées les unes des autres qui se comportent comme de réelles îles dans leurs relations espèces/espace. La quantité d'azote, de phosphore et de potassium dans la végétation et le sol de 15 de ces communautés sur une colline fut déterminée deux fois par mois durant une même saison. Ces déterminations furent réalisées en sélectionnant au hasard trois ou quatre des ces communautés en même temps, en y fauchant la végétation et en y extrayant de sol. Ce sol excavé fut traité pour extraire les parties souterraines des plantes et, après séchage, tant les plantes que le sol furent analysés pour mesurer l'azote, le phosphore et le potassium. Les fauchages et excavations furent réalisés en mars (début de la saison des pluies), mai, juillet et septembre. La

*Botanical nomenclature is according to Hutchinson & Dalziel (1954–72).

concentration de ces trois éléments dans les parties aériennes des plantes fut la plus élevée en mai pour l'azote et le potassium et en juillet pour le phosphore; ensuite ces concentrations diminuent. En sous-sol, la concentration d'azote augmente continuellement, celle du phosphore augmente un peu puis diminue, alors que celle du potassium est faible en mai puis augmente. La concentration d'azote dans le sol augmente tout au long de la saison, le phosphore fluctue et le potassium reste plus ou moins constant. Ces tapis graminéens pourraient s'avérer très valables pour le compléhension des cycles des nutrients. Dans ce contexte, la validité des résultats de cette étude est discutée.

Introduction

One of the still largely unanswered fundamental questions in tropical ecology is the way that plant nutrients are cycled in ecosystems. In many ecosystems, sources of inputs of the major nutrients are unknown and the processes that determine the exchanges of nutrients within systems are not clearly quantified. Greenland (1980), for example, states for nitrogen: 'The major processes involved in transfers of nitrogen between the different compartments of individual ecosystems are now well established. Detailed quantitative information regarding the amounts of nitrogen involved, and the rates at which it moves between different compartments is, however, largely lacking. This is particularly true of tropical regions.'

While the same can be said of all the major nutrients and several micronutrients, nitrogen, phosphorus and potassium have often been listed as limiting to production in tropical soils (Ahn, 1970). Jones & Wild (1975) stated that in West African natural savanna, granted adequate moisture, phosphorus is often a primary limiting factor to productivity and nitrogen a secondary one, but after a few years of cultivation nitrogen becomes the primary limiting factor. Potassium concentration is limiting especially in the forest zone (Ahn, 1970) and often depends on parent rock material (Wild, 1971; Okeya, 1977). Understanding the cycling of these elements is, thus, of major interest in ecosystem management.

The limits that these biologically essential elements place on the productivity of ecosystems is usually the main focus of studies. The study of the cycling of these elements also forms convenient points of entry into the analysis of ecosystems, and from the system's viewpoint the pattern of the cycling of nutrient elements can be used as an indicator of the continuity and stability of the living system. Most often the cycling of nutrients in a biological system is extremely complex and only broad generalizations can be made from cycling studies. Generally, a small portion of a land area or vegetation formation is marked out for intensive study from which extrapolations are made for the whole area. Such demarcations have their limitations since incoming and out-going material cannot be accurately measured. Islands are more useful in this regard.

MacArthur & Wilson (1967) stated that islands are important objects of study because they are simpler than a continent or an ocean, and that by studying clusters of islands, biologists view a simpler microcosm of the seemingly infinite complexity of continental and oceanic biogeography. Also, by their very multiplicity and variation in shape, size and degree of isolation, islands provide the necessary replications in natural experiments by which evolutionary hypotheses can be tested. The present study aims at contributing to the understanding of nutrient cycling within the system in the tropics by using isolated vegetation mats on an inselberg in western Nigeria to study the seasonal cycling of nitrogen, phosphorus and potassium.

Oke (1982) has shown that the number of species in 100 of these vegetation mats on the Ife inselbergs have a log–linear relationship with area with a regression slope of 0·26, which is within the range found in island studies (MacArthur & Wilson, 1967).

