OBAFEMI AWOLOWO UNIVERSITY, ILE-IFE, NIGERIA.

Inaugural Lecture Series No. 158

WHATEVER GOES UP MUST COME DOWN? THE ENVIRONMENTAL CONSEQUENCES OF NUTRIENT CYCLING IN VEGETATION

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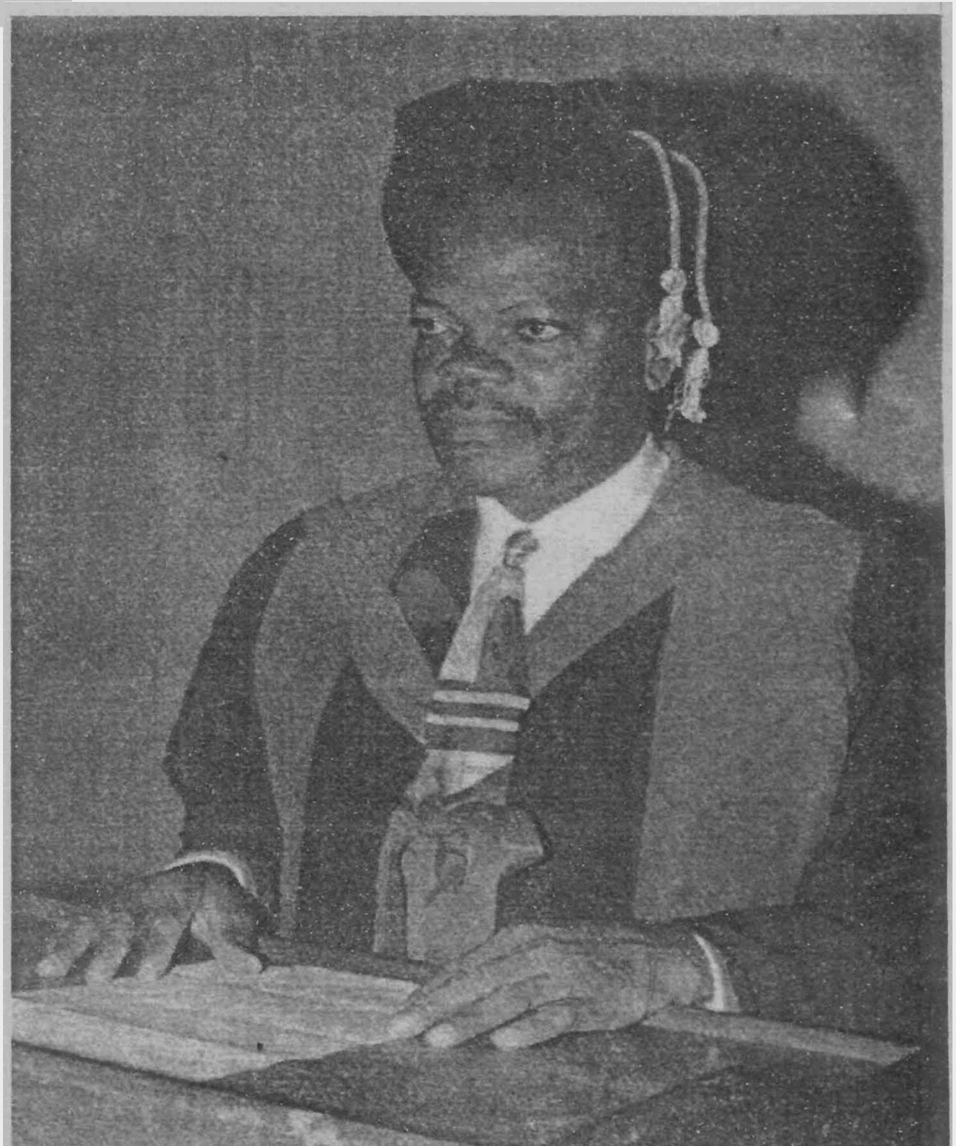

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An Inaugural Lecture Delivered at Oduduwa Hall Obafemi Awolowo University, Ile-Ife on Tuesday, 24th September, 2002

Inaugural Lecture Series No. 158

Obafemi Awolowo University Press, Ile-Ife Nigeria

ISSN 0189-7848

Printed by
Obafemi Awolowo University Press Limited,
Ile-Ife, Nigeria.

1.0 Introduction

Mr Vice-Chancellor, Sir, I have in the last twenty-six years as an ecologist been engaged in the scientific study of the factors that determine the distribution and abundance of plants. All those factors and phenomena that influence plants and other organisms constitute what we refer to as 'environment'. 'Environment' could be taken as the aggregate of external circumstances, conditions, and things that affect the existence and development of an individual, organism or group. *The Canadian Environment Protection Act* of 1999 defines environment as the components of the earth which includes (a) air, land, water; (b) all layers of the atmosphere; (c) all organic matter and living organisms; and (d) the interacting natural systems that include the above components.

According to the ancient Pythagorean doctrine, air, land, and water together with energy constitute the four elements on which life depended and would constitute non-living or abiotic environment. Inter-organism interactions constitute biotic environment. Human social interactions in terms of cultural, religious or socio-economic influences constitute 'social environment' and almost all natural ecosystems have been affected by these influences (Barret 1981). I, however, should emphasize from the onset that I am concerned with natural systems and have been studying organisms in their natural abodes or what we call habitats.

