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The effects of tree canopy cover on soil fertility in a Nigerian savanna

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ABSTRACT. The effect of tree canopy cover on soil properties was studied over three periods: mid-dry season (January), mid-growth period (August) and peak-growth period (October) in three 1 ha plots in savanna of north-west Nigeria. The objective was to find out whether tree canopies change the nutrient status of the soil under them relative to adjacent grasslands. Soils under tree canopies were found to have significantly higher levels of organic matter, calcium, magnesium, potassium, total exchangeable bases, cation exchange capacity and pH than those in open grasslands. Nitrogen and phosphorus were slightly higher in soils under tree canopies than those in the open grasslands. Trees 7 m and above had more influence on soil properties than smaller trees. Differences in soil properties among the study plots were due to differences in their soil texture. Seasonal trends were observed in organic matter, carbon : nitrogen ratio, cation exchange capacity, phosphorus, calcium, sodium, total exchangeable cations and percentage base saturation.

KEY WORDS: Nigeria, savanna, soil fertility, tree canopy, tree height

INTRODUCTION

Savannas of various types cover 80% of the land surface of Nigeria (Isichei 1979, Sanford 1982). Much of the savanna is unsuitable for cultivation or monoculture because of below average rainfall and abnormal patterns of rainfall distribution, and serves as rangeland. Motivated by the desire to increase livestock forage production, many Nigerian range workers in the past have recommended removal of shrubs and trees for range improvement to inrease the open area, reduce competition between woody and herbaceous species and allow more light to reach the ground surface, or to convert the savanna into sown legume/grass pastures without considering the effect of such policy on the fragile savanna ecosystem, especially on soil fertility.

The effects of individual trees and shrubs on soil have been investigated in a wide variety of ecosystems (Belsky *et al.* 1989, Garcia-Moya & McKell 1970, Gerakis & Tsangarakis 1970, Hattan & Smart 1984, Kellman 1979, Radwanski & Wickens 1967). These studies found that woody species increase the fertility of the soils under their canopies. In addition, trees may also alter the soil microclimate. Shreve (1931) reported a reduction of soil temperature of up to

10°C in the shade of *Parkinsonia* compared with open area in Arizona. Similar reductions in soil temperature under woody plant canopy have been reported in Rhodesia (now Zimbabwe) (Kelly & Walker 1976) and semi-arid savanna in Kenya (Belsky *et al.* 1989). An improved soil moisture regime beneath the crown of *Caenothus* shrubs relative to that in open areas was reported by Wahlenberg (1930).

Most of these studies have been carried out in arid and semi-arid areas and in most cases under canopies of specific tree species. There is a paucity of information, if any, on the relationship between woody species canopies and soil fertility in Nigerian savannas and sub-humid areas. This study was therefore undertaken in 1985 and 1986 to evaluate the effect of woody species on soil properties in Nigerian Guinea savanna.

STUDY AREA

The study area was located in the Kainji Lake Basin in north-western Nigeria (between latitudes 10°–12° N and longitudes 3° 50′–5° 50′ E). Three 1 ha sample plots, located in natural Guinea savanna, were used for this work. Plots 1 and 2 are subjected to grazing by migrant livestock early in the dry season while plot 3 is located within the Kainji National Park where it is subjected to the activities of low density wildlife (Ayeni 1982). All three plots are in the northern Guinea savanna zone (*sensu* Keay 1959) on the area referred to as Sudanian woodland with abundant *Isoberlinia* by White (1983).

Plots 1 and 2 are underlain by Nupe sandstone while rocks of the Basement complex are dominant in plot 3 (Nnadi & Balasubramanian 1982). The soil depth is shallow in some areas, and ranges from zero in some of the exposed ironstone pans to a maximum of 140 cm on the upper slopes (Klinkenberg & Hildebrand 1964).

The mean annual rainfall varies from approximately 1000 mm to 1200 mm. The length of the rainy season varies from 175 to 190 days (Walter 1967). The wet season is from May to October while the dry season is from October to April. Temperatures range from an annual mean minimum of 20°C to a mean maximum of 35°C.

