ECOLOGICAL DISASTERS IN NIGERIA: DROUGHT AND DESERTIFICATION

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RESPONSES OF SAVANNAS TO STRESS AND DISTURBANCE: THE BEGINNING OF DESERTIFICATION

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ABSTRACT

Stress and disturbance may be natural or caused by man but usually from a combination of extreme values of environmental variables. Their prevalence in the Nigerian Savanna and effect on stability and resilience and, in a sense, desertification has been examined.

The stress and disturbance identified include drought, wood cutting and land cultivation, herbivory, annual burning. It is concluded that annual burning does not constitute a destabilizing factor as such since it could be regarded as regular annual phenomenon to which the plant species are adapted, but mainly as a force that accentuates the effects of other destabilizing influences created through improper land use. Effort has been made to place different savanna systems into ranges of stability and resilience. Suggestions have been made for improving grazing system, controlling indiscriminate wood-cutting and ecologically sensitive farming systems. Drought control is distinctly impossible except through irrigation which is not yet extensively practised.

Land use and vegetation mapping must be done on a local scale permitting the application of management tools to delineated land units. Parameters of description, evaluation and prediction vary according to land use; intensive or extensive, transformational or conservational. A scheme has been proposed for assessing the phenomena of stress, disturbance/perturbation and their relationship to stability and resilience in the savanna.

Stress and disturbance and their relationship to stability and resilience

Savanna occupies well over 70% of the land area of Nigeria and most of it is sub-humid to semi-arid and suitable for agriculture. The ecologic zones range from the moist Derived Savanna (or mosaic of secondary lowland rainforest and secondary grassland (White, 1983) in the south to the semi-arid sahel zone in the north. The sahel zone borders the southern fringes of the Sahara desert and is now, with the Sudan zone just south if it, subject to desertification pressure. There is widespread concern that the potentials of the savanna may not be realised in the presence of this pressure and that the civilization that has built up through the ages in the Sudan and Sahel zones may be threatened.

Desertification is usually conceived of as laying waste of the land associated with diminishing surface water and increasingly sparse vegetation. The usefulness of such land to man and beast is reduced because of decreased plant production (Grove, 1973). Desertification is often attributed to drought stress and other stresses generated by man. Ecosystems are most of the time subjected to stresses of various kinds and if they are not excessive the ecosystems revert to their 'normal' states. Such is the case with seasonal drought stress and other periodic stresses in the savanna regions. So there must be certain intensities of stress from which dry savannas do not recover resulting in a change of configuration bringing about desertification. The first task is to identify such stresses and the intensities of application/prevalence that may lead to desertification.

Stress has been defined as a perturbation that is applied to a system by a stressor which is foreign to that system or which is natural to it but in the instance concerned, is applied at an excessive level (Barret, 1981).

Stress is further viewed as any force that pushes the functioning of a critical subsystem beyond its ability to restore homeostasis (Barret, 1981). The effects of stress are dramatically observed after certain thresholds of tolerance are exceeded, and beyond these thresholds any recovery is problematical or, at least, difficult (Auerbach, 1981). Under stress situations system energy expenditure is increased or potential energy decreased (Ivanovici and Wiebe, 1981) implying increased entropy disorder).

In dealing with the stress effects on total ecosystems, it is necessary to recognize that the impact on the ecosystem will depend on the magnitude of the perturbation (Auerbach, 1981). The total area subjected to stress also has to be taken into consideration as well as whether the stress is very highly localized or spread over a very wide area. Methods of assessments of these two types of stress vary since stress spread over a wide area is not usually easily noticeable and its effect cannot be measured unless a detailed knowledge of the ecosystem functioning is available.

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Frost *et al* (1985) define disturbance as an aperiodic event, such as flood, a severe storm, a prolonged drought, excessive herbivory, or activities such as bush clearing and cultivation, that partially or completely disrupts the structure and functioning of a system, either directly by damaging or causing the mortality of individuals, or indirectly, through altering the physical environment. In doing so, Forst *et al* further state, opportunities are created for new individuals of the same or different species to become established. Disturbance may result from one, but more often a combination of extreme values of environmental variables. Increasingly, they went on, disturbances are the result of human activities.

Thus, the difference between stress and disturbance, apart from the direct human factor involved in disturbance, is a matter of intensity.