Environment was described as the global issue of the year in 1970 when concern was building up about the fate of man as he desecrated his surroundings and his source of livelihood. To a professional environmentalist, it would seem belated that the world started serious discussions on the environment only in 1970. Actually, environment has played significant roles in the earth's biological history through its role in natural selection and other evolutionary processes. Man has always had interest in the environment but this interest centred on what man can get out of it, especially food, medicines and energy.

However, with the rapid rise of industry and automobiles in the last century, the problems associated with fossil fuel utilisation and industrial waste accumulation came to the fore. Pity that man did not realise that he had an environment until it became dirty!

But then what followed this concern, understandably, was a multiplicity of voices, some of them were over-reactions that created some confusion as to the focus of the study of the environment. But Prof. E. O. Wilson, an ecologist of the University of Princeton, U.S.A. (Wilson 1998) has a comment on this proliferation of voices on the environment. He states, "By statured scientists, I mean those who collect and analyse the data, build the theoretical models, interpret the results, and publish articles vetted for professional journals by other experts, often including their rivals." He differentiates such professionals from advocacy persons and groups and cautions on the sources to consult for factual information about the environment. Wilson concluded his cautionary note by observing that the environment is much less a controversial subject than suggested by routine coverage in the media.

1.1 The Field Of Ecology

The study of the relationships between organisms and their environment is termed ecology. The field of ecology is a relatively young science unknown until late 19th century when the German scientist Haeckel first used the term (Haeckel 1866). Bray (1958) observed that the field of ecology occurs within three primary areas: (1) the biologic study of previously defined biological species at the individual, population and community levels; (2) the biophysical study of the physico-chemical concomitants of these levels of biological organization; (3) the physical study of the cycles of matter and energy exchange in which organisms are involved. Ecology also borrows from the biological fields of taxonomy, physiology, morphology and genetics, and from the physical sciences.

Plants, the objects of my study could be broadly defined as organisms that are capable of synthesising organic molecules from inorganic elements. They usually possess chlorophyll that enables them to synthesize carbohydrate from carbon dioxide and water in the presence of light. Vegetation is the totality of plants in the waters, land and air in a given area. Ecology deals with individual plants, a population and aggregations of populations and communities. Communities, together with the physical environment acting together as a system make up an ecological system or ecosystem. Ecosystems could be combined into ecological zones of arbitrary uniformity. If I may simplify Bray's (op. cit.) first primary area, ecology involves the study of organisms at various levels of organization up to the grouping that includes that portion of the earth where life is possible, the biosphere. The overall aim of ecology is human survival and the field is of ever-increasing relevance as man continues degrading his environment.

Ours is the tropical environment, geographically that part of the world mostly lying approximately between the tropics of Cancer and Capricorn. The area is characterised by very small variations in day lengths throughout the year, rains that come mostly during the period of long days (summer) and dry periods during shorter days (winter). Seasonal variation in temperature is small and generally less than the diurnal variation. Climatic divisions are determined by the amount and seasonal distribution of rainfall. The quantity of vegetation biomass depends on the total quantity and evenness of the growing season rainfall. I studied plants individually or in groups and investigated how they interacted with their immediate environment and recycled energy and matter. I started my enquiry with attempts to understand how ecological phenomena operate in the Nigerian environment. I carried out my enquiries as a natural scientist with the hope that I can contribute to our understanding of the world around us and supply information to applied scientists for use in technological applications.

2.0 Work on Savana Vegetation

2.1 Savanna Vegetation in Nigeria

In terms of broad ecological zonation, Nigeria has forests in the south, savanna in the north, occupying about 20% and 80% of the land area, respectively. I started my ecological studies in the Nigerian savanna zone. Sanford & Isichei (1986) defined savanna as seasonal tropical vegetation with trees and shrubs at various densities underneath which is a closed or nearly closed cover of grasses at least 80 cm high and with flat, cauline leaves. Savanna is usually burnt annually. During the annual cycle, the grasses mature, turn brown and dry out while the trees, most of which are deciduous, shed their leaves. Moisture is the major environmental determinant of savannas with fire, soil nutrients and in some cases herbivores as important modifiers of the basic vegetation structure (Walker 1985; Isichei & Akobundu 1995). Savanna burning has over time resulted in the control of the size-class distribution of woody plants and in the selection of plant species that are morphologically and physiologically fire-resistant. One of the fundamental processes necessary for savanna system stability is efficient nutrient cycling. The major factors in nutrient conservation and cycling which ensures savanna persistence over time are a multi-layered tree canopy cover to lessen the impact of rain, a close network of roots to absorb nutrients as soon as they go into soil solution to prevent their loss by leaching or runoff and adequate litter fall and decomposition to return nutrients to the soil for re-use. Furthermore, vegetation community development tends towards efficiency of energy utilization based on the same structural attributes (Sanford & Isichei 1986).

The fate of millions of citizens residing in the savanna zone is very much tied to the fate of savanna as a system. One major threat to savanna stability is desertification, often attributed to drought stress.

