Acta Botanica Hungarica 39 (3—4), pp. 289—301 (1995)

SOIL-VEGETATION INTERRELATIONSHIPS IN ISOBERLINIA WOODLANDS OF NORTHWESTERN NIGERIA

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Isoberlinia woodlands in northwestern Nigeria were sampled in 280 quadrats (100 m^2) regularly spaced along established transects from upper to lower slopes. Vegetation measurements included density, basal, area, crown cover and height of woody species ≥ 3 m high. Also, total number of species and canopy cover per plot, and species diversity were determined. Soil pits were systematically excavated along the transects, and soil samples taken from each horizon in each pedon, air-dried and analyzed for physical and chemical properties. Canonical correlation analysis (utilizing principal component scores of soil and vegetation variables) was used to show the interrelationships between soil and vegetation components. Results showed a reciprocal relationship between plant size and silt, manganese and aluminium. There existed a positive relationship between plant height and species diversity, and soil reactions and nutrient status. Aluminium also related positively with plant density and canopy cover. Hence canonical correlation analysis identified soil variables which affect the vegetation components, thus suggesting that both soil and vegetation are interdependent.

Keywords: Canonical correlation, Guinea savanna, Isoberlinia woodlands, ordination, quartzite ridges

Introduction

A large number of factors are in operation in determining the distribution of floristic components of vegetation, and the study to elucidate these factors is an important ecological objective. Several explanations advanced for the existence of savanna have been linked to soil either as the primary factor or that it has an indirect effect (MONTGOMERY and ASKEW 1983). These edaphic explanations include soil moisture and nutrient status. Various soil types found in savanna exhibit variable amounts of nutrients and these reflect the occurrence of different vegetation associations. Many of these soil phases with discrete vegetational units abound in the Guinea Savanna. These repeated occurrences of certain vegetation associations on different soil within the Guinea Savanna is a subject of study. It is thus of interest to investigate and identify such soil factors or groups of factors which determine the occurrence and physiognomy of vegetation, and the influence of vegetation on soil properties.

Studies involving elucidation of edaphic factors have been carried out in the Guinea Savanna (WILD 1971, JONES 1973, KADEBA 1978, 1982, ISICHEI and SANDFORD 1980, SOBULO 1982, AYODELE 1986, MUOGHALU and ISICHEI 1991); but these have not been correlated with the distribution of vegetation associations or species. AHN (1970), and JONES and WILD (1975) have reviewed this subject and point to the fact that the distribution of these associations or species may be controlled by simultaneous interactions of several edaphic factors. This factor-complex varies along gradients within the Guinea Savanna. Therefore the study of soil and vegetation relationships presents a synthetic picture of the mosaic events occurring within the Guinea Savanna. Any analytical solution must therefore take into account these species variabilities in the vegetation. This is usually carried out by means of the multivariate analysis technique (KENKEL 1986). The work reported in this paper was carried out to investigate the relationship between soil and vegetation in Isoberlinia Craib et Staff woodlands in Northwestern Nigeria. The interrelationships between soil and vegetation present an important dynamics in the Guinea Savanna which previous studies (SIDERIUS 1974, KADEBA 1982, SOBULO 1982, MUOGHALU and ISICHEI 1991) have been unsuccessful to bring out. Their attempts have been based on site to site comparisons and did not take into account within stand variations. Observations are that within stand variations could be as large or even larger than variations between stands. These have to be quantitatively analysed. AWETO (1981) stated that interrelationships between soil and vegetation are multivariate since components of vegetation have different effects on soil and its fertility. This is an expression of major trends of events existing between soil and vegetation which form an integrated system of correlating functions.

