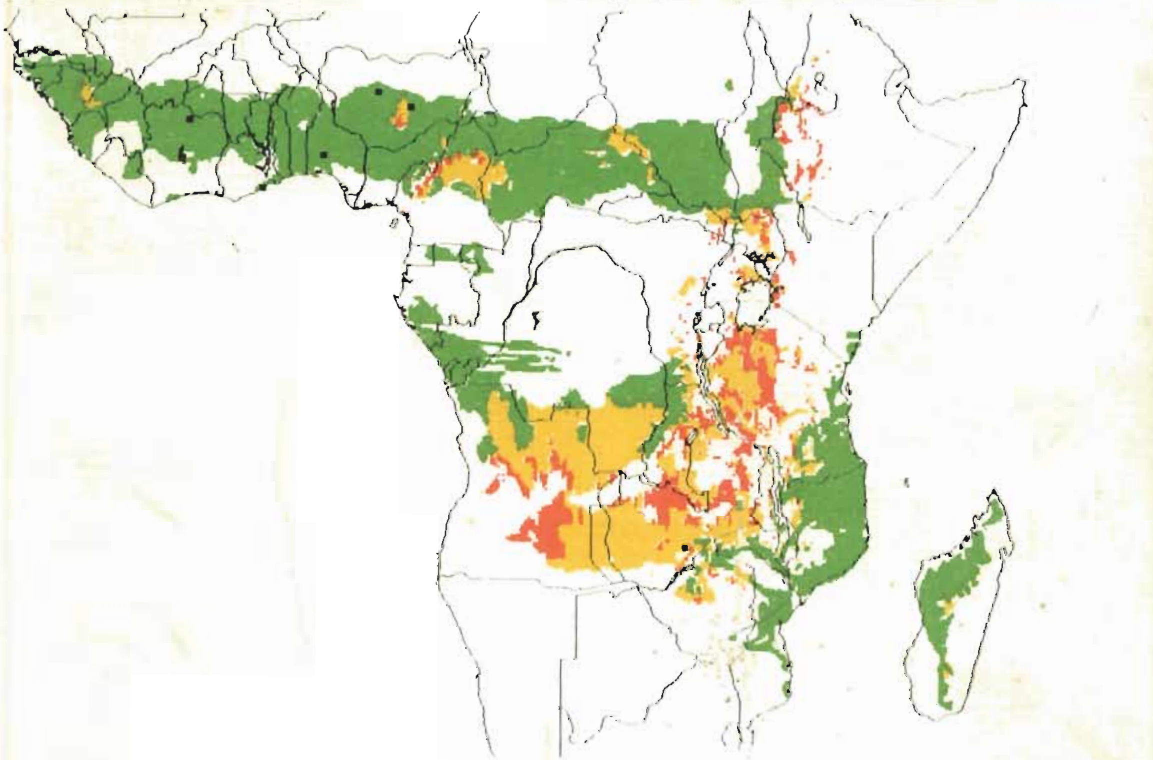
MOIST SAVANNAS OF AFRICA

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

MOIST SAVANNAS OF AFRICA: Potentials and Constraints for Crop Production

Proceedings of an IITA/FAO Workshop
held from 19-23 September 1994
Cotonou, Republic of Benin

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V.M. Manyong, R.J. Carsky
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Sanginga, N.
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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

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MOIST SAVANNAS OF AFRICA
Potentials and Constraints for Crop Production

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PART 6. WORKSHOP SUMMARY AND RECOMMENDATIONS

FOREWORD

Sub-Saharan Africa is one of the world's largest land masses. It has the world's highest human population growth rate, inherently poor soils and possibly also the world's highest pest incidence. Sub-Saharan Africa has several agroecological zones that include the Sahel, Sudan savanna, Guinea savanna, derived savanna, moist forest and the semi-arid highlands of East and Southern Africa.

The moist savanna is the largest agroecological zone in African countries south of the Sahara, and has the greatest potential for food production. This may explain why several organizations are actively involved in the search for improved technologies for crop production, livestock production and resource management, to ensure that the food production systems in the moist savannas of sub-Saharan Africa are sustainable. To ensure the efficient use of scarce resources in this search, the International Institute of Tropical Agriculture (IITA) and the Food and Agriculture Organization (FAO) decided to organize a workshop to bring together leading institutions working in the moist savanna zones to discuss their research with a view to developing a well-focused agenda for solving agricultural problems in the area. Collectively, these institutions can share their wealth of experience, minimize the duplication of effort and benefit from the bringing together of their combined human and material resources to identify critical problems and offer possible solutions.

This workshop provided a forum for (i) reviewing and prioritizing research and development needs and opportunities in the moist savannas of Africa, (ii) identifying constraints and opportunities as well as key research and development issues that will contribute to the development of improved technologies for the moist savannas, (iii) reviewing existing technologies, (iv) discussing methodologies for technology testing, and (v) identifying constraints to technology development, testing and transfer as well as impediments to technology adoption by farmers.

The workshop was expected to prepare a research and development agenda for the moist savannas of sub-Saharan Africa. The recommendations were prepared jointly by the participating scientists of CGIAR (Consultative Group for International Agricultural Research), the FAO, the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and research leaders from the national agricultural research systems (NARS) who are working in the area of moist savannas. These recommendations have been well received and have served as the main resource material for the Moist Savanna Consortium draft document.

These proceedings have brought together in one volume invited papers that have addressed various aspects of the moist savanna environment. This is another output of the workshop. We at IITA are happy to be part of these developments that seek to turn the moist savannas of Africa into the food basket of Africa. I recommend this document to all persons involved in technology development, testing, transfer and adoption in the moist savannas of Africa south of the Sahara.

I take this opportunity to thank all the institutions, donor agencies, NGOs and NARS research and policy leaders who responded to our invitation to participate in this collaborative effort. We look forward to our joint and continued cooperation as we get involved in the next step, namely, making the Moist Savanna Consortium a practical reality.

LUKAS BRADER
DIRECTOR GENERAL, IITA

INTRODUCTION

The moist savanna zone of sub-Saharan Africa, as described by the International Institute of Tropical Agriculture (IITA), extends in a band across West and Central Africa (the Guinea savanna zone) and includes the coastal lowlands in East and Southern Africa. The moist savannas of West and Central Africa are a western extension of the savanna woodlands of East and Southern Africa. The moist savannas are characterized by a growing period of 151 to 270 days, the mean daily temperature during the growing period is greater than 20° C in altitudes which are less than 800 m above sea level.

The moist savanna has a total land area of 371 x 10^4 hectares and is the largest agroecological zone in Africa south of the Sahara which is still mainly undeveloped. This is why various research and development agencies became interested in exploring the possibilities of introducing improved technologies for crops, and livestock production and resource management, in order to turn this vast tract into an area of productive and sustainable agriculture and provide relief for the chronic food shortages on the continent.

The workshop was, therefore, jointly organized by IITA and the Food and Agriculture Organization (FAO), with a view to sharing experiences in this area and identifying constraints to and opportunities for future development of the moist savannas of Africa. Although this workshop was mainly concerned with African moist savannas, two papers from similar savanna agroecological zones in South America are included in this volume for comparative purposes.

The papers presented at the workshop have been grouped into six sections: Part 1 contains the official addresses by representatives of IITA and FAO. Part 2 describes the biophysical characteristics of the moist savanna zone of Africa — the climatic delineation, the vegetation and types of farming systems. Part 3 highlights the biophysical and socio-economic constraints to agricultural development and the potential productivity of the zone under improved food crop production systems. Part 4 presents experiences and examples of technology development, testing and transfer in the zone. Part 5 presents two papers on the savannas of Brazil and Colombia in South America; as these two ecozones are similar to the African savannas, it is hoped that useful parallels can be identified and insights provided into how comparable development might be achieved in Africa. A brief synopsis of the papers, workshop recommendations and an agenda for future research in the moist savannas are presented in Part 6.

Important recommendations from the workshop include the immediate establishment of a socio-economic working group which will initiate policy and organize conferences and commission appropriate studies on how to develop sustainable agriculture in the moist savannas.

B.T. KANG AND I.O. AKOBUNDU
INTERNATIONAL INSTITUTE OF TROPICAL AGRICULTURE, IBADAN, NIGERIA

Abbreviations

ADP	Agricultural development projects
CGIAR	Consultative Group for International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CIEH	Comité Intergouvernemental d'Etude Hydraulique
CIMMYT	Centro Internacional de Mejoramiento de Maìz y Trigo (Mexico)
CIRAD	Coopération Internationale en Recherche Agronomique pour le Développement
CORAF	Réseau Riz de la Conférence de Responsables de Recherche Agronomique Africains
CPAC	Centro de Pesquisa Agropecuária dos Cerrados
CS	Coastal savanna
DS	Derived savanna
EEC	European Economic Community
EMBRAPA	Empresa Brasileira de Pesquisa Agropeuária
FAO	Food and Agriculture Organization of the United Nations
FSR	Farming systems research
GLIP	Grain Legume Improvement Program (IITA)
GTZ	Gesellschaft für Technische Zusammenarbeit
HAC	High activity clay
IAR & T	Institute for Agricultural Research and Training (Ibadan)
IARS	International agriculture research systems
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Center for Research in the Semi-Arid Tropics
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
ILCA	International Livestock Center for Africa
ILRI	International Livestock Research Institute
INEAC	Institut National d'Etudes Agronomique du Congo Belge
INRAN	Institut National de Recherche Agronomique du Niger
IPGRI	International Plant Genetic Resources Institute
IRAT	Institut de Recherches Agronomiques Tropicales
IRDP	Integrated research and development projects
ISC	ICRISAT Sahelian Center
ISNAR	International Service for National Agricultural Research
IVS	Inland valley swamps
JICA	Japanese International Cooperation Agency
LAC	Low activity clay
MSV	Maize streak virus

MSZ	Moist savanna zone
NAERLS	National agricultural extension and research liaison services
NAFPP	National Accelerated Food Production Programme (Nigeria)
NARS	National agricultural research systems
NIFTAL	Nitrogen fixation by tropical agricultural legumes
NUE	Nitrogen use efficiency
OP	Open-pollinated
OSTROM	Office de Recherche Scientifique et Technique d'Outre-Mer
RIEPT	International Network for Pasture Evaluation
SADC	Southern Africa Development Council
SGS	Southern Guinea savanna
TPRI	Tropical Pesticides Research Institute
UNU	United Nations University
WARDA	West African Rice Development Association
WASAT	West African Semi-Arid Tropics

PART 1
Official Addresses

WELCOME ADDRESS

Lukas Brader
Director General, International Institute of Tropical Agriculture, Ibadan

The subject of this workshop, Sustainable Cropping Systems for the Moist Savanna Zones of sub-Saharan Africa, clearly highlights the concerns of both the International Institute of Tropical Agriculture (IITA) and the Food and Agriculture Organization (FAO) in achieving a permanent increase in agricultural production in Africa. The workshop was originally designed as a working group to discuss the objectives of the Savanna Program within the Resource and Crop Management Division of IITA. It has since increased its scope to include not only the Crop Improvement Division and Plant Health Management Division but all the research divisions of IITA. Thanks to the participation of the FAO, it has assumed a global dimension, further widened by such partners as the World Bank and the International Development Research Centre (IDRC, Ottawa), the United States Agency for International Development (USAID) and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), together with our sister institutions from the Consultative Group on International Agricultural Research (CGIAR), the West African Rice Development Agency (WARDA), the International Centre for Research in Agroforestry (ICRAF), the International Center for Research in the Semi Arid Tropics (ICRISAT), IFPRI and the International Livestock Centre for Africa (ILCA). Something that is not mentioned in the title, is the national research and development organizations, their participation ensures that our deliberations shall be concise, focussed on African realities and practicable.

This workshop supports the efforts of CGIAR, which advocates an ecoregional approach to agricultural research. The target zone of the workshop, the moist savannas of Africa, is of particular importance. It is in these extensive and still relatively lightly populated savannas that Africa has its greatest potential to reverse the decline in per capita food production, witnessed over the last twenty years. Under similar conditions in South America, a global development plan has been set up with success. The objective of this workshop is to do the same for Africa.

The workshop goals are, (1) to draw up a manifesto which would includes a permanent review of research and technologies according to the needs of development and (2) to prioritize our programs, such that they will lead to sustainable food production in the different types of moist savannas found in sub-Saharan Africa. We have not come together primarily to present scientific papers, but to discuss the different and sometimes contradictory, ideas regarding the direction and possibilities for research and the way of bringing adapted cropping systems into being in the farmer's fields. Your recommendations will form the framework within which future projects will be developed and coordinated in the spirit of a common aim to ensure a permanent improvement in the lives of farmers, their children and the poorest parts of society.

Wishing you foresight and courage and stamina in your deliberations, I hope you have a good stay in Cotonou. Be assured that a warm welcome awaits you at IITA's Centre for Biological Control in Africa.

Long live South-South cooperation.

WELCOME ADDRESS

SUSTAINABLE CROPPING SYSTEMS FOR SAVANNA ECOLOGIES OF AFRICA: Definition of Workshop Goals

E.A. Kueneman
Crop and Grassland Service, FAO, Rome

On behalf of the Director General of FAO, Mr. Jacques Diouf, I wish to welcome all the participants and to thank you for taking time from your very busy schedules to join us for this week of deliberations and *brainstorming.*

The justification for this workshop is, I assume, largely self-evident to those who are attending. Nevertheless, a few comments of orientation should help set the stage. Providing for the basic needs of the expanding population in Africa is of great impending consequence. The current overall population density of Africa is relatively low, i.e., 17 km^{-2} compared to 108 and 223 for China and India respectively. However, the population growth rate of nearly 3% per annum (in some countries even higher) is reason for major concern; rates for Latin America and Asia are 1.85 and 2.37, respectively. For example, Nigeria, Africa's most populated country, which had a population of only 80 million in 1980, will have of about 230 million in the year 2010 and this number is expected to double again in the subsequent 15 to 20 years.[1] In addition to rapid population growth, population distribution in Africa is increasingly uneven, especially due to rapid urbanization. Some towns and cities are expanding at rates exceeding 10% a year. By the year 2010, about 50% of Africans are expected to live in urban centers.

Since 1970, Africa's population has increased more than 30% but the total food production increased by less than 20%. The gap was filled largely by food importation. African cereal imports increased 5-fold from 1970 to 1985, reaching 28 million tons. Foreign exchange limitations make the continuation of this trend unsustainable and certainly undesirable, for most African nations where improved agriculture is seen as an integral part of overall sustainable development.

How and where will more food be locally produced? Marginal, highly fragile ecologies, such as the semi-arid tropics, are not likely to support the intensification of agriculture that is required, as unreliable rainfall results in erratic productivity and makes the use of required inputs, like phosphorus and nitrogen, generally too risky.

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[1] Statistical information is drawn principally from the FAO publication, *African Agriculture: The next 25 years*, Rome, 1986.

The humid and perhumid zones are well suited to perennial crops such as oil-palm and rubber, as well as to paddy rice, but not to production of other annual crops, especially pulses and cereals. This is because soil degradation would generally be unacceptable, and yields are low due to poor solar radiation and pest and disease pressures.

The moist savannas are an enormous, largely untapped resource for Africa. Due to reasonably reliable rainfall, good solar radiation and relatively good soils, the moist savanna holds promise, if properly managed, for enhanced and sustainable food production. In many countries some useful research and development activities have taken place over the years, but in general efforts have been very fragmented. We hope that a clear picture emerges of what existing technologies can be promoted, and that a strategy evolves for coherent research for this agro-ecozone and its sustainable development.

Enhancing and maintaining crop and livestock production in the moist savannas of Africa will require an integrated approach to research and development. There are many constraints and considerations such as: requirements of phosphorus and other plant nutrients from outside the system; consideration of human and livestock disease incidence; management of regions prone to crusting of the soil surface; tillage systems and weed control; resource needs and the organization of a task force for joint planning and implementation.

The background information sent to each participant contained a section on the workshop objectives. This statement of objectives was carefully formulated by both IITA and FAO. What the organizers feel is by far the most important expected output of the meeting is:

To formulate specific action/program outlines for research and development which are based on opportunities and needs for the major ecozones within the moist savanna zones, taking into consideration the diverse scales of production.

Throughout this workshop it is essential that we focus our full attention on this purpose. There is, in fact, very little time available to realize this complex goal and consequently virtually everything done should be directed toward this end.

We view this workshop as a logical step in the sequence of actions required to ensure an accelerated, coherent, dynamic suite of programs that will lead to enhanced sustainable agricultural production from one of Africa's most valuable, albeit underutilized, resources — the moist savannas. Several other useful initiatives toward sustainable development of the African agricultural sector have been and are being taken. The organizers of the workshop hope that the workshop will be a 'link in the chain of strategy development' and that a holistic, cohesive approach develops that is perceived by all as belonging to the Research and Development Community interested in African development.

The *elements for action* are important for sustainable development. This current workshop does not intend to focus at the general strategic level as was done in the and on the activities required to realize those outputs.

We, the participants of this workshop, are to focus on what can and should actually be done now, both in research and in technology transfer (development).

On behalf of my colleagues from FAO and myself, we look forward to working with all of you during this workshop; we hope to jointly realize a project document, structured in such a way that with relatively modest revision, it can be used as an instrument for fund identification and follow-up action.

PART 2
Characteristics of the Moist Savanna Zone of Africa

ENVIRONMENTAL CHARACTERIZATION OF THE MOIST LOWLAND SAVANNA OF AFRICA

S.S. Jagtap

Agroecological Studies Unit, International Institute of Tropical Agriculture (IITA), PMB 5320, Ibadan, Nigeria

Key words: environmental characterization, sub-Saharan, GIS, RIS

Abstract: *The challenges of meeting the rapidly growing food needs of sub-Saharan Africa cannot be successfully overcome without due consideration of the capacity and limitations of the natural environment. Promoting sustainable agriculture involves coordinating information from a variety of sectors, so that the full impact of a chosen strategy on a region can be better understood. The International Institute of Tropical Agriculture has developed an interactive user-friendly raster-based Geographic Information System (GIS) called the Resource Information System (RIS) for personal computers which can be used to capture, store, retrieve and analyze spatial and descriptive data and to examine and establish spatial relations among them. RIS includes features of GIS such as overlays of multiple layers of attributes, point data, communication networks, point locations, database search, and area computations to zoom-in on a region or country.*

In this paper, examples of the use of RIS for delineating agroecological zones, mapping environmental characteristics, potentials and their constraints, assessing their suitability for specific crops, and examining links between infrastructure, population pressure and the soil resource base are given. The databases used in this paper were collected from several national and international sources.

1. Introduction

The heterogeneity of agroecosystems in sub-Saharan Africa necessitates a clear understanding of the socio-economic and ecological conditions under which improved technologies are likely to be successful. Strategies must be formulated that will foster the expansion of food production in a sustainable manner, promote the welfare of rural people and protect the environment. Some of the key ecological and socio-economic factors believed to drive this process are reviewed here.

2. The Moist Savanna Zone

The moist savanna of sub-Saharan Africa consists of three subzones — the lowland, mid altitude and highlands — defined on the basis of altitude, amount of rainfall and temperature regime during the growing period (see fig. 1 and table 1). The growing period is the period during a year when precipitation exceeds half the potential

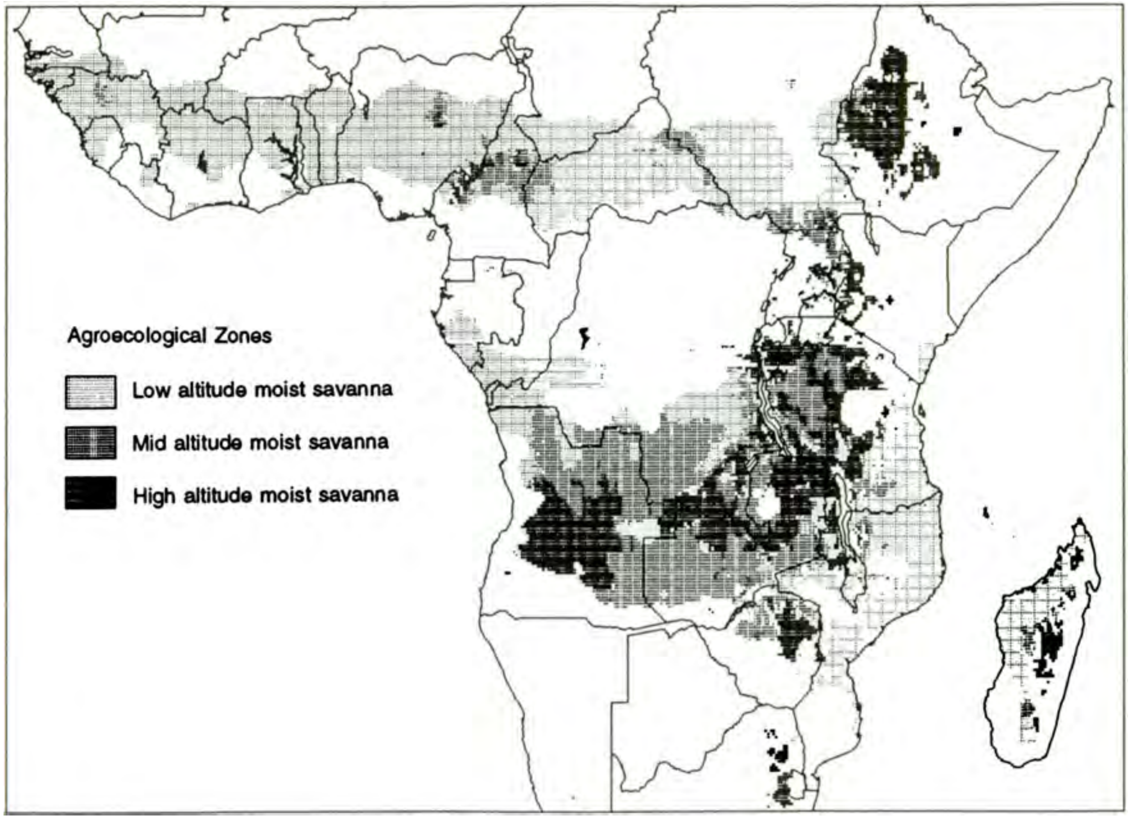

Figure 1. **Moist savanna zones by altitude in sub-Saharan Africa**

evapotranspiration, that is, the period required for an assumed 100 mm of water stored in the soil profile to be lost by evapotranspiration.

Table 1. Agroecological zones in sub-Saharan Africa (SSA), extracted from the IITA data base

Altitudinal zone	IITA subzones	LGP (days)	DMT/GP (°C)	Africa (million ha)
Lowland	NGS(MS)	151-180	> 20	116
Mid-altitude	MSA	151-180	> 20	86
Highland	MSA	151-180	> 20	1-
Lowland	SGS (MS)	181-210	> 20	100
	DS/CS (MS)	211-270	> 20	163
Mid-altitude	AW/MAS/VA (MSW)	181-270	> 20	124
Highland	AW/MAS/VA (MSW)	181-270	> 20	5
Mid-altitude	AW/MAS/VA (MSW)	271-365	> 20	23
Highland	AW/MAS/VA (MSW)	271-363	> 20	1

Notes:

Lowland	= <800 m
Mid-altitude	= 801-1200 m
Highland	= over 1200 m
LGP	= Length of growing period
DMT/GP	= Daily mean temperature during the growing period
NGS	= Northern Guinea savanna
SGS	= Southern Guinea savanna
DS	= Derived savanna
CS	= Coastal savanna
AW	= Acid woodlands
MAS	= Mid-altitude savanna
VA	= Volcanic areas
MSA	= Mid-altitude semi-arid
Areas outside IITA's ecosystems	
MS	= Moist savanna
MSW	= Mid-altitude and highland savanna and woodlands

Table 2 compares total country area to area occupied by various savanna lands in Africa. Mid-altitude savannas are predominant in central-eastern and southern Africa. Sub-Saharan Africa possesses about 389 million hectares of lowland moist savanna (LMS), 169 m ha of mid altitude moist savanna (MMS) and 57 m ha of highland moist savanna (HMS). The LMS is thus by far the largest of the moist savannas in sub-Saharan Africa.

Table 2. Area by agroecological zones ('000)

Country	Total Area sq. km	L Alt DS*	L Alt SGS	L Alt NGS	M Alt DS	M Alt SGS	M Alt NGS	Total L Alt	Total M Alt
Nigeria	922.4	247.5	133.3	114.5	6.8	11.6	2.7	495.4	21.2
Guinea	248.5	68.4	89.2	31.8	5.8	6.2	0.0	189.4	12.0
Côte d'Ivoire	324.1	94.4	92.3	2.1	0.0	0.0	0.0	188.7	0.0
Ghana	240.7	62.2	31.1	39.3	0.0	0.0	0.0	132.6	0.0
Chad	1326.5	0.0	8.5	99.5	0.0	0.0	0.0	108.0	0.0
Cameroon	467.0	55.0	17.8	31.1	71.5	2.7	1.0	103.9	75.2
Benin	117.6	26.0	36.6	37.9	0.0	0.0	0.0	100.5	0.0
Mali	1312.5	0.0	21.5	38.6	0.0	0.0	0.0	60.2	0.0
Burkina Faso	276.9	0.3	13.7	40.7	0.0	0.0	0.0	54.7	0.0
Togo	57.8	40.0	5.1	8.2	0.0	0.0	0.0	53.3	0.0
Sierra Leone	72.8	47.2	0.0	0.0	0.0	0.0	0.0	47.2	0.0
Senegal	202.4	0.0	0.0	33.5	0.0	0.0	0.0	33.5	0.0
G. Bissau	32.8	0.0	1.4	25.3	0.0	0.0	0.0	26.7	0.0
Liberia	97.1	16.4	0.7	0.0	0.0	0.0	0.0	17.1	0.0
C. Afr. Rep	620.5	243.4	190.4	8.2	16.8	46.8	1.0	442.1	64.6
Zaire	2338.8	291.6	0.7	0.0	260.5	14.0	45.1	292.3	319.7
Congo	341.9	69.4	5.5	13.0	0.0	0.0	0.0	87.9	0.0
Gabon	262.2	47.9	14.0	7.2	0.0	0.0	0.0	69.1	0.0
Sudan	2583.9	111.8	92.3	210.3	28.0	15.0	5.5	414.4	48.5
Tanzania	946.0	50.6	28.7	83.1	46.2	101.9	42.1	162.4	190.1
Ethiopia	1263.6	4.4	11.3	16.1	2.7	14.7	3.8	31.8	21.2
Kenya	583.6	11.6	0.0	1.7	2.1	3.1	0.0	13.3	5.1
Uganda	242.7	3.1	0.0	0.0	28.7	3.8	8.9	3.1	41.4
Mozambique	822.6	43.8	133.0	213.3	0.3	9.2	28.7	390.1	38.3
Madagascar	628.4	7.5	95.0	82.1	0.3	14.0	6.8	184.6	21.2
Angola	1269.1	108.4	0.0	0.0	299.5	1.4	95.4	108.4	396.2
Zimbabwe	413.7	0.0	0.3	23.2	0.0	0.0	49.9	23.6	49.9
Malawi	121.0	0.7	9.6	10.6	0.0	3.8	8.2	20.9	12.0
Zambia	769.9	0.0	0.3	9.6	0.3	32.1	338.8	9.9	371.3

Note: *See table 1 for definitions

Table 2 cont'd

Country	Percentages*							
	L Alt DS	L Alt SGS	L Alt NGS	M Alt DS	M Alt SGS	M Alt NGS	Total L Alt	Total M Alt
Nigeria	26.8	14.5	12.4	0.7	1.3	0.3	53.7	2.3
Guinea	27.5	35.9	12.8	2.3	2.5	0.0	76.2	4.8
Côte d'Ivoire	29.1	28.5	0.6	0.0	0.0	0.0	58.2	0.0
Ghana	25.9	12.9	16.3	0.0	0.0	0.0	55.1	0.0
Chad	0.0	0.6	7.5	0.0	0.0	0.0	8.1	0.0
Cameroon	11.8	3.8	6.7	15.3	0.6	0.2	22.3	16.1
Benin	22.1	31.1	32.3	0.0	0.0	0.0	85.5	0.0
Mali	0.0	1.6	2.9	0.0	0.0	0.0	4.6	0.0
Burkina Faso	0.1	4.9	14.7	0.0	0.0	0.0	19.8	0.0
Togo	69.2	8.9	14.2	0.0	0.0	0.0	92.3	0.0
Sierra Leone	64.8	0.0	0.0	0.0	0.0	0.0	64.8	0.0
Senegal	0.0	0.0	16.6	0.0	0.0	0.0	16.6	0.0
G. Bissau	0.0	4.2	77.1	0.0	0.0	0.0	81.3	0.0
Liberia	16.9	0.7	0.0	0.0	0.0	0.0	17.6	0.0
C. Afr. Rep	39.2	30.7	1.3	2.7	7.5	0.2	71.2	10.4
Zaire	12.5	0.0	0.0	11.1	0.6	1.9	12.5	13.7
Congo	20.3	1.6	3.8	0.0	0.0	0.0	25.7	0.0
Gabon	18.3	5.3	2.7	0.0	0.0	0.0	26.3	0.0
Sudan	4.3	3.6	8.1	1.1	0.6	0.2	16.0	1.9
Tanzania	5.3	3.0	8.8	4.9	10.8	4.4	17.2	20.1
Ethiopia	0.4	0.9	1.3	0.2	1.2	0.3	2.5	1.7
Kenya	2.0	0.0	0.3	0.4	0.5	0.0	2.3	0.9
Uganda	1.3	0.0	0.0	11.8	1.5	3.7	1.3	17.0
Mozambique	5.3	16.2	25.9	0.0	1.1	3.5	47.4	4.7
Madagascar	1.2	15.1	13.1	0.1	2.2	1.1	29.4	3.4
Angola	8.5	0.0	0.0	13.6	0.1	7.5	8.5	31.2
Zimbabwe	0.0	0.1	5.6	0.0	0.0	12.1	5.7	12.1
Malawi	0.6	7.9	8.8	0.0	3.1	6.8	17.2	9.9
Zambia	0.0	0.0	1.2	0.0	4.2	44.0	1.3	48.2

Note: Percentage is calculated by dividing area of the zone by country's area

The LMS is dispersed largely in West and Central Africa, and coastal Tanzania, Mozambique, and Madagascar. It is characterized by altitudes of up to 800m above the sea level, a length of growing period (LGP) of 151-270 days, followed by a distinct dry season and a daily mean temperature during the growing season above 20° C. The lowland moist savanna consists of three strata, the northern Guinea savanna, (NGS) with an LGP of 151-180 days, the southern Guinea savanna (SGS) with an LGP of 181-210 days, and the derived and coastal savanna (DS/CS) with an LGP of 211-270 days. The LGPs run parallel across the zone, and onset and length vary according to the latitudinal position. The savanna is well suited to annual crops of medium duration such as maize, soybean, and groundnut. When ecological conditions in the savanna become too severe on account of a prolonged dry season, maize is replaced by sorghum and millet and dry-season cultivation is practiced in the swamps. This paper focuses on LMS characteristics.