But other human-generated disturbances such as woodcutting, overgrazing and cultivation play major roles in desertification (see Afolayan et al. 1995). Ecological stress can be viewed as any force that pushes the functioning of a system beyond its ability to restore functional equilibrium. Disturbance, on the other hand, is an aperiodic event such as a prolonged drought, excessive grazing or bush clearing or cultivation that completely or partially disrupts the structure and functioning of a system. Stress and disturbance diminish system resilience and destabilize it. We analysed the various stresses that the Nigerian savanna ecosystem is usually subjected to and the roles of these in the desertification process (Isichei & Ero 1987) and concluded that over-grazing by livestock, cultivation to the point of soil exhaustion and firewood harvesting had the most important destabilizing effects. Reforestation, improvement of the quality of pastures and alternative energy sources were some of the measures we recommended to reduce stress.

Most of our savanna studies were carried out in ten Man and Biosphere research plots in the Kainji Basin of northwestern Nigeria (Muoghalu & Isichei 1991). The Man and Biosphere (MAB) programme was launched by UNESCO in 1971 as a new, integrated approach to research, training and action aimed at improving man's partnership with the environment. There is a MAB International Co-ordinating Council based at the UNESCO Headquarters in Paris. Nigeria as a participating country was one of the 25 member states selected by UNESCO 's General Conference to constitute the first International Co-ordinating Council of the programme. The Nigerian National Committee for MAB was inaugurated in 1971 and I participated in the planning phase of the Nigerian MAB programme and have been a member of the National Committee since 1984. There are 14 research themes in the MAB programme out of which Nigeria, based on relevance to her environmental circumstances, participates in six. I participate in Theme 3 – Impact of human activities and land use practices on grazing lands, savanna and grassland and in two other

Themes concerned with forests and conservation, respectively.

It is generally held that protein shortage is an important factor in human nutrition in the tropics. There have been strenuous efforts aimed at satisfying protein needs and plants, being the bedrock of the food chain hold the key to enhanced protein nutrition. Most of Nigeria's livestock – cattle, goats and sheep rearing takes place in the savanna zone usually under free ranging conditions with grass as the main fodder. The quality of the livestock is as good as the feedstock so the amount of primary production and level of protein in the grasses, forbs and trees is of fundamental importance to the livestock industry.

2.2 Savanna Biomass Production And Nitrogen Levels in The Vegetation

When we began our studies there was a dearth of information on the amount of grass, other herbs and woody plants in the wild savanna ecosystem. Therefore our first task was to determine these variables. Based on studies from various sites, we observed mean annual grass standing crop of about 500 g m^{-2} in the wettest savanna to about 250 g m^{-2} in our driest sites in the Kainji area (Isichei 1982, 1983). There was a strong positive relationship between herbaceous biomass production and length of rainy season. Other factors that influence herbaceous production are soil carbon and nitrogen content. Most of the grass biomass is usually in the leaves and then in the stem and rhizome. More of the nitrogen was in the roots/rhizome than the stem and leaves (Oke & Isichei 1993). The amount of standing wood in our sites ranged from 4,271 g m^{-2} in lightly wooded ('open') sites to 14,936 g m^{-2} in dense woodland (Isichei 1995).

The tree-grass structure of the savanna vegetation itself has a strong influence on herbaceous productivity. The trees have deeper roots while the grasses are mostly superficial and absorb nutrients and water from very near the surface (Walker 1985). This reduces competition and probably accounts for the co-existence between trees and grasses. We have shown that other aspects of this relationship could be beneficial. A light, high tree canopy that allows some light to pass through leads to greater production of grasses than either full exposure or dense canopy (Sanford et al. 1982). Furthermore, some shading provides a microenvironment where nutritionally favoured grass species such as the Andropogon species and Beckeropsis uniseta replace undesirable species such as Hyparrhenia involucrata. A density of trees in the range of 25 – 50 per hectare with canopies >7 m high would result in the best conditions for grass growth.

Canopy density also affects the yield (production), crude protein and fibre content of grasses (Muoghalu & Isichei 1995). Higher grass production was obtained under canopies >7m than under lower canopies. Generally, a higher crude protein and nutritional fibre content were observed in some grass species under tree canopy than in the open savanna, meaning that high tree canopies improve the nutritive quality of grasses growing beneath them. We also observed a higher production of non-grass herbs (forbs) under high tree canopies than under lower ones (Muoghalu and Isichei 1991). Forbs constitute a negligible part of the herbaceous layer in the savanna in terms of weight but could make up a significant part of the fodder especially in the dry season when some of them remain green. No significant differences in mean crude protein and fibre content were, however, observed between forbs growing under tree canopy and those in the open. But the protein-rich leguminous species - Cassia mimosoides, Crotalaria macrocalyx, Crotalaria microcarpa, Indigofera bracteolata, Indigofera dendroides, Tephrosia bracteolata, Tephrosia elegans and Vigna racemosa tended to have higher yields in the open than under tree canopy.

In addition to influencing species composition, yield and chemical composition of herbaceous plants underneath them, tree canopies also positively influence the fertility of soils (Isichei & Muoghalu 1992). Soils under tree canopies were found to have significantly higher levels of soil organic matter, calcium, magnesium, potassium, total exchangeable bases, cation exchange capacity and pH than those in open grasslands. Nitrogen and phosphorous were slightly higher in soils under tree canopies than those in the open. Generally, trees >7m high had more influence on soil chemical properties than shorter trees.

Trees serve as a nutrient reservoir through storage in roots and shoot and are a major agricultural resource in the savanna zone (Isichei and Akobundu 1995). They also capture atmosphere-borne nutrients in dust and aerosol. In addition to these, savanna trees are useful in nutrient 'pumping' whereby deep-rooted trees bring nutrients that could be inaccessible to herbaceous plants to the surface.

