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NITROGEN LOSS BY BURNING FROM NIGERIAN GRASSLAND ECOSYSTEMS

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Abstract

Nitrogen loss by burning from natural grassland ecosystems in Western Nigeria was studied over a two-year period in three areas, including sites of *Andropogon-Hyparrhenia – Schizachyrium-Brachiaria* grassland in derived, Southern Guinea and Northern Guinea savanna. The production of above-ground herbaceous material and litter fall of leaves, wood and fruit/seed was estimated and the nitrogen content just prior to burning determined. Final estimates of from 12 to 15 kg ha^{-1} yr^{-1} of nitrogen lost by burning were obtained. It is suggested that such loss may be replaced to a considerable extent by rain and blue-green algal crust fixation.

Introduction

Annual burning of grasslands has been occurring for centuries throughout the world. Sometimes the burning is accidental, but more often it is purposefully carried out by man to clear away dead vegetation, to encourage new grass growth for cattle grazing or to drive out wild game for hunting. One important ecological consequence of burning is the volatilization of nitrogen contained in the vegetation. Nye & Greenland (1960) stated that all the nitrogen is lost in burning, and Bartholomew *et al.* (1953) somewhat earlier observed that in burning woody or grass fallow, the nitrogen is almost totally lost as free nitrogen or as volatile oxides. Christensen (1973) recently working in California chapparral, reported that some nitrogen is left in the ash after burning. Metz *et al.* (1961) reported that no nitrogen remains in white ash but that incompletely burned charred remnants may contain from 0.01 to 0.76 % nitrogen.

The amount of nitrogen lost by burning has not been estimated with precision for tropical grassland systems. Nye & Greenland (1960) reported that the nitrogen lost in the burning of grass of high-grass savanna will be around 28 kg ha^{-1}. Estimates for temperate zone systems vary from 4.5 to 5.6 kg ha^{-1} as reported in a study carried out in northern Australia (Norman & Wetselaar, 1960) to an estimate of 30 kg ha^{-1} nitrogen lost from grassland in Oklahoma, USA (Elwell *et al.*, 1941); the value of 11.5 kg ha^{-1} yr^{-1} nitrogen lost by grass burning in the Venezuelan savanna has recently been reported (Medina *et al.*, 1978).

Reported effects of burning on soil nitrogen are somewhat puzzling. Vine (1953) reported only slight decrease in total nitrogen after twelve years of firing an experimental plot near Ibadan, Nigeria (forest-derived savanna area). Egunjobi (1973), working in Oyo, Nigeria (derived savanna), reported that there was no difference between burned and unburned plots after firing although the burned plot had contained slightly more previously, and Moore (1960) reported higher nitrogen in the soil below the burned plots at Olokemeji, southwestern Nigeria (derived savanna) than below the fire protected plot. On the other hand, reports of decreased nitrogen content in the soil below burned areas in the temperate zone exist (e.g., Cook, 1939 in southern Africa; Blaisdell, 1953 in Idaho, USA). It is difficult to reconcile the annual loss of as much as 28 kg of nitrogen per hectare with no change from year to year in soil nitrogen. Grass production in most Nigerian savanna areas does, however, superficially appear to be more or less stable, indicating that as much nitrogen must enter the system as is lost from it. It has been suggested (Daubenmire, 1968) that burning induces an increase in Leguminosae population and thus leads to increased biological nitrogen fixation. Such does not appear to be the case from our consideration of the data from Afolayan's (1977) short-term studies in Kainji Lake National Park, Nigeria (Northern Guinea savanna).

However, before considering such hypotheses of nitrogen stabilization, it is necessary to determine how much nitrogen is actually lost by burning. The present study is an attempt to this end.

Research sites and methods

The study reported in this paper was carried out from October 1975 to June 1978 in five plots at three sites: (1) the fire plots, each 1740 m^2, at Olokemeji Forest Reserve, 7°25′N and 3°32′E, in the derived savanna zone (Keay, 1959) of southwestern Nigeria: Plot A has been annually burned late in the season (March) since 1929 and plot B early (December). Both are high-grass *Andropogon-Hyparrhenia-Schizachyrium* savannas, with A being relatively open and B being woodland; (2) a 50 m x 50 m unfenced plot of high-grass (*Andropogon-Hyparrhenia-Schizachyrium-Chasmapodium*) savanna woodland in Old Oyo Forest Reserve, 8°N, 4°E, in the Southern Guinea zone (Keay, 1969) of Western Nigeria; (3) an open *Detarium-Burkea-Terminalia* moderately low-grass (*Brachiaria-Andropogon-Schizachyrium*) savanna unfenced plot 50 m x 50 m near to Oli River Visitors' Camp in Kainji Lake National Park, 9°45′N–10°23′N and 4°32′E–3°40′E; and a similarly sized unfenced plot in nearly closed *Isoberlinia* woodland (with the grasses *Schizachyrium-Ctenium-Hyparrhenia-Brachiaria*) at Tugan Giwa, Kainji Lake National Park (Northern Guinea savanna; Keay, 1959).