Stress and disturbance in ecosystems thus imply changes. Ecosystems that do not change in the presence of stresses and/or disturbances are regarded as stable. Stability is to be viewed on cyclical basis thus eliminating changes that may arise as a result of regular seasonal stresses. The phenomenom of stability does not apply in comparing wet season savanna ecosystem and the dry season one. Rather, when a savanna ecosystem remains the same from year to year it is said to be stable. Such an ecosystem returns to its original state after a disturbance or maintains its equilibrium. This stability can be viewed in two ways — structural stability when the species composition remains more or less the same and functional stability when ecosystem characteristics such as biomass production and nutrient cycling rates remain unchanged.

When, however, an ecosystem is subjected to stress and disturbances and is able to persist such an ecosystem is said to be resilient. An ecosystem may persist in the presence of perturbations and still fluctuate very badly, that is, have low stability. The resilience view of communities is boundary oriented and is concerned with how much disturbance the community can absorb before it shifts into a different configuration (Krebs, 1981). This means that an ecosystem can differ by varying degrees from its original state and still be regarded as resilient. Krebs, (1981) clarifies that the resiliency of a system is measured by its coefficient of extinction, that is, its probability of changing to an entirely new configuration. The resilience of an ecosystem depends on the source of disturbance and ecosystems are more resilient to some perturbations than others.

For these phenomena to be useful there have to be ways of assessing them in ecosystems. Ero (1985), has outlined a useful scheme for assessing savanna ecosystems under disturbance. The scheme includes vegetational, soil and climatic variables. His vegetational scheme includes such attributes as (i) species abundance distribution, (ii) size-class distribution of woody elements, (iii) species diversity and evenness, (iv) Markovian prediction of canopy changes and (v) canopy cover. For soils the attributes are (i) clay, sand and silt concentrations, (ii) organic carbon concentration and

(ii) topography. His climatic scheme includes rainfall amount, distribution and reliability. Ero's scheme is based on earlier works by Conrad (1977), Bazzaz (1975) and Sanford *et al.* (1982a) and the thesis is that log-normal species abundance distribution is more likely to be associated with stability then are geometric series and skewed lognormal distributions. Ero further asserts that a constant girth size distribution with enough stems in the lowest size class to ensure regeneration is indicative of stability of the vegetation and is associated with maturity. Species evenness may accompany stability and systems that are stable are expected to have the least weighted relative change over time in canopy species composition. In terms of canopy cover it is expected that savanna formations with a high percentage cover will be more efficient in dry matter production and offering protection to the soil. Soil stability will be ensured by prevention of particle removal (erosion), prevention of loss of water and soluble nutrients (run-off, leaching) and maintenance of an adequate sink of organic matter. Organic matter concentration is a measure of humus content which is essential for water holding capacity, cation exchange capacity and maintenance of soil physical structure. Humus (derived from organic matter) is the 'store house' for nitrogen, phosphorus and sulphur. Clay content is related to cation exchange capacity and water holding capacity. It may, however, be associated with compaction and run-off.

Soil topography tends to accelerate destabilizing conditions such as run-off, erosion and loss of essential nutrients in the soil. Land types with slopes in excess of 3% have been found to be unsuitable for mechanical cultivation.

In Table 1 we attempt to place different savanna systems into ranges of stability and resilience based on the attributes enumerated above. The Table also intends to clarify the difference between stability and resilience and the relationship between these phenomena and management.

TABLE 1
Relative stability and resilience of natural and managed savanna ecosystems

System	*Stability*	*Resilience*
Open grasslands and sparse tree Savanna	High	High
Woodland	Very high	Moderate
Forest and Game reserve	High	Moderate to low
Improved rangeland	Moderate to low	Moderate to low
Small-scale shifting farm	Moderate to low	Moderate
Ranching	Low	Very low
Large scale mechanized agriculture	Very low	Very low

Stress and disturbances prevalent in Nigeria savanna

Having put the concept of stress, stability and resilience and the ways of assessing them in perspective we may now explore the application of those phenomena in the Nigerian savanna ecosystems. First, the usual stresses prevalent in the savanna ecosystem will be discussed and the ways these stresses affect stability and resilience, and in a sense desertification of the savanna, will be examined. The management practices that bring about this stress will also be identified with a view of making recommendations for better ecosystem management.

Drought stress

Prolonged drought stress, as opposed to the seasonal one, is usually cited as the cause of desertification in the extreme savanna regions. The claim is usually made that rainfall failure results in desertifcation. There is no doubt that drought stress is destabilizing because under it structural (compositional) stability is diminished arising from loss of several plant species. But it has now been established (Grove, 1973) that drought in arid and semi-arid climates has been a periodic event throughout history. Periods of rainfall failure are interposed with years of abundant rainfall. What is suspected is that this alternation has some pattern which is yet to be established. Efforts are continuing so that periods of drought and abundant rainfall could be predicted with accuracy. Drought, however, only accentuates instability created through other management practices. Intervening wet years between droughts are characterized by over-stocking of fragile grazing lands accompanied by increased human population leading to loss of resilience resulting from over-grazing and soil deterioration. Were the human-generated destablizing factors absent, we feel that dry savannas will return to their original states after the prolonged drought stress because most of the plant species are drought resistant, that is, the system has low natural stability but high resilience. Thus, it may be fruitful to focus attention on those management practices and interactions between man and the savanna ecosystem that bring about loss of stability and resilience and, therefore, desertification.