3. Climatic Potential and Constraints

Agroecological conditions largely determine the production potential and population supporting capacity of a region. This condition is characterized and used to compare farming systems and production alternatives and to assess research spillovers. Characterization is essential for the improvement of resource management and for the development of sustainable production systems to meet future demands. This section aims at providing a brief account of general climatic characteristics, major climatic controls and spatial and temporal variation in the major climatic elements of precipitation, radiation, and temperature.

3.1 Precipitation

The climate of tropical Africa is the result of a series of mechanisms that maintain the global energy balance through the poleward transmission of energy. Latent heat energy gained by the trade winds passing over the heated surface of the ocean is released by a convective mechanism in the intertropical convergence zone. The resulting general circulation brings the area alternatively under the influence of a dry continental air-mass — the harmattan/north-east trade winds, and a moist maritime air-mass — the southwest Monsoon. The distribution of rainfall is influenced by the orographic characteristics of the region. Maximum rainfall tends to occur at high sun (near the equator) and minimum at low sun. The relative lengths of wet and dry seasons are a function of proximity to the primary air-mass region. Rainfall distribution ranges from monomodal, having one distinct humid period, in the northern and southern Guinea savannas to bimodal in certain parts of derived and coastal savannas, where two rainy seasons occur under the influence of the intertropical convergence zone. Within these areas, rainfall differences are still large (see fig. 2). The annual rainfall over large areas varies from 1000 to over 1800 mm. However, due to the modification of the macroclimate by local terrain, soil, biotic

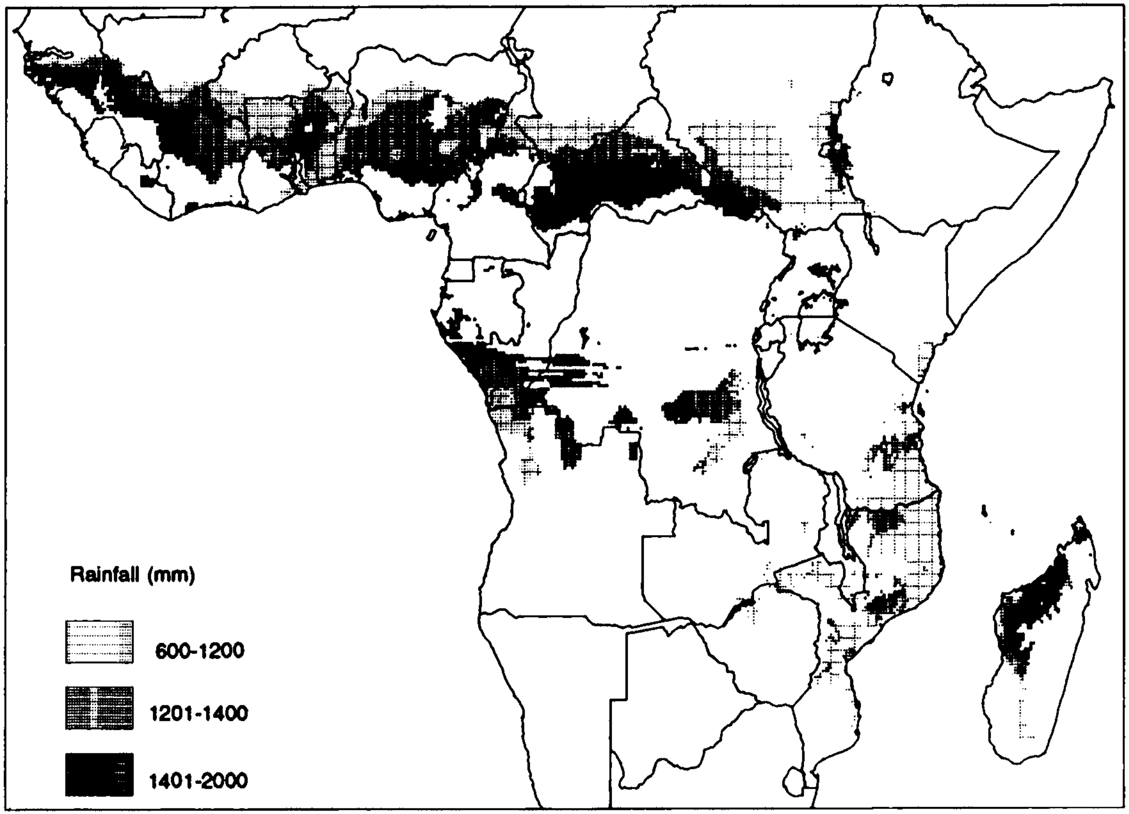

Figure 2. Annual rainfall distribution (mm) within the lowland moist savanna

influences and human disturbances in certain areas, rainfall over 1800 mm can be found both in coastal and inland countries. Rainfall exceeds 1800 mm/year in Guinea Bissau, Sierra Leone, Liberia, western Côte d'Ivoire, Togo, Nigeria, parts of central Africa, and certain areas of Madagascar. Inland from the eastern coasts of Ghana, Angola, and Mozambique, rainfall is less seasonal (low CV), and below 1000 mm.

Rainfall in the savanna zone is characterized by high variability and high intensity. The seasonality of rainfall distribution may be illustrated using the coefficient of variation, i.e., the standard deviation of monthly rainfall expressed as a percentage of the monthly mean rainfall. Values less than 50 indicate that rainfall is distributed throughout the year, although seasonal peaks may be present. This mainly occurs in the humid zones. A coefficient of variation greater than 75% indicates strong seasonal contrast. A large proportion of the lowland moist savanna falls within this category. Over most of the LMS, 90% or more of the total annual rainfall occurs during the growing period, while during post- and pre-growing seasons the precipitation is as little as 100-200 mm. Within the savanna, potential evaporation for dry months often exceeds 200 mm and leads to severe water shortages for both plants and animals. This necessitates careful matching of crop growth cycles to ensure minimum water stress and yield reductions. The spatial variation is less than 20% south of 11°N and above 25% north of it.

A study of daily rainfall from 23 rainfall stations in Nigeria for the period 1960-90 showed that in most years annual rainfall was persistently less than the average for the same period and there were declining moving averages. Compared with the 1961-1970 period, the rainfall in 1981-1990 was 200 mm less in the humid southeast, 100 mm less in the bimodal rainfall region and from 128-313 mm less in the savanna. The 900, 1100, 1300, and 1500 mm rainfall isohyets, moved south throughout the country by 167, 138, 108 and 50 km during the same 20 years (Jagtap·1993). The occurrence of dry years in succession, defined as when rainfall is less than 75% of probability or when 3 out of 4 years had less than normal rainfall, was also determined for the same 23 stations. The results indicated that the risk of drought in the savanna is about 1 dry year in 10 years, while in the humid zone it is 1 in 30 and in arid zones 1 in 6 years.

3.2 Soil erosion

A high proportion of rains in Africa are associated with wave disturbances, giving rise to strong convective activities, which result in short intense storms with peak intensities sometimes exceeding 100 mm/h. These intense rains frequently result in considerable compaction, soil erosion and a large runoff, particularly in the absence of surface cover. The net result is the gradual deterioration of the soil, both physically and chemically, and consequently a decline in productivity. While it is generally acknowledged that erosion is a more serious problem for the tropics than elsewhere, few analytical or systematic studies have been undertaken to document the problem, its consequences, or potential solutions. Due to limited data availability, only erosion by water is considered, though wind erosion is a serious problem in the drier areas. Using Fournier's (1962) empirical indices of rainfall aggressivity, a rainfall erosion hazard map for Africa was constructed from the relationship:

$$R = 5.44 \sum_{i=1}^{12} p_i^2/P - 416$$

Fournier found a strong correlation between total annual erosion in metric tons per square kilometer and the rainfall distribution factor p^2/P where p_i is the mean monthly rainfall and P is the mean annual rainfall. Fournier did not use a soil factor and therefore the extent to which erosion in any particular location departs from the values obtained by this method cannot be calculated without additional data. It is reasonable to assume, however, that the propensity of a given region to total erosion will be an indication of its susceptibility to erosion in comparison with other regions. As noted in figure 3, one-third of the LMS lies in the moderate risk category, while the remaining two-thirds lies in the high risk class. Top soil removal has been associated with reduction in yield (Lal 1976) and declines in yield as a result of erosion have been shown to be due to two factors. First, is the loss of organic matter and soil nutrients associated with removed soil. This aspect of erosion is a major consideration for subsistence farmers since they lack resources to replenish lost nutrients and thus sustain production at an acceptable level. This problem is further aggravated by the inadequate crop stands obtained on depleted soils which contribute little to soil protection against further soil erosion or against declines in organic matter. The second factor responsible for reduced productivity is physical degradation of the soil within the root zone. After the removal of the top soil, the remaining subsoil is often characterized by high bulk density or hard pans causing barriers to root prolification. Lal (1976) showed that root development of cowpea and maize was restricted with increased soil removal.

3.3 Solar radiation

The Africa-wide network of recording instruments for total solar radiation remains inadequate. Measurement and improved estimates of solar radiation provide essential input for the calculation of photosynthesis, and potential evaporation. The estimation of total solar radiation using maximum (T_{max}) and minimum (T_{min}) temperatures and extraterrestrial radiation (R) above the atmosphere on the 10 minute grid for Africa are based on the following equation:

$$R = 0.16\, R \sqrt{(T_{max} - T_{min})}$$

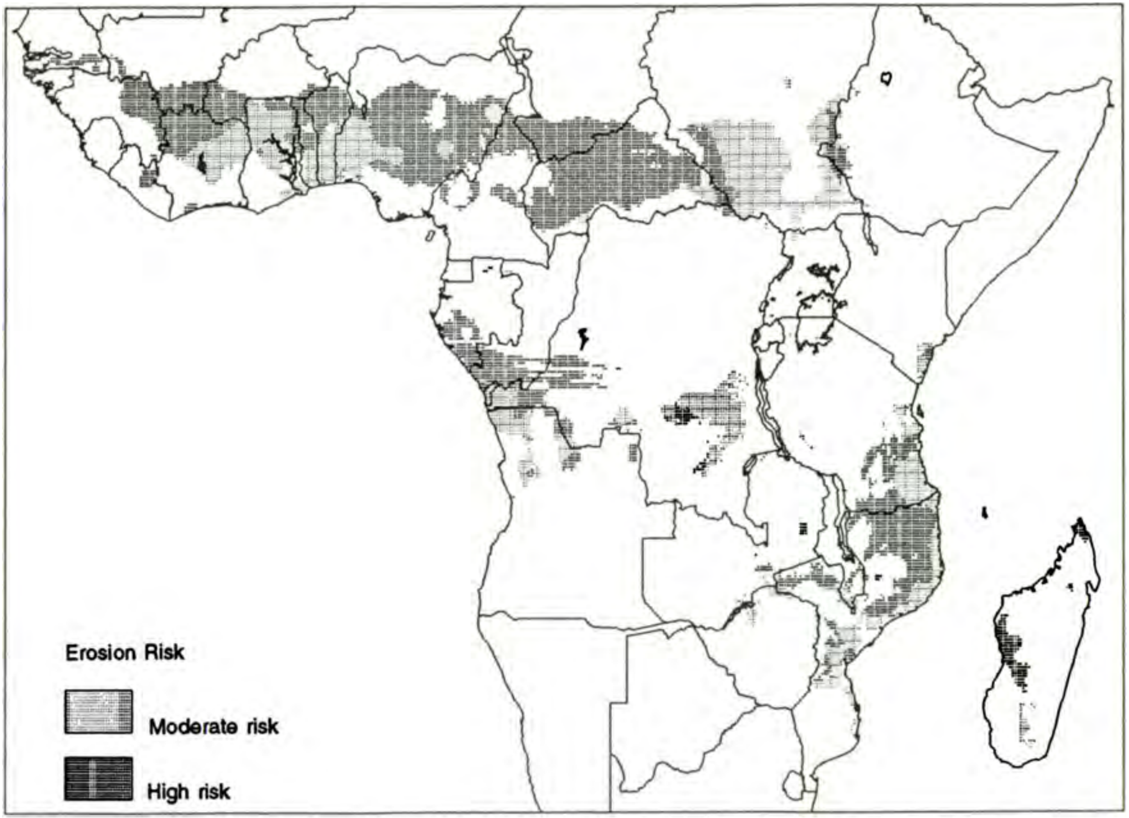

Figure 3. Erosion hazards estimated using Fournier's Index based on rainfall

The georeferenced temperature data was provided by Jones (1989) and extrapolated over Africa using data from over 1300 stations across Africa by using the inverse square distance weighing method. The results show that peak values of annual total radiation are attained at the edges of the arid and semi arid zones where clear skies and relatively high sun angles throughout the year yield annual totals in excess of 140 kcal cm^{-2} yr^{-1}. The radiation declines towards the humid zone where cloud cover and suspended aerosols (water vapors) reduce radiation receipt to values of less than 120 kcal cm^{-2} yr^{-1}. The greater areas of savanna typically have annual totals ranging from 121 to 140 kcal cm^{-2} yr^{-1}. The latitudinal position of the savanna dictates that the seasonal amplitude in solar radiation should not be large, but great contrasts are imposed by the alternating wet and dry seasons. Seasonal variation is clearly related to rainfall pattern. During the growing period, daily solar radiation receipts everywhere in the LMS fall within the range of 270-350 cal cm^{-2} day^{-1}. In this, they parallel daily values in the lowland humid tropics (280-320 cal cm^{-2} day^{-1}), while during the dry months, and in dry spells between rainfalls, daily values rise to 440 kcal cm^{-2} day^{-1} parallelling daily values in the arid and semi arid zones. Usually the highest radiation receipts occur in the late dry season, and this often results in very high temperatures due to the conversion of a high proportion of this radiation into sensible heat.

3.4 Temperature

The temperature regime in Africa is distinguished by uniformly high temperatures with little seasonal variation, and no, or relatively few, occurrences of freezing temperatures (fig. 4). Annual mean temperature values are high throughout the LMS zone and generally exceed 24° C. The influence of cold ocean currents is pronounced in southern Africa. North of the equator, the patterns are more complex and extensive areas occur with mean air temperatures between 20° C and 26° C. The broad zonal patterns of the diurnal range of temperatures are affected by topography, elevation, proximity to water, presence of warm and cold ocean currents, relative distribution of land and water masses and the relative dominance of major air masses in the general circulation.

Thus, in terms of rainfall distribution, solar radiation and temperature, large areas of the savanna are climatically more suitable than the semi-arid or humid forest zones for agriculture. Rainfall is sufficient for two crops, and the selection of crops to match land characteristics becomes an important factor.

4. Agroclimatic Crop Suitability

The agroclimatic conditions outlined above largely determine the production potential and therefore, the population supporting capacity of a region. The FAO (1978) assessed Africa's potential for rainfed crop production by matching the climatic and soil attributes of land with the climatic and soil requirements of crops at low and high

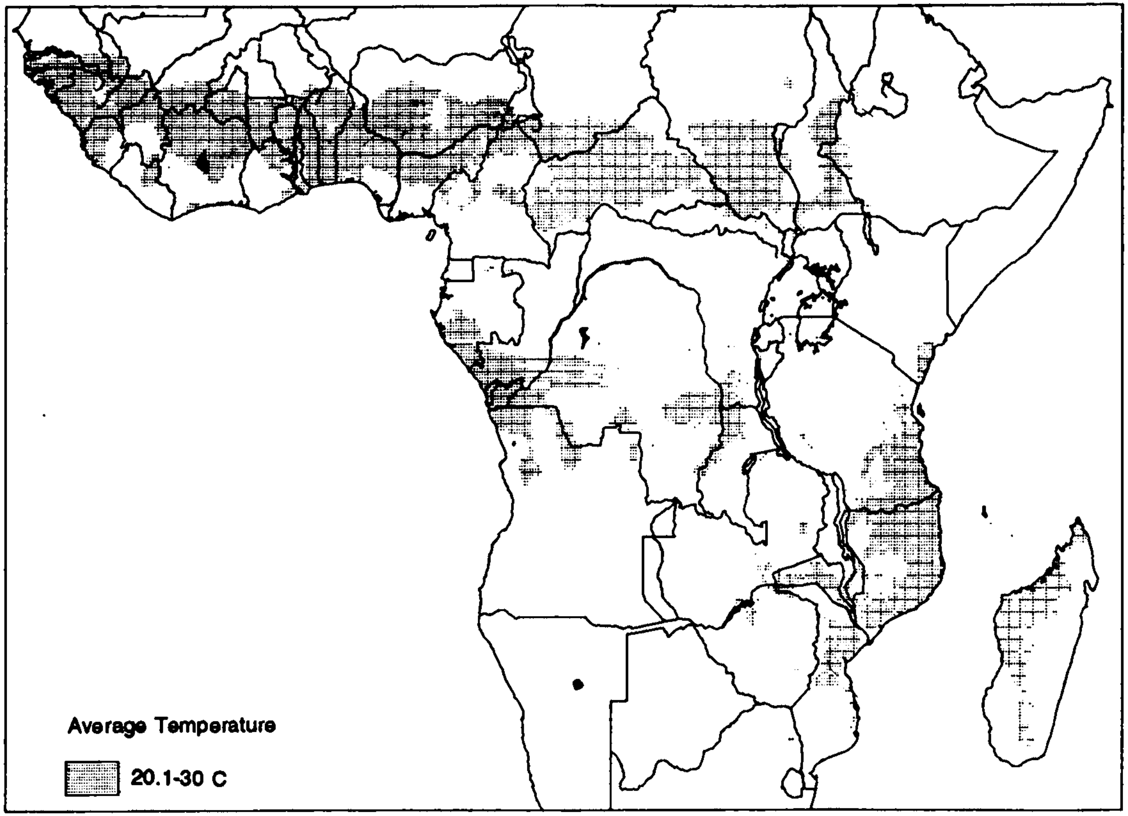

Figure 4. **Annual average temperature in degree celcius**

levels of input. The low level of input was characterized by subsistence production, manual labor, the use of local cultivars, minimal fertilization and pest control, low capital intensity, and small family holdings. With a high level of input, it was assumed that the production system would be on a commercial footing with medium to large holdings, good access to markets, improved varieties, an optimum fertility regime, timely weed and pest control, and mechanization. The agroclimatic suitability of crops was defined in terms of the range of the maximum attainable yield: 80% or more was regarded as very suitable, 40%-80% suitable, 20%-40% marginal, and below 20% not suitable. This methodology was applied to the available georeferenced data sets described above to compute agroclimatic crop suitability of maize (a C4 species) and soybeans (a C3 species) to illustrate the potential of GIS in a priority setting. Similar analysis of other crops is possible. This characterization permits a quantitative assessment of the biophysical resources upon which agriculture depends. The characterization allows farming systems and production alternatives to be compared and research spillovers to be assessed, for the improvement of resource management and for the development of sustainable production systems to meet demand.

The savanna with higher levels of insolation and a 6 - 9 months growing season is well suited to annual crops of medium duration such as groundnut, maize and soybean. For maize, 206 million hectares of land largely in the NGS and SGS are very suitable and 389 million hectares suitable, together constituting 369 million hectares of the 371 million hectares in the LMS (fig. 5). Similarly, for soybean, 110 million hectares, also largely in the NGS, are very suitable and 256 million hectares in the SGS and DS/CS are suitable for rainfed production. Joint analysis for both crops reveals that nearly 110 million hectares, largely in the NGS, are very suitable and 161 million hectares, mostly in the DS/CS are suitable.

5. Soil Resource Base

The above analysis for soybean and maize suggests that within the LMS zone different areas have differing crop potential, but within the entire MS zone there are few agroclimatic constraints to production. Analysis based on the FAO soil map for Africa (FAO/UNESCO 1977) suggests that soil fertility is the major constraint to food production. Over 80% of the DS/CS is characterized by Ferralsols (37%), Luvisols (18%), Arenosols (11.7%), Nitosols (8.8%) and Acrisols (8.2%). The SGS is dominated by Luvisols (25.3%), Ferralsols (19.2%), Acrisols (13.6%), Lithosols (11.6%), Arenosols (8%) and Nitosols (6%). The major soils of NGS include Luvisols (36%), Vertisols (12.2%), Lithosols (11.3%), Regosols (8.7%), Ferralsols (8%), with Fluvisols, Nitosols, and Arenosols each covering about 5% of the land area. These soils were classified into low, moderate, and high fertility categories (FAO 1978). The resulting map for LMS is shown in figure 6. This study of the suitability of African soils shows that all production factors are seldom at optimum level. Two

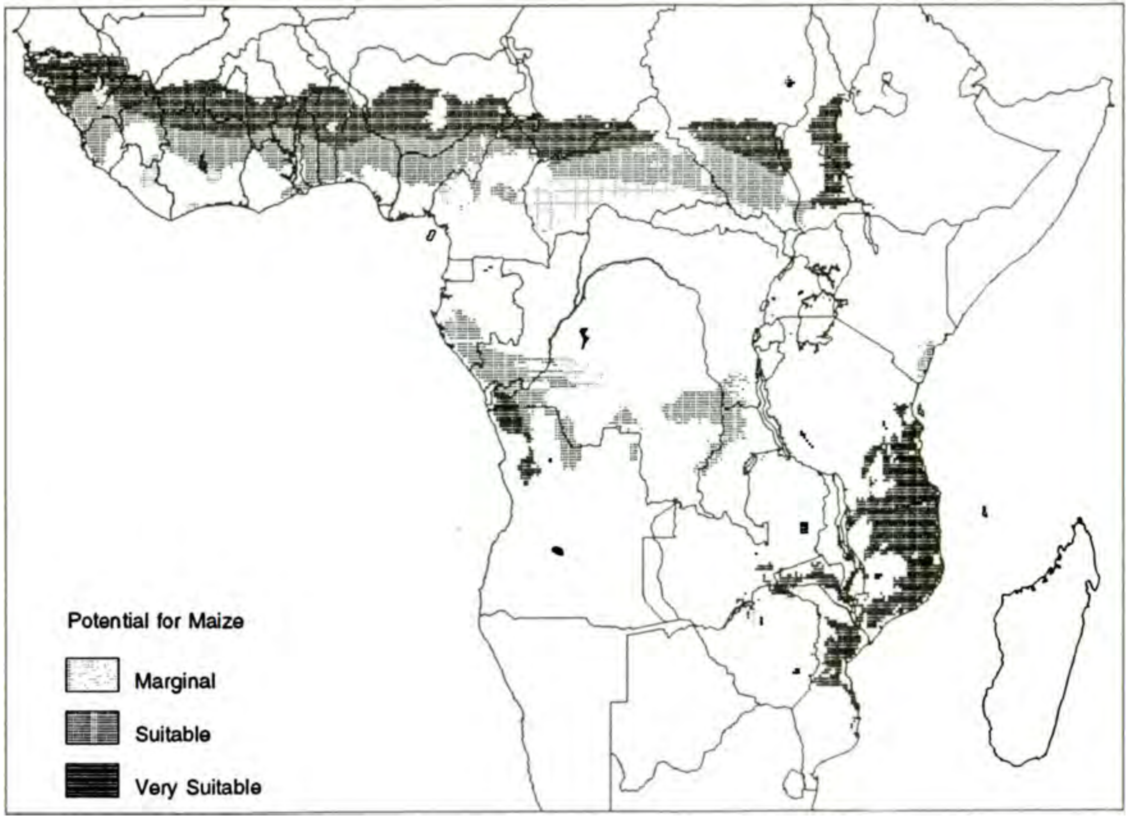

Figure 5. Agroclimatic potential of maize under low production technology

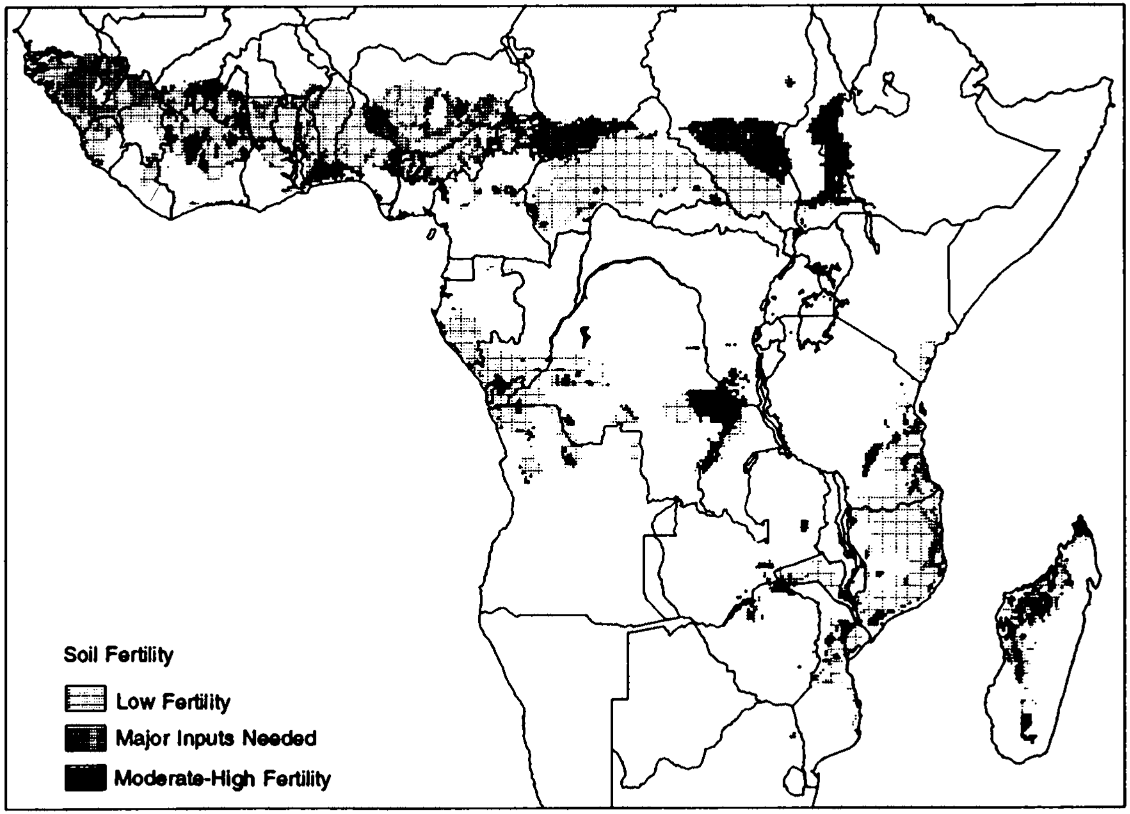

Figure 6. **Relative soil fertility within the lowland moist savanna**

hundred and twenty million hectares or 59% of the LMS soils have low inherent fertility, and a large proportion of them are found in the most productive NGS. Out of the 48 million hectares of high fertility soils, 25.7 million hectares are in the NGS, 12.6 million hectares in the SGS, and the remaining 9.7 million hectares are in the DS/CS. Comparison of rainfall for the three fertility categories shows that generally when climate conditions are less favorable, the soil colloidal complex grows richer. This poses a major challenge to appropriate and sustainable technologies for resource limited farmers of the region.