Periodic standing crop sampling of herbaceous vegetation was done in two ways: (i) selected plants of identified grass species were collected to compare above-ground and below – ground biomass in amount and in nitrogen concentration – above-ground results were used; (ii) all herbaceous vegetation from 10 or 20 randomly placed 0.25 m^2 quadrats was clipped 1.5 to 2.0 cm above the ground (the height at which burn most often stops) and sorted by species. The second method was for determining standing crop amount and N-concentration. The samples were oven dried to constant weight and total nitrogen determination (organic and inorganic) made by the Kjeldahl method in this laboratory and at the British Ministry of Agriculture, Food and Fisheries Laboratory in Bangor. Litter was periodically sampled by collection from five 1 m^2 fixed quadrats, originally randomly placed, and from five to ten 1 m^2 quadrats randomly placed at each collection. The litter was sorted into leaves, wood and seed/fruit. Drying and analysis of samples was as for standing crop samples.

For the estimation of standing crop prior to burning, after burning and the amount of nitrogen in grass samples, the Stein transformation, Z (Efron & Morris, 1977), of means was used in an attempt to obtain more reliable estimates than would be obtained by direct use of means. It was not possible to use the transformation on the litter data as samples were insufficient.

Results

Randomly collected ash samples were taken immediately after early and late burning in Olokemeji and shortly after burning in January in Kainji Lake National Park. None contained a detectable amount of nitrogen. It is therefore concluded that nitrogen is completely volatilized from vegetation burned both early and late. A crucial question now becomes that of how much nitrogen is contained in the vegetation at the time of burning. A summary of the results of analysis of grass shortly before burning is given in Table 1. The data are remarkably consistent in indicating a much lower nitrogen content than found in grass earlier in the season (unpublished data). It should also be noted that the highest nitrogen percentage was found in the early burned plot at Olokemeji. Olokemeji is on the forest/derived savanna margin, and the early burned plot is quite different in species composition and physiognomy from the other sites, including the Olokemeji late burned plot, which are more typical savanna.

Table 1. The total amount of nitrogen in the standing crop of grasses prior to burning

Research site[1)]	Sample date	Number of samples	Mean nitrogen content (%)	95 % confidence limit	Z transformation[2)] of mean values
Old Oyo	7 Dec. 1975	11	0.35	0.002	0.35
Old Oyo	4 Nov. 1977	2	0.35	–	0.35
Olokemeji A	10 Nov. 1978	9	0.34	0.0002	0.35
Olokemeji B	13 Dec. 1975	4	0.51	0.005	0.39
Kainji Lake O	15 Nov. 1975	13	0.28	0.003	0.34
Kainji Lake O	23 Oct. 1966	5	0.33	0.0002	0.35
Kainji Lake W	15 Nov. 1975	12	0.28	0.004	0.34
Kainji Lake W	14 Oct. 1976	9	0.34	0.001	0.35
Kainji Lake W	23 Oct. 1977	6	0.41	0.01	0.37
		71			
Grand mean			0.35	0.003	0.35
Range			0.28–0.51		0.34–0.39

1) A – Later (Mar.) burned
B – Early (Dec.) burned
O – Open savanna
W – Woodland savanna

2) $Z = \bar{Y} + C(Y - \bar{Y})$

$$C = 1 - \frac{(n-3)\,s^2}{(\Sigma y^2) - (\Sigma Y)^2/n}$$

In Table 2 are presented the data allowing for estimation of the amount of nitrogen volatilized by burning. The standing herbaceous crop obtained before burning varies considerably from plot to plot and from year to year. While the percentage burned varies tremendously when small areas such as quadrats are considered, the overall variation of areal means is considerably less than that of production. Using Z-transformed values, the grand mean of nitrogen lost per year is 8.77 kg ha^{-1}, with a range from 7.36 to 9.61 kg ha^{-1}.

An estimate of 0.83 ± 0.09 % nitrogen as the content of oven dried leaf litter prior to burning was obtained from collections made at plots A and B, Olokemeji, on 10 November 1977. An estimate of 0.89 % nitrogen in oven dried fruit/seed was obtained from only one collection at Olokemeji and so cannot be considered as reliable. The nitrogen content of wood (0.21 ± 0.11 %) was estimated from the results of Kjeldahl analysis of 27 core samples taken from standing trees at Old Oyo and Kainji Lake National Park. This estimate is somewhat too high as it was made from the analysis of living material, whereas wood litter will be partially decomposed and leached. The percentage of litter burned could be estimated only from sampling of Olokemeji plot B, as it was only here that we were able to sample immediately before and after firing. Taking into consideration the amount of litter decomposed during the year, it was estimated that 18.5 % of the year's fall of leaves was burned together with 11.7 % of the year's wood fall and 36.8 % of the year's fruit/seed fall. These figures were used to give the estimates of nitrogen loss from litter burned presented in Table 3.

It is now possible to arrive at an estimate of the total amount of nitrogen lost by burning. These estimates are given in Table 4. A conservative estimate appears to be from 12 to 15 kg ha^{-1} yr^{-1} nitrogen lost from burning of Guinea savanna.

