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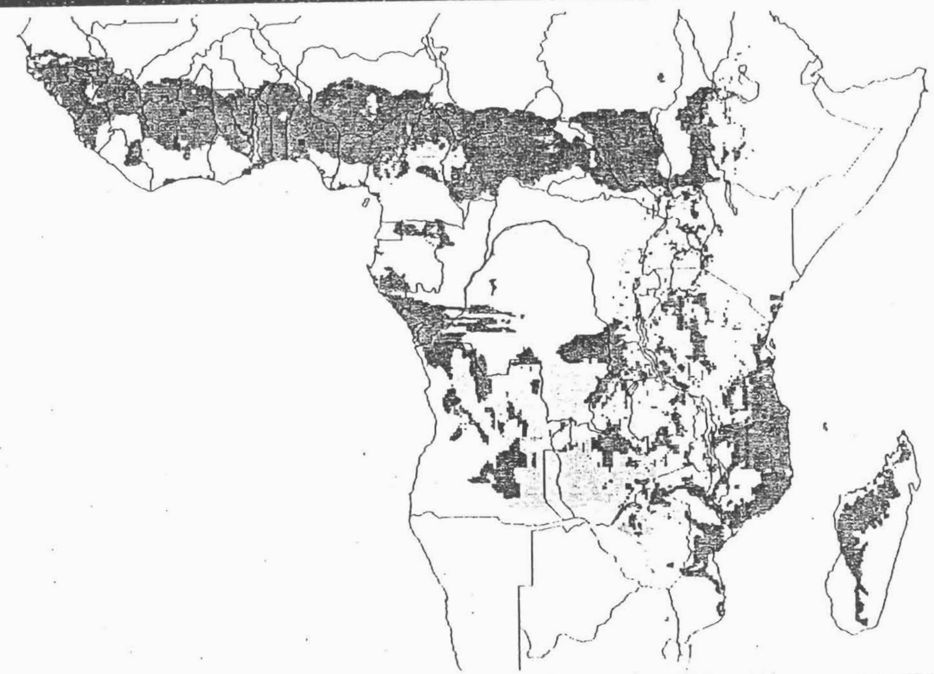
A. O. Isichei

MOIST SAVANNAS OF AFRICA

Potentials and Constraints for Crop Production



Edited by: B.T. Kang, I.O. Akobundu, V.M. Manyong, R.J. Carsky, N. Sanginga and E.A. Kueneman

Proceedings of an International Workshop

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held from 19-23 September 1994
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International Institute of Tropical Agriculture
in cooperation with
Food and Agriculture Organization of the United Nations

First printing, 1995

ISBN 978 131 098 7

Kang, B.T.
Akobundu, I.O.
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Produced by the

International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria
in collaboration with the
Food and Agriculture Organization of the United Nations, Rome, Italy

HOW TO CITE THIS PUBLICATION:
Proceedings of the International Workhop held at Cotonou, Republic of Benin, 19-23 September 1994. Produced by International Institute of Tropical Agriculture, Ibadan, 1995 xvi + 382pp + illus., index.

Errata: p. 112, in note to table 3. *Echinochloa* spp. not *chinlohcloa* spp.

COVER: The maps indicate the moist savanna zones in sub-Saharan Africa. Green = lowland savanna; brown = mid-altitude savanna; red = high altitude savanna.
SOURCE: Dr. S.S. Jagtap, Agroecological Studies Unit, Resource and Crop Management Division, IITA, Ibadan

Edited and typeset in Nigeria by
African Book Builders Ltd.
17 Arigidi Street
Ibadan, Nigeria

Printed by INTEC Printers, Ibadan

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years, annual rainfall in the region has declined, with southward shifts in the rainfall isohyets by 100-170 kilometers. The probability of drought in the savanna is approximately once in ten years. Soil fertility is the major constraint to crop production. This problem is further compounded by the fact that rainfall decreases and variability increases in areas with higher fertility status; and vice versa. This poses a challenge in the selection of crop species that will fit into the rainfall regime and thrive under low input cropping systems. The region is characterized by poorly developed networks of roads, railways and waterways resulting in poor access by farmers to urban markets, with the exception of a few countries, such as Nigeria. The lowland moist savanna is also thinly populated. Poor access and low population pressure may be an impediment to the adoption of input intensive technologies and the intensification of agriculture, unless land availability becomes a major problem. Technological innovation and/or institutional support systems must be developed to foster the expansion of food production in a sustainable manner, promote the welfare of rural people and protect the environment.

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VEGETATION AS A RESOURCE: Characterization and Management in the Moist Savannas of Africa

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Key words: moist savanna, altitude, zoning, vegetation, cultivation, mycorrhiza, perturbation, resilience