The vegetation mats are located on one of the three inselbergs at the University of Ife campus, southwestern Nigeria (7°31′N, 4°31′E). The Ife inselbergs are part of a chain of moderate height rock domes that extend for about 300 km in western Nigeria. They are pre-Cambrian age, basement complex metamorphic rocks, mainly fine grained biotite gneisses and schists (Smyth & Montgomery, 1962). Vegetation mats form on them when barriers prevent water flow along the slopes leading to accumulation of debris. Richards (1957) and Hambler (1964) document the species composition of such communities on Western Nigerian inselbergs. Isichei & Longe (1984) studied seasonal succession in one such community and reported that, at peak species richness late in the season, species abundance distribution approaches log–normal. The mat communities are characterized by shallow soil and plants that endure water shortage and nutrient stress. Similar mats on granite outcroppings in the southeastern United States have been used to investigate the effects of natural and anthropogenic stresses and energy budgets (Burbanck & Platt, 1964; Lugo & McCormick, 1981).

Materials and methods

Fifteen completely isolated mat communities on one inselberg were sampled; three mats in March, four in May, four in July and four in September, 1983. March is the beginning of the growing season in the Ife area (Fig. 1) while herbaceous plants attain peak above-ground biomass in September and October.

On each sampling occasion the dimensions of each community were recorded and soil depth was measured at several points to obtain a mean depth. Above-ground standing crop was estimated by clipping all vegetation at ground level into polythene bags. The plants were later sorted into species and dried at 80°C to constant weight in an oven and weighed. Litter was hand-picked from each plot, washed free of soil, dried and also weighed.

The below-ground crop was estimated by excavating all the soil into polythene bags. The soil was air-dried in the laboratory (for up to 2 weeks depending on the level of wetness) and sieved through a 2-mm mesh to separate the soil from the below-ground plant material. This plant material was washed free of soil, dried in an oven and weighed. The air-dried soil was also weighed.

The oven-dried plant materials were ground in a laboratory mill through a 1·5 mm mesh to produce sufficiently homogenous materials for chemical analysis.

Chemical analysis

The plant materials were analysed for total nitrogen by the Kjeldahl method, for total phosphorus by colorimetry (Molybdenum blue method of Allen *et al.*, 1974) and for total potassium by flame photometry with potassium chloride as standard.

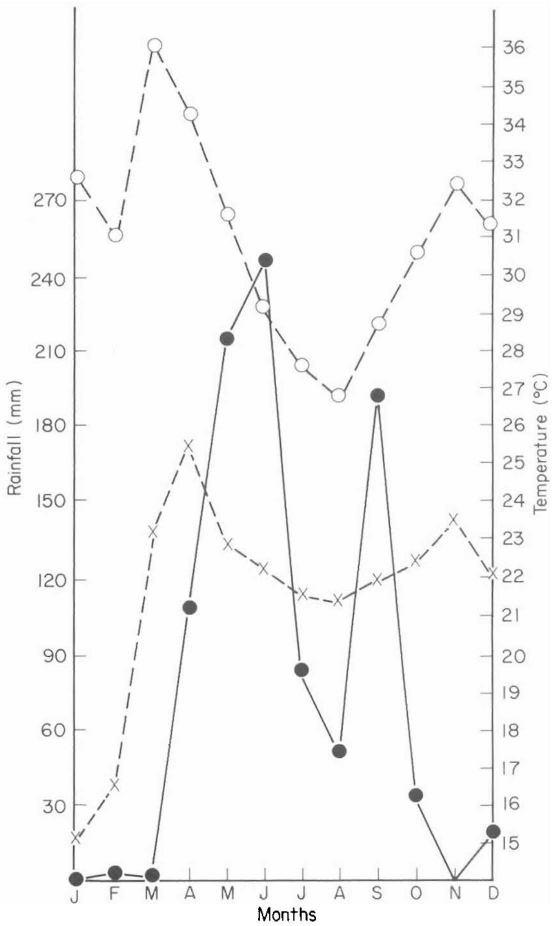

Fig. 1. Monthly temperature and rainfall at Ile-Ife, 1983. (○- - -○) Mean monthly maximum temperature, (× -- ×) mean monthly minimum temperature. (● -- ●) monthly rainfall.