But we, however, do not lose sight of the effects of devegetation on future climate. Devegetation results in increased reflection of solar-radiation from the surface (albedo) which in turn results in increased temperatures and lower rainfall. It is also claimed that the rising load of dust accompanying drought contributes to decreased rainfall (Eckholm and Brown, 1977). Even when rain does fall the ability of devegetated land to use it is reduced resulting in run-off. The underground water store is affected and incidence of floods increased. This process continues with structural destruction of the soil and loss of organic matter resulting in hardier species and change of configuration — loss of resilience. The crucial thing is just how much drought can bring about loss of plant cover, without additional disturbances imposed by man through his management practices and his interactions with the savanna. The management practices and interactions include grazing by livestock, cultivation and woodcutting and burning. It is only rarely that one of these practices acts in isolation to bring about desertification. The stresses often act together.

Grazing by livestock and wildlife.

Pastoralism has been a thriving occupation in extreme savanna regions that border deserts. The vegetation of the drier savannas are richer in nutrients than the wetter zones and are free from tse-tse fly infestation hence most of the animal rearing in West Africa are concentrated in the Sudan and Sahel zones. There are an estimated 8 million to 11 million cattle, 22 to 27 million goats and 7-21 million sheep in Nigeria (Milligan *et al* 1982), most of which are in the savanna regions and managed under the traditional nomadic or transhumance system. In Yankari Game Reserve and Kainji Lake National Park wildlife densities of 1.67 and 6.12 animals per km^2 respectively were estimated by Milligan *et al.* Generally in West Africa density of wildlife even in reserves is very low compared to East Africa (Ayeni, 1982). The same applies to small rodents (Anadu, 1982).

According to Frost *et al.* (1985) "the effects of herbivory depend on (i) the plant parts removed, (ii) the intensity, frequency and season of use; (iii) the growth stage of the plant; (iv) soil type and moisture conditions, which affect water and nutrient availability and thereby the plants' capacity to re-grow; and (v) the history of the plant, particularly the time since a previous occurrence of defoliation by other herbivores or fire. Since recovery from defoliation is not instantaneous, future events such as heavy rainfall, drought, or further defoliation by herbivores and fire can also influence the eventual outcome." Under normal moisture conditions defoliation contributes initially to lower level of water use and thereby to conservation of soil moisture.

Direct negative effects of animals on soil moisture regimes result from compaction of the surface soil and the breakdown of soil aggregates through trampling. This increases bulk density and reduces infiltration rates and water holding capacity of the soil. Run-off and erosion increase. Indirect negative effects are indicated through the impact of animals on vegetation. Thus, the presence of animals could lead to increased soil surface temperatures, higher evaporation rates and, ultimately, to the structural collapse and deflation of the soil surface. Impermeable surface seals are often formed, resulting in a cycle of degradation, reduced infiltration rates, increased run-off, lower seedling establishments, less plant production and further exposure of the soil surface (Kelly and Walker, 1976). While herbivory affects plants directly through defoliation, its major effect is on the soil which, when physically degraded becomes irreversibly incaple of supporting plant growth.

Of considerable importance are termites. Various grass and wood termites are abundant (Ohiagu, 1982). The population of the most abundant species could reach 732^{-2} in mounds that shelter grass and litter feeding termites. Ohiagu further reports that mound density could reach 232 ha^{-1}, in the southern Guinea zone (where it is highest) and that termites consumed up to 3% of the total net primary production. The litter eating termites consume about 35% of the annual litter production.