MATERIALS AND METHODS

Sampling

Each of the three 1 ha plots was divided into four quarters, each 50 m × 50 m. In each quarter five 25 m × 5 m belt transects were laid out, three starting from random locations on an outer boundary of the quarter and two from random locations on an inner boundary, and running on the opposite bearing. Every tree and shrub ≥ 1 m tall within each belt transect was identified and counted. Their heights were measured using a Haga altimeter. The trees were grouped into two height classes, those less than 7 m and those 7 m and above. A 25 m central line transect was laid within each belt transect. Soil samples were collected systematically at 5 m intervals (five per transect) to a depth of 15 cm using a soil auger. The presence or absence of woody canopy directly above each sampling point was noted. The soil samples were air-dried and ground to pass through a 2 mm sieve. Data collection was repeated three times in one year, January (mid-dry season), August (early wet period) and October (late wet period) to determine whether the effect of tree canopies on soil properties varies at different times of the year.

A total of 100 samples was collected from each plot with 42 samples from under tree canopies and 58 from open grasslands in plot 1, 39 under tree canopies and 61 in the open in plot 2, and 31 under tree canopies and 69 in the open in plot 3. Over the three sampling seasons, a total of 300 soil samples was collected from each plot.

Chemical analysis

Soil particle size distribution, pH, organic matter, total nitrogen, available phosphorus, exchangeable cations and cation exchange capacity were determined. The particle size distribution was determined by the hydrometer method after dispersing the soil in sodium hexametaphosphate (Calgon) (Day 1965). Soil pH was measured in 1N KCl (at soil : solution ratio 1:2). Organic matter was determined by the Walkley-Black method (Allison 1965) and total nitrogen by Kjeldahl method (Bremner 1965). Exchangeable cations (Ca, Mg, K, Na) were determined by analysis of neutral 1N ammonium acetate extracts. Potassium and sodium were estimated by flame emission photometry and calcium and magnesium by atomic absorption spectrophotometry. Available phosphorus was determined by Bray 1 method (Bray & Kurtz 1945) and cation exchange capacity (CEC) by magnesium acetate extraction (pH of 7.0) (Jackson 1958). Base saturation was calculated as the sum of exchangeable cations as % CEC.

The values of each soil property from all three plots for each sampling period were pooled to test the effect of tree canopies and open grasslands on soil properties. Separate one-way analyses of variance were used to analyze the data for the effects of tree canopy, differences amongst plots and seasonal variations.

RESULTS

Differences between plots

The composition and density of woody species on the plots (Table 1) differ. Plot 3 has fewer species than plots 1 and 2 but has a higher density. An estimate of canopy cover on each plot is provided by the scoring of canopy cover for each soil sampling point: plot 1: 42%, plot 2: 39% plot 3: 31%. Plot 3 has fewer trees $\geq$ 7 m than plots 1 and 2. Plots 1 and 2 have more species in common than with plot 3 which is probably due to their being physically closer to each other and in the wettest part of the study area.

Table 1. Mean number of trees ≥ 1 m tall on three 1 ha plots in Nigerian Guinea savanna. Trees were counted on twenty 5 m × 25 m transects in each plot. Botanical nomenclature is according to Hutchinson & Dalziel (1954–1972)