6. Dynamics of Traditional Farming Systems

African farming systems are evolving towards land use intensification in response to population increase, urbanization, and scarcity of land. The transformation of subsistence cultivation into more intensive modes of production is likely to call for different technologies in the high and low population density areas, depending on the pattern of farm management and how traditional practices are likely to vary in time and space.

6.1 Demographic pressure

Any increase in food production first requires a proper choice of soil and then a crop adapted to the ecological conditions. While an increase in yield through better soil use is technically possible, it often proves difficult owing to the complex socio-economic conditions in the region. Demographic pressure is a key variable in understanding the ongoing transformation of African agriculture. Yet, demographic pressure is an extremely complex concept that depends upon a variety of socio-economic issues such as land use, farming practices, livestock characteristics (customs or institutional frameworks) and land tenure. Data on these factors are difficult to obtain, because of the large variations at the subnational level. To approximate to demographic pressure, population density data for Africa was used (Deichmann and Eklunah 1991). As shown in figure 7, the population densities are relatively low, less than 50 people per square kilometer over 75% of the LMS zone. Less densely populated areas include inland Senegal, northern Guinea, Guinea Bissau, Côte d'Ivoire, Ghana and Benin, the valley of the Niger, the Benue valley in Cameroon and immense and sparsely populated zones in the Central African Republic, Sudan, western Ethiopia, Tanzania, Mozambique, western Madagascar, southern Congo, Gabon and Zaire. The population along the coasts of Africa from Senegal to Kenya is fairly dense (over 50 per sq km) with a few dense pockets in Burkina Faso (Ouagadougou, Ouahigouya), northern Ghana and over a large part of Nigeria where population densities exceed 100 per sq km. Population distribution by zones and countries of the moist savanna are shown in table 3. With the exception of countries in Southern Africa, approximately 25% of Africa's people reside in the moist savanna zones.

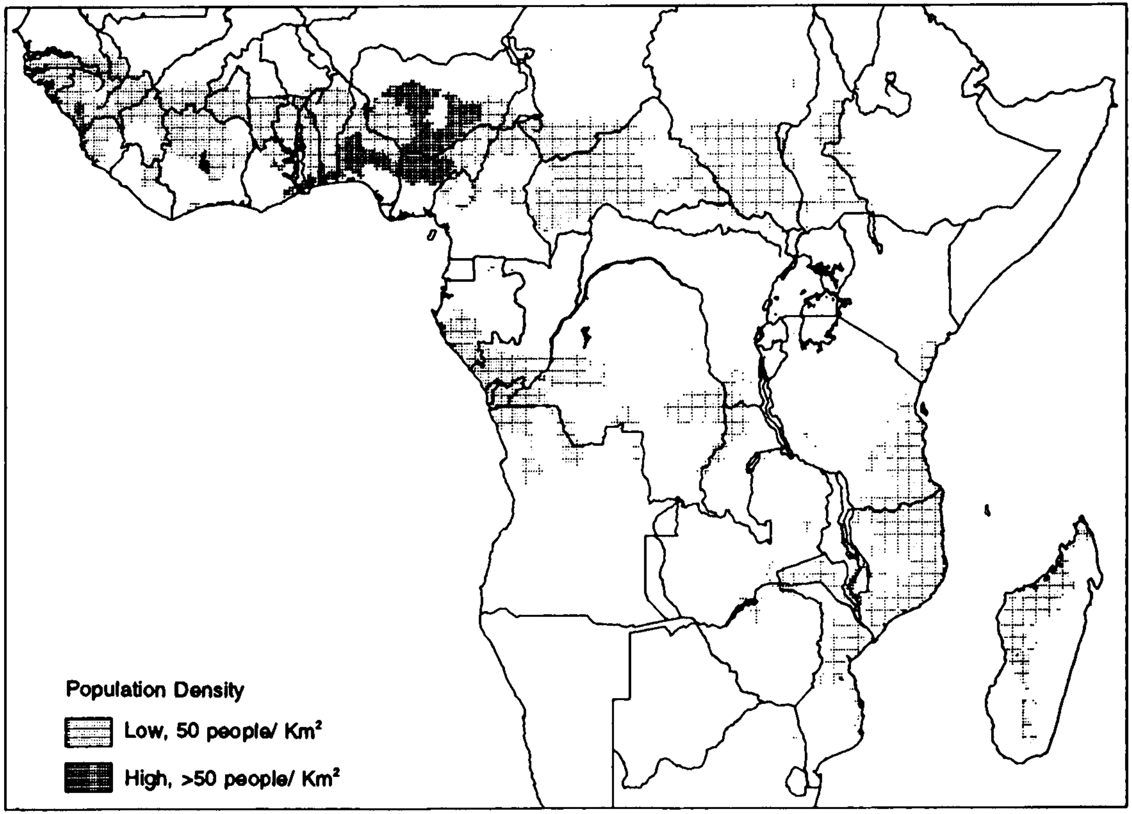

Figure 7. Demographic pressure

Table 3. Population (estimated up to 1980) by agroecological zones ('000)

Country	Total Pop.	L ALt DS*	L ALt SGS	L ALt NGS	M Alt DS	M Alt SGS	M Alt NGS	Total L Alt	Total M Alt
Nigeria	86671	27487	6175	8733	363	824	164	42395	1351
Ghana	9382	1692	584	1676	0	0	0	3952	0
Guinea	4961	1819	1477	474	145	220	0	3770	365
Benin	3060	1705	602	376	0	0	0	2683	0
Cameroon	10027	1559	357	485	1532	68	24	2401	1624
Togo	2291	1540	241	246	0	0	0	2027	0
Sierra Leone	2917	1919	0	0	0	0	0	1919	0
Burkina Faso	6834	7	293	881	0	0	0	1181	0
Mali	6914	0	348	552	0	0	0	900	0
G. Bissau	735	0	34	648	0	0	0	682	0
Côte d'Ivoire	1109	244	314	22	0	0	0	580	0
Senegal	5395	0	0	509	0	0	0	509	0
Liberia	1939	380	18	0	0	0	0	398	0
Chad	2706	0	25	240	0	0	0	265	0
Zaire	25973	4415	12	0	2175	98	392	4427	2665
C. Afr. Rep	1889	884	466	11	82	143	1	1361	226
Congo	1531	806	6	41	0	0	0	853	0
Gabon	1006	191	86	19	0	0	0	296	0
Sudan	19097	517	668	1432	137	97	29	2617	263
Tanzania	17857	784	483	1293	1102	1543	653	2560	3298
Ethiopia	37187	88	264	314	82	545	141	666	768
Kenya	16202	198	0	25	293	445	0	223	738
Uganda	11124	128	0	0	1103	346	706	128	2155
Mozambique	12421	1069	1640	3228	29	61	253	5937	343
Madagascar	8448	105	821	630	5	385	105	1556	495
Malawi	5255	59	681	648	0	231	403	1388	634
Angola	7179	828	0	0	1446	8	95	828	1549
Zimbabwe	6844	0	16	415	0	0	927	431	927
Zambia	5557	0	0	76	2	217	2377	76	2596

Note: *See table 1 for definitions

Table 3 cont'd

Country	Percentages*							
	L Alt DS	L Alt SGS	L Alt NGS	M Alt DS	M Alt SGS	M Alt NGS	Total L Alt	Total M Alt
Nigeria	31.7	7.1	10.1	0.4	1.0	0.2	48.9	1.6
Ghana	18.0	6.2	17.9	0.0	0.0	0.0	42.1	0.0
Guinea	36.7	29.8	9.6	2.9	4.4	0.0	76.0	7.4
Benin	55.7	19.7	12.3	0.0	0.0	0..0	87.7	0.0
Cameroon	15.5	3.6	4.8	15.3	0.7	0.2	23.9	16.2
Togo	67.2	10.5	10.7	0.0	0.0	0.0	88.5	0.0
Siera Leone	65.8	0.0	0.0	0.0	0.0	0.0	65.8	0.0
Burkina Faso	0.1	4.3	12.9	0.0	0.0	0.0	17.3	0.0
Mali	0.0	5.0	8.0	0.0	0.0	0.0	13.0	0.0
G. Bissau	0.0	4.6	88.2	0.0	0.0	0.0	92.8	0.0
Cote d'Ivoire	22.0	28.3	2.0	0.0	0.0	0.0	52.3	0.0
Senegal	0.0	0.0	9.4	0.0	0.0	0.0	9.4	0.0
Liberia	19.6	0.9	0.0	0.0	0.0	0.0	20.5	0.0
Chad	0.0	0.9	8.9	0.0	0.0	0.0	9.8	0.0
Zaire	17.0	0.0	0.0	8.4	0.4	1.5	17.0	10.3
C. Afr. Rep	46.8	24.7	0.6	4.3	7.6	0.1	72.0	12.0
Congo	52.6	0.4	2.7	0.0	0.0	0.0	55.7	0.0
Gabon	19.0	8.5	1.9	0.0	0.0	0.0	29.4	0.0
Sudan	2.7	3.5	7.5	0.7	0.5	0.2	13.7	1.4
Tanzania	4.4	2.7	7.2	6.2	8.6	3.7	14.3	18.5
Ethiopia	0.2	0.7	0.8	0.2	1.5	0.4	1.8	2.1
Kenya	1.2	0.0	0.2	1.8	2.7	0.0	1.4	4.6
Uganda	1.2	0.0	0.0	9.9	3.1	6.3	1.2	19.4
Mozambique	8.6	13.2	26.0	0.2	0.5	2.0	47.8	2.8
Madagasqar	1.2	9.7	7.5	0.1	4.6	1.2	18.4	5.9
Malawi	1.1	13.0	12.3	0.0	4.4	7.7	26.4	12.1
Angola	11.5	0.0	0.0	20.1	0.1	1.3	11.5	21.6
Zimbabwe	0.0	0.2	6.1	0.0	0.0	13.5	6.3	13.5
Zambia	0.0	0.0	1.4	0.0	3.9	42.8	1.4	46.7

Note: Percentage is calculated by dividing population in a zone by country's population

6.2 Infrastructure/market access

Intensification of food production in the savanna is also likely to be a result of infrastructural and technical changes: the development of roads, waterways and railways, improvement in access to markets, government price controls, and incentives for cash crop production. Transportation networks formed by primary (all weather) roads and secondary (dry season) roads, major waterways and railways were digitized from available road maps for countries south of the Sahara (except Madagascar). This map was overlaid on a 10 minute grid map of Africa. A grid unit was classified to have good access if at least one of the means of transport passed through it. The resulting accessibility map is shown in figure 8. Out of the 389 million hectares of the LMS, nearly 76% is characterized by poor access. Of the remaining 24% which has good access, nearly 80% is in Nigeria. In general, the countries in Central and East Africa have poor access, while those in West Africa have relatively good access. This diversity within the LMS requires different technological packages.

6.3 Land use patterns

People in areas with good market access tend to produce a greater quantity of cash and export commodities. However, many farming communities, because of poor roads and great distance from cities, have only limited access to urban markets. Farmers in these places will not be able to boost their income from food production significantly. Under population-driven intensification, but where access to markets is poor, farmers who are accustomed to subsistence production may try to raise the output of staple crops using low levels of purchased inputs but only succeed in depleting soil nutrients and contributing to the build up of weeds. Under the market driven scenario, good market access, proper technologies and favorable policies serve to stimulate increased production of cash crops under higher levels of purchased inputs.

Areas with low population densities (less than 30 people km^2) and poor access to markets are likely to have subsistence agricultural systems, while areas with higher population densities (over 30 people km^2) and better access to markets are likely to have market-oriented systems.

Out of the 389 million hectares of the LMS, 261 million ha or approximately 60% of the area has poor infrastructure, as well as low population density. This area has high agroclimatic potential, however, a substantial investment in infrastructure will be necessary to encourage farmers in the region to produce more.

7. Conclusions

The lowland moist savanna zone is agroclimatically suitable for crop production. It receives higher total radiation per year than the humid zone and the temperatures are favorable for year round crop production. The region exhibits considerable variability in total annual rainfall and is characterized by high seasonality. Over the last 30

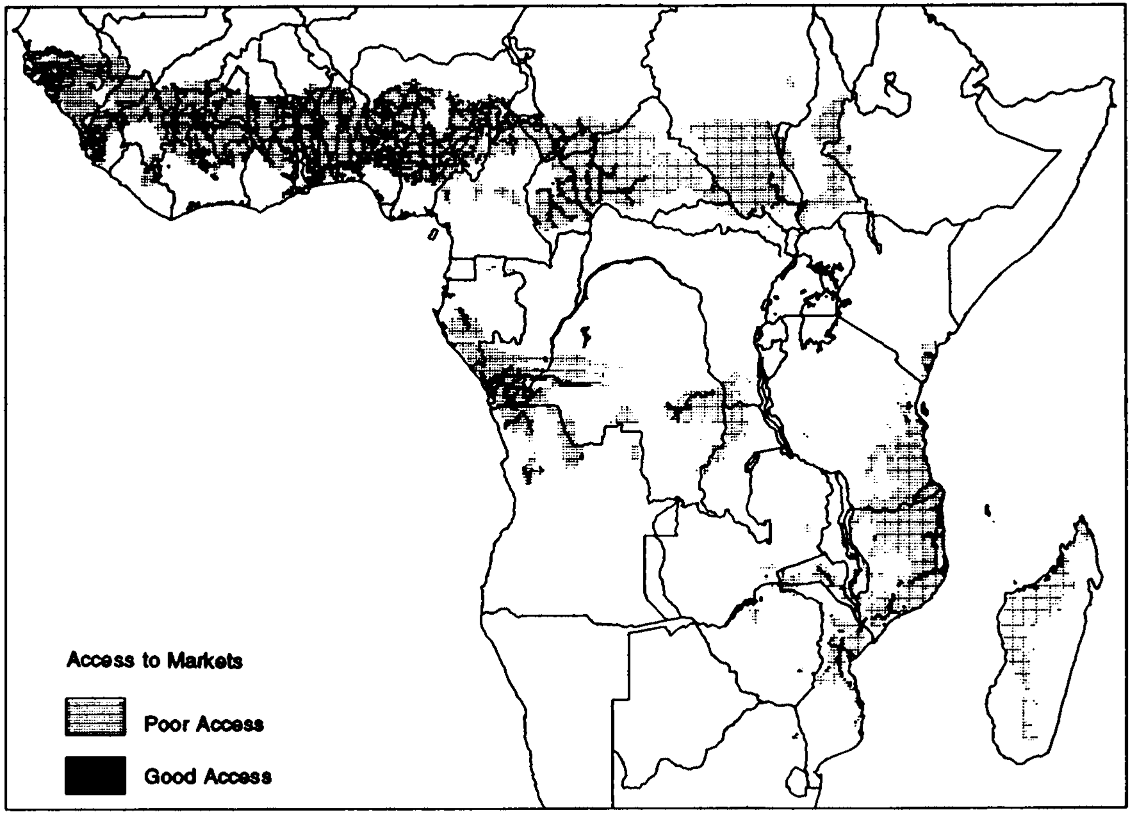

Figure 8. Access by river, rail and roads within the lowland moist savanna

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

A.O. Isichei[1] and I.O. Akobundu[2]

[1]*Department of Botany, Obafemi Awolowo University, Ile-Ife, Nigeria*
[2]*Moist Savanna Program, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria*

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).

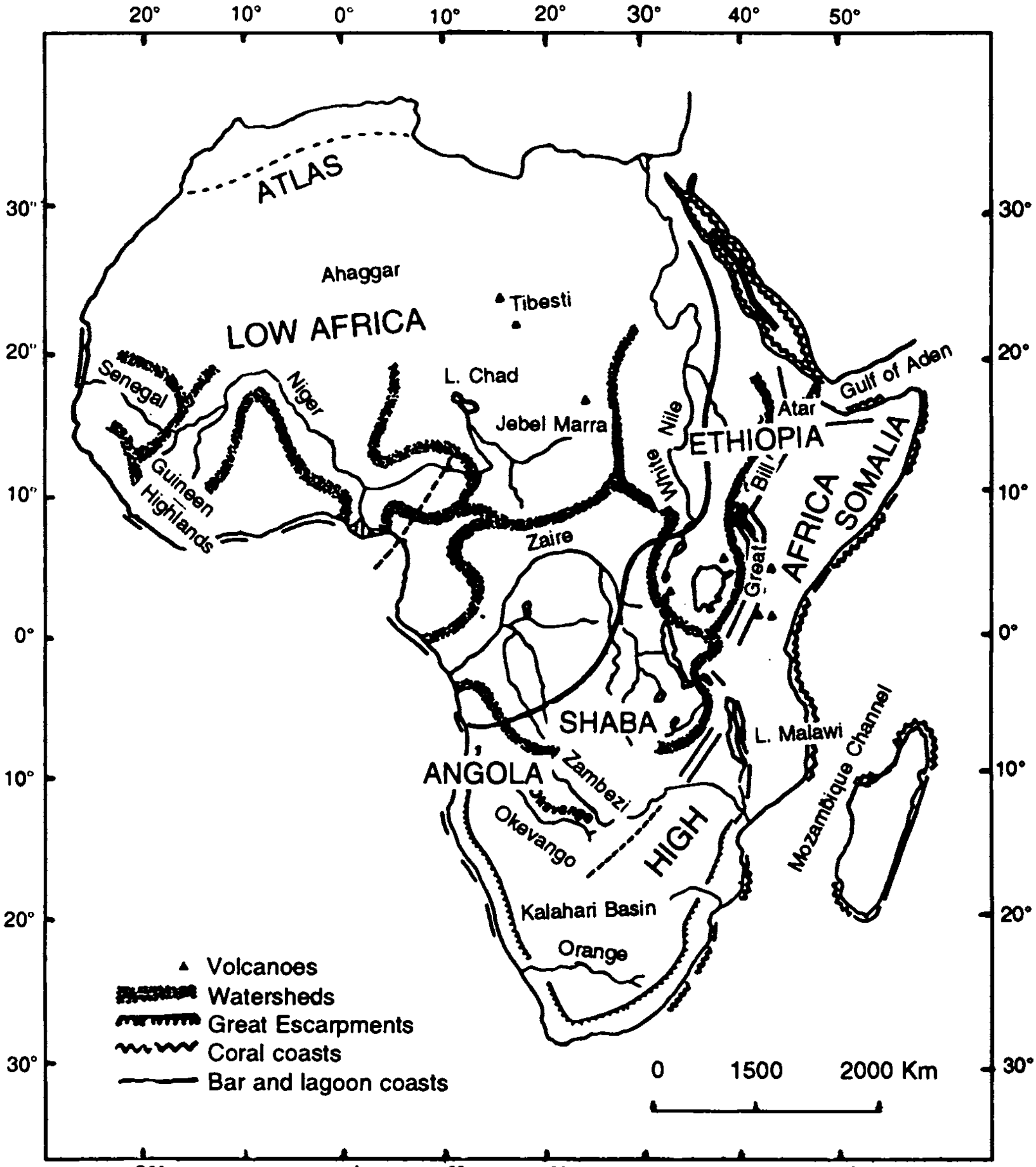

Figure 1. Physical features of Africa (after Grove 1978)

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,*

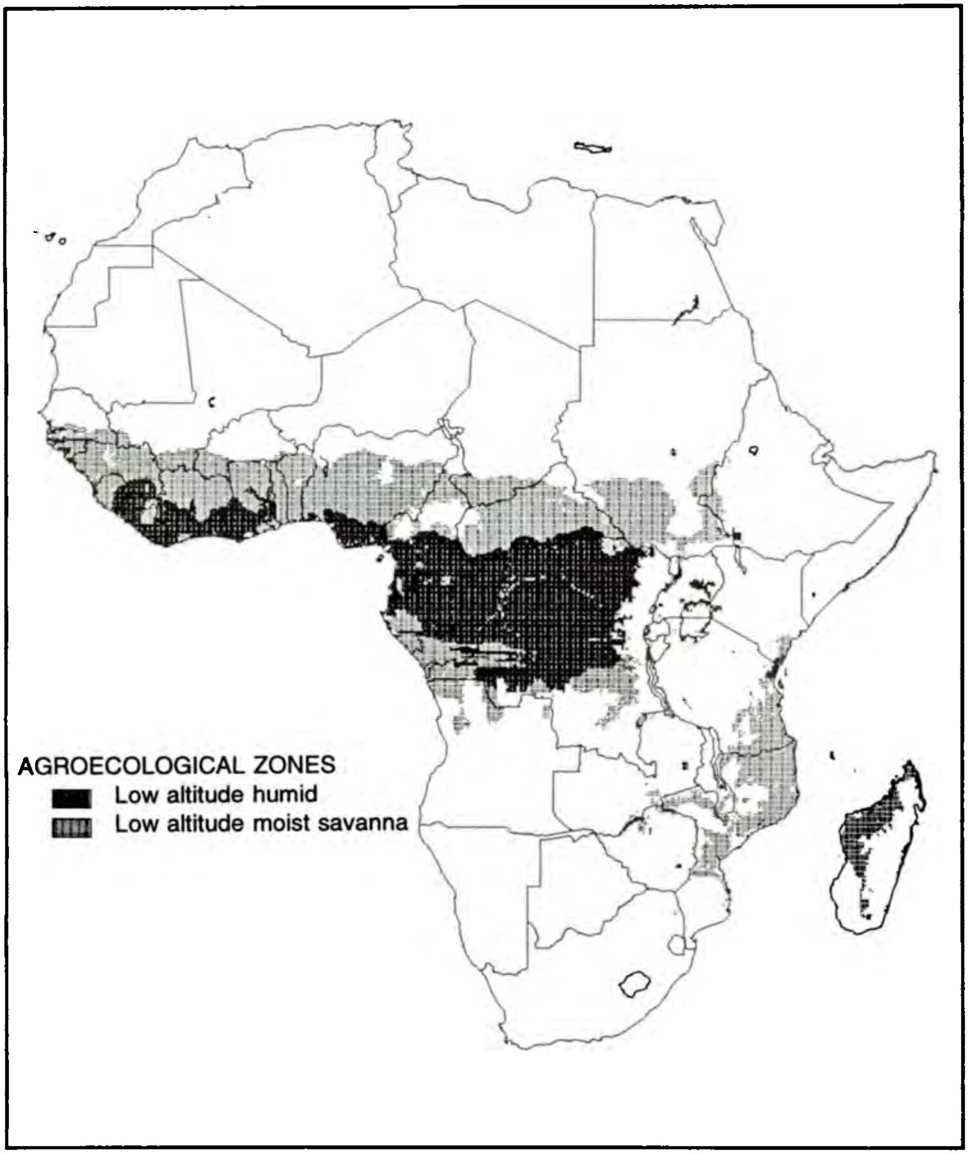

Figure 2. Agroecological zones of West and Central Africa

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 equisetifalia* 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* (Döbereiner 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, Pandanu's 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

Bede Nwoye Okigbo

United Nations University (UNU), c/o UNDP, P.O. Box 1423, Accra, Ghana

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 dominated by perennial grasses, and a *Combretum-Acacia* woodland in East Africa. In wetter areas of 1200-1500 rainfall the vegetation is mainly forest; derived savanna vegetation with southern Congolian evergreen forest and woodland. It must be emphasized that the vegetation in the zone has been greatly modified by human activities, annual fires and grazing by livestock and wild animals.

1.3 Primary productivity

The primary productivity of the moist savanna zone (MSZ) is related mainly to the prevailing rainfall and may be influenced by the incident radiation. In much of the MSZ, the net primary productivity ranges from 200-300 g/m² in West Africa as compared to less than 150-250 g in East and Southern Africa. Actual field observations in the Guinea savanna areas in West Africa report productivity of 14 t/ha in Nigeria in areas of 1200 mm annual rainfall, 19 t/ha in the *Loudetia simplex* savanna and 10-11 t/ha in the Andropogoneae savanna, both of Côte d'Ivoire.

1.4 Soils in the MSZ

The dominant soils in these areas are Alfisols in the Guinea savanna of West Africa, East African highlands, Mozambique and southern Zambia; Oxisols which are strongly weathered in parts of Zaire and highland areas of Central and East Africa; Ultisols with slightly lower base saturation in B horizon than Alfisols; Entisols and Inceptisols formed of alluvial and colluvial materials in valleys, especially in southern Sudan; and Vertisols or dark clayey cotton soils that swell when wet and crack on drying in the Lake Chad area, Accra plains, the Sudan and parts of East Africa. With the exception of the last two, most of these soils are highly weathered and of low inherent fertility.

2. Historical Background to Agriculture in the Moist Savanna Zone

The MSZ in West Africa is the so-called Middle Belt where there is low human population density. It lies between two parallel zones of higher population density — to the south is the humid area zone and to the north is the Sudano-Sahelian zone. Agriculturally, it is an area that is suitable for cereals such as maize, rice and sorghum; root crops such as cassava and yams; legumes such as Bambara nuts, groundnuts, cowpea, soybeans, pigeon pea; and several fruit and vegetable crops. Despite these potentials, however, the area has remained agriculturally under-developed and sparsely populated.