Isoberlinia woodlands represent such integrated systems of correlated functions. They are vegetation associations in the Guinea Savanna found at discrete positions on quartzite and plinthite ridges. The study was conducted in the woodlands found in Kainji Lake National Park located in Northwestern Nigeria lying between latitudes 9^{o} 45' and 10^{o} 23' N and longitudes 3^{o} 40' E and 5^{o} 47' E, and with two non-contiguous sectors: Borgu and

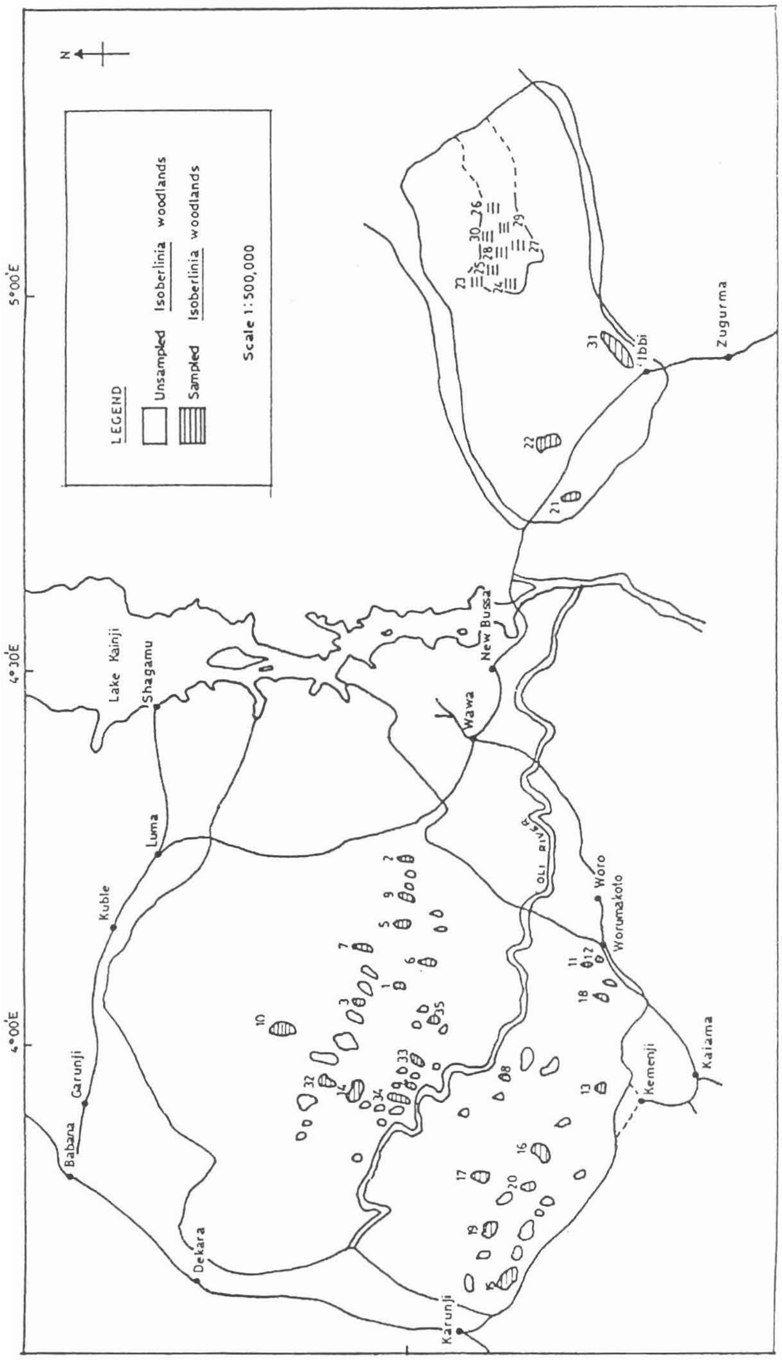

Fig. 1. Kainji Lake National Park: Identified and sampled *Isoberlinia* woodlands

Zugurma (Fig. 1). Both sectors cover an area of 5340.82 km^2 and are underlain by basement complex metamorphic rocks, mainly gneiss and granite. Isoberlinia woodlands are formed on the outcrops of these rocks.

The climate of the area has been reported by AFOLOYAN (1982). Soils are shallow and of ferruginous tropical type with low exchangeable acidity bases, nitrogen and organic carbon. The soils are slightly acidic to neutral.