	Number of trees on 0.25 ha					
	Plot 1		Plot 2		Plot 3	
Species Tree height (m)	≥ 7	< 7	≥ 7	< 7	≥ 7	< 7
Acacia gourmaensis	2 ± 1	6 ± 3	–	5 ± 2		
Acacia hockii	3 ± 2	4 ± 2	–	2 ± 1		
Acacia nilotica	10 ± 4	5 ± 3	1 ± 1	2 ± 1		
Afrormosia laxiflora	–	2 ± 1	–	2 ± 1	–	–
Afzelia africana	–	–	–	2 ± 1	1 ± 1	–
Anogeissus leiocarpus	6 ± 3	4 ± 2	–	–	–	–
Annona senegalensis			–	3 ± 2	–	10 ± 3
Bombax costatum			1 ± 1	–		
Boswellia odorata	–	–	1 ± 1	–		
Bridelia ferruginea	–	2 ± 1	–	7 ± 3		
Burkea africana	2 ± 1	–	–	5 ± 2	4 ± 2	4 ± 2
Combretum spp.	6 ± 2	33 ± 5	–	20 ± 4	–	17 ± 4
Crossopteryx febrifuga	–	1 ± 1	–	2 ± 1	–	2 ± 1
Daniellia oliveri	–	–	–	1 ± 1	–	1 ± 1
Detarium microcarpum	1 ± 1	–	–	2 ± 1	–	53 ± 6
Entada abyssinica	–	1 ± 1	–	–		
Entada africana	–	2 ± 1	–	2 ± 1		
Gardenia erubescens	–	–	–	13 ± 4		3 ± 2
Grewia mollis	–	5 ± 2	–	–		
Isoberlinia tomentosa			3 ± 2	5 ± 2		
Khaya senegalensis			–	1 ± 1		
Lannea acida			1 ± 1	5 ± 3	–	2 ± 1
Lannea kerstingii	–	2 ± 1	–	–	–	–
Maytenus senegalensis	–	–	–	11 ± 3	–	6 ± 2
Piliostigma thonningii	–	2 ± 1	–	–	–	5 ± 2
Prosopis africana	6 ± 3	–	–	3 ± 2		
Pseudocedrela kotschyii	–	–	–	2 ± 1		
Pterocarpus erinaceus	2 ± 2	2 ± 1	3 ± 2	–		
Sterculia setigera			–	1 ± 1	–	–
Strychnos spinosa	–	–	–	–	–	1 ± 1
Terminalia avicennoides	–	2 ± 1	–	8 ± 3	–	76 ± 8
Trichilia emetica	–	–	–	–	–	1 ± 1
Vitellaria paradoxa	–	3 ± 2	1 ± 1	2 ± 1	–	2 ± 1
Ximenia americana	–	–	–	4 ± 2	–	–
Totals	38 ± 7	76 ± 8	11 ± 4	110 ± 9	5 ± 2	183 ± 11

All the soil properties showed significant differences ($P<0.001$) between the plots (Table 2).

Soil properties under tree canopies and in open grassland

Comparisons of soil properties beneath tree canopies and in the open were initially done for each plot separately. With the exception of soil mechanical analyses, and C : N ratios, all properties were lower in the open than under tree canopies, and a high proportion of these differences were significant.

Notwithstanding the differences between plots, the data for the three plots were pooled to provide an overall comparison (Table 3). Mean percentage sand, silt and clay of soil under tree canopies showed no significant differences from those of the open grassland.

Table 2. Mean values (data include soil samples both under tree canopies and in open grassland) ± 95% confidence interval of soil physical and chemical properties in the study plots in the Guinea savanna zone of Nigeria. The values are the means of 100 samples repeated three times in each plot.

Soil Property	Plots		
	1	2	3
% Sand	54.64 ± 2.66	73.02 ± 2.02	76.84 ± 1.36
% Silt	30.96 ± 1.88	18.13 ± 1.54	14.66 ± 1.02
% Clay	14.41 ± 0.88	8.87 ± 0.64	8.50 ± 0.54
pH (KCl)	5.20 ± 0.14	5.81 ± 0.11	5.71 ± 0.07
% Organic matter	2.44 ± 0.09	1.53 ± 0.10	1.28 ± 0.06
% Total nitrogen	0.088 ± 0.009	0.063 ± 0.004	0.048 ± 0.003
Carbon/nitrogen ratio	15.52 ± 1.01	14.71 ± 1.70	15.38 ± 1.48
Available phosphorus ($\mu g\ g^{-1}$)	2.51 ± 0.31	6.73 ± 0.93	3.70 ± 0.44
Exchangeable cations (me $100\ g^{-1}$)			
Calcium	3.79 ± 0.21	3.90 ± 0.19	1.90 ± 0.11
Magnesium	2.03 ± 0.09	1.33 ± 0.04	0.72 ± 0.03
Potassium	0.29 ± 0.02	0.29 ± 0.02	0.13 ± 0.001
Sodium	0.20 ± 0.01	0.18 ± 0.01	0.10 ± 0.01
Total exchangeable bases (me $100\ g^{-1}$)	6.69 ± 0.33	5.75 ± 0.28	2.99 ± 0.16
Cation exchange capacity (me $100\ g^{-1}$)	9.79 ± 0.36	8.53 ± 0.37	5.27 ± 0.37
% Base saturation	64.28 ± 2.46	69.66 ± 2.05	59.09 ± 6.80