Abstract: *Savannas cover up to 65% of Africa's land area and up to 80% of West Africa and occur between the equatorial rainforests and mid-latitude deserts. They have a continuous C_4 grass stratum at least 80 cm high with flat, cauline leaves; trees and shrubs are often present and the vegetation is usually burnt annually, especially in the moist areas. Climate has been the major criterion used for zoning savannas but the structure of the vegetation and floristic composition, geology and geomorphology have also been used. There have been continental scale classifications of savanna, most prominent of which are those of AETFAT, which recognizes twelve savanna formations in Africa; and of UNESCO/AETFAT/UNSO, more recent, and partially based on that of AETFAT. There are several regional classifications including that of Keay for Nigeria whose nomenclature is now widely used in West Africa. Moist savannas are found in low altitude (< 800 m above sea level) Western and Central Africa, in the ecoclimatic zone where the moisture-indexed length of the growing season is between 151 and 270 days and where the annual rainfall/evapotranspiration ratio is between 0.40 and 1.0. Moist savannas are mainly woodlands and range from Isoberlinia woodlands to forest-savanna transition zones where oil palm, characteristic of secondary forest vegetation, is common. Moist savanna vegetation plays an important role in nutrient cycling, first through litter deposition and decay, from which soil organic matter is built up. Rhizobia and other micro-organism symbiotic and non-symbiotic associations with plants also fix atmospheric nitrogen. Some plants also have mycorrhiza which aid in nutrient absorption from the soil. Many savanna plants play secondary roles in agriculture, providing poles for fences and stakes for yam. Cultivation presents a major perturbation to the natural resilience of the moist savannas; land use should therefore ensure that the natural resiliency of the ecosystem is maintained.*

1. Introduction

1.1 The moist savannas of Africa: Their distribution and extent

Worldwide, savannas occur between the equatorial rainforests and the mid-latitude deserts, which have a continuous, mainly C_4 grass stratum and are either treeless or contain trees and shrubs of variable height and density (Cole 1986). The term has been applied to different types of vegetation in different continents, and in Africa it connotes low tree or parkland vegetation. Tropical savanna vegetation has structural and functional characteristics that enable it to exhibit seasonal rhythms of growth and productivity (Cole 1986). Sanford and Isichei (1986) have defined savanna as an area of seasonal tropical vegetation in which there is closed or nearly closed ground cover of grasses at least 80 cm high, with flat, usually cauline leaves. The vegetation is usually burnt annually, and trees and shrubs are often present. It has been estimated that the total area of savanna in Africa ranges from 42.3% (Sanford and Isichei 1986) to 60% Huntley and Walker (1982).

There have been various classifications of the savannas based on climate, flora and edaphic features. Other criteria such as vegetation life forms, horizontal spacing between plants and their heights and function; foliage form and function and woody plant density and height have also been used (see Cole 1986). One of the major classification schemes that uses vegetation structure and physiognomy is that of the Association pour l'Etude Taxonomique de la Flore d'Afrique Tropicale (AETFAT) on which the vegetation map of Africa south of the Tropic of Cancer (Keay 1959a) was based. This classification has been criticized because the number of classes in Africa, (30) are too few to cater for all the vegetation types in Africa (White 1983), and it is also heavily biased towards West African vegetation types and its classification of steppe as a non-savanna formation has been challenged (Cole 1986). Based on defined criteria, Cole (1986) has proposed that savanna be classified into savanna woodland, savanna parkland, savanna grasslands, low tree and shrub savanna, thicket and scrub, and intermediate types. Savanna has its own climatic characteristics and particular species; and soils and landscape can be associated with each class. Cole's scheme groups formations based on physiognomies in such a way that no distinction is made between West African and Southern African savannas. The UNESCO/AETFAT/UNSO vegetation map of Africa (White 1983) is based on the AETFAT map and other earlier classifications, especially that of Greenway (1973) for East Africa. This scheme, based on regional centers of species endemism, is one of the most widely used today. White does not use the term savanna, which he regards as foreign and imprecise, preferring 'grassland' and 'wooded grassland'. The most widely used classification schemes applicable to the savannas and their nomenclature are presented in table 1. The zonation of Keay (1959a) has continued to enjoy wide usage in West Africa, while schemes based on land use and vegetation associations are commonly used in East and Southern Africa. It needs to be emphasized that the nature and composition of savanna vegetation reflect total environmental conditions, including human influences, and provide a reliable index of land potential for agriculture and other uses. Sanford and Isichei (1986) have proposed a West African savanna classification which provides practical information on a scale of detail suitable for management planning.

Table 1. The two major classifications of the vegetation of Africa[1]

AETFAT[2] (Keay 1959)		UNESCO/AETFAT/UNSO (White 1983)		Nigeria (Keay 1959)	
Unit no. on map	Vegetation type	Unit no. on map	Vegetation type	Unit no. on map	Vegetation type
8	Forest-savanna mosaic	2	Guinea-Congolian forest: drier type		Derived (transition) savanna
		11	Mosaic of lowland rainforest and secondary grassland		
9	Coastal forest-savanna mosaic	15	West African coastal mosaic		Coastal savanna
		16	East African costal mosaic		
16	Woodlands, savannas — Undifferentiated, relatively moist types	12	Mosaic of lowland rainforest, *Isoberlinia* woodland and secondary grassland	-	Southern Guinea savanna
17	Woodlands, savannas — Northern areas, with abundant *Isoberlinia*	27	Sudanian woodland with abundant *Isoberlinia*		Northern Guinea savanna

Note: [1]The corresponding nomenclatures of Keay (1959b) for Nigerian vegetation have been included for comparison
[2]References and full names of abbreviated authorities are given in the text.

The scheme (Sanford and Isichei 1986) retains the nomenclature of Keay and proposes four savanna zones for West Africa, namely: transition savanna, Guinea savanna, Sudan savanna and Sahel short grassland. A hierarchical system of variables is used: first is climate defined by length of rainy season and the precipitation/evapotranspiration ratio. This is followed by topography and soil, followed by the physiognomic and structural features of the vegetation, and finally, the taxonomic features.