Methods

Vegetation and soils were systematically sampled (COCHRAN 1963) from fourteen distinct woodlands. In each woodland, a sampling plot of 250 m x 200 m was marked out and five belt transects established. Vegetation samples were taken in twenty 10 m x 10 m quadrats regularly spaced at 50 m interval from upper to lower slopes of the ridges along the established transects in each woodland. In each quadrat, density, basal area, crown cover and height of woody species $\geq$ 3 m high were determined. Three soil pits were excavated in plots with slope angle $> 1^o$ and two in those with slope angle $< 1^o$ along the transects. Each pit measured 1.5 m x 1.5 m x 1.2 m. Soil samples were collected from each horizon in each pedon and air-dried, ground and analysed for particle size (Hydrometer method), pH in 0.01 M $CaCl_2$ (1:2 soil: solution ratio), exchangeable acidity and cations (BLACK et al. 1965), organic carbon (Walkley—Black-method), available phosphorus (Bray No. 1 Method) and total nitrogen (Kjeldahl-method).

This study applies multivariate techniques to the analysis of relationships between soil and vegetation in Isoberlinia woodlands. Ordination, using principal component analysis (PCA), of soil and vegetation variables was aimed at discerning underlying gradients of the environment so as to use the factor variables for canonical analysis. Before analysis, the soil data were first normalized to logarithmic base 10 of the original values (GREIG-SMITH 1983, BERTNESS and ELLISON 1987). The ordination was then derived from the correlation matrix with the KAISER (1958) varimax rotation model. The aim was to find out if a variant of PCA could be ecologically meaningful. The patterns and structure of the interrelationships between soil and vegetation variables were investigated by canonical correlation analysis (CCA). This used the matrix of PCA scores of soil variables to avoid the problem of collinearity (AWETO 1981).

Results

Table 1 shows the summary of the vegetation variables in the sampled woodlands. Analysis reveals that plot 9 has the greatest number of woody stems with a density of 310 plants per hectare and the least numbers are in plot 26 with a density of 175 plants ha^{-1}. Other plots have variable density between these two extremes. Mean height of woody species also shows variation (plot 2 : 109.07 m; plot 26 : 51.23 m). Large-sized species are observed in plot 7 (basal area 19.29 m^2 ha^{-1}; crown cover 15976.22 m^2 ha^{-1}). Plots 24 and 26 present the lowest values of these variables. Table 1 also reveals that although plot 9 has the highest density of woody species, it nevertheless has a low basal area compared to plots 2 and 7. Canopy cover of the

Table 1

Summary of vegetation variables of *Isoberlinia* woodlands in northwestern Nigeria

Plot	Density of woody species (ha^{-1}) ± 95% C.I.	Height of woody species (m) ± 95% C.I.	Crown cover of woody species (m^2 ha^{-1}) ± 95% C.I.	Basal area of woody species (m^2 ha^{-1}) ± 95% C.I.	Canopy cover (%)	Total number of species per plot	Shannon—Wiener species diversity index	Slope angle (°)
R/2	305 ± 23	109.07 ± 2.63	7345.27 ± 845.45	17.68 ± 1.97	60.10	14.00	1.81	7.00
7	240 ± 48	64.54 ± 3.24	15976.22 ± 4102.88	19.29 ± 4.71	60.70	8.00	1.09	5.00
8	195 ± 26	72.52 ± 3.68	5160.57 ± 893.53	10.90 ± 2.05	52.30	9.00	1.52	20.00
9	310 ± 42	64.32 ± 2.15	3782.04 ± 683.38	14.84 ± 2.76	66.90	10.00	1.37	2.00
13	240 ± 13	78.12 ± 1.74	5316.60 ± 603.70	11.71 ± 1.11	50.40	13.00	2.13	0.00
14	250 ± 14	81.04 ± 1.90	4422.98 ± 539.52	8.61 ± 0.91	49.20	13.00	2.08	3.50
15	255 ± 12	82.36 ± 1.38	4307.88 ± 487.06	10.02 ± 0.96	63.80	13.00	2.02	5.00
18	190 ± 14	98.38 ± 2.64	5872.28 ± 750.54	11.29 ± 1.49	51.90	12.00	1.82	4.50
21	250 ± 29	56.97 ± 2.70	2609.42 ± 473.73	7.09 ± 1.18	50.80	8.00	1.02	3.50
24	180 ± 28	56.79 ± 2.02	2205.26 ± 431.10	6.16 ± 1.03	49.20	8.00	1.46	2.09
26	175 ± 16	51.23 ± 2.24	2547.29 ± 494.63	5.96 ± 1.16	46.50	9.00	1.74	2.19
32	220 ± 27	73.01 ± 2.60	4849.73 ± 691.31	10.51 ± 1.37	54.80	8.00	1.58	1.00
33	240 ± 16	75.32 ± 3.75	6677.44 ± 713.90	16.12 ± 2.20	44.00	8.00	1.94	1.08
34	190 ± 20	53.92 ± 3.09	3846.00 ± 920.46	8.09 ± 2.23	39.60	7.00	1.35	0.00