2.1 Reasons for low agricultural development and low population density

The MSZ is bedeviled with several endemic parasitic diseases such as onchocerciasis, tsetse-fly transmitted trypanosomiasis of both man and livestock, malaria and schistosomiasis. The overlap of areas of endemicity of these parasitic diseases contributes to the low level of agricultural development of the zone in West Africa.

It is also speculated that the route used by raiding parties during the slave trade from the coast to inland areas ran through the belt and this also contributed to the depopulation of the area.

Table 1. Farming systems encountered in the moist savanna of sub-Saharan Africa

Traditional and Transitional	Modern and their Local Adaptations
1a. Shifting Cultivation Phase 1 L >10	1. Animal Based Systems
b. Intrusive pastoralism transhumance	
	(a) Ranching
2. Recurrent Cultivation/Fallowing	
Shifting Cultivation Phases II/III, L = 3-10	(b) Intensive animal production
(a) Middle-term fallow L = 5-10	. Poultry
(b) Short-term fallow L = 3-5	. Piggery
	. Dairying, etc
3. Semi-permanent	. Fish farming
4. Permanent Cultivation L < 3	2. Crop Based Systems
1. Lowlands	(a) Intensive cropping in rotations or monoculture.
(a) Uplands:	. Non-irrigated
. home gardens	. Irrigated
. Planted rotations or short-term fallow	
. Parklands	(b) Specialized horticulture
	. Market gardening
(b) Low lying areas, valley bottoms, floodland	. Commercial vegetables
	. Commercial flowers
. wet rice and other crops	. Commercial fruits/tree crops
. Flood land cultivation	. Commercial fruits & vegetables
. Valley bottom/fadama	
	3. Mixed Farming
2. Highland areas	
(a) No terraces	
(b) Terrace farming	

Note: L = C+F/C where L = Landuse factor, C = Cropping period, F = Fallow period
Adapted from FAO (1983)

2.2 Socio-economic background

The economies of most of the 17 countries with sizeable areas of land in the MSZ are agricultural, and in most cases over 70% of the population is engaged in agriculture. Adult literacy is mainly below 60% in most of the countries and the number of newspapers per 100 people in many countries is less than one. Poverty is pervasive with per capita GDPs below US$2,000 and in most cases between US$250 and $500. The proportion of the population in absolute poverty is about 60%. The calorie intake of 95% of the population is below requirements and malnutrition is common. The percentage of underweight children ranges from 17 to 47% for under 5 years of age. In most cases more than 70% of the total population live in rural areas. The foreign debt amounts to from 70-426% of GNP. The number of R and D scientists per 10,000 people ranges from 2.2% for the Central African Republic to 12.4% for the Congo. Finally, most of the governments are politically unstable. In general, it can be concluded that most countries are poor, mainly agricultural, have populations with high rates of illiteracy, and corresponding low levels of human resource development and institutional capacity. They find difficulty in achieving self-reliance and in scientifically improving agriculture through sustainable management of their natural resources.

2.3 Land use and agricultural systems

The prevailing farming systems of this zone are commodity or co-commodities based, but at the same time they reflect specific resource management systems related to the prevailing environmental conditions and the culture of the people. In West Africa, agriculture started with indigenous domesticates in an area between the seed agriculture of the sorghum-millet zone and the vegeculture of the forest zone, involving the cultivation of yam and tree crops. The domesticates grown in the MSZ consisted of cereals, the most important of which were the hungry rice, *Digitaria exilis, Digitaria iburua* and *Brachiaria deflexa*. It would appear that with time African rice, *Oryza glaberrima*, sorghum, *Sorghum bicolor* and foxtail millet, *Pennisetum americanum*, which were domesticated further inland in the seed agricultural complex zone, made their way into some northern parts of this zone. Other grain crops of this zone consist of grain legumes such as African yam bean, *Sphenostylis stenocarpa*, Bambara groundnuts, *Vigna subterranea*, and Kerstings groundnuts, *Macrotyloma geocarpa*. Another indigenous grain legume found here is pigeon pea, *Cajanus cajan*. The indigenous root crops of the zone consist of: (a) Guinea yam, *Dioscorea* spp. which is supposed to be a domesticate of the traditional *Vegecultural complex* of the forest zone, though it is speculated that they originated outside the zone (Coursey, 1976); (b) the Hausa potato, *Plectranthus escolantus*; and (c) Piasa, *Solenostemon rotundifolius*.

Both Guinea yam and Hausa potato are labiateous root crops of the Middle Belt and are known to be endemic in the zone. There is no clear cut evidence as to the antiquity of these crops in Western Africa.

Pennisetum millets spread southwards into the savanna area during 3000-1000 BC as the Sahara desert became desiccated, about 2000 BC. Yams, which are claimed to have originated in the eastern end of the savanna forest/savanna ecozone about 2000-3000 BC, gradually spread throughout the zone and entered the forest zone through river valleys and forest margins, as iron tools became available by 1000 AD. Sheep and goats and later cattle were introduced into savanna areas by 1000 BC. Asian crops, *Dioscorea alata*, bananas and plantains, oranges, Asian rice, taro

(*Colocasia esculenta*) and tannia (*Xanthosoma mafaffa*); and American crops such as maize, cassava, groundnut, papaya, etc. were later introduced and grafted into the indigenous farming systems of the zone.

In East Africa, pastoralism preceded crop cultivation. There is evidence that cattle rearing occurred in the Serengeti area around 5000 BC. The most important crop domesticated in the zone was finger millet, *Eleusine coracana*, grown in addition to Bambara groundnuts, sorghum and other grain crops introduced from other parts of Africa. The Malayo-Polynesian crops such as banana/plantain, water yam and Asian rice were introduced via Madagascar into Maputo Bay in Mozambique by 200 AD. In Southern Africa, pastoralism also came first but in parts of Zambia and Zimbabwe African grain crops like sorghum and millet were being grown as well as the Livingstone or Kafir potato *Solenostemon* spp.

3. Farming Systems in the MSZ

A typology of the farming systems found in the MSZ is shown in table 1. The shifting cultivation farming system may be regarded as disappearing, although it is claimed to exist in isolated areas in Western, Central, East and Southern Africa. There is no doubt, however, that due to increasing population pressure, urbanization and commercialization of production, almost all farmers have become sedentary at least for varying periods of time during the year. Pastoralists found in the zone are mainly those practicing transhumance, who move into the zone during annual migrations in search of water and forage. Bush fallows in the zone are mainly woodland or thick grassland fallows since the zone is outside the real forest zone. Fallow periods rarely last for 10 years.

3.1 Recurrent cultivation

This involves the existence side by side of intercropping and relay cropping rotation on farms managed by individual households. While rotation under different lengths of fallow occurs in upland areas and valley bottoms owned by the same household and sometimes by communities, permanent farming on home gardens and on fields or plots near to the homestead is also a component of the enterprise under the same farm family. Parklands consist of almost continuously cleared and cultivated land surrounding villages or communities, where the natural vegetation has been replaced by farmland and on which only economically viable trees are dotted about the fields.

3.2 Terrace farming

This type of system exists as a relic of the past where the terraces were built for defence purposes; and also in a few areas in parts of Kenya and Tanzania where they were constructed as part of the soil conservation practices enforced during the colonial era.

3.3 Modern farming systems

Modern farming systems and their local adaptations developed as a result of changes in the environment of farming objectives and the introduction of new crops and their associated methods of production. These changes included the introduction of Asian and American crops, commercialization of farming, irrigation of crops, use of fertilizers, genetic improvement of crops, mechanization, new diseases, pests and weeds.

4. Case Studies or Examples of Farming Systems in the MSZ of West Africa

A specific case study of yam-based farming systems in the Middle Belt of Nigeria is used to illustrate some of the traditional resource management strategies, commodity diversification methods and technologies used in different locations within the same ecological zone as reported by (Diehl 1982). The three villages studied by Diehl include Tawari, located on the rolling hills of sedimentary ironstones and sandstones lying between Abuja and the river Niger north of Lokoja, Eganyi, south of the Okene-Lokoja road, and Osara to the north of the Okene-Lokoja road. Land around Tawari is relatively scarce, hilly and unsuitable for arable farming. Land in Osara is on even topography suitable for farming, and limited only by two rivers to the north and south but not in the east-west direction. Land in Eganyi is located in the interflow between two inselbergs where land is limited and many farmers have to farm either fields very close to their homes or distant fields where more land is available.

Various characteristics and practices used in resource management and production are shown in table 2. It is obvious that differences exist among villages.

These could be in farm size, number of fields and plots in uplands and lowlands, extent of fertilizer use, fallow versus cultivation period, the areas allocated to yams and other crops, etc. Crops found on the farms consisted of:

Cereals	—	maize, sorghum, pearl millet and rice (Asian and African)
Root/Tubers	—	yam, cassava, sweet potato
Grain legumes	—	cowpea, yam bean, pigeon pea, groundnut
Other crops:	—	vegetables, melon, cotton, benniseed

Table 2. Observations on farm characteristics and some practices in three villages in the Middle Belt of Nigeria

Observation		Tawari		Osara	Eganyi		Entire
		Gwari	Bassa		Near	Far	sample
1. Farm size (ha)	(i) Cultivated	2.56	2.19	1.35	2.54	1.69	2.04
	(ii) Total farm	3.66	3.13	2.42	5.08	3.38	3.40
2. No. household members per ha		3.0	3.6	6.2	5.4	7.4	5.0
3. No. of livestock —	Goats	1.93		0.81	2.14		
	Sheep	1.07		--	--		
	Poultry	2.1		3.31	11.45		
	Ducks	1.1		--	--		
	Dogs	2.4		0.25	1.45		
4. Total value of livestock (₦)		76.85		26.95	109.15		
5. No. of fields cultivated		1.9	1.7	5.6	2.6	3.0	3.0
6. No. of plots cultivated		4.2	3.1	8.1	7.0	6.7	5.8
7. No. of upland plots		--	--	7.0	8.2	5.8	
8. No. of lowland plots		--	--	1.1	0.6	0.9	
9. Plot size (average) ha		0.6	0.71	0.16	0.3	0.25	0.35
10. Use of fertilizer		Common		None/Errata	None/Errata		
11a. Fallow period (years)		5 - 6		--	--		
b. Cultivation period (years)		14 - 15		--	--		
c. Fallow period							
	Uplands (yrs)	--		4 - 5	6 - 7		
	Lowlands (yrs)	--		1 - 3	1 - 3		
d. Cultivation period							
	Uplands (yrs)	--		6 - 8	6 - 7		
	Lowland (yrs)	--		1 - 3	1 - 3		
12. Yam Preplanting Cultivation		Mounds		Ridges	Mounds		
13a. Yam crop	Uplands (ha)	1.04	0.93	0.37	0.54	0.35	0.67
	Lowlands	--	--	0.09	0.29	0.30	0.12
b. Non-yam crop		1.52	1.26	0.87	1.71	1.04	1.26

4.1 Cropping patterns

Crop rotations vary, as do the crop combinations which are adapted to changing soil and topographic conditions. Lowlands or hydromorphic areas are usually cropped with yam. Ridges and mounds in lowlands are larger in size than in uplands in order to ensure that the yam and its roots are above the water table. As one ascends the lower slopes vegetables and rice are by sorghum and melon. On the upper slopes rotation starts, with yam sometimes preceded by cowpea, melon and sorghum, with the sorghum stalks serving as trellises for the yam vines. This is a practice commonly used near Ilorin in Kwara State of Nigeria. Crop allocations vary and despite the importance of yam, more space is allocated to sorghum and millet.

5. Cropping Patterns and Systems in the MSZ

In addition to yam-based cropping systems which are important in the MSZ, other cropping systems should be considered in order to get a better picture of the farming systems, resource management and other related issues. Norman et al. (1982) reviewed the farming systems in the savanna areas of Nigeria, which included the Sudan savanna and observed the following:

1. A ring cultivation system exists in most communities, in which a set of concentric rings of cultivation are found around villages where farmers use upland fields close to their compounds and the village to grow crops permanently. They maintain fertility with household refuse and crop residue. Sheep, goats, chickens and other animals are not allowed to damage crops on neighbouring farms and are housed in the compound at the beginning of the rains and during the planting season and their droppings are used to enrich the soil.
2. Intensive husbandry decreases as one moves further away from the compounds and in these distant fields, called *gona* in northern Nigeria, fallowing of varying periods is practiced. In addition to *gonas* there are also valley bottoms and low lying areas with a high water table called *fadamas* that are used to produce such crops as vegetables, rice and sugarcane which have high water requirements.
3. Different land management practices are used for different cropping systems on gonas and fadamas. Gona crops are grown on ridges with systematic planting patterns in the Zaria area. Fadama crops are grown on the flat but sometimes on mounds.
4. Cropping patterns and systems in the savanna consist of:
   a. sole cropping
   b. mixed cropping of a varying number of crops in mixtures

5.1 Sole crops

In the Zaria survey, sole crops constituted 22.6% of the cropping systems, two crop mixtures 39% and 5 or 6 crop mixtures 5%. Plantation crops or tree crops such as citrus and mangoes may also be grown as sole crops. Sole cropping is also wide spread in some hydromorphic soil conditions of the MSZ where sugarcane, taro, bananas, rice, vegetables, etc. may be grown. Plantains have been observed growing in hydromorphic soils in the Abuja area, far north of the area to which the crop is normally adapted, because of supplementary irrigation.

5.2 Mixed cropping

This is a food security crop diversification mechanism by which the farmer selects and grows those crops that symbiotically complement each other, make more efficient use of the environment, resist pests, diseases and weeds, and ensure that the soil is covered during most of the year. The farmer may spread labor more evenly throughout the year. In mixed cropping, species with different periods of maturity, canopy types and rooting habits may be grown together or in overlapping sequences. In areas of monomodal rainfall there is greater flexibility for relay intercropping. In areas with bimodal rainfall as in the southern eastern parts of the MSZ in West Africa, special problems are encountered since any cropping pattern used must consist of crops that can withstand the varying periods of drought that occur between the two peaks of the rains.

6. Animal Production Systems

According to Kowal and Kassam (1978), rangeland productivity in the northern and southern Guinea savanna is estimated at 3097 and 3889 kg/ha respectively. Despite an abundance of forage, livestock production in the zone is hampered by parasitic diseases. In addition, only a few trypano-tolerant breeds such as the N'dama, Kateku and Bogawa cattle are found in the zone. According to the International Livestock Center for Africa (ILCA) (1990), the number of ruminant animals in the sub-humid zone (in millions) is 3.5 (West Africa), 1.77 (Central Africa), 11.31 (East Africa), and 3.05 (Southern Africa) amounting to a total of 26.4 million animals, equivalent to about 19.6% of the total number of ruminants in sub-Saharan Africa (SSA). The percentage of the total of ruminants in the sub-humid zone, by type, is cattle (22%), sheep (14%), and goats (64%). A significant proportion of these animals is found in the MSZ, despite the presence of parasitic diseases. Animal production systems in West Africa consist of:

1. Small ruminants and poultry production; often associated with the settlements of the owners. The animals are kept in free range conditions where or when they are not likely to damage crops; in pens where they are stall fed or fenced in enclosures where they are fed or allowed to graze.
2. Cattle are kept in pens or enclosures where they are fed and the manure from the pen is used in the maintenance of soil fertility.
3. Nomadic herders may also migrate into the zone with their cattle during annual migrations in search of water and pasture. They enter into the MSZ where some have developed complementary or symbiotic relationships with cultivators who allow them to feed on crop residues in the harvested fields in exchange for the benefit of animal droppings which fertilize the fields

4. Cattle and other ruminants may be driven by herdsmen through the zone on their way to markets in the urban areas of the south.
5. Some trypano tolerant cattle such as the N'dama and Kateku are adapted to the zone and are kept in small numbers. The prevailing production systems in Central Africa are not much different from those of Western Africa except that the dominant crops are mainly maize, banana, sweet potatoes and cocoyams.
6. Apart from these traditional systems, intensive animal production systems for poultry and fish are also encountered using modern techniques.

7. Agricultural Systems in East and Southern Africa

The main difference between the production systems in the MSZ in West Africa and those in East and Southern Africa is the presence of a large area of highlands east of a line drawn from north-western Ethiopia to Luanda in Angola. The highlands in parts of Africa have rendered local climatic conditions more sub-tropical than tropical. The MSZ that are lowlands or at medium altitude are restricted to small areas in coastal parts of Kenya, parts of Tanzania, Mozambique, Swaziland, Zambia, Zimbabwe, Angola and the Malagasy Republic.

In East Africa, agricultural production systems and land use are closely related to altitude and much influenced by the fact that less than 20% of the area (mainly in Uganda, Tanzania and parts of coastal areas of Kenya) has an annual rainfall over 750 mm; there are several locations with bimodal and even trimodal rainfall regimes, requiring special cropping sequences and patterns.

Hickman et al. (1973), Berry (1976), Porter (1976) and Hickman (1986) have reported the association of crops and production systems according to altitude in East Africa. According to Porter, the general pattern is as follows:

- Areas over 2000 m (wet and cool): Potatoes, wheat, finger millet and maize are present.
- Areas 1250 - 2000 m: Finger millet and maize are the best suited crops with common beans in addition to cassava, sweet potatoes and bananas where rainfall is adequate.
- Areas lower than 1250 m (Warmer with variable rainfall less in absolute amount): The crops grown here include maize and sweet potato which are increasingly being displaced by sorghum, bulrush millet, pigeon peas, Bambara nut, castor seeds, cowpea and cassava with better parts of the sub-humid and semi-arid areas producing oil crops such as sesame, sunflower and groundnut.

Valley bottoms are used for rice production. As the rainfall decreases, livestock/pastoralism become more important in non-tsetse infested areas. Unlike West Africa, Porter regards maize as the most widely grown rainfed crop in East Africa.

7.1 Farming systems in East Africa

These are in general similar to the systems in Western and Central Africa with the exception of the influence of altitude and its climatic effect. The main systems of importance in the limited areas of lowland MSZ include:

a. shifting cultivation and woodland fallowing
b. home gardening
c. market gardening
d. plantation cropping
e. animal production

7.2 Shifting cultivation and woodland fallowing

As in West Africa, shifting cultivation has increasingly if not totally given way to woodland or grassland fallows of differing duration. Sole cropping and intercropping are both practiced, with maize-based cropping systems as the most widespread with less complex crop mixtures.

It should be noted that in East Africa trees or perennials feature in the crop mixtures more than in West Africa where, in the traditional systems, they are more associated with home gardening. In the coastal areas of Kenya cashew may be intercropped randomly with coconut, mango, banana and cassava. Elsewhere along the coast in East Africa coconuts may be intersown with pastures or planted at spacings with bananas, cashew and mango. The island of Zanzibar specializes in the production of cloves, coconut, fruits and vegetables.

7.3 Home gardening

Home gardens in East Africa are not as complex as in West Africa, and are found in the more humid areas and have fewer fruit trees except along the coast. In East Africa, cowpeas grown for their leaves are planted in batches with other food crops; vegetables of the *Brassica* species called *sukumawiki* are more common than indigenous vegetables.

7.4 Plantation crops

In East Africa, plantation crops such as coffee and tea, especially in medium altitude areas, feature in the cropping system and although they are grown in large estates, smallholder production is also practiced. Tea grows best at 100 - 2200 m altitude and arabica coffee at 1000 - 1500 well outside the lowland MSZ. It is mainly banana, coconut, cashew, papaya, etc., that are grown in the coastal areas of the savanna.

7.5 Market gardening

This is more developed in East Africa than in West Africa. In both Kenya and Tanzania, coastal areas have successful market garden enterprises which supply urban areas inland and are needed to support the flourishing tourist industry. In Kenya, important market garden crops consist of vegetables, fruits and flowers. In Tanzania, market garden production according to Verheij (1982) takes place in the coastal, plateau, lake and highland areas.

7.6 Animal production systems

In the MSZ of East Africa, animal production is more important than in West Africa. In the sub-humid coastal areas of Kenya, dairy farming is growing in importance, especially in the coconut-cassava and the cashew-nut/cassava zones. The International Livestock Center for Africa (1990) reports that in the coconut zone 90% of the farmers grow coconut as a cash crop while in the cashew nut zone 51% grow cashew-nut, 25% citrus, 81% mango and 19% oil crops. Other crops grown for subsistence in addition to maize and cassava include pea, rice, banana and bean. Most of the crops are intercropped; in the coconut/cassava zone two crops were grown each year, while only one crop was grown in the cashew-nut/cassava zone. Along the coast 32% of the cattle were kept in the coconut zone and 29% in the cashew-nut zone. In the coconut zone 36% of the farmers kept no animals, 46% kept small ruminants, 13% kept cattle and small ruminants, 5% kept only cattle as compared with the cashew nut zone where there were 35% of farmers with no animals, 44% of which kept small ruminants, 15% who kept both cattle and small ruminants and 6% who kept only cattle.

7.7 Land use

In general, cropping systems are adapted to the prevailing edaphic conditions in upland, lowland and highland areas. The valley bottoms are used for dry season vegetable, banana, rice, taro, sugarcane, etc. as in parts of West Africa.

7.8 Cropping systems in relation to rainfall regime

In the monomodal rainfall areas of the MSZ, an agronomist designing new cropping systems faces the problems of variability in onset, duration, cessation and total amount of rainfall. In bimodal rainfall areas in the MSZ of East Africa, the problem is one of taking into account the same variations in addition to those of onset, duration, cessation and amount for the minor and major rains and of the dry period in between the peaks.

7.9 Farming systems of the Southern African MSZ

The most significant factor in this part of Africa affecting the farming systems, apart from the climatic conditions moderated by altitude, is the widespread occurrence of the *miombo* ecosystem dominated by the *Brachystegia* - *Julbernadia* spp, where the *chitemene* system of shifting cultivation is practiced. The system consists of a strategy of slash and burn adapted to areas of sparse vegetation or low biomass yield of cut vegetation with limited nutrient content in the ash after burning.

The settlement of Europeans and Asians in the region who own large scale farms and the suitability of highland areas for sub-tropical fruits and vegetables have had considerable influence on agriculture. These factors have caused land scarcity for Africans and have also led to the early development of commercial agriculture.

Traditional cultivation in the area consists of shifting cultivation designated as *visosa* in Malawi and *chitemene* in Zambia. In the chitemene system described by Miracle (1967), due to the limited amount of biomass in the ecosystem, farmers clear 5 to 20 times the area to be farmed, pile up the wood and plant residues when they are dry, burn them and spread the ash on the land to be farmed, thus supplying nutrients to the crops. The Bemba of Zambia who practice the chitemene system in the miombo ecosystem operate a system of fields in which a farm household may have the following:

- Typical bush fallow field cultivation
- Anthill (termite mound) cultivation
- Coleus potato garden
- River gardens
- Hutsite gardens

Each of these has specific cropping patterns. Special practices used in these cropping systems include:

i. the use of volunteer self-propagated sorghum and groundnuts which are allowed to become components of the traditional crop mixtures
ii. elaborate piling of wood and trash in the chitemene system for burning to obtain ash and fertilizer
iii. movement of homesteads to facilitate the cropping of fertile hutsites. Each year, farmers are compelled to clear farm plots further and further away from the village and may walk up to 16 km to reach them (Grove and Klein 1979). Grove and Klein (1979) also noted that the chitemene system is on the decline as many men have left the villages to work in mines and women find it difficult to do the clearing

It should be emphasized that many changes have taken place since the colonial era. For example, according to Brouillette et al. (1974), the commonest crops in Mozambique are rice, wheat, cotton, maize, kenaf, banana, sugarcane and vegetables such as tomato, potato, onion and beans. The Europeans grow mainly rice, wheat and fruits such as banana and papaya. Africans, who used to grow mainly maize and a little sugarcane for their own use are now abandoning self-sufficient maize production and turning to subsistence wheat production; while Europeans are changing from self-sufficient wheat production to maize production for sale. Cash crop production is now widely practiced, as is also mixed farming which is more developed in highland areas. Cash crops include cotton, rice, tea, tobacco, wheat, and sub-tropical vegetables such as asparagus.

In Zimbabwe and Zambia, and to a lesser extent in Malawi, Europeans and African cultivators own cattle. The cattle are kept as draught animals, source of manure, milk and, among Africans, for prestige.

In Southern Africa, as in the other MSZ areas, increasing mechanization, irrigation, fertilizer application, use of pesticides, etc. is taking place, as is local processing of agricultural products.

8. Constraints to Increased Agriculture in the MSZ

This survey of farming systems in the MSZ has so far highlighted some general characteristics, and indicated some changes but has not considered some of the constraints which have hindered countries in the region from realizing the relatively high potentials of the zone. These constraints are physio-chemical, biological, technological and socio-economic.

8.1 Physio-chemical constraints

These are climatic or soil related.

8.1.1 *Climatic constraints*

- unreliability of rainfall in onset, duration, cessation and intensity
- unpredictable periods of drought and flood/storms
- high temperatures which sometimes exceed 40° C and are detrimental to crops or biological processes
- rapid rates of decomposition of organic matter
- high rates of evapotranspiration and several months of moisture deficit
- inadequate water supplies for livestock and human use

8.1.2 *Soil-related constraints*

- highly weathered soils of low inherent fertility
- low CEC and the presence of low activity clays in the colloidal complexes
- soils prone both to water and to wind erosion on removal of vegetation
- soil nutrient deficiencies especially related to phosphorus, nitrogen, sulphur, etc.
- defiency of calcium, magnesium, boron, molybdenum under increased cropping intensity
- poor physical structure under continuous cultivation
- high rates of leaching under intense rain
- structural management problems in general or specifically associated with Vertisols in the region

- salinization problems may occur in drier parts of the region under irrigation
- poor drainage or water-logging in hydromorphic soils covering large areas.
- presence of hardpan and laterite in some areas

8.2 Biological constraints

- low productivity and adaptation potentialities in a large number of genetically unimproved crops and livestock
- susceptibility of crops and livestock to diseases and pests
- rapid losses of biodiversity in indigenous food crops and land races
- presence of several endemic parasitic diseases of livestock and man
- problems of parasitic weeds such as striga in maize and cowpeas
- problems of weeds and water borne diseases in irrigated areas
- environmental stresses and changes brought about by human development activities, over-grazing, etc. which upset the dynamic ecological balance in the prevailing ecosystem
- parasitic diseases of ruminants such as East Coast fever (Heileria para), trypanosomiasis and *peste des petits ruminants*, etc.
- unimproved forage of low nutritive value and low productivity

8.3 Technological problems

- inadequate human resources development and institutional capacity in R and D
- lack of knowledge of, and neglect of traditional technologies as a basis for designing and testing new ones
- technological weakness of NARS rendering them incapable of generating technologies or adapting, utilizing and fine tuning technologies developed at the IARCs to their location-specific conditions
- inappropriate technologies not sustainable in agriculture in the region
- limitations in basic knowledge about the environments necessary to ensure rapid progress in sustainable management of environmental resources
- ineffective management of research and information required in R and D
- ineffective use and integration of tradition and existing/emerging technologies
- farming systems and technologies more adapted to uplands than to lowlands

8.4 Socio-economic constraints

- rapid population growth and increasing pressures on the land
- unfavorable land tenure systems

- limited access to land especially in areas with European settlement
- shortage of labor at peak periods of production
- lack of credit
- high levels of illiteracy and superstition
- low income of farmers and the resultant lack of money to purchase inputs
- poor rural infrastructure including roads and transportation facilities
- inadequate prices and poor marketing services
- poor extension services
- political instability
- inadequate policies for creating a favorable environment for R and D
- low allocation of funds to research and development in agriculture
- high debt burdens and problems associated with SAP
- decline in commodity prices for over a decade

9. Progress in Agricultural Research and Development in the MSZ

The MSZ in sub-Saharan Africa is an area of high agricultural potential that has hardly been realized, despite the fact that it is already a food basket in some countries. Progress has been made, however, that could lead to sustainable development and progress in the sub-region.