One such valuable woody plant is the legume shrub, Piliostigma thonningii that dominates disturbed vegetation in the Kainji Basin and adjoining areas in north-western Nigeria. The plant is utilised for various purposes especially as animal fodder and in ethno-medicine (Irvine 1961, Skerman 1977). In an autecological study, Mbaekwe and Isichei (1990) observed that high soil sand: clay ratio and open space were the most important factors that determined the distribution and abundance of Piliostigma. These factors are associated with disturbance and /or clearing and the fact that Piliostigma thrives in open spaces makes it a candidate plant for rehabilitating degraded areas. This must be the basis for its inclusion as one of the dozen species recommended as agroforestry trees for Sokoto, Kebbi and Zamfara States (Arnborg 1988).

Vegetation management is also an important component of farming practices for maintenance of soil fertility and sustained crop production in the shifting cultivation and crop rotation systems of the humid and sub-humid tropics. But population pressure in south-eastern Nigeria has reached such levels that only a maximum of three-year fallow (soil rest period before next cultivation) is possible. Certain shrubs are now also planted to aid the soil regeneration process. I collaborated with scientists at the International Institute of Tropical Agriculture, Ibadan to study fertility restoration patterns in natural fallows aged 1 – 3 years at Umuahia in Abia State and in a Dactyladenia barteri plantation at Mbaise in Imo State (Akobundu et al. 1993). Our assessment of nutrient status of the soils showed that soil pH, organic carbon, total nitrogen and extractable phosphorus tended to increase with fallow length under natural fallow. Under the planted shrub, organic carbon and total nitrogen did not change but extractable phosphorus levels increased with fallow length. We concluded that the two fallow systems are potential means of restoring soil fertility through litter fall and pruning applications.

The enhanced nutrient status of soils under savanna trees could also be attributed to symbiotic associations either between plant roots and fungi that make them more efficient soil nutrient absorbers (mycorrhiza) or between legumes and the bacterium Rhizobium that fix atmospheric nitrogen. In the Nigerian savanna, there are 284 woody and herbaceous legume species (Sanford 1982) and legumes make up over 20% of all woody species (Jackson 1973). Species of the bacterium, Azospirillium are in loose association with the roots of tropical grasses and cereals and the association has been reported to result in yearly soil nitrogen increases of between 10 and 148 kg N ha^{-1} in West African savanna (Moore 1963, Jones and Wild 1975).

Interest in savanna also involved synecological (communities and ecosystem) studies of the dominant vegetation formations. Vegetation on quartizite ridges and plinthite extrusions in the Nigerian Guinea zone are almost exclusively dominated by the Caesalpinioid trees Isoberlinia doka and I. tomentosa which form extensive woodlands. Ubom & Isichei (1995, 1998) studied the species composition and structure of these woodlands as well as the soil factors that affect woody species distribution and abundance using multivariate techniques. Ordinations revealed that the sizes of the plants were related to the levels of silt, manganese and aluminium in the soil. Forty-two tree and shrub species were found in such woodlands. The trees attained girths of nearly 60 cm and thus have economic value as timber and serve as refuge for wildlife.

One important phenomenon that determines plant distribution and abundance is competition. Competition, in ecological terms is the utilisation of shared resources in short supply by two or more species (Grace & Tilman 1990). We investigated the competitive relationship and coexistence of the annual herbaceous legume, Tephrosia bracteolata and the perennial grass, Andropogon tectorum on the slopes of Hill I, Obafemi Awolowo University (Isichei & Awodoyin 1990, Awodoyin et al. 2000). These two plants have synchronous phenologies, are both highly palatable to livestock and are positively associated in the field so we were interested in their coexistence since competition with perennial grasses had been identified as a major deterrent to establishing introduced legumes such as Stylosanthes in pastures (Mohamed Saleem & von Kaufman 1986). The two species performed better when grown together than when each was grown alone in a replacement series, pot competition experiment. This indicates that competition between individuals of the same species was more intense than competition between individuals of different species. The fact that Tephrosia was nodulated and could therefore be a source of nitrogen for the grass may account for the positive association observed between it and Andropogon.

3.0 Work on Nutrient Cycling

3.1 The Nitrogen Cycle In Savanna

In the knowledge that the chemical elements required by plants for their metabolic processes are finite, there has been great interest in how these nutrients circulate between living organisms and between them and the non-living parts of the ecosystem, that is, in biogeochemical cycles. To the typical life scientist, nutrient cycling is of central importance because the well being of the individual, community and whole ecosystems depend on it. The cycles may be described in terms of the quantities of the nutrients in ecosystem components (pools) and the rates of movement from one component to the other, or flux rates.

Water is universally recognised as the main factor limiting vegetation production in Nigeria savanna. Mineral nutrients are most important next to water. Of these nutrients, nitrogen has been recognised to be the most often limiting (Hardy & Havelka 1975, Jones and Wild 1975, p.84). Nitrogen is a major constituent of proteins (nitrogen amount multiplied by 6.25 gives the approximate amount of protein) and I chose to study its cycling because in the 1970's the problem of protein shortage was topical. The importance of this element stimulated extensive research on how plants fix it (reduce it to ammonia) and international conferences on biological nitrogen fixation were held annually in different parts of the world in the 1970s and 1980s. For effective management of savanna, therefore, the nutrient structure especially nitrogen cycling pathways must be known.