C.I. = Confidence interval.

Table 2

Mean physical properties of soils of Isoberlinia woodlands in northwestern Nigeria (+ 95% C.I.)

Plot	% Sand	% Silt	% Clay
R/12	60.43 ± 8.76	22.66 ± 8.06	16.91 ± 2.42
7	54.40 ± 10.51	33.28 ± 8.89	12.32 ± 2.32
8	52.66 ± 11.32	20.71 ± 7.54	26.63 ± 11.20
9	66.09 ± 8.42	23.13 ± 6.97	10.78 ± 2.22
13	68.42 ± 10.65	16.76 ± 4.66	14.82 ± 12.22
14	70.88 ± 8.00	13.17 ± 2.12	15.94 ± 7.07
15	57.47 ± 5.38	19.93 ± 3.40	22.60 ± 2.99
18	45.80 ± 7.38	21.40 ± 3.89	32.80 ± 6.24
21	60.26 ± 4.54	19.02 ± 3.10	20.71 ± 5.49
24	41.24 ± 3.08	27.53 ± 2.96	31.24 ± 3.99
26	53.58 ± 5.40	20.71 ± 5.52	25.71 ± 4.84
32	69.60 ± 12.65	13.06 ± 6.28	17.33 ± 14.82
33	48.06 ± 7.56	19.73 ± 3.62	32.20 ± 7.62
34	50.76 ± 12.33	29.56 ± 4.50	19.68 ± 12.03

woodland plots shows variation and does not present any pattern either with crown cover or basal area.

The summaries of the soil properties are presented in Tables 2 and 3. Sand is the most varied property with the highest proportions. Silt and clay have comparable proportions but with clay being more variable. Of the cations, calcium is the most variable and most abundant (Table 3). Magnesium ranks second and sodium is the least abundant. Exchangeable acidity is low reflecting low levels of Al and H. There are low levels of ECEC, Fe and Mn. Organic carbon and total nitrogen contents are low with the former being more variable. Available P is higher than any of the anions. The soils range from medium acid to neutral in reaction.

Ordination of soil variables by rotation the PCA axes is given in Table 4. Components included here, account for at least 90% of the total variance. Each component is identified by the variables' loadings of 0.60 and above. Soil reaction (pH), sodium and calcium concentration and ECEC loaded on component I. The soil component is thus identified as soil reaction and nutrient status. Other components are similarly identified; their respective names and the percentages they account for in the original variance are presented in Table 5. Similar results are presented in Tables 6 and

Table 3

Mean chemical properties of soils of *Isoberlinia* woodlands in northwestern Nigeria (± 95% C.I.)