Wood cutting and cultivation

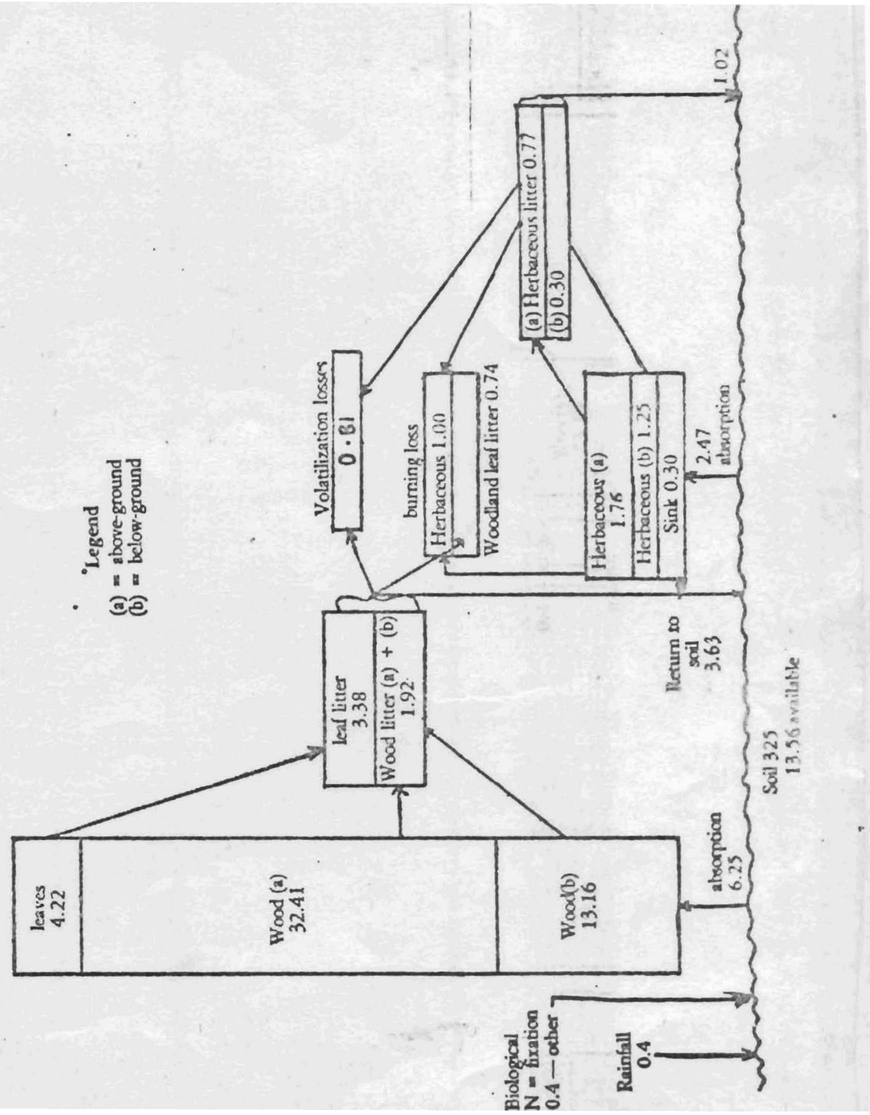
The greatest threat to savanna stability to-day is wood-cutting especially for fuel. It is estimated that in most poor countries 90% of the people depend on firewood as their major source of fuel and each year the average user burns anywhere from a fifth of a ton (in parts of India) to well over a ton (in parts of Africa and Southeast Asia), (Eckholm, 1980). It is generally held that savanna ecosystems in which woody plants comprise a high proportion of total plant biomass are more stable under stress than grass dominated systems (Frost et al 1985). Woodlands are more stable because they have conservative growth patterns and slow turnover of organic matter and nutrients. They also have large root: shoot ratios limiting the amount of material which can be consumed by herbivores and fire and easily resprout after disturbance. A reduction in the woody components of savannas, therefore, leads to a decline in their relative stability (Ero, 1985).

The inhabitants of Kano remove 75,000 tonnes of firewood every year from the surrounding woodlands as of 1965 when the population was 300,000 (Mortimore and Wilson, 1965). The rate of removal now with a higher population plus that removed around other large cities in the Sudan Zone (Maiduguri and Sokoto for example), can only be imagined.

Perhaps, the destabilizing influence of tree removal could be appreciated more if the amount of nutrients held in the woody component is considered. Figure 1 represents the nitrogen storage in the soil and various vegetation compartments in a woodland savanna ecosystem. Most of the nutrients are in the soil and then in the woody biomass. Relatively little quantities are held in the herbaceous biomass and litter. When woods are cut a great proportion of the nutrient content of the ecosystem will be lost and the nutrient cycling process will be disrupted resulting in loss of stability. Exposure of soil surface after woodcutting will also result in more run-off and soil surface compaction leading to deterioration. It has also been shown that the presence of trees in Guinea savanna result in more grass production (Sanford *et al,* 1982b), that in East Africa the more nutritious grasses grow under shade (Pratt and Gwynne, 1977) and that there is more nitrogen and organic matter around trees in semi-arid savanna of Senegal (Bernhard-Reversat, 1982). Generally, the horizontally extensive root systems of trees allow them to concentrate nutrients from a wide area. They also have deep root systems enabling them to extract nutrients at depths in the soil and so counter the effects of leaching (Kellman, 1979).

