Global Biomass Burning
Atmospheric, Climatic, and Biospheric Implications

edited by Joel S. Levine

The MIT Press
Cambridge, Massachusetts
London, England

Emissions of Carbon, Nitrogen, and Sulfur from Biomass Burning in Nigeria

Funso Akeredolu and A. O. Isichei

Savanna—321,550 square kilometers (km^2) of Sudan savanna, 376,070 km^2 of Guinea savanna, and 71,150 km^2 of Sahel savanna—occupies over 80% of Nigeria's 924,000 km^2 land area. Most of it is burned annually. It is estimated that swamp forest of the Niger Delta and coastal belt cover about 24,040 km^2, while the lowland rainforest proper covers about four times this area (89,630 km^2), although not more than 10% of the latter has escaped farming in recent times and no significant areas of high forest now remain outside the forest reserves (Onochie, 1979). The rest of the land area is made up of forest-savanna transition zones.

The rate of deforestation in Nigeria, estimated as 0.285 million hectares per year (ha/yr) (FAO, 1981), ranks ninth in the world (Woodwell, 1984) and proceeds at about 4.8% per annum (FAO, 1981). Existing subsistence farming practices, such as shifting cultivation, are largely responsible for the high rate of deforestation (Osemeobo, 1988). Biomass burning is an integral part of the shifting cultivation and slash and burn agriculture, which is common in many parts of West Africa. Burning takes place in the dry season between November and March annually in most of the forest and savanna zones.

There have been numerous studies on the effects of burning on vegetation in Nigeria (see Sanford, 1982), but the atmospheric implications have never been discussed. The objective of this chapter is to discuss some of those implications based on available data on biomass burning in Nigeria.

Extent of Biomass Burning by Geographical Area

Virtually any part of the country that experiences up to three months' dry season is affected by burning. What matters is the intensity of burning, which itself is dependent on the vegetation type and the time of year of burning. The amount of litter produced, especially leaf litter, is crucial in the burning of forest vegetation and plantations. Reported litter fall in savannas range from 1 to 4 tons per hectare per year (tons/ha/yr), in forest from about 5 to 8 tons/ha/yr, and over 11 tons/ha/yr in plantations (Table 21.1). Okali and Ola-Adams (1987) reported standing woody biomass of 229.6 tons/ha in a primary forest and 91.1 tons/ha in a 28-year-old plot, both in a dry rainforest in southwestern Nigeria. Isichei (1979) reported between 10 and 55 tons/ha standing wood in various savanna formations in western Nigeria. Based on analysis of bole cores, these woody materials contained between 12 and 78 kg N/ha. When forests and savannas are burned, an estimated 10% of the woody plants, the small branches, are usually burned, while the main stems may be smoldered to various degrees. In savanna, standing dead herbaceous material is burned in addition to litter. Herbaceous biomass production varies widely, and Milligan and Sule (1982) reported a range of 1.5 to 18 tons/ha/yr, with the range of 2 to 6 tons/ha/yr being more typical (but see Egunjobi, 1974). The time of year when burning occurs is important. Egunjobi (1971) reported a 56% burn in December for a transition savanna in Nigeria and an 86% burn for an adjacent site in February and March. Higher burn figures could be obtained for the late dry season (see Isichei, 1979). The loss of C, N, and S will vary according to the mass of material burned and its elemental content at the time of burning.

Burning has for a long time been restricted to the savanna zone, but burning of forest and transition (between forest and savanna) areas is escalating. We have observed that most degraded forest vegetation with abundant *Chromolaena odorata* (formerly *Eupatorium odoratum*), which colonizes cleared forest lands, and almost all savanna lands are burned even if the burning may be spotty. Ajaiyeoba (1983) reported the following percentage losses of established pine plantations in five southern states in Nigeria at various times between 1976 and 1982: Anambra, 38% (90 ha); Bendel, 50% (32 ha); Ogun (percentage loss not available but 62.8 ha measured); Ondo, 36% (81 ha); and Rivers, 15% (3.5 ha). Kadeba and Aduayi (1985) reported litter production values in 7–9 and 9–11-year-old northern Nigerian pine plantations of 3