Soil samples were analysed for total nitrogen by the Kjeldahl method, exchangeable potassium by extraction with neutral ammonium acetate and flame photometry and for available phosphorus by the Bray I method.

Soil pH was determined in 1 N KCl (1 : 1 soil : solution ratio) and mechanical analysis for textural composition was carried out by the hydrometer method with the soil dispersed in 5% sodium hexametaphosphate ('Calgon').

Results

The vegetation of the mats

Plant species present in the plots are listed in Appendix I with the relative contribution of each species to the overall seasonal total above-ground standing crop. Twenty-eight different species were encountered. *Loudetia arundinacea*, a grass of shallow and rocky habitats contributed over 43% of the total weight, *Cyanotis arachnoidea* and *C. lanata*, drought resistant perennial creeping herbs, contributed

Table 1. Sampling times, mat area, number of species, total standing crop, below-ground biomass and Shannon-Weiner diversity index (H′) in vegetation mats on an inselberg in southwestern Nigeria

Sampling month	Mat no.	Mean soil depth (cm)	Mat area (m^2)	No. species	Species: area ratio	Total standing crop (g)	Below-ground biomass (g)	H′
March	1	8·40	4·84	4	0·83	2136·00	2636·07	0·933
	2	5·75	0·92	2	2·17	569·75	607·10	0·162
	3	5·75	4·36	3	0·69	2167·89	2546·13	0·431
May	4	0·83	9·63	6	0·62	580·34	1011·81	0·946
	5	8·66	2·32	9	3·88	1048·74	1006·97	0·426
	6	7·00	3·47	10	2·88	2076·53	765·63	0·944
	7	9·43	5·61	11	1·96	3067·60	3051·50	0·661
July	8	6·67	2·15	8	3·72	322·70	1011·67	1·218
	9	9·00	9·02	14	1·55	2728·24	8073·17	1·732
	10	3·71	0·87	3	3·45	435·50	486·75	0·767
	11	7·75	5·35	11	2·06	1858·36	2325·16	1·432
September	12	4·00	3·26	6	1·84	521·89	178·71	1·364
	13	7·75	7·33	9	1·23	565·83	393·60	1·772
	14	9·33	3·90	7	1·79	1209·07	501·65	1·514
	15	7·00	1·99	6	3·02	394·08	785·04	1·488

Table 2. The mean weight of standing crop, litter and below-ground biomass in the vegetation mats on an inselberg in southwestern Nigeria ±95% confidence limit

Month	Above-ground biomass (gm^{-2})	Litter (gm^{-2})	Below-ground biomass (gm^{-2})
March	519·28±226·12	151·94±255·99	596·16±145·57
May	414·38±387·79	72·22±9·77	325·28±317·72
July	325·36±77·89	178·94±481·95	589·92±334·24
September	185·08±153·53	146·88±155·54	157·91±257·04

over 20%, while the least weight contributor (0·01%) was *Indigofera* sp. Overall, a total of 19,682·52 g plant material was collected from the fifteen communities.

The order in which the mats were sampled, their areas (sizes), number of species found in each mat, the total standing crop, the below-ground biomass and the Shannon-Weiner diversity index for each mat are presented in Table 1. The highest number of species (20) was encountered in July. The lowest number was found in March. The number of species found in each mat is related to area and soil depth, even though those with high mean depths but great variability in their depth tend to have fewer species. The standing crop weight and below-ground biomass vary with mat size, soil depth and species composition.

The pattern of mean standing crop throughout the season is shown in Table 2. The highest standing crop was recorded in March because whatever new growth

Table 3. Mean percentage nitrogen, phosphorus and potassium concentration of the above-ground biomass, litter and below-ground biomass based on oven dry weight for the vegetation mats on an inselberg in south-western Nigeria ±95% confidence limit