The distribution of moist savannas in Africa is linked to altitude. A line drawn across Africa from Angola to western Ethiopia divides the continent into a 'low' western Africa where most of the land is between 150 and 600 m above sea level, and a 'high' eastern and southern Africa, which mostly rises to 1000 m and higher above sea level (figure 1).

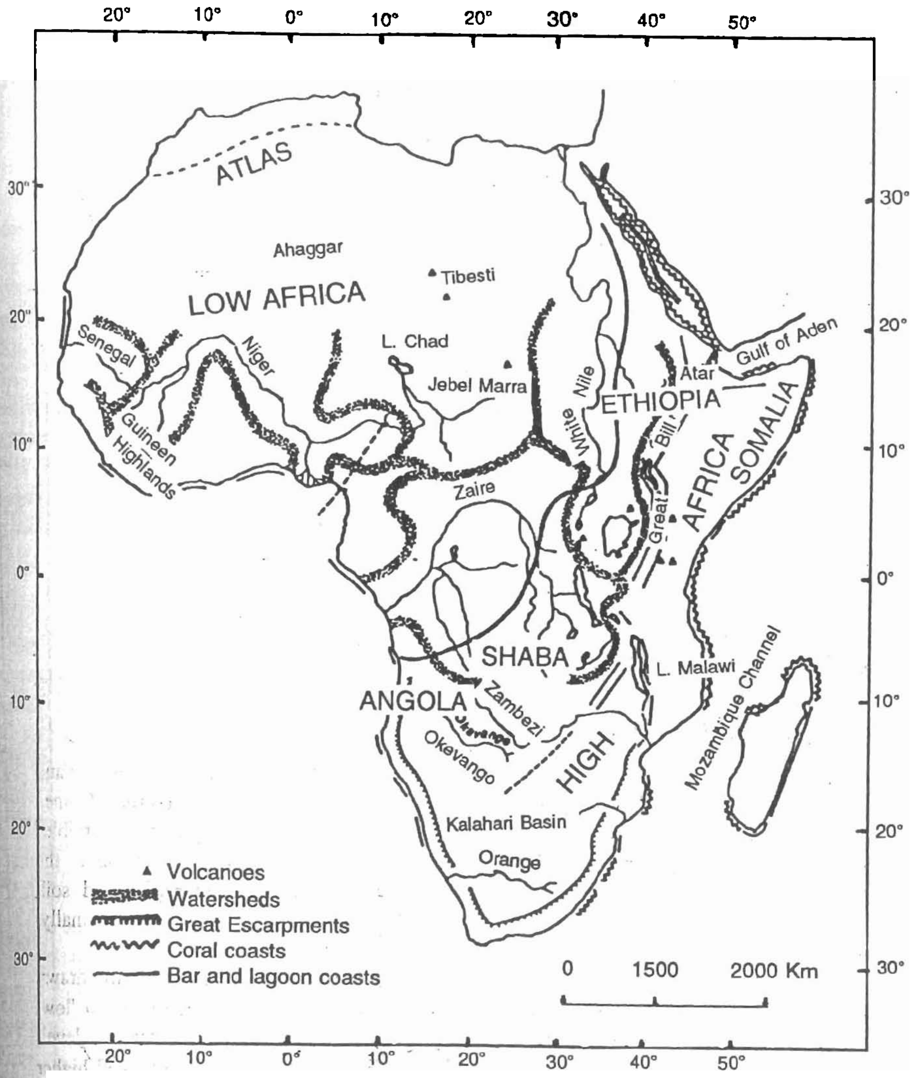

Figure 1. Physical features of Africa (after Grove 1978)

In West Africa, due to the general low altitude, the climate pattern is determined by distance from the sea and vegetation zonation closely follows the isohyet. This is not the case in East and Southern Africa where the altitude is high, the climate more temperate and the physiography more complex. The land mass of Africa between 3° S and 26° S is occupied by Zambezian woodlands (White 1983), which, due to their high altitude, are not included in this discussion. The transition zone from the Guinea-Congolian rainforest to the Zambezian woodland lies in and around Zaire. The greater part of this transition zone is occupied by secondary grassland (derived/transition savanna) and wooded grassland (Guinea-type savanna). There is also a narrow zone of savanna woodlands on the low lying East African coastal belt extending from southern Somalia (1° N) to the mouth of River Limpopo (25° S), a moist savanna formation described as 'Enclaves of Zanzibar-Inhambane coastal mosaic' by White (1983).

In West and Central Africa, north of the equator, two savanna systems may be distinguished: (a) savanna formations in a sub-humid climate which derive from the degradation of dense dry forest and woodlands; (b) Guinea-type savannas in humid climate which have replaced moist semi-deciduous forest (UNESCO 1979). These two formations correspond to the southern and northern Guinea and derived (transition) savanna zones (Keay 1959), and to the Sudan woodlands and the Guinea-Congo secondary grassland and wooded grassland mentioned by White (1983). These two formations, located in the ecoclimatic zone where the moisture-indexed length of growing season is between 151 and 270 days, or where the precipitation/evapotranspiration ratio is between 0.40 and 1.0, constitute the moist savannas (figure 2).