Table 21.1 Litter fall rates by vegetation types in Nigeria

Location	Vegetation type	Litter fall (tons/ha/yr)	Reference
Olokemeji	Forest	7.2	Hopkins (1966)
Olokemeji	Forest	5.6	Madge (1965)
Ibadan	Forest	6.9	Swift et al. (1981)
Olokemeji	Forest	5.9[a]	Isichei (1979)
Sapoba	Forest (mature)	8.7	Oguntala (1983)
Omo	Forest	4.6	Hopkins (1966)
Sapoba	Forest (young)	6.5	Oguntala (1983)
Olokemeji Plot A	Savanna	0.6[a]	Isichei (1979)
Olokemeji Plot B	Savanna	3.6[a]	Isichei (1979)
Igbeti	Savanna	1.3[a]	Isichei (1979)
Borgu woodland	Savanna	2.7[a]	Isichei (1979)
Borgu	Savanna	1.5[a]	Isichei (1979)
Mokwa	Savanna	2.4	Collins (1977)
Plantation	*Species*		
Sapoba	*Triplochyton*	8.2	Oguntala (1983)
Sapoba	*Nauclea*	6.5	Oguntala (1983)
Ore	*Gmelina*	10.5	Oguntala (1983)
Gambari	*Gmelina*	10.4	Oguntala (1983)
Gambari	*Melia composita*	5.2	Oguntala (1983)
Gambari	*Nauclea*	6.2	Oguntala (1983)
Ibadan	*Tectona*	6.5	Oguntala (1983)
Afaka	*Pinus* (9–11 yrs)	3.7	Kadeba and Aduayi (1985)
Afaka	*Pinus* (7–9 yrs)	3.0	Kadeba and Aduayi (1985)

a. Indicates leaf litter plus floral parts, etc.
b. Oguntala has indicated that most plantation litter is leaves.

and 3.7 tons/ha/yr, which was estimated to contain 15 kg N/ha. Assuming that only litter was burned in these southern plantations, and assuming the same nitrogen content, N emissions from them will be 4035 kg. It is estimated that about 2000 ha of forest zone plantations are affected by fire annually.

Based on Landsat images of the Kainji Basin of northwestern Nigeria acquired on 21 October 1986 (when the savanna was at its growth peak) and on 18 December 1984 (shortly after the annual savanna burning), Isichei (unpublished data) estimated that over 70% of the area had been burned. Although it is to be noted that burning is spotty, this areal extent of burning is applicable to most natural savanna formations in Nigeria. Bushfires are a common phenomenon in the West African region, and their causes are the same throughout this region (see Ampadu-Agyei, 1988). It is estimated that 20.7×10^6 ha of savanna and 2×10^6 ha of semi-deciduous forest are burned annually.

As with most developing countries, fuel wood remains an important source of energy for the rural population (which accounts for 70% of total) in Nigeria. It is estimated that 80 million cubic meters (m^3) of wood are consumed for this purpose annually (FAO, 1981).

Timber processing amounted to 11 million m^3 in 1982 (Alviar, 1983). Wood residue production (bark, sawdust, and shavings), estimated using a residue generation factor of 17.6 kilograms of dry wood per cubic meter wood processed (Environment Canada, 1975), is 193,600 tons per year. This residue is disposed of mostly by incineration.

Estimation of Emission Rates

Methodology

According to Seiler and Crutzen (1980), the amount of biomass burnt (M) is given by the following equation:

$$M = A \times B \times a \times \beta \tag{21.1}$$

where

A = land area burned (m^2/yr),

B = biomass density (kg/ha),

a = fraction of biomass in the ecosystem that is above ground,

β = fraction of the above-ground biomass that is burned.

An emission factor was then applied to calculate the mass of CO_2 emitted from the burning of the biomass. By employing the molar ratios of given trace species to CO_2 (see Crutzen et al., 1985; Hao et al., 1989; etc.), the emissions of these trace gases are then calculated. As noted in the previous section, the biomass densities in Nigerian ecosystems cover a wide range. The biomass densities, fraction of aboveground biomass, and burning efficiency adopted (see Table 21.2) were employed to compute the emissions summarized in Table 21.3.

Published emission fluxes (see Delmas, 1982; Isichei and Sanford, 1980; and Robertson and Rosswall, 1986) were also employed to calculate the overall emissions from known land areas in different ecosystems. Closed forest, open woodland, and scrub (31×10^6 ha in total) receive some 460×10^6 kg N in the annual rainfall of 1200 to 2000 mm, assuming 15 kg/ha as the amount of N returned in rainfall. The rest of the country receives about 300×10^6 kg N per year, assuming 5 kg/ha as the amount returned in rainfall (Robertson and Rosswall, 1986).