Soil pH of all the plots showed that they are slightly acidic. However pH under tree canopies was significantly higher than in the open grasslands in January, August and October (Table 3).

Soil organic matter content under tree canopies was higher than in the open grassland in all three sampling periods.

Total soil nitrogen showed a similar trend to soil organic matter content in that nitrogen content tended to be higher under tree canopies than in the open. However, the differences were not statistically significant.

There was no consistent trend in the carbon : nitrogen (C : N) ratio between soil under tree canopies and in the open grassland.

There was no significant difference in available soil phosphorus under tree canopies and in the open.

The mean soil content of the exchangeable cations calcium, magnesium, potassium and sodium in soils under tree canopies was higher than that in the open (Table 3). This is statistically significant for calcium in all three periods, for magnesium only in January, for potassium in January and August and for sodium only in January.

The total exchangeable bases followed the same trend as the individual cations with respect to tree canopy, being higher in soils under tree canopies than in those in the open. This is statistically significant in only January and August.

Soil cation exchange capacity under tree canopies was higher than that in the open grassland in August and October.

The percentage base saturation under tree canopies was higher than that of

Table 3. Mean values ± 95% confidence interval (N = 112 under canopy and 188 in the open for each sampling period) of soil physical and chemical properties under woody canopy and in the open in the Guinea savanna zone of Nigeria at different periods of the year. Indications of significant differences are between pairs of means within each season.

Soil property	January (mid-dry)		August (early wet)		October (late wet)	
	Canopy	Open	Canopy	Open	Canopy	Open
% Sand	68.56 ± 1.30	68.21 ± 1.08				
% Silt	20.86 ± 0.94	21.34 ± 0.80				
% Clay	10.58 ± 0.40	10.44 ± 0.32				
pH (KCl)	5.88 ± 0.45	5.55 ± 0.18***	5.54 ± 0.12	5.41 ± 0.11***	5.76 ± 0.27	5.24 ± 0.39*
% Organic matter	1.95 ± 0.17	1.71 ± 0.13*	2.12 ± 0.15	1.86 ± 0.15*	1.76 ± 0.17	1.38 ± 0.10***
% Total nitrogen	0.077 ± 0.011	0.062 ± 0.009	0.072 ± 0.010	0.062 ± 0.010	0.064 ± 0.010	0.062 ± 0.001
Carbon:nitrogen ratio	15.04 ± 1.60	13.17 ± 1.28	16.54 ± 1.20	16.54 ± 1.06	12.84 ± 1.00	13.24 ± 1.58
Available phosphorus ($\mu g\ g^{-1}$)	4.17 ± 0.72	3.38 ± 0.98	5.02 ± 0.97	5.08 ± 0.74	3.58 ± 0.62	2.57 ± 0.48
Exchangeable cations me $100\ g^{-1}$						
Calcium	3.16 ± 0.29	2.59 ± 0.77***	4.79 ± 0.38	4.20 ± 0.39***	3.11 ± 0.32	2.36 ± 0.17***
Magnesium	1.50 ± 0.14	1.31 ± 0.10*	1.41 ± 0.16	1.20 ± 0.32	1.35 ± 0.26	1.24 ± 0.14
Potassium	0.28 ± 0.03	0.21 ± 0.02***	0.25 ± 0.03	0.20 ± 0.03*	0.26 ± 0.02	0.22 ± 0.04
Sodium	0.15 ± 0.02	0.12 ± 0.01**	0.19 ± 0.02	0.17 ± 0.02	0.21 ± 0.02	0.20 ± 0.01
Total exchangeable bases (me $100\ g^{-1}$)	5.32 ± 0.46	4.50 ± 0.35**	6.71 ± 0.52	5.78 ± 0.52	4.38 ± 0.48	4.03 ± 0.43
Cation exchange capacity (me $100\ g^{-1}$)	9.42 ± 0.72	8.78 ± 0.64	8.07 ± 0.56	7.23 ± 0.55*	7.69 ± 0.66	6.24 ± 0.37***
% Base saturation	56.54 ± 2.75	52.02 ± 2.51*	81.66 ± 2.94	81.18 ± 3.68	58.93 ± 5.94	54.70 ± 5.54