Month	N	P	K
Above-ground biomass			
March	0·81±0·27	0·04±0·02	0·64±0·13
May	2·02±0·32	0·14±0·02	0·71±0·14
July	1·33±0·18	0·19±0·04	0·68±0·08
September	1·27±0·18	0·11±0·01	0·66±0·02
Litter			
March	0·84±0·04	0·06±0·02	0·49±0·04
May	1·05±0·22	0·09±0·06	0·20±0·13
July	0·32±0·38	0·05±0·02	0·30±0·19
September	1·09±0·54	0·07±0·03	0·41±0·06
Below-ground biomass			
March	0·75±0·12	0·06±0·30	0·45±0·09
May	0·92±0·03	0·10±0·06	0·15±0·09
July	1·05±0·41	0·17±0·09	0·30±0·22
September	1·25±0·57	0·11±0·03	0·39±0·06

there was at this time was collected along with standing dead from the past year. This was not intended as a production study so standing dead was not separated from the living crop. Analysis of variance, however, shows no statistically significant difference in plant weights, above-ground and below-ground, among the four collection times. The standing crop varies more with species composition than with season. The leaves of two of the major species, *C. lanata* and *C. arachnoidea*, die off in the dry season leaving the succulent stem. When growth resumes, young leaves arise from the nodes still with the old leaves on the plant. This habit will definitely affect the seasonal standing crop.

The mean percentage nutrient concentration of the different components of the vegetation at the different sampling dates are given in Table 3 and the trend in Fig. 2. The above-ground biomass has the higher mean percentage concentration of the three elements and the litter and below-ground biomass has less. The concentration of potassium in each of these components was always intermediate between those of nitrogen and phosphorus. The concentration of the three elements in the above-ground biomass was highest in May for nitrogen and potassium and in July for phosphorus and, thereafter, the concentrations started declining.

Unlike the trend in above-ground biomass there was a continuous increase in nitrogen concentration in the below-ground biomass; the phosphorus concentration increased for some time then dropped, while the potassium concentration first dropped in May then later increased.

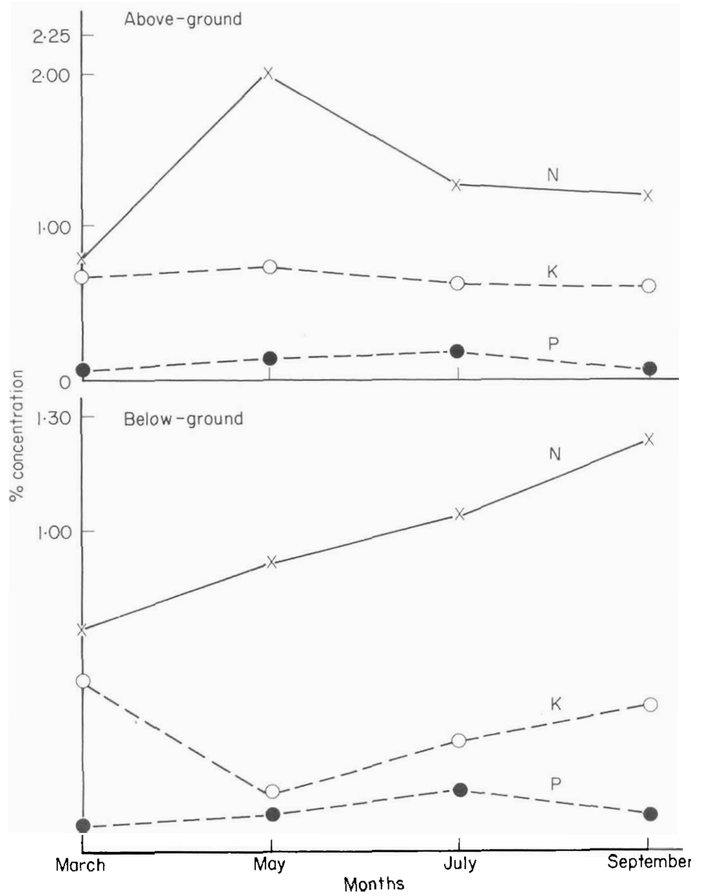

Fig. 2. The seasonal trend in the concentration of nitrogen, phosphorus and potassium in above-ground and below-ground plant material in isolated vegetation mats on an inselberg in southwestern Nigeria.

The pattern of the concentration of these elements in the litter shows two peaks for nitrogen, the first in May and the highest in September. The highest concentration of phosphorus in the litter occurred in May and that for potassium in March.