1.2 The vegetation

Moist savannas in their natural state, especially in the northernmost parts in West Africa, are mainly woodlands — that is — have open stands of trees whose crowns form canopies 8 to 20 m or more in height. The crowns of adjacent trees are often in contact but not interlocking. The natural vegetation has been profoundly modified by cultivation. Where the intervening period between cultivation is short and fires frequent, the trees are often represented by coppiced shoots and mature trees of specially preserved species of economic importance. Around the large towns, cultivation is permanent or semi-permanent for several kilometres, but valuable trees are protected, leaving a parkland savanna (White 1983).

Widespread in northern Guinea savanna (Keay 1959) are *Isoberlinia* woodlands. These woodlands are mostly associated with plinthite and quartzite ridges. They have a thin but continuous main canopy of *Isoberlinia doka* and *I. tomentosa*. *Isoberlinia* woodlands are often flanked by savanna where *Afzelia africana, Monotes kerstingii* and *Xeroderris stuhlmanii* are dominant. Other common trees include *Parkia biglobosa, Vitellara paradoxa* and *Terminalia spp. Andropogon gayanus,*

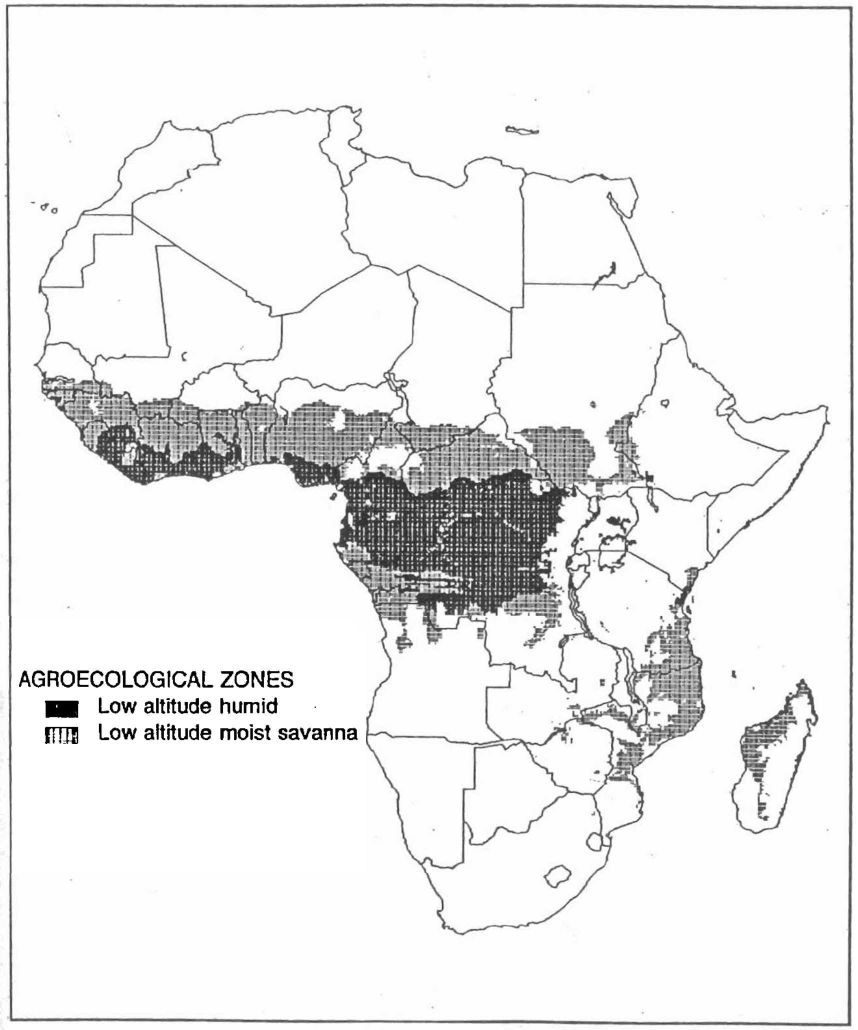

Figure 2. Agroecological zones of West and Central Africa

Hyparrhenia spp. and *Schizachyrium* spp. dominate the herb layer. The woodlands are regarded as the equivalent of the 'miombo', a typical Zambezian woodland formation, but the two characteristic genera of miombo, *Brachystegia* and *Julbernadia* are absent. *Isoberlinia* woodland and miombo, however, occur in similar geological situations, on early tertiary and late cretaceous plantation surfaces, and their physiognomies are very similar (Cole 1982).

South of these formations are the wetter zones which include the forest/savanna transition zones. These are generally regarded as fire climaxes, burning being a regular feature. These savannas have been derived from forest formations which have been denuded by human activities. The dominant trees in this zone include *Daniellia oliveri, Erythrophleum africana, Lophira lanceolata* and a scattering of oil palm, *Elaeis guineensis.* Tall grasses (up to 4 m) of the tribe, Andropogoneae of which *Andropogon tectorum* is the most common, dominate the herb stratum.

In conclusion, it could be said that 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 (Johnson and Tothill 1985). Savannas could also be classified on a floristic basis. Vegetation structure, a product of soil moisture and nutrient regime, has been most frequently used for classification in Africa.