FIGURE 1

Compartmental storages of nitrogen in various vegetation and soil compartments in woodland Guinea savanna in Nigeria. Most of the nitrogen in the above ground compartments is in the woody vegetation. Adapted.



Land clearing and wood cutting usually accompany cultivation in the savanna zones. Cultivation, apart from affecting above-ground vegetation also affects the soil. This means soil exposure with the usual effects. At Afaka in the N. Guinea zone Jenkin (1964) found that cultivation stimulates rapid mineralization of nitrogen, particularly by improved aeration conditions, resulting in a higher oxidation rate and partially due to increased microbial activity. Jenkin also pointed out that the capacity of microflora to mineralize and utilize amino acids is greatly affected by the method of cultivation. Subsoiling to a depth of 30-50 cm stimulates ammonifying bacteria while inverting the soil promotes nitrifiers.

Savanna burning has raised more public comment in Nigeria than any other management practice. Some state governments even promulgated edicts banning burning because of its supposed deleterous effects. Sanford (1982) has discussed savannas burning and concluded that most of the notions on burning do not have scientific data to back them up. It is true that nitrogen, sulphur and carbon are volatilized during burning. But at the time of burning most of these elements, especially nitrogen (Isichei, 1983) have been translocated to underground parts. Burning also bares the soil surface exposing it to raindrop impact, wind and sun. Fire also kills seedlings, saplings and small trees.

Burning has certain advantages. Ash from burns has fertilizing effect (Jenkin, 1964 and phosphorus availability increases after burning (Jones and Wild 1975). Dry season burns could in fact be regarded as advantageous because it leads to the resprouting of grasses and forbs and helps to maintain the tree-grass combination in the savanna. Most of the drier savanna areas prone to desertification, however, do not have enough herbaceous material for burning so that annual burning may not be an issue in desertification. We also did point out earlier that ecosystem stability involve oscillations around equilibrium and that periodic events such as annual, dry season fires contribute to these oscillations. Fire could, in the savanna, be regarded as a constant parameter in savanna management and a contributor to the oscillation.

CONCLUSIONS AND RECOMMENDATIONS

(a) The following stresses and disturbances were identified to be in operation in the Nigerian savanna: drought, woodcutting and land cultivation, herbivory and annual burning. It was concluded that annual burning does not constitute a destabilizing factor as such since it could be regarded as a regular annual phenomenon. Drought was viewed mainly as a force that accentuates the effect of other destabilizing influences particularly woodcutting, land cultivation and herbivory. The control of drought is distinctly impossible except through irrigation which as at now is not extensively practiced in Nigerian savanna.

(b) The focus has to be on woodcutting, land clearing and herbivory through pastoralism. These are destabilizing forces difficult to control

because they are very closely related to human population increase which in Nigeria today is still high.

Woodcutting in Nigerian savanna is mainly for fuel. We are tempted to go along those who can see the solution as reforestation but reforestation is usually a slow process and cannot cope with rate of wood loss. What has to be done is to find an alternative source of energy. The best source we can recommend in the short term is kerosene. It is cheap and the technology associated with its use is uncomplicated and cheap. It is only when kerosene and stoves for burning it or any other easily accessible energy source is available in our rural areas that the pressure on wood will be reduced.

(c) Land cultivation is a 'necessary' destabilizing factor but the issue is by what ways could its destabilizing influence be ameliorated? We noted the effect trees could have on nutrient cycling and on the soil itself and cultivation involves tree removal and soil exposure. Continuous cultivation leads to organic matter loss, increasing soil acidity and incipient potassium deficiency and a deficiency of some trace elements in the Sudan Zone (Heathcot, 1969). Traditional shifting agriculture permits replacement of lost nutrient and restoration of soil physical attributes. There is need to continue with this shifting system but to reduce the fallow period through careful management. Managed fallows can bring about soil restoration within a very short time resulting in a system that is intermediate between shifting agriculture and continuous cultivation. Sanchez and Salinas (1983) for example, report that fallow under *Pueria phaseoloides,* a nitrogen fixing creeper, for two years has the same restorative effect as 25 years of forest fallow. Continuous cultivation could also be undertaken using the alley-cropping system or well developed agro-forestry system (ICRAF, 1985). Better management will mean better yield per unit land area so that marginal areas do not have to be cultivated. It is estimated that between 1950 and 1980 the cultivated area in Nigeria has multiplied two and half times, pushing farms into marginal areas resulting in decreased productivity.