9.1 Crop improvement

With the exception of some indigenous African food crops, a wide spectrum of commodities produced in the region is being genetically improved. The improvement is not only aimed at increasing yields but at improving resistance to diseases and pests, tolerance to environmental stress, adaptation to certain cropping and farming systems, earliness and improvement of storability. Crops affected include maize, sorghum, cowpea, cassava, yam, pigeon pea, rice, fruit, vegetables, flowers and pasture species. A good example is the production of an early maturing cowpea that can take advantage of residual moisture at the end of the cropping season or mature during either peak in a bimodal rainfall regime.

9.2 Soil management

Research has been directed at improving soil physical, chemical and biological properties that usually decline under continuous cultivation. In addition to the identification of nutrient deficiencies, their causes and elimination, progress has been made in tillage and biological nitrogen fixation. Progress has also been made in soil conservation, ranging from tie-ridging to agroforestry cropping systems that ensure minimum erosion damage.

9.3 Arable crop production

Considerable progress has been made in the improvement of traditional cropping systems to diversify production and increase productivity and sustainability. It was in this area that some early intercropping experiments were carried out that identified the importance of a competition gap in determining the compatibility of crops in intercropping.

9.4 Animal production

The problems of animal production in this zone were not addressed much, prior to the establishment of ILCA. Since ILCA has a specific program for the sub-humid areas, progress is being made in the provision of dry season feeds and the improvement of nutrition during the dry season, in addition to the integration of crops and livestock.

9.5 Agroforestry

This focuses on a strategy that has a wide spectrum of advantages, for example *alley cropping* includes maintenance of soil fertility while minimizing fertilizer use, achieving the benefits of shifting cultivation in miombo ecosystem areas without tying up the land for many years of fallow; controlling erosion, enabling production of fuelwood, forage, staking and fencing materials, miscellaneous products, and raw materials.

9.6 Pasture and fodder management

The progress made in agroforestry has opened up opportunities for immediate production *pari passu* with food production, fuelwood production, etc. The evaluation of several species has started to yield benefits from such species as *Pennisetum purpureum* and *Clitoria ternata* grown in *Leucaena* alley cropping; use of fodder banks and use of alley cropping to produce forage, maize and mulch. The progress in coconut/pasture agroforestry appears to offer a promising production system as well as a pasture and fodder management strategy.

9.7 Extent and problems of adaption

The introduction of on-farm, adaptive, client oriented and participatory approaches that link research, extension and the farmer while also making the farmer an actor in research and production has successfully replaced the top-down approaches that hampered the adoption of earlier technologies.

9.8 Development in disease control

Development progress in the MSZ includes the advances made in tsetse-fly eradication programs, elimination or combating onchocerciasis (river blindness) in eleven states in West Africa all of which have significant areas of land located in the MSZ.

10. Potentials and Strategies for Increased Production in the Zone

The MSZ, especially in West Africa, has been regarded as an area of high productivity, the potentials of which have not been fully realized despite the fact that it is already a food surplus zone in many countries in West Africa. In Ghana, Ivory Coast and Nigeria the zone is a major source of yam. Other reasons for considering the zone to have high agricultural potential include the following:

a. As an ecozone between the humid tropics and the dry, moisture deficit areas in tropical Africa it can produce cereals, roots, tubers, legumes, etc. that are normally produced in only one or other zone.
b. It could have relatively high biological productivity due to the fact that it is not affected by the several months of intense cloud cover of the humid tropics or the serious moisture deficits of the Sudano-Sahelian areas and the desert.
c. The low population densities in the Middle Belt of West Africa may reduce the danger of increasing pressures on the zone's land resources.
d. Located in the MSZ are large areas of hydromorphic and valley bottom soils of high productivity potential, that if utilized, will contribute to Africa's food security.
e. The MSZ is not as land-locked or far from the sea as the Sahelian countries. Thus countries in the zone have access to ports and urban areas where markets exist.
f. Considerable progress has been and is being made in the eradication of parasitic diseases that have hampered development and progress in the zone.

11. Recommendations for Increased Agricultural Production

Since the level of development in the MSZ is not commensurate with its potentialities, measures to be taken to realize these fully should include:

a. High priority should be given to the development of the MSZ in planning, policy formulation, program designs and execution in addition to long-term commitment and adequate allocation of resources to R and D.
b. The current paradigm of sustainable development should provide an umbrella under which R and D support, program design and implementation in the region should be carried out.
c. Agricultural development and production should aim at the diversification of production based on integrated resource management systems, integrated land use, planning and development, integrated pest management and integrated

production systems such as agroforestry. Above all, it should aim at the integration of traditional, modern and emerging technologies.

d. High priority should be given to the development of hydromorphic soils in the region by using practices or technologies that reduce current labor costs in land preparation while at the same time exploring the potentialities for providing adequate drainage as an alternative to the current techniques of building large mounds and ridges.
e. In the agricultural development of MSZ, the highest priority should be given to the strengthening of NARs by bringing together all necessary institutions in each country, including universities and research institutes, so that each country has a critical mass of its nationals trained and qualified in relevant disciplines.
f. Emphasis should be given to strategies for improving moisture availability and use, including ways of improving moisture intake, such as by mulching; reduction of evaporative losses, e.g., by cover management and optimizing soil moisture use, e.g., by relay cropping, (Barrow 1987). Genetic improvement of crops to minimize moisture loss and increase efficiency of use should also be emphasized.
g. Methods of land husbandry should be used that integrate production practices with soil conservation measures.
h. The commodities to be produced should be selected, genetically developed and grown in the place or area within the zone where they are most adapted and have ecological and economic advantages.
i. The current programs for the extermination of parasitic diseases and their vectors should be continued and measures taken to ensure a subsequent environmental management that does not encourage a relapse or cause adverse environmental effects.
j. A strategy for developing the MSZ may also be used to find solutions to some problems of livestock development in the Sudan and Sahelian zones.

12. Conclusion

The moist savanna zone in tropical Africa has a very high agricultural productivity potential; but physical, biological, socio-economic and technical problems have prevented the realization of this potential. Significant progress has been made in research and development activities and programs that promise to make the realization of the full potentials of this relatively under utilized region possible. It is recommended that high priority be given to strategies and programs to achieve this.

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THE MOIST SAVANNAS OF EAST AND SOUTHERN AFRICA: Potentials for and Constraints to Research and Development

Hezekiel M. Mushala

University of Swaziland, Kwaluseni, Swaziland

Key words: lowland savanna, resource utilization, research and development, constraints, collaborative research

Abstract: *The paper describes characteristics of the lowland savannas of Malawi, Mozambique, Tanzania, Zambia and Zimbabwe by analyzing the respective country resource profiles and constraints to sustainable resource utilization. Institutions engaged in specific aspects of research on lowland savannas are identified together, with constraints related to research, technology development and transfer, overall development and sustainability. The majority of the population is resource-poor and sustainable resource utilization is constrained by climate, soils, population growth and distribution, and land tenure. These factors have contributed to overexploitation of some resources and hence the declining resource base.*

1. Introduction

The savanna can be described technically as a tropical or near-tropical seasonal ecosystem with a continuous herbaceous layer, usually dominated by grasses or sedges, and a discontinuous layer of trees and/or shrubs (Skarpe 1992). This ecosystem is modified by human beings, fire and herbivores to bring about variations in vegetation, fauna, soils, nutrients and physiognomy. The moist lowland savannas of East and Southern Africa incorporates areas which, according to the International Institute of Tropical Agriculture (IITA), have growing periods of between 151 and 270 days. The average daily temperature during the growing season is over 20° C at elevations below 800 m above sea level.

Some determinants and constraints of savanna land use, applicable to the lowland savannas of East and Southern Africa have been identified (Murphee and Cumming 1993). Seasonality determines the length of the rainy season and total precipitation, thus influencing the character of agricultural systems. Soils of low and variable fertility are a major constraint to agricultural development in most of the savanna. Soil fertility may determine the extent of sustainability of agricultural systems within the context of technological and social limitations. Fire constitutes a powerful management tool. Its abuse, however, can lead to adverse changes in biomass, species and productivity and may initiate erosion. Savanna land-use systems also have unique cultural characteristics, often involving traditions that do not change easily. Yet with some innovation and improved management, moist savannas generate appreciable amounts of revenue and can sustain multipurpose land-use systems.

This paper analyzes the utilization of the lowland savannas of East and Southern Africa (Malawi, Mozambique, Tanzania, Zambia and Zimbabwe) by outlining the resource profile of each country and the major constraints to the sustainability of land-use systems, given the existing resource base. In addition, the main themes addressed by research activities and the constraints to research and development are outlined. The aim is to provide a background for establishing a research and development agenda.

2. Malawi

2.1 Resource profile

Malawi is a long, narrow country stretching almost 900 km from 9° to 17° S and 200 km east and west from 33° to 36° E; it covers an area of 118,484 km^2.

The physical features of the country are dominated by the Rift Valley that cuts across the country from north to south and contains Lake Malawi and the Shire Valley. The lowland savannas of Malawi are found in this region. The Central Region plateaux rise to the east and west of the Rift Valley to an altitude of between 800 and 1600 metres above sea level. The highland areas form some isolated tracts, some of which rise to an elevation of 2300 m. In addition, there are the isolated mountains and plateaux of Mulanje (3000 m) and Zomba (2400 m) in the east.

Malawi possesses some of the most fertile soils in south Central Africa. The soils of the lake shore plains and the upper and lower Shire Valley are highly suitable for agricultural production. The plateau regions are very fertile but the mountain areas are inaccessible.

The climate ranges from semi-arid to sub-humid. Annual rainfall ranges from 750 to 1600 mm but varies from year to year, with 80-90% of the rainfall falling between December and March. The average annual temperatures vary with altitude, and range between 13° C and 25° C. The high plateaux experience occasional frost (Pereira et al. 1985).

Most of the arable land is under traditional landholder tenure systems. Smallholders live under the control of family heads, village headmen and traditional chiefs. Cultivation rights, as opposed to ownership, are granted by the village headman. Average farm size is about 1.7 ha with most of the smallholder farmers producing maize intercropped with beans for household use. Other crops include groundnuts, cotton, sorghum, millet and tobacco (Chirwa n.d.).

The vegetation varies with rainfall. Semi-arid savanna and thickets, lakeshore savanna, *Brachystegia/Julbernadia* woodlands, montane grasslands and evergreen forests are present (Chirwa n.d., Pereira et al. 1985, Zimkonde-Mhango et al. 1992).

2.2 Constraints to sustainable resource utilization

Malawi's population is estimated at 8 million with about 48% of the population under 15 years and an average annual population growth rate of 3%. The population puts pressure on land resource utilization. Declining agricultural production, in general, is a consequence of low and/or declining soil fertility and crop yield. It is generally considered that declining agricultural production is exacerbated by escalating costs of fossil fuel-based inputs and deteriorating natural resources (Pereira et al. 1985). Constraints to agricultural production by smallholder farmers have been identified as unpredictable and poor distribution of rainfall; soils that are difficult to manage; lack of high yielding crop varieties resistant to insect pests, able to withstand unreliable rainfall and limiting soil conditions; and the non-availability of cost-effective insect and weed control techniques. Poorly developed input and product market structures resulting in untimely availability of inputs, lack of capital to purchase inputs, low commodity prices and hence low gross margins of crops, and lack of organized markets for perishable crops such as vegetables were also identified as constraints to agricultural production by smallholder farmers. Other institutional constraints include the structural aspects of land tenure, farm size implications, the extent of illiteracy among smallholder farmers and the social system of governance and decision making (Maida 1986).

2.3 Research and development

Agricultural development policy in Malawi has, hitherto, placed emphasis on surplus production of staple food crops to guarantee supplies during poor harvest seasons (Chirwa n.d.). The policy also includes the promotion of sustained agricultural productivity by introducing farming methods that incorporate soil conservation and fertility improvement; encouraging farm planning, better land tenure systems, land use and farm layouts; and diversifying production in order to establish viable farming systems (Saka et al. 1991).

Research in Malawi aims at increasing the number of crop varieties adapted to farmers' conditions; the maintenance of vegetation and soil productivity under varying population density; crop pest management strategies applicable to different agroecological zones; and improved land management of inland valleys.

The Department of Agriculture, through its various research stations, commodity research teams, adaptive research teams and donor-supported collaborative international research projects, manages to tackle most of the research themes effectively.

The Ministry of Forestry and Natural Resources also conducts research for developing new or improved agroforestry technologies which address the needs of smallholder farmers. The research program is focused on the following problems:

a. low and/or declining soil fertility and crop yield

b. inability of farmers to purchase or gain access to mineral fertilizers and other inputs
c. soil erosion, runoff and deforestation on steep slopes
d. fuelwood shortages
e. fodder deficiencies

The University of Malawi, through its individual departments, collaborates with government departments, international organizations, regional research networks and individual universities to conduct research on the land and water management systems of inland valleys (*dambos*), improving diagnosis of resource management systems, maintenance of vegetation and soil productivity under varying ecological conditions and crop pest management strategies applicable to different ecological zones.

2.4 Constraints to research

Malawi has one of the best developed research infrastructures in Central and Southern Africa, supported by explicit government policies. However, some of the major research activities fail to reach a reasonable conclusion or are terminated due to inadequate financing. This applies equally to government departments and the University of Malawi.

Despite a rigorous training program in government departments it is becoming increasingly difficult for some of the departments to retain their trained staff, mainly because of poor conditions of service. Experienced and trained staff often find alternative employment in the private sector or outside the country.

Foreigners are subjected to a great deal of red tape before they can undertake research in Malawi. The restrictive guidelines and procedures set out by the government are a hindrance to innovative research. In addition, most of the research conducted by government departments is not client-driven. The general focus of research does not look at the needs of smallholder farmers, and the technologies developed are, therefore, not adopted. A major constraint to the adoption of some of these technologies is the poverty of the smallholder farmers. In addition, illiteracy among smallholder farmers is another constraint which should be seriously tackled.

2.5 Suggested areas for collaborative regional research

A regional research project should be set up with the aim of standardizing land resource evaluation procedures for South African Development Council (SADC) countries. A regional collaborative research project based on the improvement of soil fertility or soil conservation using indigenous forest species should be initiated. Smallholder farmers should be involved in the evaluation of technologies, assessing the impact on the environment and rural communities and identifying determinants and constraints to technology adoption. Any development effort must take into consideration the knowledge and skills of the local people.

3. Mozambique

3.1 Resource profile

Mozambique covers an area of 801,590 km^2. The northern part of the country experiences two rainy periods during November/December and March/April while the south experiences unimodal rainfall from October to March. The average total annual rainfall varies from 400 mm to 2200 mm, with the highest precipitation occurring in the western highlands and the north, and the lowest precipitation in southern inland areas (Pereira et al. 1985).

The soils are highly variable. The alluvial soils have a high potential for agricultural development after reclamation by drainage, as do the Vertisols properly managed. The sandy soils have medium-to-low agricultural potential and brown soils require careful management because of their limited soil depth, and stoniness. The medium to heavy textured, deeply weathered soils have a considerable agricultural potential, but require good management and adequate fertilization. The shallow soils have limited agricultural potential.

Eighty per cent of the country lies in the semi-arid tropical agricultural belt which reflects the spatial distribution of rainfall. The sub-humid zone comprises about 15% of the area, a wetland agricultural belt. Sorghum and cotton are grown in the wet semi-arid zones; pearl millet is grown in the arid zone and along the boundary of the arid/dry semi-arid zone; and paddy-rice is found in the sub-humid zone. Maize is grown in the dry semi-arid to sub-humid zone (Pereira et al. 1985, Ponce-Hernandes et al. 1991). The natural vegetation is variable but is dominated by low natural forest and woodlands, which are affected by rainfall regimes and altitude.

3.2 Constraints to sustainable resource utilization

Most of the country is semi-arid with very erratic rainfall. Smallholder farmers, therefore, intercrop maize with other crops to minimize the risk of monocrop failure due to drought. Alternatively, the farmers stagger the planting of their multiple crops over a number of weeks within the growing season in the expectation that some moisture will be available for some crops at critical points of their growth. Even then, dry spells occur frequently during the growing season and crop failures are not uncommon.

Most of the work is undertaken by women and children because many of the men have migrated to urban centres or neighboring countries to work in the mines. If technologies can be developed to counter the impact of the labor shortage, these have to be accessible and appropriate for women.

Soils are a constraint to sustainable resource utilization. Acronosols (sandy soils) occupy large areas of the southern part of the country. Given their coarse texture and the limited rainfall in the area, their agricultural potential is relatively low. The Vertisols, found mainly along the northeastern coastal plain and the alluvial plain of Rio Buzi, require very careful management to be of high potential, but appropriate agricultural practices have been hampered by the prolonged civil war. This has paralyzed not only agricultural production but social development as a whole.

Further physical limitations to agricultural production are drought and floods. The prolonged dry periods experienced during the past two growing seasons were usually followed by floods. The very dry conditions pulverized the soils which were subsequently washed away during the wet season. These adverse conditions make planning extremely difficult.

3.3 Research and development

Agricultural research in general is carried out by the National Institute of Agricultural Research (INIA), Eduardo Mondiane University and the National Seed Company (SEMCO). International research organizations, such as IITA, the International Center for Research in the Semi-arid Tropics (ICRISAT) and the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) carry out research under regional programs or through specific commodity research teams.

The main focus of the research teams at INIA is towards (a) increasing the diversity of crop varieties to suit on-farm conditions (b) identifying determinants of and constraints to technology adoption by smallholder farmers; (c) improving methods of technology dissemination through extension agents; and (d) developing cost-effective crop pest management strategies applicable to different agroecological zones.

The research themes at the Eduardo Mondiane University do not differ substantially from those of INIA. Given the critical manpower shortage in each of the institutions, sustainable research programs have depended on the collaboration of the two institutions.

3.4 Constraints to research and development

The prolonged civil war has made on-farm research extremely difficult and for the most part impossible. Most experiments have had to rely on laboratory conditions or on-station experiments. Even where research could be undertaken, efforts were often frustrated by the lack of trained or experienced scientists.

At the same time, the poor conditions of service in government employment do not guarantee staff retention once they are trained. There are always better opportunities outside government and the scientists are easily absorbed elsewhere. These institutional constraints are further compounded by lack of finance, equipment, vehicles and infrastructure.

At the farm level, poverty negates most measures intended to encourage the adoption of technologies that require financial investment. Illiteracy and general civil strife also mitigate against the adoption of new technologies for sustainable development.

3.5 Areas for collaborative regional research

The present priorities of Mozambique are to resettle displaced people and maximize food production. As there may be little room for research work, there is a need to utilize research results obtained from other areas in the region, such as the use of fast growing, high yielding crops under depressed conditions. In this way Mozambique can utilize and spread the available technology into newly settled areas.

Collaborative research efforts should be directed towards (a) establishing appropriate land management techniques for Vertisols, (b) the generation and development of technology to increase and improve the production of cassava, sweet potato, maize, sorghum, etc.

Mozambique needs more support in human resources capacity-building to embark on different areas of research. Where possible, long-term and short-term training programs should be initiated and staff exchanges on regional projects increased.

4. Tanzania

4.1 Resource profile

Tanzania covers an area of 939 702 km^2 and is flanked by the Indian Ocean on the east, Mozambique and Malawi to the south, Zambia to the south west, Zaire, Rwanda and Burundi to the West, and Uganda and Kenya to the north and northeast respectively.

Elevation varies from sea level to Mount Kilimanjaro (6000 m). The long central plateau with its rolling plains is at an elevation of 1200 m.

Tanzania has four main climatic zones. The coastal zone, which on average is lower than 500 m above sea level is characterized by high humidity (60%), an annual average rainfall above 700 mm and an average temperature of 20° C. The semi-arid zone is between 500 to 1500 m above sea level and receives an average annual rainfall of less than 700 mm. It also experiences a long dry season with very low humidity. The interior lowland zone rises to the same level as the semi-arid zone with extensive areas that are 1000 m above sea level. Annual rainfall is over 700 mm and the average temperatures are above 25° C. The highland zone experiences temperatures of below 20° C and an annual rainfall of over 700 mm. In most cases the annual rainfall exceeds 1000 mm.

Much of the country experiences a rainy season from November/December to March/April except in the north and northeast, where the rains generally occur between March and May. This is in addition to the country-wide November/ December rainy period. The areas around Lake Victoria experience rainfall throughout the year (United Republic of Tanzania 1991).

Although Tanzania's ecosystem is diversified, approximately half of the land is wooded. Of this area, about 1.5 million ha comprises closed forests and mangroves and about 43 million ha are open woodlands. Plantations occupy about 0.15 million ha. Miombo woodland, dominated by *Brachystegia* and *Isoberlinia* species, comprises the largest woodland.

Most of the land area is covered by soils with low fertility and little organic matter. Elevated areas and floodplains have very rich soils with high agricultural potential.

4.2 Constraints to sustainable resource utilization

As noted above, the physical limitations of soils and climate restrict the utilization of the resource base. Without improved farm methods, most soils cannot sustain permanent agriculture, and agricultural production is particularly limited in areas of low and often erratic rainfall.

In the lowlands, frequent floods limit the extent to which sedentary agriculture can be established on floodplains, which are usually fertile.

Tanzania's poorly developed road network cripples the marketing of goods and services and serves as a disincentive to farmers to produce more. The problem is further compounded by the general poverty among smallholder farmers, who work poor soils under an unfavourable climate and are not capable of purchasing farm inputs. Low productivity is very common in many lowland areas.

4.3 Research and development

Agricultural research in Tanzania is carried out by the Department of Research and Training under the Ministry of Agriculture, Livestock Development and Cooperatives (MALDC); and by the Tropical Pesticides Research Institute (TPRI) and the Uyole Agricultural Centre (UAC), both of which are semi-autonomous parastatals under the same Ministry.

Some research is also being undertaken by the Sokoine University of Agriculture, and to a lesser extent, the University of Dar es Salaam. A number of private estates also undertake research. The universities undertake research mainly as part of their postgraduate programs, and the private estates concentrate on their respective crops (United Republic of Tanzania 1991).

There are over fifty research institutes and associated centres/substations that deal with main areas of crop and livestock research in Tanzania. The main research effort comes from seven zonal research and training centres that have responsibility for applied and location-specified adaptive research and training. The main themes covered by the research institutions in Tanzania include increasing the diversity of crop varieties to better fit farmers' conditions, maintaining plant and soil productivity and developing appropriate strategies for crop pests in different agroecological zones.

4.4 Constraints to research and development

There are various constraints to research and development in Tanzania.

a. For the most part research facilities in the research institutions are in need of repair, rehabilitation or replacement. (Laboratories and laboratory equipment are deficient).
b. Tractors and field equipment are in poor operating condition and some of the equipment are not suited to Tanzanian conditions.
c. Though the scientists are highly trained and there is a favourable ratio of research support staff and a good multidisciplinary staffing pattern in most research programs, there is a scarcity of staff in several key disciplines (e.g., weed science, socio-economics), a shortage of experienced staff at some stations and in some cases a lack of critical mass. Despite the good number of trained research staff there is a critical lack of research management ability.
d. Government financing is inadequate. Commodity marketing boards contribute only limited amounts. Without donor support, there would be little agricultural research in Tanzania.
e. Few of the technologies developed reach the farmer, due to poor or non-existent extension services, inefficient research-extension dialogue and a lack of well-balanced national priorities. Moreover, the level of poverty and some traditional customs preclude the adoption of some innovations.

4.5 Areas for collaborative regional research

Except for research work at Sokoine University of Agriculture (SUA), soil, water, agroforestry and agroclimatology have received very little attention. Research in Tanzania would benefit from such research programs as agroforestry for the evaluation of multipurposes trees and especially the development of agroforestry for improving soil and water management. Another useful area would be fertilizer trials for major food and other crops.

5. Zambia

5.1 Resource profile

Zambia is a land-locked country and it covers an area of 752,600 km^2, of which 743,400 km^2 is land area and 9,200 km^2 are covered by bodies of water.

The elevation ranges from 325 to 2148 m. The climate is characterized by three main seasons. The warm wet season lasts from the end of October to March/April, and the main rains fall in late November and December. The rains last longer (max. 190 days) in the northern part and are of shorter duration in the south (120 days). The dry cool season is from April/May to August with occasional frost in June/July. The dry hot season is between August and October with the highest temperatures in October. Droughts are frequently experienced in the Luangwa-Zambezi rift valley. The mean annual rainfall ranges between 1200 mm in the north and 700 mm in the south. The annual maximum temperatures range between 27° and 35° C and the annual minimum temperatures vary between 3° and 10° C (Muchinda and Spaargaren 1985).

Zambia has variable soils. The percentage of the land covered by different soil borders are: Entisols (25%), Inceptisols (24%), Oxisols (15%), Ultisols (15%), Alfisols (10%), Vertisols (7%), Spodosols (3%), Mollisols (<1%), Aridisols (<1%) and Histosols (<1%) (Magai 1985).

The vegetation is mainly woodlands, forest and grasslands. Some woodlands with a dense tree cover have a more or less closed canopy and sparse grass cover. Open woodlands have an unclosed canopy and a well established luxuriant grass cover. Forests have thickets in the understory, a mostly closed canopy and very sparse grass cover. Grasslands are associated with areas of poor drainage, especially *dambos,* swamps and floodplains (Shalwindi 1985).

Zambia has four agro-ecological zones. The northern high rainfall zone is covered for the most part by highly leached sandy veld soils of low fertility. Annual rainfall ranges from 1000 to 1500 mm, and annual mean temperature is 21° C. The western semi-arid plains are covered by extensive infertile Kalahari sands which extend into Botswana and Angola. This zone receives an average annual rainfall of 600 to 1000 mm and the annual mean temperature range is 21° to 24° C. There is occasional frost. The central, southern and eastern plateau zone has some of the most fertile soils in Zambia. As a result, this zone has the highest population density in the country. The average annual rainfall ranges from 800 to 1200 mm. The Luangwa-Zambezi rift valley is the hottest and driest zone in the country. The soils here are mainly chestnut sands that have marginal value for agriculture. The zone is mainly utilized for national parks and game reserves. It receives less than 700 mm annual rainfall. Annual mean temperature is 26° C (Muchinda and Spaargaren 1985).

Crops grown in the country include cereals (maize, wheat, sorghum, rice and millet), oilseeds (cotton, soybeans, sunflower and groundnuts), traditional cash crops (tobacco, coffee and tea) and other minor crops (cassava, vegetables and fruits). Sugar cane is grown on sugar estates.

5.2 Constraints to sustainable resource utilization

The utilization of the lowland savanna in Zambia is constrained mainly by the erratic rainfall. This prevents as much diversification of crop production as many farmers would have liked. Furthermore, the soils (chestnut sands) are only marginally suitable for agriculture. This area is also infested with the tsetse fly, which makes livestock rearing difficult. Physical constraints are compounded by the general poverty of smallholder farmers, which limits their ability to opt for alternative methods of farming.

5.3 Research and development

Research activities on the lowland savannas in Zambia are carried out by the research branch of the Department of Agriculture, the University of Zambia through its School of Agricultural Sciences, the Rural Development Studies Bureau, and to some extent the National Council for Scientific Research. The areas covered include maintenance of vegetation and soil productivity under different land use systems, improved soil and water management systems, increasing the diversity of crop varieties better suited to lowland savanna conditions and crop pest management strategies applicable to different agroecological zones. There is collaboration with national institutions, regional research projects and international institutions based on commodity research or specific disciplines.

5.4 Constraints to research and development

The main constraint to research activities is the lack of adequate funds. Much research continues to be carried out along colonial lines with emphasis given to cash crops. Training of personnel has also followed along similar lines so that research into traditional crops, which are of particular significance to smallholder farmers is not investigated by trained scientists. It will be difficult to investigate traditional land use systems since most of the training did not include this.