2. The Role of Vegetation in Nutrient Cycling in Moist Savannas

The process of litter fall and accumulation is very important in the build-up of organic matter in the soil and also in nutrient cycling in tropical terrestrial ecosystems. When soil organisms consume and decompose litter a totally transformed, particulate organic matter which is incorporated into the soil as soil organic matter, SOM, results. These organisms also aid in SOM build-up when they die and their bodies get incorporated into the soil. Litter input to soil is the major determinant of the equilibrium level of organic matter within a given environment. In the West African savanna, organic matter concentrations in soil are determined by the mean annual rainfall and its distribution (Jones 1973), both of which are important determinants of primary production.

Soil organic matter can be transformed further into humic and non-humic substances by the process of humification. The non-humic substances are attacked readily by microorganisms and decompose rapidly and are thus likely to be a ready source of nutrients. Humic substances, on the other hand are composed of complex compounds and they decompose slowly. The humic substances, however, serve a useful purpose because the carboxyl and some of the phenolic hydroxyls in them provide exchange sites for cations (Barber 1984). The quality of organic matter and its rate of decomposition are thus dependent on its chemical composition. It has been observed, for example, that the rate of decomposition and nitrogen mineralization in the prunings of four different plants varied and that in some of the plants the parameters considered were age-dependent (Kachaka et al. 1993).

Vegetation serves as a nutrient reservoir through the storage of nutrients in roots and shoots. Most of the nutrients in tropical ecosystems are held in the vegetation biomass and these nutrients are rapidly cycled in a thick, superficial and highly mycorrhized root mat, functioning like a filter (Lavelle 1984). Forty kilograms of the 70kg N ha^{-1} required annually by savanna grasses in moist savanna in Côte d'Ivoire was supplied through rapid decay of root litter (Abbadie et al. 1992). Vegetation management is an important component of farming practices for sustained crop production in the humid and sub-humid tropics (Akobundu et al. 1993), through the influence of vegetation on soil fertility. Restoration of soil fertility during the bush fallow is one of the best documented instances of plants affecting the nutrient-supplying power of the soil beneath them (Grubb 1989). This enrichment of surface soils is effected through the absorption by deep-rooted trees of phosphate and cations from lower down the soil profile, a process usually referred to as 'nutrient pumping'. There is increasing evidence that soil enrichment comes about essentially as a result of the trees capturing the nutrients that come more effectively with precipitation (Kellman 1989, Abbadie et al. 1992). The cycling of the nutrients either 'pumped' or 'captured' is mainly through litterfall.

Thus, the build-up of soil nutrients in fallows starts with the acquisition of nutrients by plants through 'pumping', 'capture' from atmospheric sources, and biological nitrogen fixation in loose or symbiotic association with microorganisms. Some plants are organically linked to nitrogen fixing organisms in symbiotic or loose associations or have symbiotic relationship with mycorrhiza that enhance the uptake of poorly mobile nutrients (Hogberg 1989). The nutrient stock acquired through these processes is transferred to the soil through exudation, leaching from plants and decomposition of litter.

Nutrient exudation, canopy leaching and litter decomposition are all essentially transfer processes. Exudation and leaching have been subjects of localized studies, for example, stemflow and canopy through-fall studies of nutrients in rainwater, and are less important than litter decomposition in terms of the quantities of nutrients transferred. However, irrespective of the transfer process, the nutrients get to the soil where the effects of the transfer are expressed as an enhanced level of the nutrients in the soil.

2.1 Woody and herbaceous life forms

Several studies in a variety of ecosystems have shown that woody species increase the fertility of soil under their canopies (Belsky et al. 1989, Kellman 1979). In the Nigerian Guinea savanna, soils under canopies have significantly higher levels of organic matter, calcium, magnesium, potassium, total exchangeable bases, cation exchange capacity (CEC) and pH than those in open grasslands (Isichei and Muoghalu, 1992). Soil under trees 7 m and above in height had significantly more organic matter, higher CEC, silt and clay than soils under trees < 7 m high (Isichei and Muoghalu 1992). The higher levels of nutrients under trees could be explained in terms of higher organic matter production reduced soil leaching and a general amelioration of microclimate which reduces organic matter mineralization rate and volatilization of some nutrients.

Trees and other vegetation also capture atmosphere borne nutrients. The nutrients come as wet or dry deposits of oxides of nitrogen and sulphur released during biomass burning. An annual emission of 12-15 kg N ha^{-1} is estimated from biomass burning in the most savanna of Nigeria (Isichei and Sanford 1980); while an annual sulphur emission of 1.4 kg ha^{-1} is estimated from the moist savanna of Côte d'Ivoire (Delmas 1982). It is reported that an annual deposit of 2039 x 10^6 kg N in the bulk precipitation takes place over those areas of West Africa with an annual rainfall between 800 and 1800 mm (Robertson and Rosswall 1986). It has also been observed that 5 kg out of the 70 kg N required annually in the moist savanna in Côte d'Ivoire was derived from bulk precipitation (Abbadie et al. 1992). West Africa also experiences extensive deposition of dust borne by the north-east trade winds or harmattan in the dry season. An annual dust deposition of 1620 kg ha^{-1} for Kano (12°N, 8°31'E) has been reported with a decreasing rate westwards and southwards over West Africa (McTainsh 1985). A geochemical analysis of the dust shows it is composed mainly of SiO_2 (66.03%), Al_2O_3 (11.08%), Fe_2O_3 (4.45%), K_2O (2.04%), CaO (1.13%), etc. (McTainsh and Walker 1982). The dust is reported to have very little nitrogen — 0.01% (Robertson and Rosswall 1986). But the deposition of metallic ions can be substantial, as atmospheric dust has been reported to be responsible for the high potassium concentration in early rains in West Africa (Isichei et al. 1990). The structure of the vegetation will be influential in determining the quantity that is deposited in any particular locality and direct foliar absorption of some nutrients is possible.