My study of nitrogen cycling looked into its inputs, cycling within, and losses from the savanna ecosystem. The aim was to determine the overall balance of nitrogen for the ecosystem and the implications for vegetation and the general environment. Knowledge of savanna vegetation structure and function, already discussed, was an important pre-requisite for such a study.

Nitrogen cycling can be assumed to begin with biological fixation from the atmospheric pool where the gas forms 78% of the air. Bacteria and cyanobacteria (blue-green algae) have the capability to fix atmospheric nitrogen as compounds that are eventually converted to proteins. Some cyanobacteria occur on the surface of soils as crusts that are masses of algal filaments in the Nigerian savanna. The genus Scytonema, a nitrogen fixer was dominant in all the crust samples collected. Using the acetylene reduction assay at the laboratory of Prof. W.D.P. Stewart in Scotland, we observed that the dry crust samples fixed atmospheric nitrogen 24 hours after re-wetting. This nitrogen fixing ability was affected by hydrogen ion concentration, temperature, light and moisture. By our estimates, based on these crusts covering 30% of the soil surface and being active for about 120 days in the year, nitrogen amounts of between 3 and 9 kg ha^{-1} per year could be fixed, enough to replace part of the amount lost through annual savanna fires (Stewart et al. 1977, Isichei 1980).

In addition to nitrogen fixation, these cyanobacteria could play major roles in the physical improvement and protection of arid soils. Their primary biomass production has found use in food, secondary production and as organic fertilizers in rice paddies, attributes now very much enhanced by biotechnology (Borowitzka and Borowitzka 1988). One example of the use of cyanobacteria as food comes from the Kanem people of Chad who have been using Spirulina platensis as food for ages. Perhaps the modern practice of producing protein-rich foods for athletes (given the commercial name of Spirulina!) must have been borrowed from the Kanem people. I was invited by a group in the United States (Isichei 1990) to review the roles of algae and cyanobacteria in arid lands. We were later invited to discuss the use of algae in industry, agriculture and environmental conservation in Nigeria (Isichei & Okusami 1993). We observed that even the worldwide, ancient applications of algal culture especially in the food industry were yet to be put to use in Nigeria in spite of algal abundance.

The pattern of nitrogen cycling within vegetation was studied by determining the stock of the nutrient in plants. We observed that the nitrogen content of savanna herbaceous production was low. This is related to the low nitrogen content of the soils. We also observed that the nitrogen content of the herbaceous plants decreases northwards (Isichei 1982, 1983), just like the pattern reported for soil organic matter. Furthermore, without exception, there is a well-marked seasonality in nitrogen concentration in grasses with the highest concentration at the beginning of the growing season.

Of particular interest is the fact that rhizomes and parts of grasses below ground have their highest concentrations in the dry season. This is due to the translocation of this vital element from the aboveground to the belowground parts as the grass plant matures and the dry season approaches. We made similar observations with laboratory-grown grasses, Andropogon tectorum and Schizachyrium sanguineum (Oke & Isichei 1990). We also observed that in the same locality some species are better accumulators of nitrogen than others. Andrpogon species and Beckeropsis uniseta were the best accumulators of nitrogen in the wild. Plant litter is an important means of nutrient cycling and in the savanna litter falls late in the dry season, after the annual fires, an indication that most of the litter will naturally decompose and re-cycle the nutrients contained in them instead of being burned off. There is variation in nitrogen concentration in leaf and wood litter from site to site but not from season to season (Isichei 1982).

We used one of the three inselbergs located within the built-up area of the Obafemi Awolowo University estate to gain further insights into nutrient cycling in vegetation systems. The typical inselberg surface is usually a mosaic of 'bare' rock patches and vegetation mats, both of varying sizes and shapes. The 'bare' patches provide microhabitats which are colonised by lichens and cyanobacteria. The vegetation mats, colonised by ephemerals and drought-enduring perennial plants behave like true islands by the nature of their species-area relationships. We used the inselberg mats to study the cycling of nitrogen, phosphorus and potassium in soil and vegetation by carrying out analyses through the annual cycle in March, May, July and September (Muoghalu & Isichei 1989). Concentrations of nitrogen and phosphorus in the above ground plant materials were highest in May while the highest concentration of potassium was observed in July. For roots and other underground parts, nitrogen concentration increased continually, phosphorus concentration showed an increase for sometime and then dropped while potassium started low and later increased. Nitrogen concentration in the mat soil increased throughout the season, phosphorus fluctuated while potassium remained more or less constant.

These results obtained from the mat microcosms could be used to explain in a general way, observed trends in plant-soil systems. First is the indication clearly demonstrated that the level of nutrients in plants is related and at times correlated with the levels in the soil. We also observed a plant: soil nitrogen content ratio of between 1:20 and 1:22. This shows a nitrogen mineralisation rate of about 4%, a figure identical with the 4% rate in savanna soils (Jones & Wild 1975) with which inselberg surface communities share some characteristics (Adejuwon 1971). Concentration of potassium in the aboveground vegetation was 7.27% of exchangeable ('absorbable') potassium in the soil as compared to 42.02% in the belowground vegetation, a clear indication of leaching of potassium from plants by rainfall, most of the compounds of the element being soluble in water.