Table 2. Standing crop herbaceous production and estimated nitrogen loss in five research plots at three locations in Western Nigeria

Research site[1]	Mean standing crop prior to burning ($g\ m^{-2}\ yr^{-1}$)	Z transformation of standing crop means[2]	Mean percentage burned	Z transformation of percentage burned[2]	Nitrogen loss ($kg\ ha^{-1}\ yr^{-1}$)[3]
Olokemeji A	358.0	316.1	95.7	85.3	9.43
Olokemeji A	182.4	277.5	53.2	75.8	7.36
Olokemeji B	431.4	332.3	83.8	82.6	9.61
Old Oyo	300.0	303.4	84.9	82.8	8.80
Old Oyo	316.7	307.4	84.0	82.7	8.88
Kainji Lake O	359.5	316.5	71.7	79.9	8.85
Kainji Lake O	287.7	300.7	87.6	83.5	8.78
Kainji Lake W	183.1	277.6	73.0	80.2	7.79
Kainji Lake W	334.4	310.9	100.0	86.2	9.38
Mean	304.3	304.3	82.3	82.3	8.77

1) For research site code, see Table 1.
2) For Z transformation, see Table 1.
3) These values were obtained by using the value for nitrogen content of 0.35 % and the Z values for standing crop and percentage burned.

Table 3. Litter fall and estimated nitrogen loss in five research plots in three locations in Western Nigeria

Research site[1]	Leaf Litter fall (g m^{-2} yr^{-1})	Nitrogen loss (kg ha^{-1} yr^{-1})	Wood Litter fall (g m^{-2} yr^{-1})	Nitrogen loss (kg ha^{-1} yr^{-1})	Fruit/seed Litter fall (g m^{-2} yr^{-1})	Nitrogen loss (kg ha^{-1} yr^{-1})
Olokemeji A	62.9	0.97	987.0	2.45	0.8	0.03
Olokemeji B	316.8	4.90	330.8	0.82	36.8	1.21
Old Oyo	112.6	1.74	671.9	1.67	15.5	0.51
Kainji Lake O	148.2	2.29	69.6	0.17	1.5	0.05
Kainji Lake W	240.7	3.72	175.9	0.44	27.5	0.90

1) For research site code, see Table 1.

Table 4. The total amount of nitrogen lost by burning in Western Nigeria grasslands

Research site[1]	Nitrogen loss (kg ha^{-1} yr^{-1}) Herbaceous standing crop	Litter Leaves	Wood	Fruit/seed	Total	Z transformation of total[2]
Olokemeji A	8.40	0.97	2.45	0.03	11.85	12.50
Olokemeji B	9.22	4.90	0.82	1.21	16.15	14.66
Old Oyo	8.84	1.74	1.67	0.51	12.76	12.96
Kainji Lake O	8.59	2.29	0.17	0.05	11.50	12.13
Kainji Lake W	8.82	3.72	0.44	0.90	13.77	13.52

1) For research site code, see Table 1.
2) For Z transformation, see Table 1.

Discussion

Yearly losses of nitrogen from the natural grassland ecosystem are accounted for by migratory grazing, burning and harvesting and leaching and run-off. A considerable amount is also immobilized each year in below-ground biomass and above-ground woody vegetation. In spite of these losses and immobilizations, the Nigerian grassland very often appears stable in fixed carbon production from year to year, indicating that as much nitrogen must enter the system as is lost and not recycled from the amount immobilized. The present estimate of loss from burning of from 12 to 15 kg ha^{-1} yr^{-1} is much lower than the figure of Nye & Greenland of 28 kg ha^{-1} yr^{-1}. This latter figure appears, however, to have been derived from estimates involving the total burning of nearly pure forage grass stands. It is also possible that the nitrogen content of the grass was assessed near peak maturity rather than at the low level found in natural systems immediately prior to burning. Our data, as yet incompletely analyzed, also suggest that the amount of nitrogen in herbaceous material is greater in forest and derived savanna areas than in so-called "true" savanna. This is certainly the case with leaf litter, where leaf fall from the fire protected plot at Olokemeji – typical lowland rainforest vegetation – averaged 0.95 % nitrogen in November, whereas that from plot A, with typical Guinea savanna vegetation, averaged 0.77 % nitrogen, the difference in means being significant as tested by analysis of variance at $P < 0.01$.

Our figures of nitrogen loss are in line with those reported for various temperate situations, such as Grant *et al.* (1963) for England, and Hunter *et al.* (1964) for Scotland. We believe the figures will prove typical for Guinea savanna in West Africa. They are particularly significant in that they strongly suggest that the nitrogen lost by burning may be almost replaced by fixation by blue-green algal crusts (up to 4–8 kg ha^{-1} yr^{-1}; Isichei, 1975) and by rain (4–5 kg ha^{-1} yr^{-1}, Jones & Bromfield, 1970, North Nigeria).

The major remaining amount of nitrogen to be added to the system each year is that needed to replace the nitrogen immobilized in wood and below ground biomass. Part of this amount may be met by nitrogen recycled from litter and the bodies of soil microorganisms. A considerable amount may also be added through biological nitrogen fixation by Leguminosae associations and possibly by grass – *Spirillum lipoferum* associations.

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