Plot	pH	Al^{+3}	H^{+}	Na^{+}	K^{+}	Ca^{+2}	Mg^{+2}	Fe^{+3}	Mn^{+}	% Total	Avail.	% D.C
		meq/100 g soil										
R/2	5.80	0.04 ± 0.02	0.34 ± 0.09	0.14 ± 0.03	0.28 ± 0.06	2.11 ± 0.59	0.58 ± 0.12	0.12 ± 0.02	0.05 ± 0.03	0.08 ± 0.02	1.94 ± 0.99	1.14 ± 0.59
7	5.74	0.12 ± 0.19	0.35 ± 0.10	0.12 ± 0.04	0.38 ± 0.06	2.06 ± 0.89	0.56 ± 0.02	0.16 ± 0.04	0.06 ± 0.04	0.09 ± 0.05	2.82 ± 2.06	1.24 ± 0.61
8	6.56	0.08 ± 0.04	0.18 ± 0.04	0.20 ± 0.09	0.26 ± 0.05	3.20 ± 1.49	1.69 ± 0.34	0.15 ± 0.02	0.04 ± 0.02	0.08 ± 0.05	8.92 ± 2.68	1.07 ± 0.73
9	5.78	0.04 ± 0.02	0.25 ± 0.06	0.06 ± 0.02	0.21 ± 0.07	1.32 ± 0.38	0.48 ± 0.05	0.16 ± 0.04	0.06 ± 0.02	0.06 ± 0.02	1.98 ± 0.72	0.54 ± 0.19
13	6.25	0.08 ± 0.05	0.19 ± 0.06	0.16 ± 0.03	0.12 ± 0.04	2.45 ± 0.98	0.76 ± 0.43	0.14 ± 0.02	0.01 ± 0.01	0.05 ± 0.02	6.50 ± 3.85	0.60 ± 0.48
14	6.30	0.06 ± 0.04	0.16 ± 0.09	0.17 ± 0.02	0.34 ± 0.09	2.94 ± 1.06	1.46 ± 0.36	0.14 ± 0.03	0.07 ± 0.04	0.13 ± 0.06	10.42 ± 2.00	0.95 ± 0.63
15	6.60	0.05 ± 0.04	0.18 ± 0.06	0.13 ± 0.02	0.26 ± 0.12	3.92 ± 1.64	1.70 ± 0.63	0.14 ± 0.05	1.06 ± 0.03	0.10 ± 0.03	7.86 ± 2.08	0.86 ± 0.69
18	6.54	0.05 ± 0.06	0.17 ± 0.05	0.17 ± 0.06	0.34 ± 0.16	2.95 ± 1.44	1.52 ± 0.49	0.14 ± 0.04	0.06 ± 0.03	0.09 ± 0.04	7.78 ± 2.80	1.06 ± 0.69
21	6.34	0.02 ± 0.06	0.16 ± 0.04	0.13 ± 0.02	0.16 ± 0.05	1.68 ± 0.57	0.66 ± 0.38	0.10 ± 0.10	0.06 ± 0.02	0.05 ± 0.02	8.10 ± 2.54	0.62 ± 0.38
24	5.98	0.06 ± 0.04	0.21 ± 0.06	0.12 ± 0.02	0.12 ± 0.03	1.72 ± 0.45	0.86 ± 0.24	0.08 ± 0.02	0.08 ± 0.03	0.04 ± 0.01	6.36 ± 1.43	0.69 ± 0.38
26	5.78	0-13 ± 0.10	0.20 ± 0.04	0.14 ± 0.01	0.16 ± 0.06	1.84 ± 0.77	0.74 ± 0.30	0.11 ± 0.02	0.10 ± 0.04	0.10 ± 0.04	6.02 ± 2.20	0.69 ± 0.52
32	6.70	0.06 ± 0.02	0.24 ± 0.13	0.12 ± 0.01	0.23 ± 0.09	1.99 ± 1.53	1.67 ± 0.54	0.06 ± 0.02	0.04 ± 0.03	0.12 ± 0.07	2.13 ± 1.16	8.62 ± 0.52
33	5.63	0.34 ± 0.38	0.23 ± 0.09	0.13 ± 0.02	0.15 ± 0.12	1.29 ± 1.25	0.90 ± 0.79	0.12 ± 0.02	0.06 ± 0.05	0.09 ± 0.05	9.88 ± 2.88	0.88 ± 0.61
34	6.12	0.09 ± 0.03	0.18 ± 0.05	0.14 ± 0.01	0.36 ± 0.11	3.38 ± 0.79	2.09 ± 0.44	0.07 ± 0.01	0.04 ± 0.02	0.13 ± 0.08	1.29 ± 0.88	0.45 ± 0.33