The vegetation immediately adjacent to inselbergs is usually lusher than in the surrounding areas, giving an impression that there is some improvement of the soil environment around the inselbergs. Hambler (1964) attributes the lush vegetation to an improved soil water regime but other evidence from the literature suggest that the soils might contain more than average levels of nutrients. We carried out a study involving mathematical modelling here in Ife and at Imperial College, London to evaluate the nutrient contribution of inselbergs and their associated organisms to their immediate surroundings through drainage (Isichei et al. 1990). Nitrogen and potassium were the nutrients considered because rock surface microorganisms (lichens) could fix nitrogen while potassium is a significant component of inselberg rocks. The amounts of these nutrients in incident rainfall and in water draining through inselberg surfaces were measured over the 1985 rainy season. The model predicted that an inselberg of 100 m diameter and half covered by bare patches and half covered by vegetation mats would discharge, per square metre to its immediate surroundings, 16 times more potassium and 13 times more total nitrogen than is present in incident rainfall. The enrichment of the surrounding soils with nutrients and water thus accounts for the more lush vegetation observed around inselberg surroundings and may explain why crops flourish near inselbergs. Due to their small sizes and ease of manipulation, we also used the inselberg surface mats to study vegetation succession and other ecological phenomena. We observed that the seasonal numbers of species and individuals as well as the species abundance patterns were similar to what obtains in long-term vegetation succession (Isichei & Longe 1984).

4.0 Pollution and Climate-Change Related Research

Most of the nitrogen held in vegetation biomass are lost through volatilisation during biomass burning that occurs annually in savanna. Through measurements of nitrogen contents of soil, above and belowground parts of plants and using figures from the literature on inputs from rainfall and biological fixation, we were able to determine the stocks and flows of nitrogen in savanna woodland and open savanna (Isichei 1995). The bulk of the nitrogen is in the soil with the woody biomass containing about one-sixth of the soil amount and the herbaceous vegetation much less.

Under conditions of increased temperature and CO_2 levels, two aspects of climate change, interactions between carbon and nitrogen cycles have ramifications on a diversity of ecosystem properties (Rastetter et al. 1992). With the construction of the nitrogen stocks in the savanna ecosystem components, we were in a position to postulate on the possible effects of increased carbon dioxide levels on the savanna ecosystem. We concluded that increased CO_2 levels would favour trees and forbs as against grasses, grasses being able to carry out photosynthesis at relatively low levels of carbon dioxide while trees and forbs perform best under elevated CO_2 levels, other necessary conditions being optimal. The amount of nitrogen in the vegetation and soil should increase, a result of higher rate of nitrogen fixation by forbs under increased carbon dioxide levels (Kristiansen 1993). Elevated CO_2 levels will also increase the levels of nitrogen emissions from savanna fires, further exacerbating the global warming problem.

One important environmental consequence of the annual burning of savanna is the volatilisation of nitrogen contained in the vegetation. We obtained estimates of between 12 and 15 kg nitrogen ha^{-1} per year loss from burning in moist and sub-humid savanna sites (Isichei & Sanford 1980). In addition to burning during wild fires and as part of the shifting cultivation and slash-and-burn agriculture, wood is also used as fuel in most localities. The increased concern about climate change/global warming made it necessary that the ecological, atmospheric and climatic implications of burning be examined. We assessed the ecological effects of a severe ground fire that occurred in our Biological Gardens in January 1983 (Isichei et al 1986; Kayode & Isichei 1998) and observed that the fire affected small trees especially and that some species were more sensitive than others. Trees characteristic of human disturbances and early to mid-successional stages such as wild cassava, Manihot glaziovii showed massive increase in their numbers and proliferated to the detriment of trees associated with mature rainforest which were eliminated.

Some compounds of carbon, nitrogen and sulphur emitted during vegetation fires have been implicated in global warming and environmental pollution. Carbon dioxide is a commonly known global warming gas and if its global warming potential is taken as 1, that of methane, CH_4 is 22 while nitrous oxide, N_2O has a warming potential of 270. In our study of the atmospheric and climatic implications of burning, we estimated the amounts of these elements emitted from burning plant litter, herbaceous vegetation, consumption of 80 million cubic metres of firewood annually and incineration of wastes from 11 million m^3 of timber in Nigeria (Akeredolu & Isichei 1991; Akeredolu et al. 1995). We estimated that about 54 Tg (10^{12}g) CO_2 and 2 x 10^9

kg N yr^{-1} were emitted from forest and savanna fires annually in Nigeria while the figure for sulphur amounted to about 29 x 10^6 kg per year. We used molar emission ratios to also estimate the emissions of other chemical species derivable from carbon and nitrogen. These include: CO_2, CO, CH_4, non-methane hydrocarbons, carbonyl sulphide, oxides of nitrogen including nitrous oxide, ammonia and hydrogen cyanide. Most of these are produced in small quantities but as pointed out above, their global warming effects could be tremendous especially when some of them have long life spans in the atmosphere. So it is apparent, Mr Vice-Chancellor, that when nutrients are cycled in ecosystems, some of them that go up do not really come down immediately. They stay up there, accumulate and may cause harm.

The principles of the greenhouse effect have been known for well over a century and the United Nations Framework Convention on Climate Change (UNFCCC) was initiated at the 1992 Rio Summit. The ultimate objective of the UNFCCC is to achieve stabilisation of greenhouse gas (GHG) concentrations in the atmosphere within a time frame and at a level that would prevent dangerous anthropogenic interference with the climate system. Article 4 of the UNFCCC mandates parties to develop, periodically update and publish national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases (excluding Chlorofluorocarbons), using comparable methodologies.