(d) We believe that most ecosystems can satisfy the needs of the human population in that system but what is needed is adequate planning to maximise use of resources. Ero (1985) showed from his studies in the Guinea savanna zone that within-locality variations are often greater that inter-site variations meaning that whatever planning that has to be done has to be on a micro scale. Often the necessary criteria to be used in assessing ecosystems for land use are ill-defined and too generalised to be useful on a small scale. We have listed in Table 11 the parameters that could be useful in assessment of savanna ecosystems for various uses. These uses included ranching, large scale agriculture, improved rangeland, small scale farming, forest woodland reserves and wildlife reserves. We have also indicated the scale on which assessments are to be made.

(e) Pastoralism as a destabilizing influence in the savanna operates when there is over-stocking of ranges. Animal rearers have to be educated

to attach more value to well fed and healthier stock than many but ill-fed stock. This means more Government input into education, animal health and range management.

One way of raising the quality of animials is through better range management. Grasses growing in the savanna are of very poor nutritive quality being very low in protein (Isichei 1983). One means of range improvement is through seeding grasslands with legumes which are palatable and more nutritious than grasses (Agishi 1982), Mohamed, 1984). Growing of browse plants (trees) is desirable because it creates a more stable system but trees take a long time to grow. However, the cover value of trees and their soil enrichment potential makes the use of trees a more attractive option. The autecology of indigenous savanna trees has to be studied and a promising start has been made with the study of *Piliostigma* species (Mbaekwe 1985). Other species, especially *Acacia* species, are worthy of intense study with a view of utilization for soil cover and other uses such as in wind breaks and for extraction of fibres, and non-wood products such as tannin, gum, resin and food.

TABLE 2

Summary of land uses and field parameters useful in assessment in Savanna (After Ero, 1985)

Recommended land-use		Characterising parameters	Scale of parameter
1. Ranching	i.	Topography — <3% slope	1 ha
	ii.	Soil — good depth >1m, clay>3%, sand <76%, organic carbon >1.25% at 0-15cm	¼ ha
	iii.	Vegetation: 20-30% woody cover; ground cover of perennial grass and leguminous herbs; (basic formation:) young/juvenile bushland, scattered trees or shrubs;	1 ha
	iv.	Rainfall reliability: C.V. ≤ 16%	regional data for 20 years
2. Large-scale agriculture	i.	Topography — 3% slope	¼ ha
	ii.	Soil — good depth (1m) and texture; sand ≤ 70% clay > 5%, sand/clay ratio 5-15	¼ ha
	iii.	Soil — stability — high as assessed by sand, clay analysis and topography	
	iv.	Rainfall reliability — C.V. ≤ 16%	regional data for 20 years
3. Improved "natural" rangeland		Tree size classes distribution — young/ juvenile bushland; scattered shrubs/trees to only moderate clumping	1 ha
	ii.	Woody plants density < $0.35m^{-2}$	1 ha

TABLE 2 — *continued*

Recommended land-use	*Characterising parameters*	*Scale of parameter*
	iii. Species composition to include leguminous herbs and woody plants	1 ha
	iv. Adequate grass cover	1 ha
	v. Vegetation stability/resilience high to moderate as assessed by tree size class distribution and Markovian change	1 ha
4. Small-scale farming	*i.* Topography as for ranching — <3% slope	¼ ha
	ii. Rainfall — moderately reliable (C.V. ≥15%)	Rainfall data for at least 20 years required
	iii. soil clay ≥3% organic carbon ≥1%	
	iv. Vegetation formation young/juvenile bushland, good representation of leguminous herbs and woody plants	¼ ha
	v. Stability moderate but plot to plot variability permissible. Estimated by soil analysis, topography and tree size distribution	¼ ha
	vi. Low population density	regional data every 10 years
5. Forest/woodland reserves	*i.* Topography — Broken or sloping	5 ha
	ii. Soil — characterised by high sand,>76% low clay 0.25-5.00% organic carbon 0.80-1.27%-fragile, shallow soil permissible	¼ ha
	iii. Vegetation formation from open grassland to woodland or dry forest.	5 ha
	Stability and resiliency high to moderate as estimated by density of vegetation cover	
6. Wildlife reserves	*i.* Vegetation formation: heterogenous structure and composition; juvenile, to senile woodland open grassland to dry forest	1 ha
	ii. Natural water points available	5 ha
	iii. Adequate population and variety of wildlife in relation to carrying capacity	5 ha
	iv. Stability and resilience high to moderate as assessed by vegetation cover, tree size distribution and Markovian change	1 ha
7. Open grazing	*i.* Topography — Broken or flat	5 ha
	ii. Soil — Low clay, high sand low organic carbon, fragile; soil organic carbon sometime 1.50% at 0-15cm depth	1 ha
	iii. Vegetation formation open grassland to woodland with grass cover	1 ha
	iv. Stability and resilience; high to moderate as assessed by vegetation cover and Markovian change.	1 ha