Table 4

Rotated principal components matrix of soil variables of *Isoberlinia* woodlands

Variable	Principal components I	II	III	IV	V	VI
Soil reaction (pH)	0.70	0.11	0.19	-0.23	0.48	0.04
Aluminium concentrations	0.05	-0.21	-0.04	-0.16	0.92	-0.07
Hydrogen concentrations	0.47	0.52	0.29	-0.13	0.21	-0.09
Sodium concentrations	-0.77	-0.42	0.06	-0.03	0.07	-0.16
Potassium concentration	-0.52	0.69	0.26	-0.13	0.07	0.31
Calcium concentration	0.93	-0.11	-0.12	0.01	0.15	0.06
Magnesium concentration	0.17	-0.87	-0.07	-0.09	0.28	-0.04
Effective cation exchange capacity	0.98	-0.09	0.02	-0.02	-0.07	-0.03
Total nitrogen concentration	-0.49	0.39	-0.02	0.29	0.53	0.46
Organic carbon concentration	-0.43	0.02	0.52	0.02	0.58	0.18
Phosphorus concentration	0.21	0.87	-0.31	-0.11	-0.01	-0.20
Iron concentration	-0.01	-0.08	0.92	0.01	0.16	-0.01
Manganese concentration	0.17	-0.12	-0.09	-0.19	-0.10	0.94
Sand proportion	-0.06	-0.28	-0.13	-0.90	0.14	0.22
Silt proportion	-0.20	-0.39	-0.14	0.87	-0.04	0.03
Clay proportion	0.30	0.67	0.31	0.47	-0.09	-0.29

7 for vegetation variables. These components are used in canonical correlation analysis.

The relationships between soil and vegetation are sought by canonical correlation analysis performed on PCA matrix of soil and vegetation variables. The analysis produced three canonical correlations ($r_1 = 0.98$, $r_2 = 0.92$, $r_3 = 0.88$) significant at $P < 0.001$. The canonical correlations with their respective weights are shown in Table 8. The significance of the correlations represents the pattern of interrelationships between these two sets of data. Each component is identified by soil and vegetation components

Table 5

Soil components, their descriptions and proportion of total variance accounted for

Component	Description	Variance accounted for (%)
I	Soil reaction and nutrient status	26.45
II	Clay, magnesium and phosphorus concentrations	22.19
III	Iron concentration	15.35
IV	Sand and silt proportions	13.27
V	Aluminium concentration	13.23
VI	Manganese concentration	9.50

Table 6

Rotated principal components matrix of vegetation variables of *Isoberlinia* woodlands

Variable	Principal components I	II	III	IV
Woody plant density	-0.08	-0.48	0.69	-0.15
Woody plant height	-0.16	-0.66	0.01	-0.51
Woody plant crown cover	0.85	0.27	0.04	0.17
Woody plant basal area	0.77	0.02	0.33	0.11
Total number of species per plot	0.22	0.56	-0.08	0.15
Species diversity	0.34	0.26	-0.15	0.73
Percentage canopy cover	0.21	-0.03	0.83	0.15

Table 7

Vegetation components, their descriptions and proportion of total variance accounted for

Component	Description	Variance accounted for (%)
I	Woody plant size	23.93
II	Woody plant height	20.15
III	Woody plant density and canopy cover	20.08
IV	Species diversity	12.32

Table 8

Canonical factor structure of vegetation — soil interrelationships of Isoberlinia woodlands