The weight of each element stored in each component of the vegetation is given in Table 4. The quantity of each element stored in the above-ground biomass was calculated by multiplying the mean concentration of the element in all the species by the mean biomass per square metre. For the litter and below-ground biomass the quantity of each element was calculated from their biomass estimates.

More nitrogen was stored in the vegetative material than potassium and phosphorus throughout the season (Table 4). The total amount of nitrogen in the vegetative material was 114·53 g m^{-2}, of which 40·70% was in above-ground biomass, 11·56% in litter and 47·74% in below-ground biomass. The quantity of potassium stored in the vegetative material is intermediate between those of nitrogen and phosphorus, but more potassium is stored in the above-ground biomass: 52·37% of the potassium was in the above-ground biomass, 36·58% in below-

Table 4. Total nutrient content of above-ground biomass, litter and below-ground biomass in the vegetation mats on an inselberg, southwestern Nigeria

Component	Biomass ($g\ m^{-2}$)	Nutrient elements $g\ m^{-2}$ N	P	K
Above-ground biomass	5236·17	46·61	4·70	28·03
Litter	1545·67	13·24	0·86	5·91
Below-ground biomass	22,080·87	54·68	6·17	19·58
Total		114·53	11·73	53·52

ground biomass and 11·04% in litter. The amount of phosphorus stored in the vegetation follows the same pattern as that of nitrogen with more of the phosphorus contained in the below-ground biomass than in any other component.

There were fluctuations in the quantities of the elements stored at different sampling dates. The highest amounts of the elements stored in above-ground biomass were found in May for nitrogen, March for potassium and July for phosphorus; the lowest in September for nitrogen, March for phosphorus and May for potassium. In below-ground biomass, the highest was in July for nitrogen and phosphorus and March for potassium. This variability reflects the differences in biomass production and species composition of the plots on the different sampling dates.

The soil

The properties of the soils of all the study plots are listed in Table 5.

The total quantity of soil collected from all the plots was 967,282 g. The mean pH of the soils was $4{\cdot}20 \pm 0{\cdot}13$, which shows that the soil is acidic in reaction. The mean soil depth was $6{\cdot}92 \pm 1{\cdot}35$ cm. The mean nutrient concentrations were: $0{\cdot}55 \pm 0{\cdot}14$% total N, $0{\cdot}0021 \pm 0{\cdot}001$% available P and $0{\cdot}21 \pm 0{\cdot}03$% exchangeable K. The soil fractions below 2 mm averaged $70{\cdot}21 \pm 2{\cdot}11$% sand, $9{\cdot}05 \pm 0{\cdot}85$% clay and $20{\cdot}73 \pm 2{\cdot}73$% silt with a mean sand : clay ratio of 7·76. The vegetation : soil ratios at each collection were 0·12, 0·03, 0·08, 0·03 with a mean of 0·05, that is on the average, 1 g of vegetation is supported by 20 g soil.

The concentration and quantity of nutrients stored in the soil per square metre are given in Tables 6 and 7. The quantity of nutrient in the soil has been calculated by multiplying the air-dry weight of the soil of each plot by its mineral concentration.

The concentration of total nitrogen more or less generally increased as the season went on, available phosphorus fluctuated while exchangeable potassium did not show any appreciable change.

When the quantities of the nutrients in the plants in Table 4 are expressed as ratios of their total quantities in the soil (Table 7), it is found that the total nitrogen in the soil is 20·57 times that in the plant, in the standing crop plus litter. The values for phosphorus and potassium are 0·79 and 13·75, respectively. For below-ground biomass the amounts of total nitrogen, available phosphorus and exchangeable

Table 5. Characteristics of the soil of vegetation mats on an inselberg in southwestern Nigeria