5.5 Areas for collaborative regional research

Zambia also has a well established research infrastructure through the various research stations in the country. Some of the collaborative regional research work could be in the characterization of soils in the region with particular emphasis on the lowland savanna. Zambia has done a lot of work along those lines and it could be extended to other countries.

Another area of collaboration regionally could be investigations into the management of lowland areas for increased productivity and multipurpose land use. This would include the improvement of agro-pastoral systems.

6. Zimbabwe

6.1 Resource profile

Zimbabwe shares borders with Mozambique in the east and north east; South Africa in the south, Botswana in the west and south west and Zambia in the north west. Almost 20% of the country stands at 1200 m above sea level, about 60% lies between 600-1200 m above sea level and the remainder is below 600 m above sea level.

The climate is characterized by three seasons. The hot dry season is from August until the onset of the rains (which may begin as early as October or as late as January). The warm to hot season is from the onset of the rains until March/April. Thunderstorms are very common during this time and mid-season dry spells occur in February. The dry season is from April to September with cool nights and warm sunny days that result in high evaporation rates. Average annual rainfall ranges from 400 mm in the lowland areas to 900 mm over the central watershed to over 1000 mm in the eastern highlands. Most rain falls from November to March.

Zimbabwe soils are predominantly derived from granite and are often sandy and light-textured with fair agricultural potential. The heavier soils in some areas have a higher potential for food crops. Most fersiallitic soils are found on the central watershed where most land is occupied by commercial farms. These soils are generally fertile and respond to irrigation. They are liable to swelling and therefore require careful management. Most Vertisols are found on the Great Dyke and are known to contain toxic minerals. The siallitic group which occurs in drier areas, are fertile moisture-retaining soils ranging from thin sandy soils to thick loam. They respond well to cultivation (Government of Zimbabwe 1992).

The vegetation pattern in Zimbabwe is influenced by soils, climate and altitude with distinct, sometimes very abrupt transition from one dominant woodland type to another. The natural climax vègetation comprises woody plant communities grading into one another in response to changing soils and climate. The characteristic vegetation includes savanna woodlands interspersed by open grassed drainage lines or dambos. Impeded drainage gives rise to limited areas of open grassland and patches of subtropical forests which are found in the rainfed eastern mountains (Child and Health 1992).

In terms of land use, the communal areas account for 42% of the total land area, commercial farming areas 36.2%, resettlement areas, 6.8% parks and forests 14.4% and urban and other areas 0.6%.

Zimbabwe has five agroecological zones. Region 1 (1.6% of total land area) is in the eastern highlands and receives above 1000 mm rainfall annually with temperatures under 15°C due to the high altitude. Region 2 (18.8%) is mainly the high-yielding north-eastern. It receives reliable rainfall of 750-1000 mm annually between November and March. Region 3 (17.6%) covers mainly the midlands and receives annual rainfall of 650-800 mm. However, it experiences mid-season dry spells and high temperatures. Region 4 (33%) covers mainly the low lying areas in the north and south. It receives between 450-650 mm annual rainfall and is subject to periodic seasonal droughts and severe dry spells during the rainy season. Region 5 (27%) is mainly lowland, generally below 900 mm. It receives erratic rainfall (usually <650 mm), which is too low for rainfed agriculture.

6.2 Constraints to sustainable resource utilization

The main constraints to sustainable resource utilization are climatic and edaphic limitations, pressure on land by population increase and land tenure arrangements. The lowland savanna areas of Zimbabwe are found mainly in Regions 4 and 5 both of which receive low erratic rainfall and are subject to periodic seasonal droughts and severe dry spells during the rainy season. This restricts crop and livestock production. The soils also have some limitations and require careful management.

Pressure on land is created by the uneven distribution of population caused by the existing land tenure arrangements. Most of the population (57%) is confined to the communal areas formerly known as 'Tribal Trust Lands', where land is communally owned but households cultivate the land separately in small fields allocated by the community leadership. Ownership of the land is vested in the community, while grazing, forest resources and water are open to everybody. Human and bovine populations in these areas are high, causing overexploitation of the resource base beyond the land carrying capacities and a decline in environmental quality.

6.3 Research and development

Research on lowland savannas in Zimbabwe is conducted by the Departments of Research and Specialist Services and National Parks and Wildlife Management. The research in these areas focus on farming systems applicable to drought resistant crops, livestock production and game ranching. The World Wildlife Fund (WWF) in collaboration with the University of Zimbabwe and the relevant government departments also conduct research.

The themes covered include improving diagnosis of resource management issues, increasing the diversity of crop varieties to suit farmers' conditions in the lowland areas, improved management systems for multipurpose uses, of lowland areas, crop pest management strategies for lowland areas, and maintenance of vegetation and soil productivity under varying population pressure.

The research infrastructure is very well developed and maintained so that records of research carried out in the past can be obtained. The organization of research based on client and community needs is commendable and there are advances in the utilization of indigenous knowledge and local experience.

An area now gaining much attention in research is the analysis of socio-economic aspects wherever other scientific research projects are undertaken. This broadens the perception of existing problems and facilitates the adoption of technologies developed. Commodity Research teams are effectively linked with Adaptive Research Teams.

6.4 Constraints to research and development

There are fewer constraints to research in Zimbabwe given the established infrastructure and support from government and donor agencies. The training program ensures sustainability of research programs, although recently there is a tendency for scientists to seek green pastures elsewhere and, in some cases, there is sufficient funding to cover all the necessary research.

6.5 Areas of collaborative regional research

Research in Zimbabwe has advanced more than most other countries in the region. The SADC countries could benefit from collaborating with Zimbabwe in the establishment of a Communal Area Management Programme for Indigenous Resources (CAMPFIRE). CAMPFIRE projects promote self-sufficiency, encourage income-generating activities, and incorporates aspects of grassroots project planning and implementation.

Another area of regional collaborative research effort would be the introduction or strengthening of social science perspectives in Natural Resources Management in the SADC region along the lines of the IUCN project in Zimbabwe. Several institutions could be involved in research on various aspects of natural resources management and should include specific social science perspectives along with natural sciences studies.

Thirdly, a regional collaborative research project could be initiated to strengthen and improve adaptive research activities as a way of bridging the gap between commodity research teams and the end user of research, i.e., the farmer.

7. Options for Organizing the Regional Initiative

A survey on the utilization of lowland savannas in East and Southern Africa reveals, inter alia, the following:

a. There are substantial limiting factors in sustainable resource utilization imposed by climate, soils, population distribution and land tenure arrangements with spatial and temporal variations.
b. Erratic rainfall (in terms of amount and distribution) is a major constraint in most lowland savanna areas of East and Southern Africa.
c. The management of some soils along inland valleys and flood plains is problematic with available technology.
d. Unequitable population distribution caused by land tenure arrangements or civil strife has caused the overexploitation of some resources and declining resources in some areas.
e. With the exception of a few countries, there has not been proper evaluation of the land resources of the lowland savannas, and therefore, the level of utilization cannot be determined with precision.
f. The impact of land use patterns on environmental systems locally, nationally, regionally and globally is not well understood.
g. The extent to which indigenous knowledge can be used to improve the management of land resources is limited.
h. Territorial boundaries constrain the management of land resources in lowland savannas which spread across borders.
i. The majority of land users in the lowland savannas of East and Southern Africa are poor.

Following on these, the organization of the regional initiative should be based on the following (given without any order of priority):

i. a regional initiative on the evaluation/assessment of the contribution of land use systems in lowland savannas on global emissions contributing to global change (environmental impact of land use systems of the lowland savannas)
ii. establishment and improvement of standard procedures for land resource evaluation with special emphasis on lowland savannas
iii. characterization of indigenous farming/land use systems
    - technology
    - environmental conservation
    - sustainability
    - response to natural catastrophes
    - socio-economic determinants and constraints
iv. development and improvement of water harvesting techniques the lowland moist savanna for resource-poor farmers
v. social science perspectives on the management of natural resources in the lowland savannas (IUCN)
vi. development of improved technologies to assist the CAMPFIRE projects
vii. strengthening of adaptive research initiatives in the SADC region. (Establishment of an Adaptive Research Network for East and Southern Africa)
viii. characterization of land resources of the lowland savanna as a basis for improving multiple land use technologies
ix. development and improvement of technologies for improved management of inland valleys (soils)

8. Conclusion

The utilization of the lowland savanna in East and Southern Africa is based on smallholder cultivation, game ranching and livestock production. The level of technological development within these areas is relatively low. Increasing population and the slow adoption of improved technologies threaten the sustainability of the farming systems. There is an overexploitation of the resources and a declining resource base whereever land tenure arrangements are limiting. Given the diverse nature of the research infrastructure in the countries reviewed, and the level of emphasis on the different research themes, plus the different human resources capacity in these countries, there is ample room for collaborative regional research. A regional initiative should be based on the constraints experienced by the individual countries especially in those areas of research which seem to be given little attention either nationally or regionally.

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ENERGY AND THE EVOLUTION OF FARMING SYSTEMS: The Potential for Mixed Farming in the Moist Savannas

M.A. Jabbar

International Livestock Research Institute, Livestock Policy Programme
P.O. Box 5689, Addis Ababa, Ethiopia

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Abstract: *The moist savanna zone in sub-Saharan Africa is regarded as a high potential area for crop and livestock production. Currently, human labor is the principal source of power for crop production and the level of commercial energy use is very low. Agropastoralism and pastoralism are the principal methods of livestock production. Crop-livestock mixed farming in which manure and animal power are important energy sources in the production process is just emerging.*

In this paper, the possible paths of crop-livestock interaction and integration and their implications for the sources of agricultural energy are discussed in relation to: population pressure and labor intensity; intensification of crop production with and without livestock; the role of traction in general and in specific niches; food versus the input contribution of livestock in the development process; and the role of public policy and intervention in development.

1. Energy and Farming Systems: Background and objectives

Production is essentially a process in which one form of energy is transformed into another. Humans and animals are chemical converters of food energy into mechanical energy or work. Man's power capacity is limited and the productivity of a production system based only on human muscle power is very low. The history of human civilization is largely a story of man's progress in harnessing energy from various sources and converting it into useful forms. The only source of energy for primitive man was food, and the principal use of energy was for hunting and gathering food. Compared to primitive man, people in the most advanced societies now use over one thousand times more energy per capita; mainly in the form of electricity, gas and petroleum. Only a tiny share (3-5%) of this is used in agriculture for food and feed production (Stout et al. 1979).

The source and quantity of energy used in agriculture have evolved along with the evolution of production systems. Its uneven development around the globe has led to different production systems with their associated sources and levels of energy use. For example, shifting cultivation and pastoralism, two of the oldest agricultural practices, are still widely practiced in a large part of Africa, where human muscle power is the primary source of energy in agriculture (table 1). The use of commercial energy and the crop yields are lowest among the developing regions (table 2). In West Africa, only about 7.5 kg of chemical fertilizer is currently applied per hectare of arable land and cereal yield is about 900 kg per hectare compared to over 3000 kg in the developed countries (Fischer et al. 1992).

Table 1. Share of different sources of power in agriculture in selected developing regions

Region	Share of power source (%)		
	Human	Animal	Mechanical
Africa	81	16	3
Far East	64	34	2
Near East	63	25	12
Latin America	56	25	19

Source: FAO 1981, Ahmed and Kinsey 1984.

In order to meet the food, fibre and fuel needs of the growing population of sub-Saharan Africa, a higher level of agricultural and industrial production will be required. This necessitates harnessing much more energy than human muscular capability. The principal objectives of this paper are to establish the relationship between energy and the evolution of farming systems, assess how the increased agricultural energy needed in the moist savanna region could be generated; and particularly to assess the potential for the development of mixed farming and its role in meeting future energy needs.

Table 2. Commercial energy use and cereal yield in selected regions

Regions	Energy/ha -10^9 joule	Energy/work -10^9 joules	Output/ha kg	Output/worker kg
Developed countries	24.8	107.8	3100	10508
Developing countries	2.2	2.2	1255	877
Africa	0.8	0.8	829	538
Far East	1.7	1.4	1328	781
Near East	3.8	4.4	1335	1386
Latin America	4.2	8.6	1440	1856
World	7.9	9.9	1821	1671

Source: Stout et al. 1979.

2. Current and Projected Land Use and Energy Needs in the Moist Savanna

The moist savanna agroecological zone roughly corresponds with the sub-humid zone, so the two names will be used synonymously in this paper. It has 1000 to 1500 mm of annual rainfall and a growing period of 180 to 280 days. It covers 22% of the land area and accommodates 27% of the human and 20% of the livestock population of

SSA (table 3). The overall population density in the zone is somewhat similar to that in the semi-arid and humid zones. Rural population density, however, is about 27 compared to about 14 in the semi-arid and humid zones. This is because most of the major cities are located either in the humid or in the semi-arid zones, and therefore, a higher proportion of the population of these zones is urban. Livestock density in the zone is lower because in the past, the high incidence of trypanosomiasis made sedentary cattle production difficult, though this constraint is rapidly disappearing, and more cattle are being reared in the zone.

Table 3. Distribution of land, human and livestock population in sub-Saharan Africa by agroecological zone

Zone	% of SSA total			Density/km^2	
	Land	Population	Livestock	Population	Livestock
Arid	36	11	30	7	5.5
Semi-arid	18	25	27	31	10.4
Sub-humid	22	27	20	28	6.3
Humid	19	21	6	26	2.3
Highlands	5	16	17	80	26.8
All Zones	100	100	100	23	7.1
SSA total	21.6 mil ha	498 million	153.8 mil TLUs		

Note: TLU - Tropical Livestock Unit
Source: Adapted from Winrock 1992.

On a regional basis, moist savanna covers 16% of the land area each in West and in East Africa, 29% in Central Africa and 38% in Southern Africa. Details of the current land use pattern in the zone are not fully available. An FAO study has shown that among the regions of SSA where the sub-humid environment exists, all the suitable and moderately suitable cropland in West Africa has been used up, while suitable unused land exists in East and Southern Africa (table 4). In West Africa, increased population pressure has resulted in shorter fallow periods and annual cropping in some places and the expansion of crop production into forest and grassland in others (FAO 1986).

The FAO study also assessed future requirements for cropland, grazing land and forest land to meet the food, fuel and feed needs of projected human and livestock populations. The assessment was made on the assumption that all potentially cultivable land would be used for fifteen major food crops or grassland under different input levels and circumstances. The results indicated that at a low input level[1], the land area available in East and Southern Africa would be insufficient to meet the needs of the projected population in the year 2010 (table 4). In West Africa, nearly all available arable land will be used up and cropland will expand substantially at the expense of forest and grassland. At intermediate input level,[2] the land requirement for the projected population in the year 2000 may be met in all three regions, but at the country level, 6-7 countries will still fail to meet the needs of their projected populations from domestic production.

Table 4. Current and projected land use in selected regions of SSA

Land supply and use	Humid+ sub-humid West Africa	Sub-humid+ mountain East Africa	Sub-humid+ semiarid Southern Africa
Total land area (mil ha)	206.6	251.0	559.2
Sub-humid area (%)	62	38	60
Humid area (%)	35	14	3
Semi-arid area (%)	3	48	37
Potentially cultivable (mil ha)			
Very suitable + suitable	49.1	49.1	141.9
Marginally suitable	49.7	28.1	87.9
Total	98.8	77.2	229.8
Present use (mil ha)			
Cropland + temp. fallow	55.4	29.0	32.7
Forest	49.4	47.4	212.4
Shrub, bush fallow and grassland	101.8	82.7	160.4
Projected land need for year 2010 at low input (mil ha)			
Cropland	69.6	37.3	46.3
Forest	22.0	43.0	198.0
Grassland	98.6	248.2	445.0
Total	190.2	328.5	689.3

Source: FAO 1986.

[1] Low input level has been defined as: the currently grown mixture of crops; no fertilizer; no chemical control of pests, diseases and weeds; no conservation measures; hand tools and human labor; little or no use of crop residues for feed and planted forage (FAO 1986, p 73).

[2] Intermediate level input has been defined as: half of the optimum mixture of traditional and improved cultivars, some (30-50 kg/ha) chemical fertilizers, some chemicals for pest, disease and weed control, some conservation measures, manual labor and animal traction, some crop residues as animal feed (FAO 1986, p 73).

The low input option will not only fail to meet land requirements, in the absence of conservation practices and investment on land improvement, the expansion of crop production into marginal areas will make soil and grassland degradation ever more severe. Even with intermediate input level, marginal land will have to be used. A significant proportion of the available land in all three regions has physical and/or chemical constraints (table 5). A recent survey has shown that only 25% of arable land in the West African moist savanna is sufficiently fertile (Manyong et al. 1994). The use of marginal land for crop production, therefore, will require a substantial amount of energy in the form of labor and other inputs. Crop cultivars resistant to water and soil chemical stress conditions are not yet available, so energy efficiency in the marginal areas is expected to be low.

Table 5. Proportion of land with physical and chemical constraints in selected regions in SSA

Constraints	Humid+sub-humid West Africa	Sub-humid+mountain East Africa	Sub-humid+ semi-arid Southern Africa
Physical constraints (% land)			
Steep slope	7.4	21.8	8.8
Sandy texture	27.8	7.6	48.5
Other problems	30.5	20.8	9.1
Chemical constraints (% land)			
Low nutrient retention	54.2	24.2	69.3
Aluminium toxicity	32.5	18.1	30.2
Phosphorus fixation hazard	18.4	13.6	17.7
Low potassium supply	41.8	24.2	30.7

Source: FAO, 1986

Fischer et al. (1992) expanded the FAO population supporting capacity analysis for the 13 countries in West Africa by incorporating (a) three additional food crops, meat and milk, (b) six forage legumes for soil improvement and forage supply, (c) ten different methods for cattle and small ruminant production under pastoral and sedentary management, using feeds from sown and natural pastures, crop residues and by-products, and (d) meeting commodity specific national demand targets or attaining self-sufficiency as objectives of production systems. They did not, however, give any attention to forest land and its use.

Their analyses show that the 13 West African countries can attain basic food self-sufficiency, including meat and milk, by the years 2000 to 2025 by using intermediate level inputs in crop production and raising livestock supplementing the feed with planted forage legumes. The optimum land allocation would comprise 136 million hectares of food crops, 65 million hectares of forage legumes, and about 270 million hectares of pastures. Forage legumes could also be cultivated on half of the crop fallow land of over 50 million hectares. The model results showed that forage legumes had the potential to contribute up to 30% of the feed needs of a potential livestock population of about 140 million. Soil conservation would be an important additional contribution.

The specific amount of labor and inputs required for achieving the optimum production strategy were not qualified. Although pastoral and sedentary cattle and small ruminant production systems have been distinguished in the model, it is not clear from the optimum production plan how much land would be involved and how many animals would be reared under sedentary or mixed farming systems. However, the intermediate level input assumption implies the need for over five million tons of chemical fertilizers and a substantial input from forage legumes and animal traction. Whether these are achievable is a function of how the overall production system evolves in the sub-region. The study under reference did not elaborate on this issue.

3. Energy, Technical Change and Evolution of Production Systems

In the classical economic theories of growth and technical change, energy is not mentioned as a discrete factor of production. Only since the oil price crisis of the mid 1970s has serious attention been given to energy as a factor alongside labor and capital.

Technical change and transition to more intensive production methods have occurred differently in different parts of the globe. The theory of induced innovation is one of the most recent proposed to explain the causes of such variation. According to this theory, the nature of technical change in a given society was induced by the society's endowment of resources, particularly land and labor, reflected in their relative prices and their relation to product prices (Hayami and Ruttan 1985). In America, Australia and Western Europe, where land was inexpensive, compared to labor, engine powered mechanization replaced animal traction to increase output per worker. Later, when both land and labor became expensive, more sophisticated large scale mechanization and biochemical inputs were used to increase both land and labor productivity. In South and East Asia, where land was scarce relative to labor, a strategy of labor intensive agriculture was adopted, until biochemical technologies were available, in order to support an increased population on limited land. Large quantities of labor were used for land improvement, land levelling, drainage and water control measures, all of which contributed to increased land and labor productivity. Once biochemical technologies became available, land productivity increased significantly; but labor intensity and labor productivity also increased because more labor per unit of land was used for improved irrigation, land and crop management. Small-scale mechanization was adopted at a later stage when urbanization and industrialization started pushing wages up.

Although the theory of induced innovation explains variation in the nature of technical change in terms of relative prices of land and labor, history shows that the price of commercial energy played a significant role in the choices of mechanical and biological technologies (Jabbar 1982). The period of major capital investment in agriculture and industry coincided with a sharp decline in the price of energy relative to other productive factors (Carter and Youde 1974, Lockeretz 1977). Relative prices of coal, oil and electricity to wages showed consistently declining trends over a long period (figure 1), i.e., the quantities of these sources of energy which could be bought with an hour's wage steadily increased.

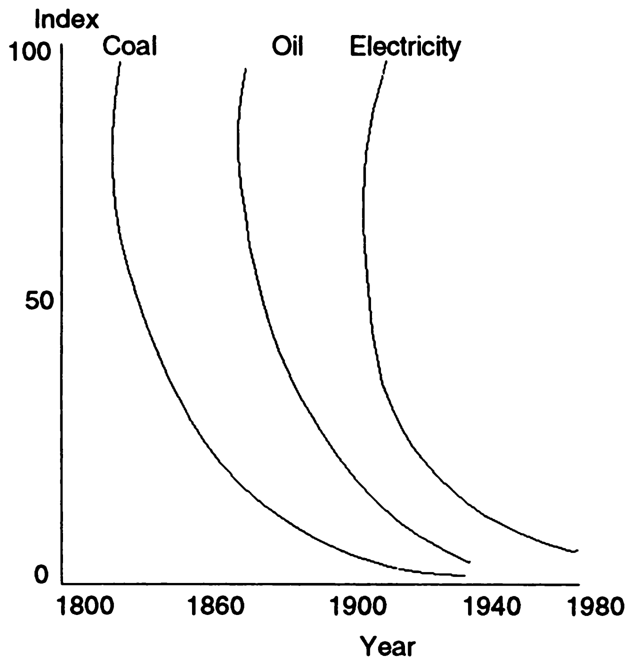

Figure 1. Indices of the prices of coal, oil and electricity, relative to wages
Source: Adapted from Simon 1981.

The commercial energy required annually to operate farm machinery is roughly twice the requirement for its manufacture and the energy required to operate irrigation equipment is about five times that required for its manufacture (Stout et al. 1979). Petroleum is the main input for the manufacture and the distribution of pesticides. Natural gas is the main ingredient for nitrogenous fertilizer, by far the most important chemical fertilizer in terms of the amount of plant nutrient supplied to world agriculture and in terms of the requirement of energy for its production and distribution. The price of natural gas is so low that much of it is wasted. For example, the OPEC countries annually flared about 60% of their natural gas production in the mid 1970s. The quantities flared annually would have been sufficient to meet about five times the annual nitrogen fertilizer consumption of developing countries for that period (FAO 1974). In the late 1960s, one dollar's worth of petroleum was equivalent in energy terms to 3800 hours of human labor (FAO 1976) or 'two human energy slaves working for about a year' (Leach 1975). This explains why agriculture in the advanced countries became extremely energy intensive after the Second World War. The initial success of the green revolution in Asia also depended on the availability of cheap energy.

A green revolution of the Asian type and scale has not taken place in SSA; the level of commercial energy use is very low. High energy prices from the mid-1970s have contributed to some extent to this low use. However, the need for increased productivity to support a rapidly growing population implies that commercial energy use, particularly of chemical fertilizers, has to be increased. If the prices of commercial energy and of fertilizers remain high, the importance of organic fertilizer from animal manure, nitrogen fixing trees and forage legumes will increase, which may induce a growth in crop-livestock interaction and integration. This will also increase labor intensity in agriculture for animal and crop production.

The theory of induced innovation principally used 'choice of technique analysis' to explain the process of transition from mixed farming to specialization in the advanced countries and the intensification within the framework of long established mixed farming in Asia (Gass and Biggs 1993). Little has been said about the circumstances that led to the evolution of mixed farming in Asia, Europe and North America at different times and in different forms. An adequate understanding of the historical and institutional dimensions of the process of technology development, application and diffusion would provide important perspectives about possible developments in SSA, particularly in the moist savanna zone where the evolution of mixed farming is at a rudimentary stage and the possible paths of the intensification of crop production and development are yet unclear. The role of research and policy in the intensification and development of mixed farming is therefore of particular importance.

4. Potential of Mixed Farming in the Moist Savanna

Some authors have postulated that population pressure will induce agricultural intensification in SSA (Boserup 1965, 1981, Ruthenberg 1980), others have laid more emphasis on the intensification of crop production and the development of mixed farming (Pingali et al. 1987, McIntire et al. 1992). Yet others have mentioned market access, the presence of cash crops, the dominance of cereals in cropping patterns and relative prices as additional factors fostering crop-livestock interaction and integration in specific situations (de Wilde 1967, McIntire et al. 1992, Smith et al. 1993). The sub-humid zone and the higher rainfall areas of the semi-arid zone in West Africa have been identified as higher potential areas for crop-livestock farming (FAO 1986, Winrock 1992). Although population pressure has resulted in reduced fallow and annual cropping and degradation of land in some areas of the sub-humid zone (Jahnke 1982), there are still large areas in the zone with sparse settled populations. The rural population density is lower than in the semi-arid zone and livestock density is also low. However, both are increasing rapidly because, due to more and less variable rainfall, crop production is less risky and pastures are potentially more productive than in the drier zone. Pastoralists from the drier north are moving into the zone, settling and adopting crop-livestock farming. Some sedentary crop farmers are also adopting cattle rearing. Some migration into the zone from the densely populated humid zone has also been reported (Jabbar 1993). Such migration and multiplication of the local population creates pressure on available land resources.

Some suggested indicators of crop-livestock interaction and integration, related causes or driving forces can be observed, scattered throughout the sub-humid zone. However, the possible evolutionary path of and time frame for the development of mixed farming is still unclear from existing literature. In Ruthenberg's (1980) classification of seven types of production systems and their implied evolution from a less to a more intensive nature, there is no integral role for livestock, implying that intensification in crop production may proceed without (significant) interaction or integration with livestock. On the other hand, Pingali et al. (1987) and McIntire et al. (1992) have characterized the role of livestock in intensification as an evolutionary process. They postulate that population growth expands cropland and contracts fallow periods and the area of pasture land, so that external inputs are required to maintain soil fertility. Where livestock is kept, farmers paddock animals on cropland or collect and use manure and crop residues as feed. As population pressure increases further, more intensive technology is required to increase production including heavier applications of manure and fertilizer. A shift from paddocking to the collection, processing and incorporation of manure takes place. Herders settle and engage in crop production and increasingly use crop residues. Animal grazing of natural pasture reduces crop residues, and the crop residue available is harvested and preserved for feeding and manure is more intensively used in cultivation. Finally, human labor is replaced by animal traction and by mechanization, which have become economically viable due to the higher intensity of land use. As a further step, farmers may grow legumes and forage to improve soil fertility and crop yield as well as livestock productivity.

From the foregoing, several questions arise about the possible paths and forms of intensification and their implications for sources of energy in agriculture:

a. Will increased population pressure increase labor intensity in agriculture?
b. Can intensification in crop production proceed without significant interaction or integration with livestock?
c. Will traction become important? Where and when?

d. Can food rather than the input contribution of livestock become a driving force for integration?
e. What can policy and government intervention do to accelerate the process of intensification and integration?

4.1 Labor intensity

Currently about 70% of the SSA population is found in rural areas. This proportion is projected to decrease to 56% in 2010 and 44% in 2025. However, the actual numbers are projected to increase from 354 million in 1990 to 593 million in 2025, an increase of 68% (Winrock 1992). The growth rate of the rural population is expected to increase rapidly due to migration and new settlement in the sub-humid zone, which is currently thinly populated.