TABLE 2 — *continued*

Recommended land-use		Characterising parameters	Scale of parameter
	v.	Natural water points	5 ha
8. Tree plantations (both monoculture of exotic and mixed indigenous species)	*i.*	Topography — plain to gentle sloping ⪅ 3% slope	1 ha
	ii.	Soil — Good depth > 1m, texture as in woodland reserves	1 ha
	iii.	Rainfall — mean annual>100mm (CV⪅ 16%); at least 5 -6 months of rain.	regional data for 20 ears
	iv.	Soil stability/resilience high to moderate as assessed by sand, clay, organic carbon analysis and topography.	1 ha
	v.	Vegetation stability/resilience of natural mixed woodland for pulpwood, etc, exploitation: moderate as assessed by tree size class distribution and Markovian change.	1 ha
9. Agro-forestry	*i.*	Topography — plain gentle slope	¼ ha
	ii.	Soil — Fragile, — low organic carbon, high sand. Soil fertility dependent on organic matter.	¼ ha
10. Large-scale irrigated agriculture	*i.*	Topography — plain to moderate slope	1 ha
	ii.	Soil, dark grey, soil carbon > 2% at 0-15cm depth, good mix of sand, clay; pH adequate; sand: silt: clay 65:27:7	¼ ha
	iii.	Water is available from suitable Dam/Lake	
	iv.	Stability is high	
11. Flood plain agriculture	*i.*	Juvenile and alluvium soil, not so fertile in the banks of the River	¼ ha
	ii.	Moderately stable sugar-cane/rice ecosystem can be achieved through management	—
	iii.	Flood plain topography already exists.	¼ ha

REFERENCE

Agishi, E.C 1985. Nigerian indigenous legumes and their forage value. Paper presented at Annual Conference of the Nigerian Society for Animal Production, University of Ife, 1985.

Anadu, P.A. 1982. Small terrestrial vertebrates of the Nigerian savanna. In: Nigerian Savanna-selected papers from the state of knowledge workshop. W.W. Sanford, H. M. Yesufu and J.S.O. Ayeni, eds. Kainji Lake Research Institute, New Bussa. pp 92-99.

Auerbach, S.I. 1981. Ecosystem response to stress: In: Stress Effects on Natural Ecosystems. G. W. Barret and R. Rosenberd, eds. John Wiley and Sons Limited pp 29-41.

Ayeni, J.S.O. 1982. A general review of wildlife and wildlife policy in Nigeria In: Nigerian savanna-selected papers from the state of knowledge workshop. W. W. Sanford, H. M. Yesufu and J.S.O. Ayeni, eds. kainji Lake Research Institute, New Bussa. pp 51-65.

Barret, G.W. 1981. Stress Ecology: An Intergrative Approach. In: Stress Effects on Natural Ecosystems. G. W. Barret and R. Rosenberg, eds. John Wiley and Sons Ltd., pp 3-12.

Bazzaz, F.A. 1975. Plant species diversity in old-field successional ecosystems in southern Illinois. *Ecology* 56, 485-488.

Bernhard-Reversat, F. 1982. Biogeochemical cycle of nitrogen in a semi-arid savanna. Oikos, 38, 321-332.

Conrad, M. 1977. The thermodynamic meaning of ecological efficiency. American Naturallist III, 99-106.

Eckholm, E. and Brown, L.R. 1977. Spreading Deserts — the hand of man. Worldwatch Paper 13. Worldwatch Insitute, New York. 40pp.

Eckholm, E. 1980. In: Introduction to firewood crops. (Shrub and Tree species for energy production) Report of an Ad Hoc Panel of the advisory Committee on Technology Innovation. BSTID. *National Academy of Sciences*, Washington. DC.

Ero, I.I. 1985. Guinea Savanna structure and land-use in Northwestern Nigeria. Unpublished Ph.D tesis, University of Ife.

Frost, P. Menaut, J., Medina, E., Solbring, O.T., Swift, M. and Walker, B. 1985. Responses of savannas to stress and disturbance — A proposal for a collaborative programme of research. Special Issue, "Biology International" IUBS, Paris.