* Significant at $P < 0.05$ ** Significant at $P < 0.01$ *** Significant at $P < 0.001$

Table 4. Effect of tree height on the physical and chemical properties of soils beneath them in the Guinea savanna zone of Nigeria (Mean ± 95% confidence interval). NS: not significant at 0.05 level.

Soil property	Tree height < 7 m	Tree height ≥ 7 m	Significance of difference
% Sand	71.32 ± 1.79	65.98 ± 1.81	P<0.05
% Silt	18.86 ± 1.30	22.72 ± 1.32	P<0.05
% Clay	9.64 ± 0.54	11.47 ± 0.57	P<0.05
pH (KCl)	5.66 ± 0.14	5.67 ± 0.17	NS
% Organic matter	1.80 ± 0.14	2.05 ± 0.13	P<0.01
% Total nitrogen	0.062 ± 0.009	0.073 ± 0.008	NS
Carbon/nitrogen ratio	15.29 ± 1.78	14.70 ± 1.75	NS
Available phosphorus ($\mu g\ g^{-1}$)	4.62 ± 0.89	4.31 ± 0.66	NS
Exchangeable cations (me 100 g^{-1})			
Calcium	3.40 ± 0.32	3.83 ± 0.25	P<0.05
Magnesium	1.23 ± 0.14	1.63 ± 0.12	P<0.05
Potassium	0.23 ± 0.02	0.28 ± 0.02	P<0.05
Sodium	0.17 ± 0.02	0.19 ± 0.02	NS
Total exchangeable bases (me 100 g^{-1})	5.29 ± 0.49	6.14 ± 0.41	P<0.01
Cation exchange capacity (me 100^{-1})	7.34 ± 0.57	9.19 ± 0.49	P<0.001
% Base saturation	67.49 ± 3.22	68.68 ± 3.69	NS

soils in open grassland only in January. The base saturation is dominated by calcium and magnesium in all the plots.

There were significant variations at the different periods of the year in soil organic matter ($P < 0.001$), carbon : nitrogen ratio ($P < 0.001$), calcium ($P < 0.001$), sodium ($P < 0.001$), total exchangeable bases ($P < 0.001$), cation exchange capacity ($P < 0.001$), percentage base saturation ($P < 0.001$) and phosphorus ($P < 0.05$).

On the whole, more significant differences between soil properties under tree canopy and in the open grassland are recorded during the dry season than the wet.

Tree height and soil properties

There was significantly higher soil organic matter, cation exchange capacity, calcium, magnesium, potassium, total exchangeable cations, silt and clay under canopies of trees ≥ 7 m than under canopies of trees < 7 m (Table 4). Only percentage sand is significantly higher under canopies of trees less than 7 m. There was no difference in soil pH, total nitrogen, carbon : nitrogen ratio, phosphorus, sodium and percentage base saturation.