In Asia, before the green revolution, the principal response to population pressure on a given land area was to increase labor intensity. The low opportunity costs of labor meant that labor use could be extended until the marginal productivity of labor was near zero. Sanders et al. (1995) reported a similar response in semi-arid areas with high population densities and low opportunity costs of labor, where off-season labor is used in various land improvement and water control measures to maintain and increase the productivity of degraded land.

Most of the more productive land in the West African sub-humid zone has been used, so the impact of increased rural populations may be expected to increase labor intensity in at least three ways:

a. decrease the fallow period and increase annual cropping, thereby increasing labor intensity per unit of land. Increased land use intensity will reduce soil fertility, so more effort will be required for better land and crop management to maintain yield
b. extend crop production to more marginal areas, which will also require high labor input per unit of land and per unit of output
c. among other reasons, reduced pasture will force pastoralists to settle in increasing numbers and adopt crop-cattle farming, thus increasing labor intensity as compared to pastoral herding

Both land and labor use intensity may increase further if improved technologies become available and if market conditions permit their extensive use. However, the density of population in the sub-humid zone is not expected to become as high as in Asia, so the extent of labor intensity may not reach the level of Asia before the green revolution.

4.2 Intensification without livestock

Before mixed farming evolved in Asia and West Europe, crop growers, who were more intensive land users, pushed pastoralists who were less intensive land users on to more marginal pasture land. A time came when neither group could sustain productivity without the other. Crop growers needed manure and animal power and pastoralists needed crop residues as animal feed and these needs became driving forces for crop-livestock interaction and subsequent integration. Improved crop cultivars, chemical fertilizers and engine power were not available as substitutes for land, manure and animal power as they are now.

In the ecological stratification of West Africa transhumant pastoralism made cattle production viable through inter-seasonal movements which take advantage of varying vegetation and water sources. Pastoralism is still the dominant cattle production system in the region. Crop-livestock interaction and integration are however, evolving; and this process is slightly more advanced in the drier regions because of the greater possibility of settled/sedentarised crop-cattle production in a more disease free environment. However, the unidirectional linear evolutionary process of crop-livestock interaction postulated by Pingali et al. (1987) and McIntire et al. (1992) may not always hold in West Africa, particularly in the sub-humid zone. There are indications from field studies that the initial mutually beneficial interaction between nomadic herders and settled crop growers through paddocking (manuring) and crop residue grazing may be disrupted if chemical fertilizer is cheap and easily available. If improved crop varieties and market access are also available, then, due to intensive cropping on good land, herders are pushed away from cropping areas for fear of damaging crops and potential conflicts. Intensification in crop production in fertile land areas may then advance without cattle and without manure. However, crop farmers may adopt cattle rearing on a small scale, generally as a form of investment, giving the cattle to herders for management or they may hire herders before eventually taking up management themselves (Jabbar 1993, Jabbar et al. 1995). These crop farmers may use animals for traction; traction and cash income from the sale of fattened animals may be the primary motive for the adoption of cattle. Manure may be considered a secondary benefit for intensive crop/vegetable production near the homestead, distant crop fields being treated with chemical fertilizers.

This scenario is unlikely to hold for areas less suitable for crop production where most new settlements in the region are likely to take place. In the absence of improved biochemical technologies for degraded land, mutual interaction involving manure and crop residue exchanges remains a viable option. Animal traction may also be useful for reclaiming degraded grassland for crop production, although not for opening up bush fallow or forest.

4.3 Animal traction

Mechanization in the advanced countries moved from the use of manual tools and animal powered equipment to engine power; while in parts of Asia, the process stagnated for a long time after the initial transition from hand tools to animal power (table 6). In most cases, power intensive operations such as tillage and threshing were mechanized before control intensive operations such as weeding and planting (Binswanger 1982).

Table 6. Evolution of main sources of power for energy intensive farm operations

Time period	Western Europe	North America	Japan	South Asia	SSA
300 BC	Human labor		Human labor	Human labor+ oxen	Human labor
400 AD	Oxen				
1400 AD	Horses	Human labor	Human labor+ horses		
1800 AD		Horses			
1930 AD	Machinery	Machinery			
1950 AD			Machinery		

In SSA, there is a long history of animal traction use in the East African highlands, particularly in Ethiopia. Traction has been introduced in parts of semi-arid West and Southern Africa as part of a package involving cash crops (cotton, groundnut) and/or improved technology (hybrid maize, millet) both of which provided opportunities for higher profitability. Autonomous adoption of traction as part of a crop-livestock integrative process is rather limited. In the sub-humid zone, animal traction is only emerging.

Several studies have shown that the transition from hand tools to animal traction is profitable only at high levels of capacity utilization of the animals and/or at high levels of farming intensity, neither of which are extensively found in the semi-arid zone except in limited areas of cash crop and improved technology based farming (Pingali et al. 1987, Jaeger and Matlon 1990, Ehui and Polson 1993). Animal traction was considered to have a high potential for acceptance in the semi-arid zone because the low rainfall and short growing season creates a need for labor-intensive activities such as land preparation and planting. A closer observation, however, shows that since soils in the semi-arid areas are light textured and erosion prone they do not need intensive tilling. As a result, time and labor may not be major constraints for small- scale farmers (Ehui and Polson 1993, Sanders et al. 1995).

In the sub-humid zone, rainfall is greater and extends over a longer period than in the semi-arid zone, so timeliness may not be a problem in upland cultivation on small-scale family farms. But it is important for commercially oriented medium-scale farming and where only inland valleys (lowlands) or both upland and lowlands are cultivated. Lowlands are potentially productive resources in the moist savanna which have not been properly exploited. The heavy clay soils in most lowlands make land preparation by human labor time consuming and difficult. Proper utilization of uplands and lowlands with improved technologies will require easy and timely land preparation which could be achieved by animal traction. There are indications that it may be possible to use traction well before the stage when high intensity in farming or mature mixed farming conditions are reached. If animal traction should not prove suitable/acceptable, power tillers could fill the vacuum. Power tillers are smaller than tractors; therefore, they are more likely to succeed, though they have not been adequately tested in SSA.

4.4 Livestock's contribution to integration

The main contributions of livestock to farming are food (beef and milk) and inputs to crop production (draft and manure). As pastoralism and specialized crop farming evolve into mixed farming, the input contributions of livestock became more important. This is evident from the differences found in livestock contributions when mixed farming societies in Asia and predominantly pastoralist societies in SSA are compared (table 7). Input contributions have been driving forces for crop-livestock interaction and integration. Market forces, urban demand and cash generation through sales of livestock feed have not been important contributors to the process of interaction and integration in rural areas far from towns. In present day SSA, particularly in West Africa, the food contribution of livestock has a great potential for fostering the process of development through supplying more food for the domestic population, saving foreign exchange, generating farm income, and promoting the intensification of agriculture.

Table 7. Main contribution of large ruminants in selected regions/countries

Region/Country	Contribution			
	Draft	Manure	Milk	Beef
India	****	**	**	
Bangladesh Indonesia	****	***	**	*
East Asia	**	*		***
South/Central America	**	*	***	****
Sudan			****	***
Ethiopia	***		***	****
Dry West Africa	*	**	****	***
Wet West Africa			**	***

Note: The number of stars indicate relative importance within a location.

Currently about 50% of milk and dairy products and 5% of meat consumption in West and Central Africa are imported, compared to 12 and 5% for the whole of SSA. The failure of the subsistence-oriented domestic production sector to keep pace with the growing demand caused by population growth, urban growth and income growth has resulted in increased imports at the expense of valuable foreign exchange. Valuable resources have been diverted from investment in domestic production to current consumption.

The currently dominant pastoral and agropastoral production systems are efficient in the given context; but their productivity is low, as is their offtake rate for milk and meat. Large herds may not be fully milked if the product cannot be sold in the local rural market. Instead calves may be better fed to reduce mortality and increase herd size. Cattle are sold to meet cash needs. Supply response is generally low and backward bending because cash needs may be better met by fewer sales at higher prices. The needs of the vast urban market for animal products cannot be served by such a system. Higher productivity and higher offtake are required, and this may come from an integrated crop-livestock (dairy) system. Unlike crops, which generate cash at specific harvest times, dairy farming has the potential for generating a regular cash income, from the marketed surpluses of milk and beef (typically 20-40% of the income of a dairy farm comes from the sale of male calves and culled cows). An enhanced cash income from dairy farming with manure and animal traction as secondary benefits may be a stronger driving force for intensification than integration of crops and livestock, where the inputs from livestock are limited to manure and animal traction.

The regular cash generation of the dairy enterprise may enable a higher level of investment in both crop and livestock enterprises in the form of seeds, fertilizers, pesticides, drugs and feeds, and thus enhance production and income. Increased crop income may also be invested in animal production (Brumby 1986). There is evidence to suggest that livestock provides a dominant part of the cash income and gross margin of crop-livestock farmers (Gryseels 1988, ILCA 1987, Debrah and Sissoko 1990) and that gross margins of crop-livestock (dairy) farmers are higher than for crop farmers (Gittinger et al. 1990, Okoruwa 1994). Dairy based mixed farming also provides more productive employment than crop farming.

The system described is dependent on access to regular markets, so it is most likely to develop in the peri-urban areas, i.e., in the supply hinterlands of urban areas. Such a phenomenon has already been observed in the sub-humid zone (Waters-Bayer 1988, Agyemang and Dogoo 1992, Jabbar 1993, Jabbar et al. 1995). Pastoralists are trying to settle in areas that are accessible to markets for milk and dairy products. Crop farmers and retired civil servants making investments in cattle also locate in the peri-urban areas.

4.5 Policy and intervention

While appropriate policies and interventions may help and accelerate the autonomous process of farming systems evolution; inappropriate polices and interventions may distort and stifle the process of development. An example may be given with respect to traction and mechanization.

In the 1960s, differences in technological achievement in crop production between the developed and developing countries were sometimes attributed to differences in the amount of power applied, and theories of 'farm power ladder, and, minimum power levels' were advocated for agricultural development (Giles 1967a, 1967b, USGP 1967, Weil 1970). Such arbitrary comparisons provided the basis for the initiation of many tractor mechanization projects in SSA and in Asia by national governments with or without support from aid agencies. In some cases, the tractorization program was part of a policy to develop large-scale commercial agriculture under parastatal or private sector management, without giving attention to the small-scale family farm sector (Ahmed and Kinsey 1984). Most of these projects were later found to be technically inefficient and socially unprofitable; though they could be privately profitable in some cases when given large subsidies. They eventually failed. The theoretical possibility of transition from hand tools to engine powered mechanization in the family farm sector also turned out to be unrealistic.

Nigeria is a classic example of this experimentation. Animal traction was first introduced in 1928 as a component of cash cropping systems in the semi-arid part of Nigeria by the colonial government. Training schemes for animals and ploughmen were also introduced. As a result, the number of farms using animal traction increased to 1820 in 1940, 3052 in 1950, 15452 in 1955, and about 34000 in 1963 (Calvin Antonza and Lawrence Stifel, personal communication). Adoption of animal traction spread into some parts of the sub-humid zone as well (Blench 1988 quoted in McIntire et al. 1992). However, in the late 1960s, with the emergence of the oil boom, tractorization rather than animal traction was emphasized. Federal government expenditure on the tractorization program increased from ₦11 million during the first five-year plan period (1970-1974) to ₦54 million during the second (1975-79) and ₦240 million during the third (1980-85). Two tractor assembly plants and a national center for agricultural mechanization were established in 1980 with the aim of releasing 5000 tractors per year. During 1975-83, 22,000 (mostly imported tractors) were sold at subsidized prices to parastatal agencies such as River Basin Development Authorities and large-scale private companies. Meanwhile, the draft animal training centers closed down, animal traction adoption slowed down greatly but a small amount of farmer to farmer diffusion of the process continued.

The oil boom was accompanied by a policy of indirect taxation of agriculture through an overvalued exchange rate, which also encouraged imports and discouraged domestic agriculture. By the mid 1980s, the oil boom collapsed. Policy changes started taking place slowly, but over two decades of misdirected intervention and distortion had stifled the natural process of development and evolution of production systems.

Similar examples abound throughout SSA. As a result of the introduction of structural adjustment programs, or such components as currency devaluation, in some countries in recent years, the environment for agricultural development and the possibilities for rapid crop-livestock interaction are reappearing. For example, in the face of rising prices of fertilizer after currency devaluation in the francophone countries, farmers responded by applying more manure, making compost in a systematic manner, and patronizing a developing market for manure (Sanders et al. 1995). This is certainly a short-term survival oriented strategy, because without chemical fertilizers higher productivity cannot be expected. However, this temporary backward movement may put the natural process of development back on track. Government policies need to be supportive of this process.

5. Conclusions

The moist savanna zone is a high potential area for agricultural development. Crops, animals and forests are important components of the ecosystem. Any strategy for agricultural development in the zone should take into account current and possible future changes in relationship among the three components.

In the past, nomadic pastoralism was dominant in the zone because of the risk of trypanosomiasis. With the decrease of this risk, sedentary cattle production and crop-livestock mixed farming is evolving. Human labor is the main source of power for crop production and the level of commercial energy use is very low. In Asia and Europe, mixed farming developed at a time when improved technologies (hybrid seeds, chemical fertilizers, machine power) were not available and the external influences of government policy and international market were small, if they existed. In SSA, the availability of some improved technologies and associated government policies and interventions are likely to influence the path, form and time frame for the evolution of mixed farming. Researchers and policy makers need to learn from historical experiences elsewhere and identify appropriate niches for technology development and intervention in order to facilitate the autonomous process of evolution.

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PART 3
Potentials and Constraints to Crop Production

FOOD PRODUCTION IN THE MOIST SAVANNA OF WEST AND CENTRAL AFRICA

G. Tian, B.T. Kang, I.O. Akobundu and M. Manyong

Resource and Crop Management Division, International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria

Key words: weed control, chemical fertilizer, residue, intercropping, woody fallow

Abstract: *The moist savanna zone (MSZ) of West and Central Africa can be divided into four subzones namely: the coastal savanna (CS), the derived savanna (DS), the southern Guinea savanna (SGS) and the northern Guinea savanna (NGS). The CS, DS and SGS subzones are characterized by bimodal rainfall and a length of growing period (LPG) that ranges from 181-270 days. The NGS subzone has a monomodal rainfall distribution, LGP of 151-180 days, and the highest insolation among the moist savanna subzones. Soils in the MSZ are characterized by coarse-textured surface soil with low activity kaolinitic clays, high base status, low effective cation-exchange capacity, deficiencies of N, P, K, S and Zn, and high susceptibility to soil compaction and erosion. Major weeds of the MSZ are speargrass (Imperata cylindrica), witchweed (Striga spp.) and sedges (Cyperus spp.). The severity of weed infestation increases with increased rainfall while the persistence of weeds that are difficult to control increases with a decrease in rainfall. Land use intensification within a given subzone in the MSZ also increases weed infestation. Food production in the CS and DS of West and Central Africa is affected by poor market access, lack of appropriate processing technologies and poor extension services. The SGS is well suited for long duration crops like yam and cassava. The NGS is well suited for short or medium duration cereal and grain legume crops such as maize, soybean, cotton, cowpea and groundnut. Crop yield under on-farm conditions is low, due to the use of unimproved cultivars, the lack of appropriate soil and crop management technologies and unfavorable socio-economic conditions. Incorporation of herbaceous and woody fallow species in cropping systems, coupled with the integration of livestock into the farming systems for animal traction and more efficient use of crop residue and manure shows promise for sustainable crop production in the MSZ.*

1. Introduction

The moist savanna zone (MSZ) of West and Central Africa covers a large area of sub-Saharan Africa. Most of the countries located in the zone, have low per capita income and have serious food and nutrition problems (Mudahar 1986). The rapid increase in human population and exploitive use of non-renewable resources in the area has worsened food shortages. Producing adequate food supplies is a major challenge for this area.

In order to develop innovative technologies for sustained and high crop yields in the MSZ, growing conditions in the MSZ must be fully understood. The purpose of this review is to assess the biophysical, socio-economic factors and the crop production potential and constraints for sustaining food production in the MSZ.

2. Biophysical and Socio-economic Constraints of the MSZ

2.1 Climate

The MSZ is characterized by biophysical heterogeneity. Based on the climate, vegetation and agricultural potential, the MSZ of West and Central Africa is divided into the following four subzones: the coastal savanna (CS), the derived savanna (DS), the southern Guinea savanna (SGS) and the northern Guinea savanna (NGS) (Jagtap 1995).

The climatic and other biological features are shown in table 1. The CS, DS and SGS subzones are characterized by rainfall bimodality and a longer growing period (LPG). The SGS gradually merges into the NGS which has a shorter growing period and monomodal rainfall distribution. The MSZ in general is characterized by high rainfall intensity with a rainfall erosion index ranging from 500-700, that increases with annual rainfall and frequency of rainstorms (Roose 1986). Annual precipitation varies substantially from year to year, with a trend of lower precipitation in the 1970s and 1980s as compared to the 1960s. In contrast to annual rainfall data, the incidence of solar radiation is higher in NGS than in the other subzones (table 1).

2.2 Soils

The Alfisols, Ultisols/Oxisols and Vertisols are the major soils in the MSZ (table 2). The low activity clay (LAC) Alfisols, Oxisols and Ultisols dominate the CS, DS and SGS subzones, while the LAC Alfisols and high activity clay (HAC) Vertisols dominate the NGS subzone. Vast areas of the MSZ are also occupied by weakly differentiated coarse textured Entisols and Inceptisols (Regosols, FAO legend; *sols peu* evolves, INRA classification) and alluvial and hydromorphic soils in the lowlands consisting of Aquepts and Aquents in catenal association with the major upland soils.

Alfisols (mainly haplustalfs, paleustalf and plinthustalfs) are less leached and have a high base saturation (> 35% of ECEC in the subsoil). These soils generally have low effective cation exchange capacity (ECEC) in the top soil, due to the fact that clay fraction is mainly kaolinitic, and contributes little to the soils' exchange capacity. Soil organic matter contributes the major portion of soil effective cation exchange ratio (ECEC) (Juo and Adams 1986).

Table 1. Gradient in natural biophysical features of the MSZ of West Africa

Parameters	DS	SGS	NGS
1. Radiation	-->		
2. Length of growing period	211-270 days	181-210 days	151-180 days
3. Rainfall	BM**, >1300 mm	BM**, 1200-1500 mm	MM***, 900-1200 mm
4. Fire	--		
5. Erosion	-->		
6. Soil compaction	-->		
7. Soil organic matter	<--		
8. Potential soil acidification problem	-->		
9. Soil fertility	<--		
10. Biomass production/yr	<--		
11. Weed infestation:			
(a) Parasitic	-->		
(b) Non-parasitic	-->		
Grasses	-->		
Broadleaf	<--		
Sedges	-->		

Notes: * Direction of arrow indicates increment
** BM - Bimodal; ***MM - Monomodal

The inherent fertility of soil greatly depends on parent material and soil organic matter level, and ranges from low to moderate. Benefits from N, P and K applications for intensive cropping on the Alfisols and associated soils have been well documented. With intensive cropping, N is the primary limiting nutrient, followed by P. Deficiencies of these nutrients are more acute in the NGS. Sulphur deficiency which is linked to soil organic matter status, is also more important in the NGS than in the other subzones of the moist savanna. Potassium is generally needed with long-term continuous cropping, particularly on soils derived from sedimentary rocks. Alfisols and associated soils have low P fixation and a high residual effect from applied P. In addition, the presence of mycorrhiza is common in these soils, resulting in a low P requirement for crop production.

Continuous cultivation and fertilizer application can significantly affect the properties of Alfisols and associated soils. Cropping, coupled with continuous N fertilizer application, reduces soil pH, soil organic matter, and extractable cations. This lowering of soil pH can result in increased Al and Mn toxicity (Bache and

Heathcote 1969, Jones 1976, Pichot et al. 1981, Kang and Balasubramanian 1990, and Kang 1993).

Table 2. Major soils and level of fertility components of uplands in the various subzones of the moist savanna of West Africa

Parameters	Moist Savanna		
	Coastal and Derived (CS, DS)	Southern Guinea (SGS)	Northern Guinea (NGS)
1. Upland	26.9*	31.5	41.5
Alfisols (Luvisols + Nitsols, FAO legend; Sols Ferruginuex tropicaux, INRA)			
	44.9	32.9	10.8
Oxisols/Ultisols (Ferralsols/Acrisols FAO legend; sols Ferrallitiques,INRA)	1.8	3.5	12.3
Vertisols			
2. Lowland	1.5	3.1	2.5
Aquepts, Aquents (Gleysols, FAO legend; Sols hydromorphes, INRA)			
Fluvents (Fluvisols, FAO legend; Sols mineraux bruts et sols peu evolues d'apport alluvial et colluvial)	1.8	4.2	4.2
3. Soil fertility status, uplands			
• Organic carbon	moderate	low	very low
• Available N	moderate	low	very low
• Extractable P	moderate	low	low
• Extractable S	moderate	low	low

Note: Per cent total area (157.9 x 106ha for coastal and derived savannas; 98.2 x 10^6 ha for southern Guinea savanna and 112.5 x 10^6 ha for northern Guinea savanna).

Source: Personal communication Dr. S.S. Jagtap.

The Alfisols show a significant clay increase with depth, and part of the clay fraction is readily dispersible in oxic Alfisols. The Alfisols (with the exception of Nitosols, which have high structural stability) have coarse to medium-textured surface horizons and a sharp transition to clay B horizons. Because these soils do not have a stable structure they are prone to soil compaction and erosion.

Ultisols and Oxisols and associated soils are LAC soils, which are highly weathered and leached. The Ultisols are acidic and have a low base saturation (< 35% of ECEC in the subsoil). Both Utisols and Oxisols have very low nutrient levels in the soil solution and consequently a low capacity to provide nutrients to crops. The low productivity of these acid soils has also been attributed to Al and Mn toxicity. In earlier studies, acid soils in the humid tropics were limed to neutralized pH, with generally poor results due to nutrient imbalance. Following the findings of the 1950s that acid soils contain more exchangeable Al^{3+} than H^{+}, primary consideration has been given to the removal of toxic factors which limit plant growth (Kamprath 1984). Research on acid soils in West Africa has confirmed these findings. The application of 0.5 to 1.0 t lime per hectare was found to be adequate to reduce toxic levels of Al^{3+} and Mn^{2+} for highly acid soils. Liming also has a high residual effect which lasts for a few years. These soils are also usually deficient in P. Rock phosphates can be used on unlimed acid soil as an inexpensive and efficient way of supplying P to acid tolerant crops (Juo and Kang 1979).

The physical properties of Ultisols are similar to those of Alfisols, but different from Oxisols. Ultisols are prone to soil compaction and erosion. In the Oxisols, the clay is highly resistant to dispersion. The Oxisols are less subject to erosion (Lal and Greenland 1986).

Vertisols are poorly drained heavy textured soils. These HAC soils have high ECEC and smectite (montmorillonite) as the dominant clay mineral. Vertisols are largely underutilized by peasant cultivators because of their difficult physical properties and the narrow range of water content at which these soils can be tilled. Their advantages in crop growth include a relatively high water-storage capacity and the fact that though difficult to till, they need less cultivation than most soils because of their 'self-loosening' properties. Crop yield in Vertisols can be substantially improved by proper water management. Vertisols are rich in Ca, and Mg, but soil organic matter and N status are generally low. The P content varies in relation to parent material, and ranges from moderate to low. Sulphur and zinc deficiencies are common in Vertisols.

2.3 Weeds

A majority of noxious tropical weeds occurs in the savanna zone (table 3). The SGS is predominantly an open savanna woodland with tall tussocky grasses, such as *Andropogon tectorum*, *Panicum maximum* and *Pennisetum purpureum*. Other perennial grasses are *Imperata cylindrica* and *Cynodon dactylon*. Nutgrasses (*Cyperus rotundus*, *C. esculentus* and *C. tuberosus*) is the dominant sedge. Other noxious weeds include *Striga* spp. The NGS has more drought-tolerant grass weeds such as *Andropogon gayanus*, *Cymbopogon giganteus*, *Digitaria gayana*, and *Hyparrhenia* spp. Other grass weeds such as include *Imperata cylindrica*, *Pennisetum* various spp. and *Rottboellia cochinchinensis* occur in patches of land with poor drainage or as dry season weeds in the valley bottoms. Parasitic weeds are endemic in this subzone. The DS has a mixture of forest species and true savanna vegetation. *Imperata cylindrica*, *Panicum maximum,* perennial sedges and annual broadleaf weeds constitute serious problems to food production in this subzone.

Table 3. Major weeds of arable crops in the MSZ of West Africa

MSZ	Broadleaf weeds	Grasses & sedges
Derived savanna	*Commelina benghalensis*	*Imperata cylindrica*
	Ageratum conyzoides	*Andropogon tectorum*
	Mimosa invisa	*Pennisetum* spp.
	Euphorbia heterophylla	*Panicum maximum*
Southern Guinea savanna	*Vernonia* spp.	*Imperata cylindrica*
	Ageratum conyzoides	*Andropogon gayanus*
	Mitracarpus scraba	*Hyparrhenia involucrata*
	Indigofera spp.	*Digitaria, Brachiaria*
	Commelina	*Eleusine indica*
	Striga spp., *Leucas* spp	*Cyperus* spp.
Northern Guinea savanna	*Striga hermonthica*	*Hyparrhenia rufa*
	Commelina spp.	*Andropogon gayanus*
	Vernonia spp.	*Cyperus* spp.
	Leucas spp.	*Digitaria chevalieri*

Note: *Oryza longistaminata, Chinlohcloa* spp., *Panicum laxum*, and *P. repens* are serious weed problems of flood plains and inland valleys in the MSZ wherever rice culture is practiced.

The removal of natural vegetation, particularly woody vegetation, coupled with intensive crop production is known to increase the infestation of weeds that are difficult to control. Example of such weeds are *Imperata cylindrica* and *Striga. Imperata* is a serious problem in the DS and SGS especially under intensified annual cropping. *Striga hermonthica* has been identified as one of most serious threats to cereal crop production in the drier NGS subzone and in the Sudan savanna (Lagoke et al. 1991). In parts of the MSZ where adequate moisture is available sedges become serious weed problems.

Weeds of arable fields in the savanna of West and Central Africa were reviewed by Ogborn (1980), Olunuga and Akobundu (1980), and Zehrer (1980). While there is hardly any difference in the spectrum of annual weeds that occur in the moist savanna, there is a gradient in the type of weeds as one moves from the SGS to the NGS zone (table 1). A major difference is the time when the weeds are abundant. The early weed flora in the SGS is dominated by annual grasses with a considerable proportion of non-grassy weeds such as *Ageratum conyzoides, Commelina spp, Indigofera* spp, *Convolvolus* and *Ipomoea* spp. Where these species are controlled during the first weeding, the next flush of weeds is usually dominated by such fast-growing broadleaf weeds as *Mitracarpus scraba, Amaranthus* spp., *Leucas* and *Vernonia* spp. Ogborn (1974) reported that the grasses *Dactyloctenium aegyptium,* *Eleusine indica*, *Digitaria chevalieri*, *Brachiaria* spp., and *Paspalum* spp. tend to dominate early weed flora in the southern and northern Guinea savanna agroecological zones. It must be mentioned that there are differences in floral composition within zones.

Some hydromorphic soils of the moist savanna are extensively cropped with a variety of upland crops during the dry season. In some others, paddy rice is grown during the wet season. Irrespective of the season, excessive weed growth is a major constraint to crop production in the inland valleys and other hydromorphic fields of the MSZ. Among the most serious weeds of the fertile valleys and flood plains in the MSZ are *Oryza longistaminata*, *Cyperus esculentus*, and *C. rotundus*. *Cynodon dactylon* thrives well in moist uplands as well as in the lowlands (Akobundu and Fagade 1978).