Table 21.2 Values of parameters for equation 21.1

Biomass type	Biomass density (kg/ha)	Fraction above ground (%)	Burning efficiency (%)
Savanna			
Woody species	20	0.68[a]	25
Herbaceous species	6	0.47[a]	75
Forest	80	0.95[b]	25

a. Menaut and Cesar (1982).
b. Seiler and Crutzen (1980)

Table 21.3 CO_2 and trace gas emissions from savanna and forest burning in Nigeria

Species	Molar emission ratios relative to CO_2	Mass emission of species (Tg)	
		Savanna fires	Forest fires
CO_2	1	37	17.1
CO	0.1[a]	2.4	1.1
CH_4	0.012[b]	1.6	7.5E-2
NMHC[c]	0.01[d]	1.4E-1	6.4E-2
COS	10.8E-6[e]	5.4E-4	2.5E-4
NO_x[f]	1.6E-3[g]	4.1E-2	1.9E-2
N_2O	5.0E-5[h]	1.8E-3	8.6E-4
NH_3	1.0E-3[i]	1.4E-2	6.6E-3
HCN/CH_3CN[j]	6.0E-4[k]	1.4E-2	6.3E-3

a. Greenberg et al. (1984); Crutzen et al. (1989).
b. Hao et al. (1989); Greenberg et al. (1984).
c. NMHC = nonmethane hydrocarbons expressed as CH_4.
d. Crutzen et al. (1985); Bonsang (1990).
e. Nguyen (1990).
f. NO_x = NO + NO_2, expressed as NO.
g. Crutzen et al. (1985); Hao et al. (1989).
h. Hao et al. (1989); Crutzen et al. (1985).
i. Andreae et al. (1988).
j. HCN/CH_3CN, expressed as HCN.
k. Hao et al. (1989).

Delmas (1982) obtained an emission value of 1.4 kg S/ha from savanna burning in Ivory Coast. Applied to Nigeria, this would result in a value of 29×10^6 kg sulphur emitted over 20.7×10^6 ha of savanna usually burned annually. For the 2×10^6 ha of burned semi-deciduous forest, the sulphur emission is estimated based on 0.2% sulphur content in woods (Bowen, 1966) and a biomass density of 80 tons/ha as 8×10^4 kg/yr.

Fuel wood burns almost completely. Assuming a burning efficiency of 90% and using the emission factors reported by Dasch (1982), the burning of fuel wood generates 5.84×10^8 kg/yr of particulate matter, 6.42×10^9 kg/yr of CO, 8.76×10^7 kg/yr of hydrocarbons, 4.09×10^7 kg of oxides of nitrogen, and 2.60×10^4 kg/yr of benzo(a)pyrene (see Akeredolu, 1989a).

Impact on Biogeochemical Cycling of Elements

The monthly NO_3 concentration reported for Calabar showed a significantly higher value for January (more than twice the annual mean value) than for other months, which was attributed to bush burning emissions (Ette and Udoimuk, 1984). Bromfield (1974) also reported that a combination of low precipitation amount and high input of anthropogenic-S in the form of ash and gaseous-S released during bush burning by farmers was responsible for very high concentrations of $S\text{-}SO_4$ (about 10 times the annual mean) in rainfall samples for 11 sites in northern Nigeria. Ash and carbonaceous material were found on the gauges at the April collection. Jones and Wild (1975) concluded that the only source of S for the West African savanna soil apart from fertilizers is the atmosphere. Bromfield (1974) found 0.099 to 0.429 (mean 0.226) kg/ha of sulphur in dust and 0.49 to 1.89 (mean 1.14) kg/ha of sulfur in rain.

Nitrogen loss by burning from natural grassland ecosystems in savanna locations in western Nigeria was estimated to be 12 to 15 kg ha^{-1} yr^{-1} (Isichei and Sanford, 1980). Jones and Bromfield (1970) report the mean mineral N in rain in February (3.11 parts per million) (ppm), which is almost 10 times the annual average (0.37 ppm) and has a lower NH_4–N:NO_3–N ratio (0.86) than the annual average ratio of 1.26. This supports the hypothesis of volatilization of NO_3–N through fire as the predominant source of N in February. Also in support of this hypothesis, Isichei et al. (1990) obtained a nitrate-nitrogen concentration of 0.8 milligrams per liter (mg/l) in March, the first month of the rainy season after the fires, 0.4 mg/l in April, and 0.2 mg/l for the rest of the season ending in October. Robertson and Rosswall, 1986 estimated that fire accounts for the bulk (about 87%) of all nitrogen lost from West Africa. According to those authors, approximately 8300 × 10^6 kg were lost by this pathway in 1978. About 67% of this loss occurred on clearing and burning forest vegetation, less than 4% via burning crop residues, and the remainder during near-annual burns of savanna, Sahel, and sub-desert systems.