	Mat no.	Mat area (m^{-2})	Soil depth (cm ± 95% confidence limits)	pH	Sand : clay ratio	N (%)	Available P (%)	Extractable K (%)
	1	4·84	8·4 ± 4·95	4·9	6·14	0·44	0·00230	0·21
March	2	0·92	5·75 ± 2·38	4·5	7·65	0·48	0·00280	0·15
	3	4·36	8·50 ± 3·31	4·4	6·95	0·42	0·00210	0·29
	4	9·53	0·83 ± 0·51	4·2	8·37	0·39	0·00099	0·25
May	5	2·32	8·66 ± 4·30	4·4	7·14	0·44	0·00110	0·20
	6	3·47	7·00 ± 2·48	4·3	8·13	0·45	0·00069	0·18
	7	5·61	9·43 ± 1·02	4·2	11·66	0·45	0·00114	0·17
	8	2·15	6·67 ± 2·33	4·3	8·13	0·42	0·00011	0·16
	9	9·02	9·00 ± 7·23	4·1	9·79	0·61	0·00075	0·19
July	10	0·87	3·71 ± 2·68	4·4	6·36	0·77	0·00498	0·15
	11	5·35	7·75 ± 5·72	4·3	7·33	0·59	0·00588	0·28
	12	3·26	4·00 ± 1·15	3·8	7·89	1·38	0·00555	0·30
	13	7·33	7·75 ± 1·52	4·5	8·37	0·47	0·00120	0·18
September	14	3·90	9·33 ± 1·88	4·4	6·56	0·52	0·00066	0·18
	15	1·99	7·00 ± 2·05	4·3	8·86	0·42	0·00063	0·19

Table 6. Mean percentage concentration of total nitrogen, available phosphorus and exchangeable potassium ± 95% confidence limits in the soils of vegetation mats on an inselberg in southwestern Nigeria

Month	N	P	K
March	0·45 ± 0·09	0·0024 ± 0·0009	0·22 ± 0·17
May	0·43 ± 0·03	0·00098 ± 0·00032	0·20 ± 0·06
July	0·60 ± 0·22	0·00293 ± 0·0005	0·20 ± 0·09
September	0·70 ± 0·64	0·002 ± 0·0003	0·21 ± 0·09

T ble 7. Amounts of total nitrogen, available phosphorus and exchangeable potassium in the soil of vegetation mats on an inselberg in southwestern Nigeria

Date	Weight of air-dried soil (g)	Total N ($g\,m^{-2}$)	Available P ($g\,m^{-2}$)	Exchangeable K ($g\,m^{-2}$)
March	124,080	180·26	0·98	86·76
May	406,101	350·59	0·83	159·72
July	240,842	432·79	2·20	121·83
September	196,259	267·18	0·48	98·23
Total		1230·82	4·49	466·54

Table 8. Correlation matrix of soil and vegetation attributes of mat communities on an inselberg in south-western Nigeria

	Soil N	Soil P	Soil K	Sand : clay ratio	Plant N	Plant P	Plant K	Biomass	No. spp	Plot area	Soil depth
Soil N	—										
Soil P	0·68*	—									
Soil K	0·38	0·45	—								
Sand clay ratio	−0·10	−0·37	−0·18	—							
Plant N	0·14	−0·02	0·23	−0·30	—						
Plant P	0·18	0·26	0·25	0·23	0·59*	—					
Plant K	−0·06	−0·04	−0·19	−0·08	−0·07	0·24	—				
Biomass	0·57*	−0·06	0·13	0·37	0·04	0·11	0·10	—			
No. species	−0·05	−0·07	−0·03	0·08	0·42	0·64†	0·20	0·49	—		
Plot area	0·25	−0·02	0·99†	0·40	0·37	0·30	0·04	0·41	0·51	—	
Soil depth	−0·31	−0·29	−0·17	0·16	−0·16	−0·43	−0·06	0·62*	0·42	0·22	—

*Significant at $P=0{\cdot}05$
‡Significant at both $P=0{\cdot}05$ and $P=0{\cdot}01$.

potassium are, respectively, 22·51, 0·71 and 2·38 times more in the soil than in the plant. Thus, while the soil total nitrogen and exchangeable potassium are larger than in the biomass, the amount of soil-available phosphorus is less than in the vegetation. It is not the intention here to compare the quantities of the three elements either in the plant or soil.