DISCUSSION

Several other workers (Belsky *et al.* 1989, Bernhard-Reversat 1982, Hattan & Smart 1984, Kellman 1979, Tiedemann & Klemmedson 1973) have reported similar higher values in soil properties under tree canopies than in open grassland as found in this study. This may be partly as a result of organic matter accumulation under them and reduced leaching. The organic matter accumulation may be mainly a result of higher organic matter production by trees and its slower rate of mineralization under tree canopies due to reduction in temperature there. Also leachates from tree canopies, nutrient inputs from through-fall and nutrient transport by tree roots from rooting zones to tree canopies may also be sources of nutrients under tree canopies.

As well as being a dependable source of plant nutrients, organic matter has been shown to provide much of the cation exchange capacity of surface soils in the Nigerian savanna zone (Jones 1971, Kadeba & Benjaminsen 1976). The higher organic matter under tree canopies may account for the higher cation exchange capacity leading to a greater adsorptive capacity for cations. It may also possibly contribute to more stable soil structural aggregates. Coupled with the tree canopies reducing the force of rain drops striking the surface, the soil beneath tree canopies is likely to be more resistant to rain splash, water and wind erosion.

Comparison of the mean values of soil properties under canopies of trees less than 7 m high and trees 7 m and above showed significant differences in soil organic matter, calcium, magnesium, total exchangeable cations, cation exchange capacity, sand, silt and clay between them. Similar observations have been reported by Bernhard-Reversat (1982) and Kellman (1979). This is probably due to the ability of these trees to establish gradually an enlarged plant-litter-soil nutrient cycle within the savanna as a result of prolonged persistence at one site (Kellman 1979). Our results support the assertion of Sanford *et al.* (1982) that small trees would not be as effective as large trees in temperature amelioration, mineral cycling and addition of organic matter to the soil. They also support their recommendation that only large trees should be left in savanna in order to minimise the reduction of herbaceous production.

The less sandy soil under canopies of bigger trees is not expected since these big trees are expected to accumulate aeolian material under their canopies.

Seasonal fluctuation in some of the soil properties has also been observed. The consistently higher values, especially of exchangeable calcium and carbon : nitrogen ratio in August compared with January could be attributed to availability of moisture with the onset of the rains which initiate a rapid decomposition of accumulated litter, releasing these nutrients to the soil. The accumulation of bases released as a result of the decomposition possibly accounts for the markedly higher base saturation observed in August. It is also possible that more nutrients were leached from the tree canopies because of the rains.

The higher carbon : nitrogen ratio observed in August could be due to the depletion of soil mineral nitrogen through immobilization by the microorganisms during decomposition. Jones (1973) has indicated that in grass-dominated savanna soils, residues from the natural vegetation are usually poor in nitrogen and seem likely to initiate a period of vigorous soil nitrogen immobilization when returned to the soil.

The decline in some of these elements in October (late growth period) is quite likely the result of leaching losses and uptake by the vegetation.

There are plot-to-plot variations in the soil properties studied. These variations among the plots are probably due to the difference in soil texture in the plot. In West African savanna, Jones (1973) and East Africa, Birch & Friend (1956) have shown that soil texture is the most important factor controlling soil organic matter. The differences in soil organic matter in the plots may also account for the differences in soil total nitrogen, exchangeable cations and cation exchange capacity. This is because significant positive correlations have been reported between soil organic matter and total nitrogen (Balasubramanian *et al.* 1984, Isichei 1982), total extractable cations (sum of Ca, Mg, K and Na) (Kadeba 1974) and cation exchange capacity (Kadeba & Benjaminsen 1976) in Nigerian savanna. Differences in grazing, topographic position (moisture relations) and soil parent material may also have contributed to the variation between plots.

CONCLUSION

The results of this study indicate that trees in Nigerian Guinea savanna have a beneficial effect on soil nutrient status. Big trees have greater effect on soil properties than smaller trees. The common practice of clearing all woody trees in order to establish farms and improve rangeland should be reconsidered. The practice not only removes these beneficial effects on soil but also removes the other beneficial effects of trees such as the provision of shade for grazing animals, habitat for birds and wildlife and browse for livestock and wildlife for several months in the dry season when the grasses are not available. Therefore trees must be taken into consideration in managing Guinea savanna as rangeland.

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