Between 29 May and 2 June 1995, a workshop sponsored by the United States Country Studies Program and the United Nations Environment Programme was held near Johannesburg, South Africa to address GHG emission inventory development and emission mitigation in the forestry, land use change and agriculture sectors in Africa. I was opportuned to have led a team mandated to compile GHG emission inventory for these sectors in Nigeria. I also chaired one of the three Working Groups and co-edited the proceedings (Fitzgerald et al, 1995). Our estimates show that 145 gigagram, Gg

(10^9g, 1 billion grams) methane, 3831 Gg carbon monoxide, 2 Gg nitrous oxide and 49 Gg oxides of nitrogen are released from savanna burning in Nigeria. An additional 300 Gg methane, 4375 Gg CO, 2.4 Gg N_2O and 24 Gg NOx are estimated to be released from the burning of cleared forests and woodlands (Isichei et al, 1995).

4.1 Work on the Effects of Gas Flares on Vegetation

Mr. Vice-Chancellor, Sir, it is remarkable that my very first scientific paper addressed environmental pollution (Isichei & Sanford 1976). In the early 1970's when Nigeria had been producing crude oil for just about two decades, concern was mounting on the impacts of gas flaring on the environment. Natural gas associated with crude oil is burnt off from stacks after separation of the gas from water and crude, producing flares that burn continuously as long as the oil well is producing. We carried out a study on the effects of these gas flares on vegetation using ten stacks in the Port Harcourt area. We observed that air, soil, and leaf temperatures increased and relative humidity of the air decreased within 110 m of the flare stacks. Leaf chlorophyll content and internode length of the common plants decreased near the flares. Plant flowering was suppressed. Some plants that could withstand fairly high temperatures grew rather poorly near the flares.

It is noteworthy that two and half decades after the study of the effects of flaring were reported, the flares are still glowing in Nigerian oil fields. And as more environmental knowledge accumulates new concerns are being expressed. For example, Nigerian natural gas has some quantities of sulphur and nitrogen which are precursors of acidifying compounds and global warming gases. It is comforting, however, that a date has been set when all flaring must stop and that some liquefied natural gas projects are functional.

5.0 Studies in Biodiversity Conservation

Biodiversity, short-form for biological diversity is the full range of variety and variability within and among living organisms, their associations and habitat-oriented ecological complexes. The term encompasses ecosystem, species, and landscape as well as intraspecific (genetic) levels of diversity.

Biological processes interact strongly with physical and chemical processes to create the planetary environment, but biodiversity plays a much stronger role than previously thought in keeping earth's environment within habitable limits (IGBP 2001). Nigeria was one of the over 100 countries that signed the Convention on Biological Diversity (CBD) at the UN Conference on the Environment and Development (UNCED) in Rio de Janeiro, in June 1992. The three main objectives of the CBD are: conservation of biological diversity, sustainable use of its components and fair and equitable sharing of the benefits that are gained through the use of genetic resources.

These objectives are best attained through Biosphere Reserves. A typical biosphere reserve has three zones namely: a core area where no other human activity except research and monitoring are allowed; a buffer zone which is clearly delineated and which surrounds or is contiguous with the core area; and an outer transition area or area of co-operation extending outwards which may contain a variety of human activities. The concept of biosphere reserves is part of the UNESCO's MAB Programme and it arose as a result of the general failure of past conservation efforts in forest and game reserves where entry restrictions were imposed on local people who felt estranged from their resources and tended to undermine conservation efforts.

Nigeria has one biosphere reserve, the Omo Biosphere Reserve in Ogun State which is one of the global total of 408 in 94 countries as at May 2002. I was commissioned by UNESCO in 1995 to report on the current status and utilization of biological resources in the reserve and make suggestions on how the reserve could be sustainably managed. I recommended that alternative resource utilization strategies be developed so as to reduce pressure on the reserve's timber resources (Isichei 1995a). Non-timber forestry activities that could be economical and sustainable include bee-keeping, snail-raising, domestication of some rodents and growing of horticultural plants. Some identified non-timber forest products that could be extracted include the sweetener berries which have protein-based sweeteners instead of sugar – Synsepalum dulcificum (miracle berry), Thaumatococcus danielli (miraculous berry) and Dioscoreophyllum cumminsii (serendipity berry). The study of the ecological profiles of these plants is in progress so that their successful domestication can be assured (Ahuama, work in progress). I also contributed to the compendium of methodologies for biodiversity assessment and monitoring published by the Nigerian MAB national committee (Isichei 1996) and have assessed the impacts of land use on biodiversity in the savanna, also under the MAB programme (Isichei 1995b).