Grove, A.T. 1973. Desertification in the African environment. In: Drought in Africa D. Dalby and R. J. Harrison Church, eds. CEntre for African Studies, School of Oriental and African Studies, University of London. pp 33-45.

Heathcote, R.G. 1969. Soil fertility under continuous cultivation in Northern Nigeria. 1. The role of organic manures. *Experimental Agriculture* 6, 229-237.

ICRAF 1983. Agroforestry systems for small farmers. International Council for Research in Agroforestry, Nairobi.

Isichei, A.O. 1983. Nitrogen concentration in the major grasses of the Derived and Guinea savanna zones of Nigeria in relation to season and site. Tropical Agriculture (Trinidad) 60, 48-52.

Ivanovici, A.M. and Wiebe, W.J. Towards a Working "Definition" of stress. A review and Critique. In: Stres Effects on Natural Ecosystems. G. W. Barret and R. Rosenberg, eds. John Wiley and Sons. pp 13-27.

Jenkin, R.N. 1964. The effect of different cultural treatments on the normal annual cycle of variation in the ammonia and nitrate-nitrogen contents of the soil In: The Role of Forestry in the Economic Development of the Savanna areas of Nigeria. Proceedings of the 1st Nigerian Forestry Conference. pp 93-100.

Jones, M.J. and Wild, A. 1975 Soils of the West African savanna. Commonwealth Agricultural Bureau, Slough, United Kingdom.

Kellman, M. 1979. Soil enrichment by Neotropical savanna trees. *Journal of Ecology* 67, 565-577.

Kelly, R.D. and Walker, B.H. 1976. The effects of different forms of land use on the ecology of a semi-arid region in southern Rhodesia. Journal of Ecology 64, 553-576.

Krebs, C.J. 1981. The experimental analysis of distribution and abundance. 2nd Edition. Harper and Row. New York.

Mbaekwe, E.I. 1985. The ecology and biology of *Piliostigma thonningii* in the Guinea savanna zone of Nigeria. Unpublished Ph.D thesis.

Milligan, K: Von. Kaufman, R. and Ajayi, S.S. 1982. The abundance, distribution and productivity of large herbivores in Nigera. In: Nigerian Savanna-Selected Papers from the State of Knowledge Workshop. W.W. Sanford, H.M. Yesufu and J.S.O. Ayeni, eds. Kainji Lake Research Institute, New Bussa. pp 69-91.

Mohammed Saleem, M.A. 1984. Fodder bank Paper presented at the symposium on Livestock production in the subhumid zones of Nigeria. ILCA/NAPRI Symposium. October 30-November 2nd 1984.

Mortimore, K.J. and Wilson, J. 1965. Land and People in the Kano.close settled Zone. Ahmadu Bello University, Department of Geography Occasional Papers No. 1. ABU, Zaria.

Ohiagu, C.E. 1982. Grass and deadwood feeding termites in Nigerian savanna. In: Nigerian savanna-selected papers from the state of Knowledge workshop. W.W. Sanford, H.M. Yesufu and J. S. O. Ayeni, eds. Kainji Lake Research Institute. New Bussa pp 100-110.

Pratt, D.J. and Gwynne, M.D. 1977. Rangeland management and ecology in East Africa. Hodder and Stoughton, London.

Sanchez, P.A. and Salinas, J.G. 1983. Low input technology for managing oxisols and ultisols in tropical America. *Advances in Agronomy.* 34, 279-405.

Sanford, W.W. 1982. The effects of seasonal burning: A review. In: Nigerian Savanna-selected papers from the state of knowledge workshop. W. W. Sanford, H. M. Yesufu and J. S. O. Ayeni, eds. Kainji Lake Research Institute, New Bussa pp 160-188.

Sanford, W.W. Obot, E.A. and Wari, M. 1982. Savanna vegetation succession, a means of assessment by the distribution of girth sizes of woody elements. In: Nigerian savanna-selected papers from the state of knowledge workshop. W. W. Sanford, H.M. Yesufu, and J. S. O. Ayeni, eds. Kainji Lake Research Institute, New Bussa, pp 418-432.

Sanford, W.W., Usman, S. Obot, E.A. Isichei, A.O. and Wari, M. 1982b. Relationship of woody plants to herbaceous production in Nigerian savanna. *Tropical Agriculture* (Trinidad) 59, 315-318.

White, F. 1983. The vegetation of Africa — A descriptive memoir to accompany the UNESCO/AETFAT/UNSO Vegetation map of Africa. UNESCO, Paris.