Annual burning also affects nutrient cycling in that it quickens the release of non-volatile nutrients held in biomass which are then deposited as ash. The addition of ash appeared to have a long-term affect on the productivity of *chitemene*, a type of slash and burn system in Zambia (Araki 1993). The other effect is that burning caused increased mineralization of organic matter (Araki 1993), an indirect use of vegetation to hasten nutrient cycling.

The enhanced nutrient status of soils under savanna trees could also be attributed to associations with microorganisms which make them more efficient nutrient absorbers (different from nutrient pumping) and/or fixers of atmospheric nitrogen. Improved efficiency of absorption is achieved through a symbiotic association between plant roots and fungal mycorrhiza. Biological fixation of atmospheric nitrogen is achieved when plants are in loose or symbiotic association with certain microorganisms. Mycorrhizas, when present in plants, enhance the uptake of poorly mobile nutrients in soil (Hogberg 1989). Non-nodulated ectomycorrhizal trees conspicuously dominate the moist savannas such as the *Isoberlinia* woodlands which are characteristic of the Guinea savanna of West Africa (Hogberg 1989). Most tropical trees form vesicular-arbuscular (VA) mycorrhizas and nodulating species are usually VA mycorrhizal; but ectomycorrhizas are found in the families Amherstieae and Detarieae in the subfamily Caesalpinioideae; the most poorly rhizobia-nodulated of the Fabaceae.

Savanna soils are reported to have generally low concentrations of available nitrogen and phosphorus. In general, there is a decline in nitrogen relative to phosphorus along transects from moist to dry conditions. Nitrogen fixing trees are often dominant in dry savannas where nitrogen is low and soil phosphorus is relatively higher. Ectomycorrhizal species may be good at taking up less available forms of both nitrogen and phosphorus, while non-nodulated VA mycorrhizal species dominate soils poor in phosphorus but relatively rich in nitrogen. Savanna grasses form VA mycorrhizas and tree species may be connected with them (Hogberg 1989).

Nitrogen has been recognized as the most limiting nutrient for plant growth in the savannas (Hardy and Havelka 1975, Danso 1992). Where plant species are capable of utilizing atmospheric nitrogen, this is a cheaper source of nitrogenous fertilizers. A few prokaryotic microorganisms fix atmospheric nitrogen and these are in symbiotic or some loose association with plants or are free living.

Rhizobia bacteria which have a symbiotic association with legume plants contribute the greatest amounts of biologically fixed nitrogen in agriculture (Giller and Wilson 1991). There are 16,000 to 19,000 species in about 750 genera in the legume family, Fabaceae (Allen and Allen 1981). There are three subfamilies, Papilionoideae, Mimosoideae and Caesalpinioideae. The Mimosoideae and Caesalpinioideae are almost completely restricted to the tropics (Giller and Wilson 1991). In the Nigerian savanna, there are 284 legume species — 141 herbaceous Papilionoideae and 75 woody ones, one herbaceous Mimosoideae and 33 woody ones and 2 herbaceous and 32 woody Caesalpinioideae (Sanford 1982). Legumes make up over 20% of all woody species in northern Nigeria (Jackson 1973) and in tropical *Isoberlinia* woodlands constitute over 70% of the woody species.

Worldwide nodulation capacity has been surveyed in 3395 legume species, representing 20% of all species and including members of about 57% of the genera. Of these, 97% of the Papilionoid, about 90% of the Mimosoid and only 23% of the Caesalpinioid species examined nodulated (Giller and Wilson 1991). Table 2 lists the legume species in the Nigerian savanna that were observed to have nodules (Sanford 1982). A more extensive survey of wild plants is needed to establish the nodulation status of moist savanna legumes. Tree legume densities ranged from about 30% to 70% of stem numbers in the moist natural savanna woodlands of Nigeria (Jackson 1973). Okigbo (1977) has listed the edible legumes found in or of potential importance in the farming systems of the African humid tropics.

Table 2. Wild legumes (Fabaceae) from Nigerian savanna on which nodules have been reported

Sub-family	Species
	Herbaceous plants
P	*Alysicarpus ovalifolius*
P	*A. rugosus*
C	*Cassia mimosoides*
P	*Crotalaria confusa*
P	*C. graminicola*
P	*C. microcarpa*
P	*C. retusa*
P	*Desmodium hirtum*
P	*D. gangeticum*
P	*Dolichos chrysanthus*
P	*Indigofera astragalina*
P	*I. bracteolata*
P	*I. hirsuta*
P	*I. nummulariifolia*
P	*I. kerstingii*
P	*I. paniculata*
P	*I. pulchra*
P	*I. subulata*
P	*Eriosema glomeratum*
P	*Psophocarpus palustris*
P	*Sesbania leptocarpa*
P	*S. pachycarpa*
P	*Stylosanthes mucronata*
P	*Tephrosia barbigera*
P	*T. bracteolata*
P	*T. linearis*
P	*T. pedicellata*
P	*Vigna racemosa*
P	*V. reticulata*
P	*V. sinensis* (*V. unguiculata*)
	Woody plants
M	*Acacia spp*
M	*A. dudgeoni*
P	*Adenodolichos paniculatus*
M	*Albizia adianthifolia*
M	*A. zygia*

Notes: C = Caesalpinioideae, M = Mimosoideae, P = Papilionoideae
Source: Sanford 1982.