In our belief that conservation should be practised first at home we took interest in the remnant forests of our campus. Seventeen sample plots enumerated in the Biological Gardens and on the slopes of Hill I showed that trees ≤30 cm girth at breast height were the most numerous compared with timber-size trees of >60 cm girth (Chukwuka & Isichei 1997, Oke & Isichei 1997). Big trees ≥120 cm, especially Brachystegia eurycoma were found on steep slopes unsuitable for farming. Of interest to us were uncommon species that were present as single individuals and in just one plot. There were 28 such species and the list included such commercial timber species as Khaya grandifoliola, Hylodendron gabunense, Canarium schweinfurthii as well as the rare species, Monodora myristica and Pierrodendron africanum. The fact that such species were seen at all gives some hope that the prohibition of farming in some areas coupled with the reforestation project embarked upon by the Obafemi Awolowo University authorities will restore these sites to mature secondary forest especially as some of their seeds may still be found in the soil seed bank (Oke & Isichei 1997; Oladipo, work in progress). A full enumeration of woody plants in the University estate that would guide proper planning is underway (Onwumere, work in progress).

The benefits of forest conservation can be assessed from the results of our study on the relationship between vegetation physiognomy and indices of soil erosion in the University Estate (Oke et al. 1999, 1999a). Young plots without shade and with little vegetation cover produced the highest values of runoff and sediment followed distantly by natural forest plots with moderate canopy openings while disturbed, thickety plots with close to 100% cover had the lowest runoff and sediment yield. The fate of Opa Lake without vegetation along its watershed and on its banks can be inferred from the results of this study.

As human interference with natural vegetation intensifies and there is degradation, weeds dominate the landscape. Weeds have been defined as plants that form populations in habitats cultivated, markedly disturbed or occupied by man and potentially depress or displace the resident plant populations which are deliberately cultivated or are of ecological and/or aesthetic interest (Navas 1991). We have investigated the conditions under which more weed invasions occur in agricultural systems. We compared air-borne weed seeds (or 'seed rain') and weed seed reservoir in the soil ('soil seed bank') under different fallow cover types and varying frequency of cultivation. Farms planted with Pueraria, a creeping cover plant, and Leucaena a leguminous shrub, and left to fallow had 50% and 40% lower soil seed bank, respectively than natural bush fallow. Weed seed bank was highest in continuously cropped plots and declined with increasing fallow period (Ekeleme et al. 2000a). Weed seed rain was also significantly higher in continuously cultivated plots across all fallow cover types than in plots with fallow periods. Seed rain was lowest in plots cultivated after a Pueraria fallow followed by that after Leucaena and then natural bush (Ekeleme et al. 2000).

6.0 Recommendations

Mr. Vice-Chancellor, Sir, in the course of my work presented here, I have had the opportunity of participating in scientific meetings, conferences, symposia and workshops in seventeen countries in Africa, Asia, Europe and The Americas. I have also supervised 6 Master's and 5 Ph.D theses in ecology and had the unique experience of being part of the team that carried out the botanical survey of the Federal Capital Territory while it was still an unopened jungle. I have led survey teams, participated in over thirty environmental consultancies in all parts of Nigeria and beyond and was a proud co-author of Nigeria's best selling book on our environment (NEST 1991). Though severely constrained by lack of resources, we are still very involved in savanna vegetation studies and have been collaborating with other stakeholders in forest conservation efforts. Based on these experiences, I feel obliged to make suggestions on how the Nigerian environment could be sustainably managed and hereby wish to make the following recommendations:

1. Humans have survived through the ages by extracting resources required for life from nature. Low intensity extractions ensured that natural balance was maintained and that life support systems continued to persist. But human activities are now threatening the very basis of human existence making it mandatory that we apply the principles of homeostasis, or balance in nature. This can be achieved through the preservation of natural processes in ecosystems so that functional (physiological), historical and evolutionary limits are not exceeded. This is the basis on which the principle of sustainable development rests and should guide our economic activities.

2. Scientific discoveries are continuing but as man intensifies efforts to understand nature, new discoveries become elusive and difficult requiring greater inputs in the form of efforts, human and material resources etc. Most third world governments erroneously await

targeted breakthroughs and new discoveries to solve their socio-economic problems from scientists but these are often not forthcoming for various reasons. In the process, the principle of using science to transform and modernise age-long practices gets ignored. It is my belief that the strength of Nigeria and other developing countries in the southern hemisphere lies in their natural resources especially biodiversity and these should form the bedrock of economic growth. Maximizing these resources will involve digging into Nigerian local science and sifting out the information that could indeed transform our lives.

3. The agony of Nigerians associated with transhumance could be considerably reduced if managed and properly enriched grazing reserves are established along transhumance routes used by nomadic herdsmen in their search for pasture. Fatal conflicts between herdsmen and farmers are now frequent and they can be avoided if the available information on grass production, nutrient accumulation and cycling and grass coexistence with herbaceous legumes are harnessed. This is indeed an important aspect of the use of biodiversity.

4. Biodiversity conservation has been adequately emphasised but the point has to be made that the practice needs to be localised to be effective. For example, Obafemi Awolowo University should establish a reserve within its estate. Every Nigerian village and hamlet should be encouraged to do the same. For bigger reserves, the biosphere reserve concept should be encouraged because local people get involved as stakeholders. Vegetation conservation is particularly important in the preservation of watersheds and amelioration of climatic extremes. The looming shortage of water in Nigeria and other tropical countries makes watershed protection by vegetation an immediate priority.

5. Industrialisation may pollute the environment but it also creates employment. One important implication of industrialisation is the

reduction of the numbers of people directly dependent on the land for their living. Biodiversity conservation is best achieved when there is a reduction in pressure on the land. Employment-generating industries should be encouraged to reduce stress on land resources.

Mr. Vice-Chancellor, Sir, distinguished ladies and gentlemen, I thank you for your attention.

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