	Canonical correlations		
	r_1	r_2	r_3
(Vegetation weights)	0.98	0.92	0.88
Woody plant size	-0.66	0.18	-0.24
Woody plant height	-0.12	0.87	-0.10
Woody plant density and canopy cover	-0.50	0.22	0.59
Species diversity	-0.53	0.60	0.22
(Soil weights)			
Soil reaction and nutrient status	-0.40	0.53	-0.51
Clay, magnesium and phosphorus concentrations	0.09	-0.32	-0.41
Iron concentration	0.51	-0.06	0.24
Sand and silt proportions	0.63	0.16	0.24
Aluminium concentration	-0.56	-0.09	0.72
Manganese concentration	0.54	-0.41	0.25
Degrees of freedom	42	30	20
Probability level	0.001	0.001	0.001

with weights of 0.50 or more. The first canonical correlation has a strong reciprocal relationship between woody plant size, density, canopy cover and species diversity, and iron and manganese concentrations, and sand and silt proportions. The second correlation shows a strong positive relationship between woody plant height and species diversity, and soil reaction (pH) and nutrient status. On the third correlation is a positive relationship between woody plant density and canopy cover, and aluminium; but negative with soil reaction and nutrient status. The most highly weighted soil and vegetation components are those describing woody plant size/height and aluminium concentration cum sand and silt proportion.

Discussion

The vegetation of the woodlands shows variations in the structural characteristics. Some woodlands have high woody species density while others have low density. This reflects the stage of development of the woodlands.

High woody species density is mostly observed in plots with samplings indicating juvenile stage of development. Low density reflects maturity of the woodlands with large girth-sized species. Hence species are abundant in woodlands with smaller basal area and lower height. Woodland tree height averaged between 14 m and 18 m and increases down the slopes of ridges probably due to deeper and richer soils at lower slopes.

Soil physical properties show that the surface soils are sandy; clay and silt contents are low. Thus the structural stability, water-holding and exchange capacity of the woodland soils are poor. The low nutrient values may also be attributed to low mineralization rate due to reduction in temperature and greater stability of organic residue under tree canopy as in the woodlands.

The canonical correlation analysis identifies three patterns of interrelationships between soil and vegetation. The first canonical correlation indicates a reciprocal interrelationship between vegetation and soil variables. Plant size, for instance, would have been expected to be positively related to silt since silt is known to influence plant growth by improving water-holding capacity and porosity of soils (ETHERINGTON 1975). The use of standardized components rather than actual data scores might have brought about this (AWETO 1981). The relationship between the vegetation and manganese might be that this element is limiting to plants growth. The association with aluminium is direct as this contributes to the pH of the soils. The soils are mildly acid to neutral, conditions that favour the availability of nutrients at exchange sites. The relationship in the second canonical correlation between woody plant height and species diversity with soil reaction and nutrient status is positive. An increase in soil nutrient leads to increased vegetation height and species diversity and the latter would lead to much vegetation cover that will ameliorate the soil environment (through protection and litter production). Hence adequate vegetation cover replenishes soil with nutrients. The third canonical correlation shows a positive association between woody plant density and canopy cover with aluminium. This confirms the relationship between these two soil and vegetation components as observed in the first canonical correlation and for the reason advanced therein. The relationship of the two vegetation and nutrient status is negative; the negative sign on the soil components might be spurious as simple correlations between these two sets of data is positive. Again this suggests that the component scores used for this analysis might place arbitrary signs on the results due to standardization.

Conclusion

It is clear from the canonical correlation analysis that nutrient status and particle size proportions exert marked effects on the vegetation components of Isoberlinia woodlands. Though of low concentrations the micro-nutrients affect species diversity, density, size and canopy cover. Thus the vegetation parameters influence the amount of nutrients the soil holds and subsequently its fertility. Isoberlinia woodlands are therefore dynamic eco-systems and the relationship between the soil and vegetation cannot be sought by stand comparisons alone. A multivariate technique used in analyzing these ecosystems identified soil variables that affect the vegetation and vice versa. This suggests that the soil and vegetation components of the woodlands are interdependent and exert reciprocal influence on each other.

Acknowledgements

I thank dr A. O. ISICHEI for supervising the work and Drs A. S. OKAEME, A. E. ONYEANUSI and A. A. NCHOR for advice and suggestions.

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