Symbiotic nitrogen fixation in legume-rhizobia systems is quantitatively the most important of all nitrogen-fixing systems in the savanna (table 3). There are other systems which are at least potentially important. One is the *Casuarina*-Actinmycetales symbiosis. There are 45 species of *Casuarina*, 25 of which form symbiotic association with the actinomycete genus *Frankia* (Becking 1982).

Casuarina, an introduced plant, is not common in moist African savannas but it has been reported to fix 58-262 kg N ha^{-1} yr^{-1} (Dommergues et al. 1984, Giller and Wilson 1991). *Casuarina equisetifolia* has been successfully used for sand dune fixation in Senegal and along the coast of northwestern Africa.

Another symbiotic association that is very important in tropical agriculture is that between the fern *Azolla* and *Cyanobacteria*. An average of 27 kg N ha^{-1} yr^{-1} is reported fixed by the *Azolla-Cyanobacteria* association (Giller and Wilson 1991). This association should be exploited in rice cultivation in savanna wetlands inland valleys and flood plains and *Azolla* mulch could also serve as a source of nitrogen in upland rainfed savanna agriculture.

Table 3. Estimated contribution by biological nitrogen fixation (BNF) to the overall nitrogen balance in Nigerian savanna systems (Kg N ha^{-1} yr^{-1})

N input source	Natural savanna	Grass pasture	Legume pasture	Rotational bush fallow	Semi-intensive	Intensive	
						Single	Double
Symbiotic fixation	20.0	10.0	40.0	25,0	25.0	50.0	100.0
Asymbiotic and rhizosphere fixation	15.0	5.0	0.0	10.0	5.0	0.0	0.0
Fertilizer	0.0	75.0	20.0	0.0	30.0	65.0	130.0
Other N inputs — plant residues, rainfall, animal excreta	17.5	22.5	22.5	17.4	15.0	35.0	35.0
% contribution of BNF to all inputs	66.7	13.3	48.5	66.8	40.0	37.0	37.7

Source: Extracted from Singh and Balasubramanian (1980).

These are also useful loose associations between microorganisms and savanna plants that are of great value in the nitrogen enrichment of savanna ecosystems. The most outstanding is the association between the rhizosphere of C4 grasses and some cereal crops and species of the bacterium, *Azospirillum* (Dōbereiner and Pedrosa 1987). The grass-*Azospirillium* system has been reported to result in yearly soil nitrogen increases of 10 kg N ha^{-1} in an Andropogoneae moist savanna of Côte d'Ivoire, 112 - 148 kg N ha^{-1} in southern Nigeria under *Eleusine coracana* (Moore 1963) and 59 kg ha^{-1} at Shika, also in Nigeria (Jones and Wild 1975). Using the ^{15}N dilution technique, it was shown that rhizosphere fixation supplied 5 kg N out of the 70 kg ha^{-1} required in a moist savanna in Côte d'Ivoire (Abbadie et al. 1992).

The cyacad, *Encephalartos transvenosus* has an endophyte in its roots identified as a *Nostoc* (Cyanobacteria) species and which has been shown to fix atmospheric

nitrogen — acetylene reduction activity (Grobelaar et al. 1984). A species of *Encephalartos*, *E. barteri* Garruth occurs in restricted parts of the West African Guinea savanna. There is no evidence that West African cycads have been examined for nodules/N-fixation ability.

In conclusion, biological nitrogen fixation and mycorrhizal associations that enhance nutrient acquisition by savanna plants have great potential for improving arable agriculture in moist savannas. Alley cropping can be extended to moist savannas, but the species to be used would have to be selected based on their ability to be mycorrhizal and/or nitrogen fixing.

3. Secondary Uses of Vegetation

In addition to being a direct and indirect nutrient source, vegetation also plays auxiliary roles in farming in moist savannas. These roles range from being used in farm fencing to serving as stakes for yams and beans in mixed cropping.

In Nigeria's Jos Plateau the cactus-like plant, *Euphorbia kamerunica* is used as fencing in smallholdings to protect them from herbivores or from human intruders. In more humid places *Newbouldea leavis* is extensively used to make boundaries and occasionally for fencing. Other species that may serve as fence plants, depending on the humidity of the location, include *Gliricidia sepium*, *Moringa oleifera*, *Pandanus candellabrum* and *Jatropha* spp.

The use of some woody species as stakes in yam cultivation is the subject of a recent study (Budelman 1991). The study was carried out in the sub-equatorial zone of Côte d'Ivoire, a location much more humid than the savanna, but the study procedures and some observations are applicable to savannas. The species studied were *Leucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophylla*. The attributes of the species used to assess their roles in yam cultivation were as follows:

a. capacity for dry matter production
b. nutrient composition
c. size of leaf
d. decomposition of leaf matter
e. effect of leaf mulch in retarding weed emergence
f. effect of leaf mulch on soil temperature reduction
g. effect of mulch on soil moisture conservation
h. nyctitropic movements of leaflets
i. coppicibility and rate of regrowth
j. fine roots in upper 40 cm of soil profile
k. ease of propagation
l. risk that species turns into weed
m. suitability for use as live stakes in yam cultivation

Gliricidia sepium was found, overall, to be the most useful for yam staking because of its architecture, its relatively lower yield of leaves and its rooting pattern, which is not concentrated at the surface and did not compete very much with yam roots.