Table 8 summarizes the result of correlation analyses of the soil properties and those of the vegetation. There is consistent but not significant negative correlation between soil concentrations of these elements and soil depth. A very strong significant positive correlation (0·99) is found between soil K and mat area. Other significant positive correlations are between soil N and soil P, soil N and total biomass, plant N and plant P, and biomass and soil depth.

Discussion

The vegetation mats used for this study have one outstanding characteristic—shallow soil. This means that xeric conditions will exist most of the time and the species turnover rate will be high in response to moisture flushes. Niche pre-emption governs establishment and succession in such communities.

Isichei & Longe (1984), in their study of seasonal succession in one of these vegetation mats, observed that the peak of species diversity was attained when the ephemerals in the community were joined by late starting perennials. The findings of the present study are in agreement with this observation. The highest number of species per unit area was found in July, and by September perennials like *Cyanotis* spp. and *L. arundinacea* formed a significant percentage of the standing crop. In March *L. arundinacea*, which survived from the previous growing season, contributed 77·18% of the biomass in the three communities sampled.

Of interest is the very high below-ground : above-ground crop ratio. Struik & Bray (1970) have indicated that root : shoot ratios of herbaceous plants tend to increase with xeric conditions. The conditions in the mats with their shallow soils and the attendant moisture shortage is definitely xeric.

Because of the peculiar nature of the communities, nutrient cycling may not necessarily follow the patterns observed in more stable, large communities. The mats could also be of more use in nutrient cycling studies if the inputs and outputs of the elements are known and quantified with precision. The inputs include fixation of nitrogen and inflow of nutrients down inselberg slopes. There could also be absorption from the atmosphere. The shallowness of the soils and a rocky base could make whatever is leached out of the communities easy to determine. The results obtained, however, have clarified the relationships between the soil and vegetation compartments as regards the cycling of the three elements.

The total soil nitrogen levels are about five times the values obtained in the surrounding soil, tropical ferruginous (alfisols), of the Ife area. This is related to the very high organic matter content—over 10% when crudely estimated as loss on ignition. The range of organic matter for the soils of the rain forest zone is from 0·01 to 9·5% with most of the areas between 0·5% and 3·0% (Okeya, 1977). The level of exchangeable potassium is exceptionaly high compared to surrounding soils. This suggests active addition by weathering from the inselberg, which according to Smyth & Montgomery (1962) have biotite gneisses and feldspar as minerals. The fact that mat area is significantly positively correlated with potassium is an indication of this. The larger the mat area the larger the area exposed to K accumulation.

The level of available phosphorus, in contrast to nitrogen and potassium, is very low despite the high organic matter content of the mats. This must be due to low pH, which enhances immobilization of phosphorus by the oxides and hydrous oxides of iron and aluminium.

The clay content of the soil is low ($<10\%$) compared with surrounding soils where clay contents range is mostly around 20% (Okeya, 1977). This is not surprising considering the fact that the soil is formed mainly from debris of dead plants and particles weathered from the inselberg surfaces.

The concentration of the three elements in plants of the communities is higher than would be expected in natural vegetation. The concentration of nitrogen in plants is highest at the beginning of growth, but as more supporting tissues are added with age the concentration declines, and in savanna grasses this decline is exponential, as Isichei (1983) has shown. The situation is similar here except for the seemingly peculiar situation in March.

Figure 1 shows that the rainy season at the study area started in March, which means that growth may have started later. The low nitrogen concentration in March goes to back our earlier assertion that the high standing crop at this time resulted from a combination of standing dead plants from last season and new growth. From May, a steady decline, following the usual pattern, is seen until September. The observations of nitrogen applies to phosphorous to some extent, while the concentration of potassium remains more or less steady.

If it is assumed that the level of nutrient in a plant is indicative of the level available in the soil, barring volatilization losses and canopy leaching, the ratios of nutrients in the plants to that in the soil is instructive in the present case. The ratio of nitrogen in the plant to that in the soil is 1 : 20·57 for above-ground vegetation and 1 : 22·51 for below-ground. If available nitrogen is equivalent to that mineralized then the mineralization rates will come to at least 4·44%. If volatilization and leaching losses are taken into consideration, then the mineralization rate will be closer to 5%. A rate of 4% is higher than those reported for rain forest soils in which the study area is located. For example, Adebayo & Akaeze (1976) reported a mean of 2·15% for forest soils and 3·23% for derived savanna soils, and further concluded that mineralization rates increase northwards with drier conditions in Nigeria. Jones & Wild (1975) reported a mean rate of 4% for savanna soils. The estimated rate of mineralization points to the fact that xeric conditions exist in the mats. The quality of organic matter plays some role and the mats have mostly herbaceous plants, which means easily decomposed litter.