It is of interest to know whether the inputs of the magnitudes estimated above have detectable impact on the lower troposphere of Nigeria. Elemental ratios are commonly used as tracers in source apportionment studies. The ratio of K/Fe in the ambient particulate matter has been used as a tracer for firewood emissions (e.g., Wolff et al., 1981; Courtney et al., 1980). Two different elemental ratios were calculated from the data reported for Bagauda, a rural location close to Kano, and Ile-Ife, both in Nigeria; Pelindaba, South Africa; and Chilton, England (see Table 21.4).

Most sources have K/Fe ratios of 0.35 or less (Dasch, 1982). The K/Fe ratio for wood smoke is between 15 and 230 (Watson, 1979, cited in Dasch, 1982). Therefore the ambient K/Fe will increase if wood smoke is a major source of air pollution. Crozat et al. (1978) found that zones with values of (Ca + K)/(Na + Mg) ratio higher than 3 correspond to those where bush burning is widespread. It is clear that the elemental ratios for Chilton contrast with those for Bagauda, Ile-Ife, and Pelindaba. It also appears that high contributions from soil-derived Fe may have made the K/Fe ratios for the latter three locations to be low.

Table 21.4 Elemental ratios in some Nigerian aerosol samples

Location	Ratio K/Fe	Ratio $\frac{Ca + K}{Na + Mg}$	Reference
Bagauda, Nigeria	0.3	3.0	Beavington and Cawse (1978)
Chilton, England	1.6	1.6	Beavington and Cawse (1978)
Pelindaba, S.A.	0.4	4.1	Beavington and Cawse (1978)
Ile-Ife, Nigeria	0.1	3.6	Akeredolu (1989b)

Discussion

It is estimated that savanna and forest burning generate 37 × 10^6 tons per year (37 Tg/yr) and 17 × 10^6 tons per year (17 Tg/yr) of CO_2, respectively. For a comparison, the gridded CO_2 emission data reported by Crutzen et al. (1989) when interpolated over Nigeria's latitude and longitude coordinates, yield CO_2 emission estimates for savanna and forest in Nigeria as 35 Tg/yr and 15 Tg/yr, respectively. The estimated CO_2 emissions estimated in this work is equivalent to a carbon flux of 550 kg C/ha/yr compared with 3600 kg/ha/yr estimated by Delmas (1982) for Ivory Coast.

The emission of nitrogen in all the species produced by biomass burning (including fuel-wood burning) was estimated as 2 × 10^9 kg N/yr. By comparison, prorating the estimated nitrogen emission from biomass burning obtained for West Africa (Robertson and Rosswall, 1986), on the basis of land area, nitrogen emission for Nigeria amounts to 1.4 × 10^9 kg N/yr. Thus, both emission estimates are in rough agreement. Greenberg et al. (1985) reported CO flux from fuel-wood burning in Kenya as 0.4 g cm^2 day^{-1}. On this basis, the emission from fuel-wood burning in Nigeria is estimated as 1.3 Tg. By comparison, 6.3 Tg was calculated in this work.

Comparing these emission estimates with those for energy-related fossil fuel combustion in Nigeria (Akeredolu, 1989a), the ratios for biomass burning emissions expressed as percentages of fossil fuel emissions were 35% (for CO_2), 147% (for CO), and 5% (for NO_x). These values suggest that biomass burning generates a measurable impact on the cycling of carbon and nitrogen. With sulphur, no data were found with which to compare the estimates.

There are as yet no reported direct measurements of emissions of carbon, nitrogen, and sulphur in the Nigerian environment. Extrapolations here have been based on the composition of the sources before burning. The accuracy of the analysis of the chemical compositions of the vegetations is, however, not in doubt, so that at their face value, the estimates are fairly reliable. Most estimates have been pantropical (see Crutzen et al., 1989) and therefore involve extreme generalizations. The present estimates will help in arriving at better global estimates. There are however, some assumptions made which would need to be validated through further experimentation. First, the emission projections are based on the areal extent of the burned vegetation. Areal extent cannot be enough because, as we noted, burning could be spotty. Further, it is mainly the leaves that are burned both in litter form and in standing trees and other vegetation life forms. Field observations and on-the-spot measurements will give more accurate results.

There is also some promise of improvement in the estimates through the use of remote sensing. Remote sensing can accurately establish the areal extent of burning of vegetation and it can also be used to directly measure the concentrations of some pollutants in the atmosphere (e.g., Hamilton et al., 1978, for SO_2).

Acknowledgment

Funso Akeredolu acknowledges with thanks receiving a partial travel support from the National Science Foundation and NASA to attend the Chapman Conference on Global Biomass Burning, Williamsburg, Virginia, at which the material in this chapter was originally presented.