Flemingia was found to be the most effective in preventing weed growth due to the high C/N ratio of its leaves which reduces their rate of decomposition. It was observed that in the eastern part of the moist savanna of Nigeria, *Nauclea latifolia* was commonly used as yam stakes. *Nauclea* is not N-fixing but the farmers choice appeared to be based on the plant's ease of propagation by cuttings and its low leaf density. As fallow periods are shortened in the shifting cultivation systems of the moist savannas, new technologies must take into consideration the environment, the projected benefits and the bases for observed cultural practices.

4. Moist Savanna Ecosystems: Resiliency and vegetation response to perturbation

Perturbation, when applied to a system like the moist savanna vegetation, implies some stress of an unusual magnitude. Such stress includes, for example, prolonged drought, as opposed to seasonal drought, and extensive vegetation removal. Stress has been defined as any force that pushes the functioning of a critical subsystem beyond its ability to restore homestasis (Barret 1981). The effects of stress are dramatic after certain thresholds of tolerance are exceeded, and beyond which any recovery is problematic. (Auerbach 1981).

Bush clearing and cultivation is an aperiodic event that partially or completely disrupts the structure and functioning of the savanna system either directly, by damaging or causing the mortality of individual plants, or indirectly through alteration of the physical environment. This creates opportunities for new individuals, especially weeds, to establish. If, however, the ecosystem is able to re-establish itself after such a perturbation, then we can say it is stable. Such stability has to be viewed in two ways; structural stability, when species composition remains more or less the same; and functional stability, when ecosystem characteristics such as biomass production, nutrient cycling pathways, etc., remain the same. It is not possible to attain structural stability under cultivation, but functional stability is attainable and should form the basis of sustainability.

When an ecosystem is subjected to stress and disturbance and is able to persist, such a system can be said to be resilient. An ecosystem may fluctuate wildly under perturbation, that is, have low stability, but be able to persist without any appreciable change in system configuration. In dealing with resiliency it is necessary to set boundaries beyond which the system can be said to have become irretrievably altered (Krebs 1981). System resiliency is measured by a coefficient of extinction, that is, the probability of that system changing to an entirely new configuration under different forms of management. In moist savannas this will be applicable to forest transition

zones which are prone to change even under mild disturbances. Return to forest is easily disrupted.

The concepts of stability and resiliency are important in savanna management and Isichei and Ero (1987) have outlined a scheme for assessing the stability and resilience of natural savanna ecosystems. For example, completely protected savanna woodlands can be rated high in both stability and resiliency; large-scale mechanized monoculture cropping, because of its deleterious effect on soil and vegetation, is rated low in both. These ratings are attributable to the conservative growth pattern and slow turnover of organic matter and nutrients in savanna woodlands. Woodlands also have large roots and high root/shoot ratios which limit the amount of material which can be destroyed by fire and facilitate re-sprouting after disturbance. Mechanically cleared savanna, on the other hand, will rapidly lose its production base by way of soil and vegetation loss and loss of nutrients through increased mineralization rates (Jenkin 1964). There is also high susceptibility to pest and disease infestation. The question of which management strategies to adopt in moist savanna cropping to ensure functional and/or structural stability needs to be addressed.

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MAJOR FARMING SYSTEMS OF THE LOWLAND SAVANNA OF SUB-SAHARAN AFRICA AND THE POTENTIAL FOR IMPROVEMENT

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Key words: Farming systems, moist savanna zone, environmental, traditional and transitional systems, modern adaptations, potential strategies

Abstract: The environmental background of the moist savanna zone is reviewed and the historical background of the domestication and production of crops in different regions in presented. Case studies of cropping patterns in West, Central, East and Southern Africa are presented and those potentials of the moist savanna zone not being realized are emphasized. Strategies and recommendations for realizing the agricultural potentials are presented.

1. Introduction

As defined by various authors (Deshmukh 1986, Hopkins 1965, Money 1987, Pomeroy and Service 1986, and Simmons 1978), the savanna is that biome of varying vegetation types on both sides of the equator, containing varying proportions of herbaceous grasses and sedges, forbs, trees and shrubs. The herb layer has predominately C4 grasses and forms a continuous cover, while trees and shrubs are discontinuous in varying degrees.

1.1 Geographical background

Although the boundaries are not clearly defined, the savanna and associated grasslands occupy about 12.3 million km² which amounts to 42.3% of the area of the African continent (Onochie 1977). North of the equator the savanna is about 450-800 km wide from north to south and about 5,600 km long from east to west. It covers areas in about 38 different countries. The moist savanna forms about half of all the identified savanna in Africa.

1.2 Vegetation

According to the FAO (1986), areas in West Africa with 600-1200mm annual rainfall are dominated by *Parkia-Vitellaria-Khaya* woodland with tree and shrub grassland and *Andropogon* grasses, as compared to the *Brachystegia* and *Julbernadia* woodland of the Miombo ecosystem in Central/Southern Africa, with tree and shrub grassland