It is also possible that nitrogen, which is not part of mineralized soil nitrogen, is absorbed by the grasses from the atmosphere. This would then mean that the level of mineralization is lower than suggested here.

The ratio of the amount of phosphorus in the above-ground plant material to that in the soil is 0·79 while below-ground is 0·71. Based on the assumptions for nitrogen, this means that more available phosphorus, as determined by the Bray I method, is in the plants than in the soil. This may mean there is storage from previous seasons and/or that there are no losses after the nutrient has been absorbed or that the plants use more than the 'available' phosphorus.

Concentration of potassium in the above-ground vegetation is 7·27% of exchangeable K in the soil, while in below-ground vegetation it is 42·02%. The disparity between the concentration above-ground and below-ground on the one hand and the large difference between what is in the plant compared to that in the soil on the other is a clear indication of leaching of potassium from plants (Swift, Russell-Smith & Perfect, 1981).

Sekhon (1982) noted that the amount of exchangeable potassium in soils directly available to plants is related to the clay content and on the intensity of mineral decomposition. Mineral decomposition should be a major factor here because of the inselberg but Beringer (1982) reported that potassium availability is affected by moisture, and that the distance to which roots can deplete the surrounding rhizosphere of phosphorus is less than 2·5 mm and for potassium it might only be slightly higher. The inselbergs used for this study have mean root weight to soil weight ratio of 1 : 35, a high value compared to land areas, but the shallowness of the soils will make leaching inevitable. The low pH values of the soil also point to this fact. It is evident that to get a clearer picture of nutrient cycling in these mats all sources of inputs and all outputs have to be investigated.

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Appendix I. Species found on fifteen mat communities on an inselberg in southwestern Nigeria

Species	% contribution
1 *Aeolanthus pubescens* Benth.	0·16
2 *Borreria scabra* (Schum. & Thonn) K. Schum	2·22
3 *Borreria saxicola* K. Schum	0·86
4 *Brachiaria distichophylla* (Trin) Stapf.	1·97
5 *Brachiaria deflexa* (Schumach.) C. E. Hubbard ex Robyns	0·19
6 *Bulbostylis densa* (Wall.) Hand-Mazz	0·27
7 *Cassia mimosoides* Linn	0·33
8 *Ceropegia linophyllum* H. Huber	0·77
9 *Cyanotis* spp.	20·58
10 *Desmodium hirtum* Guill & Perr	0·15
11 *Dissotis idanreensis* Brenan	2·15
12 *Dissotis theifolia* (G. Don) Hook.f.	5·92
13 *Euclasta Condylotricha* (Hochst. ex Steud) Stapf.	4·78
14 *Fimbristylis hispidula* (Vahl) Kunth	0·50
15 *Hibiscus panduriformis* Brum.f.	0·21
16 *Hibiscus scottellii* Bak.f.	2·83
17 *Imperata cylindrica* (Linn) P. Beauv	3·26
18 *Indigofera* spp.	0·01
19 *Indigofera welwitschii* Bak	0·84
20 *Ipomoea eriocarpa* R.Br.	0·02
21 *Ipomoea heterotricha* F. Didr.	1·63
22 *Loudetia arundinacea* (Hochst. ex A. Rich.) Steud	43·53
23 *Pennisetum* spp.	2·76
24 *Sida linifolia* Juss. ex Cav.	1·21
25 *Solenostemon monostachyus* (P. Bauv.) Briq.	0·09
26 *Tephrosia bracteolata* Guill. & Perr.	0·04
27 *Urginea ensifolia* (Thonning) Hepper	0·43
Total dry weight for all species = 19,682·52 g	