The severity of annual weed infestation in the MSZ of West Africa follows the rainfall gradient. Consequently weed pressure decreases as one moves from the derived savanna to the northern Guinea savanna zone (table 1). Exceptions to this pattern are the infestation of such weeds as *Imperata cylindrica* in the DS and SGS, and *Striga hermonthica* in the NGS. The number of fundamental studies on weed-crop interaction in the Guinea savanna is limited.

2.4 Socio-economics

One of the main socio-economic constraints in the MSZ is poor access, particularly in the DS/CS (table 4). Poor access increases the cost of inputs and leads to marketing problems. In addition, the lack of a highly profitable major cash crop for most of the agricultural systems of MSZ (table 3), and the absence of appropriate credit channels, reduce farmers' ability to re-invest in agriculture for improving and sustaining food production.

Table 4. Accessibility and high profitability of cash crops in agricultural systems of the MSZ in 8 countries* of West and Central Africa (M. Manyong, unpublished data)

Subzones	Area ($x10^{-3}$ km^2)	Accessibility		Profitability of cash crops	
		Good**	Poor	High	Low
		(%)		(%)	
NGS	161	41	59	42	58
SGS	259	36	64	34	66
DS/CS	588	19	81	12	88
Total	1008	27	73	23	77

Notes: *Benin, Burkina Faso, Côte d'Ivoire, Congo, Gabon, Guinea Conakry, Mali and Zaire
**Good access is defined if road density ≥ 15 km/100 km^{-2} or if many villages are well connected to wholesale markets throughout the year.

The collapse of world prices of cash crops (cocoa, oil-palm, coffee) during the seventies and eighties has discouraged farmers from using purchased inputs such as fertilizers, pesticides, etc., in the DS. Recent socio-economic characterization studies in the NGS, showed that market access combined with the biophysical productivity of the area have stimulated agricultural development (table 5).

Table 5. Socio-economic characteristics and constraints of agricultural systems of the MSZ in West and Central Africa and driving forces for agricultural intensification

	Population driven	Market driven
Expansion phase	Low inputs/ha	Moderate levels of input use/ha
	Low surplus from farming	High surplus
	Moderate/long fallow	Moderate/long fallow
	Poor infrastructure	Good infrastructure
	Minimal cash crop production	Profitable cash crop production
Intensification phase	Low level of purchased inputs	High input use/ha
	Low surplus	High surplus
	Short/no fallow	Short/no fallow
	Poor infrastructure	Good infrastructure
	Minimal cash crop production	Profitable cash crop production

Source: Smith and Weber (1994)

The lack of appropriate processing technologies is also a constraint to expanding crop production. Nweke (1992) reported that the land area under cassava expanded with the mechanization of gari production. Results of an ongoing study (M. Manyong unpublished data) also indicate that farmers are reluctant to adopt some improved maize varieties in the NGS because the grains do not meet the local processing requirements.

Annual bush fires reduce the return of organic biomass to the soils, encourages the persistence of noxious weeds and can in turn restrict the adoption of an improved technology (Versteeg and Koudokpon 1990). Macro-economic policy such as over-valuation of local currency in CFA countries, while exports are over taxed, favors importation of food and reduces the market for local products as well as the incentives for planting crops (Dorosh and Akanji 1987). Extension services in the MSZ are poorly organized and in the past have only benefited industrial crops. This may have restricted the adoption of improved technologies that could promote the production of non-industrial crops. The role of women has also not been fully taken into account, and knowledge about the heterogeneity of agricultural systems in the MSZ is still limited (table 6). Without this background, it is difficult to select the technologies for appropriate environments and socio-economic conditions.

Table 6. Research problem prioritization in the moist savanna zone

Problem	DS[1]	SGS	NGS
Soil			
Erosion	+2	++	+++
N deficiency	++	+++	+++
P deficiency	++	++	++
S deficiency	+	++	+++
Micronutrients	+	+	+
Acidification	+	+	+++
Compaction	+	++	++
Vegetation			
Plant residue	+++	+++	+++
Animal feed	+	++	+++
Imperata cylindrica	+++	+++	+
Weed infestation:			
Non-parasitic weed	+++	+++	++
Parasitic weed		++	+++
Climatic			
Drought stress	+	++	+++
Socioeconomic			
Incomplete knowledge of system	++	+++	+
Systems mgt.			
Systems development and management	++	+++	+++
Resource conservation	+++	+++	+++

Notes: [1]DS = Derived savanna; SGS = southern Guinea savanna; NGS = northern Guinea savannah.
2+ = low priority, moderate problem; ++ = medium priority, serious problem; +++ = high priority, very serious problem.

3. Potential of MSZ for Crop Production

3.1 Short to medium-duration annual crops

Maize, sorghum, millet, upland rice, soybean, groundnut, cowpea, and cotton are currently the main crops grown in the NGS. The NGS has higher potential for certain crops than the other moist savanna subzones (figures 1a-c). Maize grain yield increased from DS to NGS under both researchers' and farmers' conditions because of the more favorable growing environment. Soybean yield in the various MS subzones followed the same pattern as that of maize (figure 1b). Under experimental conditions, soybean seed yield in the NGS was 54% higher than in the DS. The NGS also showed higher yield potential for groundnut production. With proper management the use of improved cultivars and pest control, over 5 t ha^{-1} of groundnut seed yield was obtained in the NGS (Rotimi 1970). Cotton is widely grown in the NGS and Sudan savanna. Yields of 2.5-3.0 t ha^{-1} of seed cotton have been obtained in the NGS in a long-term trial (Prentice 1972). However, cowpea yield was higher in DS, and lowest in SGS (figure 1c).

High insolation and more reliable rainfall distribution (monomodal) contribute to high yields for the short to medium-duration annual crops in the NGS (table 1). Lower night temperature in the NGS also promotes dry matter accumulation and partitioning, leading to a higher harvest index (Kassam et al. 1975). The exception to this is cowpea yield which may be attributed to other factors.

Although the MSZ has a high potential for production of short to medium duration annual crops, the yield level obtained under farmer conditions is still very low. Figures 1a-c show large yield gaps for maize, soybean and cowpea between experimental and farmer yields. Farmer yields for both maize and soybean are, on the average, about one third of that of experimental yield. Such a yield gap is more pronounced with cowpea. For well-endowed areas with a high degree of marked intensification in the NGS, maize yield in farmer fields already approaches 50% of that observed in experimental fields.

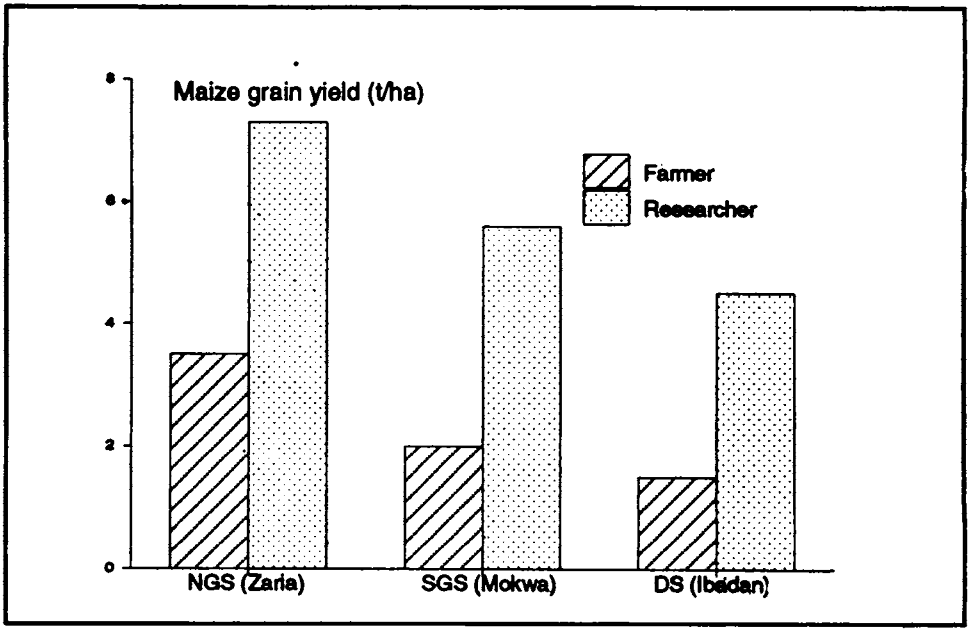

Figure 1a. Grain yield of maize under researcher and farmer conditions in the MSZ
Source: Zaria and Mokwa (SS Kim personal communication); Ibadan (IITA 1987)

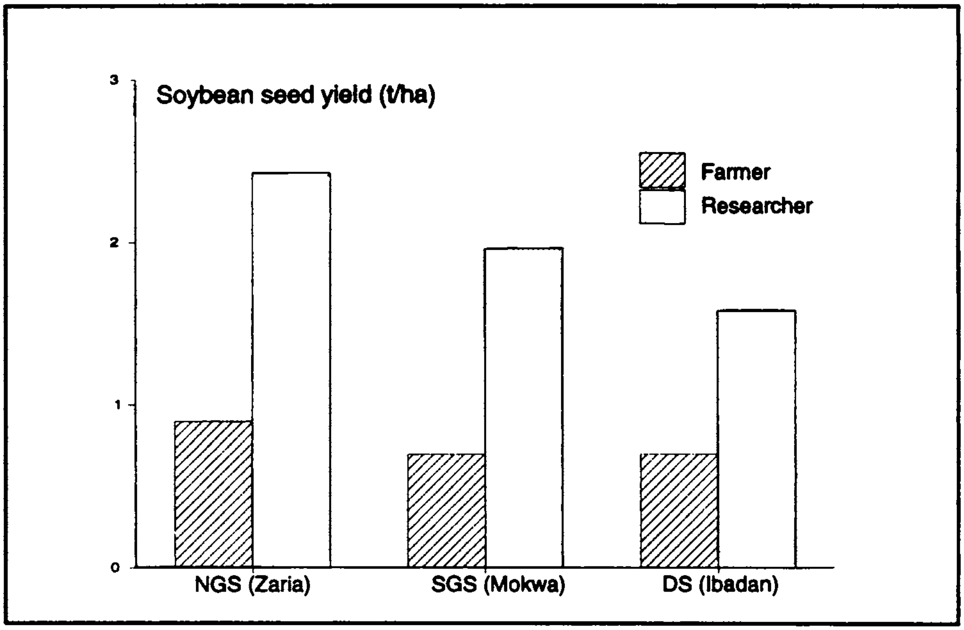

Figure 1b. Grain yield of soybean under researcher and farmer conditions in the MSZ
***Source*: Ibadan, researchers' yield (K Dashiell personal communication), farmers' yield (IITA 1987); Zaria and Mokwa (Smith et al. 1993)**

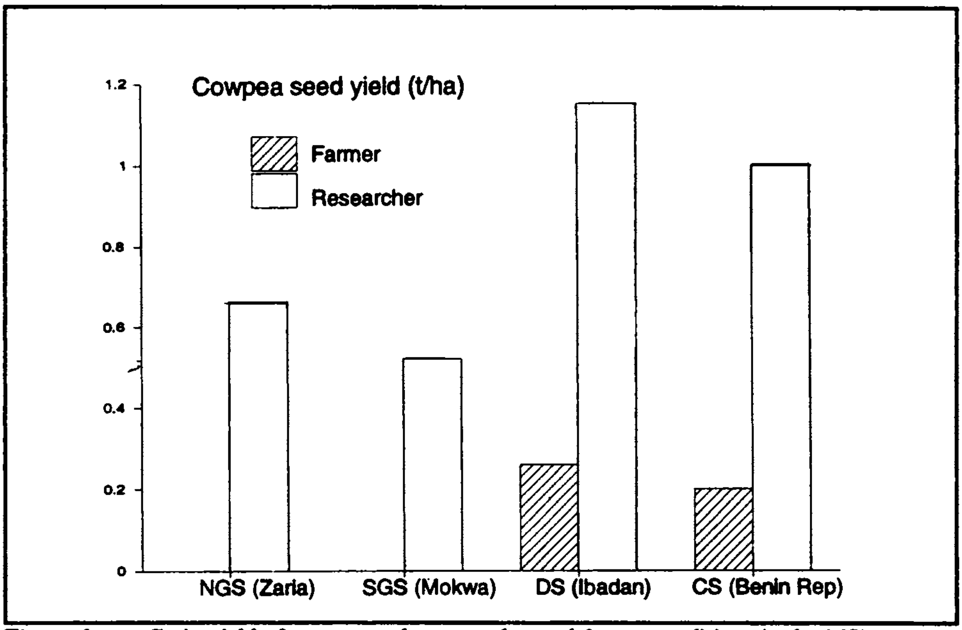

Figure 1c. Grain yield of cowpea under researcher and farmer conditions in the MSZ
***Source:* Benin Republic (IITA 1987); Zaria, Mokwa, Ibadan (IITA 1986)**

3.2 Long-duration crops

The SGS provides a suitable environment for long-duration crops such as cassava, yam and rainfed rice, Although cassava is a hardy plant with a high degree of drought and temperature tolerance, its yield is lower in the NGS than in the SGS (figure 2). The longer growing season in the DS and SGS is also more suitable for yam production. The estimated mean yam yields are about 7 t ha^{-1} in the DS and SGS, and about 3-5 t ha^{-1} in the NGS (Kowal and Kassam 1978). An investigation carried out at Benue (SGS) and Enugu (DS) States in Nigeria under farmer conditions showed that the yam yield in the SGS is higher than that in the DS. Large yield differences were also observed for cassava between experimental and farmer fields, suggesting significant scope for yield improvement under farmer conditions (figure 2).

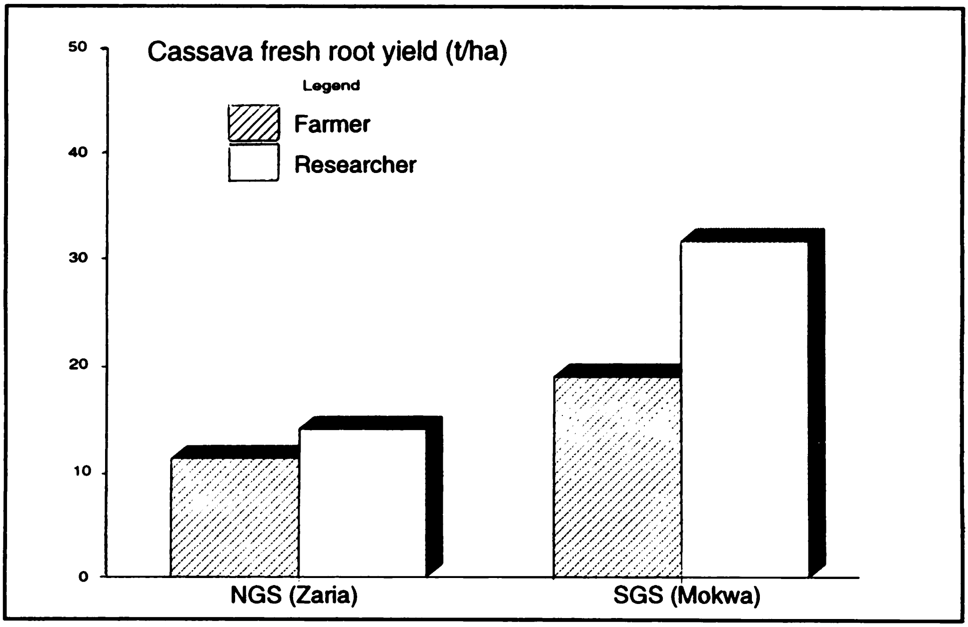

Figure 2. Fresh root yield of cassava under researcher and farmer conditions in the MSZ
Source: Researchers' yield (AGO Dixon personal communication), farmers' yield (F Nweke personal communication)

3.3 Other crops

The DS is more suitable for production of perennial crops such as plantain, particularly in hydromorphic areas. Some of the lowland areas of the MSZ are used extensively by farmers for the production of root crops (cocoyam and sweet potato) and vegetable (tomato, onion, fluted pumpkin and pepper) crops during the dry season. Yields of dry season vegetable crops are greater in the NGS than in the SGS and DS (Quinn 1971). This is largely attributed to higher solar radiation and lower incidence of leaf diseases and pests in the NGS than in the SGS (Kowal and Kassam 1978).

4. Towards Increased and Sustainable Crop Production

Many factors have contributed to the large yield gap between experimental and farmers' fields in the MSZ. These include the use of unimproved crop varieties, the low level of pest management, and the lack of agro-chemical inputs. This paper focuses on technologies which could tackle soil and weed problems for an increased and sustainable crop yield on the LAC Alfisols and associated soils.

Traditionally, farmers use the natural fallow vegetation including trees/shrubs to restore the soil fertility exhausted during the cropping period. However, fallows are getting shorter due to the expanding population and the traditional fallow systems can no longer restore soil fertility. Much effort has been invested on the development of more productive and sustainable farming systems. Research undertaken during the past few decades has shown, that to sustain crop production on the LAC soils, which are dominant on the MSZ, certain soil management components are essential, namely: (a) production of adequate *in situ* mulch to protect the soil from erosive rains; (b) reduction of tillage to minimize soil disturbance, traffic and compaction effects; (c) judicious fertilizer use to minimize soil acidification; and (d) crop rotation (Kang et al. 1991). Akobundu (1993) has reported an integrated weed management technology superior to the use of any one method of weed control. For example, relay planting of *Crotolaria verrucosa* into maize, maize/cassava or any other appropriate crop mixture was shown to reduce weed frequency, prevent soil degradation and sustain crop yield. Table 6 shows a prioritization of problems associated with the major constraints to food production in the different subzones of the MSZ of West Africa.

4.1 Constraints to the use of chemical fertilizers

Although, as indicated earlier, fertilizer use is essential for continuous and intensive crop production (FAO 1983), fertilizer use in sub-Saharan Africa (SSA) is generally low due to a variety of factors particularly the unavailability of fertilizer at affordable prices for smallholder farmers. The efficiency of fertilizer use under farmer conditions is often low because of the inappropriate timing of fertilizer application or the use of incorrect fertilizers. In market-oriented areas of the NGS, fertilizer use is increasing mainly for cotton and maize production. The continuous use of N fertilizers is known, however, to result in soil acidification (Jones 1976) which can affect the sustainability of the production system in the long run. For achieving increased and sustained food production in the MSZ, there is a need to find alternative integrated and practical soil fertility management methods which incorporate organic nutrient sources that can also serve as a buffer for minimizing the negative effects of fertilizers.

The integration of improved bush fallow into land-use systems provides a logical source of organic matter from decaying plant residue. The benefits of fallows are well known: (a) nutrient recycling particularly with the presence of deep rooting fallow species, (b) build up of surface soil organic matter mainly through litter fall, (c) improvement of soil fertility, particularly with the presence of N_2-fixing fallow species, (d) better habitat for soil fauna that can improve soil physical conditions, (e) weed suppression because of better canopy cover, and (f) suppression of soil-borne pests and diseases.

In the humid zone, traditional farmers have retained woody and shrub fallow multipurpose species such as *Anthonata macrophylla*, *Alchornea cordifolia* and *Dactyladenia barteri*. There are hardly any known tree species that are so well integrated into the savanna fallow management system as those cited for the humid forest, possibly because of persistent annual burning of the natural vegetation in the MSZ. Repeated bush burning has led to either the degeneration of the fallow vegetation or the development of a climax vegetation of difficult to control grasses such as *Imperata cylindrica, Rottboellia cochinchinensis* and *Hyparrhenia* spp.

The potential of planted herbaceous and woody fallows particularly of N_2-fixing species for soil fertility improvement in the tropics have been researched for over six decades in southeast Asia and in West and Central Africa. Although the inclusion of N_2-fixing legumes has been shown to have positive benefits for improving crop production, their use in actual farming is still limited. Considering the biophysical constraints and socio-economic problems of food production in the MSZ of SSA, the potential of improved fallows particularly those of N_2-fixing leguminous species in alleviating the problems of food production need to be reassessed.

4.2 Herbaceous fallow and grain legume-based systems

The inclusion of herbaceous legumes in farming systems is known to increase crop yield. Rattray and Ellis (1953) reported that maize yield grown in rotation with *Mucuna pruriens* var. *utilis* or *Crotalaria juncea* was 41% higher, compared to continuous maize cropping in a 22-year trial. Vine (1953) also observed that in the DS, stable maize yield can be obtained in rotation with *Mucuna* on N-poor soil.

Results of long term trials carried out with *Mucuna* showed that *Mucuna* fallow temporarily improved the soil physico-chemical properties (Vine 1953). Lal et al. (1978) observed that after a two-year fallow period, soil organic C, total N and CEC were higher under *Centrosema pubescens, Glycine wightii* and *Pueraria phaseoloides* compared to a natural bush control plot.

The effects of fallow plant residues are dependent on the chemical plant composition (Tian 1992). Plant residue high in N and low in lignin and polyphenols could have high nutritional effects, whereas those low in N and high in lignin and polyphenols could have a high mulching effect on soil microclimate and could also enhance crop nutrient uptake.

With proper management, herbaceous legumes can be used to suppress weeds. Under *Centrosema pubescens* and *Psophocarpus palustris* live mulches, weed biomass and weed seed population were greatly reduced (Akobundu 1980, 1984). Observations in southern Nigeria also showed that herbaceous legumes such as *Stylosanthes gracilis*, *Centrosema pubescens*, *Pueraria phaseoloides*, *Mucuna pruriens* var. *utilis* and *Psophocarpus palustris* reduced nematode populations to approximately one third of the preplanting number (IITA 1976).

Herbaceous legumes can be used as relay or rotation crops in association with food crops. In the market-driven intensification area of MSZ, where fallowing is no longer practiced, herbaceous legumes can be introduced as a relay crop. In the population driven area of the MSZ where the pressure on land is low and fallowing is still practiced, herbaceous legumes can be used in rotation systems.

In the NGS where grain legumes have a high production potential, groundnut, soybean and cowpea can be used as alternative legumes in rotation or relay intercropping systems. The beneficial effect of rotation with grain legumes on cereal yield has been well documented. Talleyrand et al. (1992) showed that maize or sorghum rotated with soybean, cowpea or groundnut in northern Cameroon has higher grain yield, compared to those under continuous cereal production (figure 3).

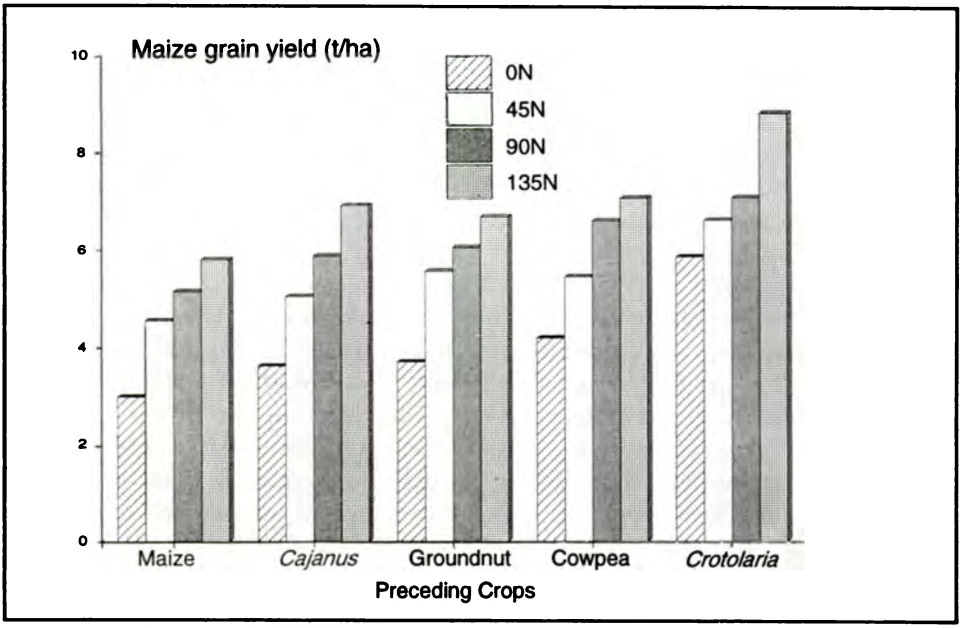

Figure 3. Grain yield of maize (cv CMS-8501) as affected by preceding crops and fertilizer application on an Alfisol in northern Cameroon
Source: Talleyrand et al. (1992)

In Ghana, Schmidt and Frey (1988) carried out maize/groundnut rotation trials for six years and observed that under rotation, maize grain yield increased by 116% compared to continuous maize. Steiner (1991) estimated that the residual effect of grain legumes on succeeding cereals was equivalent to the application of 30-40 kg N ha^{-1}. The N contribution of various grain legumes in rotation systems is, however, dependent on species and cultivars (Kang 1988). Short duration crops and those with a high harvest index tend to contribute less to soil fertility improvement. Rotation with grain legumes could also contribute to suppression of nematodes. Inclusion of pigeon pea, soybean or cowpea in crop rotation greatly reduced the population of root-lesion nematodes (Caveness 1975).

4.3 Woody fallow species based systems

Research on an improved woody fallow assumed that the regrowth of a mixture of species in natural fallow may not be the most efficient method of restoring soil productivity. In addition, regeneration by the natural vegetation is usually slow and may take many years. The approach taken is to incorporate fast-growing and deep-rooting N_2-fixing leguminous species in multicropping, agroforestry or rotation systems.

Results of recent rotation trials conducted at Djalingo in the NGS/Sudan savanna transition zones of northern Cameroon have shown significant positive effects of preceding shrub legumes such as *Cajanus cajan* and *Crotalaria caricea* on the grain yield of maize (figure 3). Even without N application, maize yield following *Crotalaria* was comparable to a maize-maize rotation receiving 90-135 kg N ha^{-1}. Removal of the preceding crop residue lowered maize yield by about 17%, but the order of how the preceding crops affected the maize yield was still the same as with residue retention (Talleyrand et al. 1992). This indicates that the below ground residue of the preceding crops also contributes to soil fertility enrichment. An additional advantage of a rotation system with *Crotalaria caricea*, is the suppression of *Striga hermonthica* in fields that are heavily infested with *Striga*. Studies on intercropping maize, sorghum and cotton with *Cajanus cajan* and *Crotalaria caricea* in the NGS/Sudan savanna zones showed mixed results (Talleyrand et al. 1992). Successful results have been obtained by incorporating fast growing N_2-fixing woody leguminous species in alley cropping with food crops in the DS and CS. The inclusion of multipurpose woody species such as *Leucaena leucocephala* and *Gliricidia sepium* on non-acid Alfisols and associated soils can contribute to: (a) nutrient recycling; (b) N-supply; (c) soil conservation; (d) partial weed suppression; (e) sustaining crop production; and (f) provision of fodder (Kang and Wilson 1987, Kang et al. 1990).

The frequent addition of plant residue is required to sustain soil productivity in the tropics because of the rapid decomposition of crop residue and the decline in soil organic matter (SOM) levels with continuous cropping. Alley cropping can meet this need through the periodic addition of hedgerow prunings. The inclusion of N_2-fixing woody legume species can also reduce N fertilizer requirements (Kang 1988). Since organic N sources are less acidifying than chemical N sources, soil acidification can also be reduced. Results of long-term observations on degraded Alfisol in southern Nigeria showed that maize yield can be sustained at reasonable levels in alley cropping with *Leucaena leucocephala* and a moderate rate of N application (figure 4). The adaptability and potential of the alley cropping systems for a cross-section of the MSZ still needs reassessing, mainly to take socio-economic constraints into consideration.

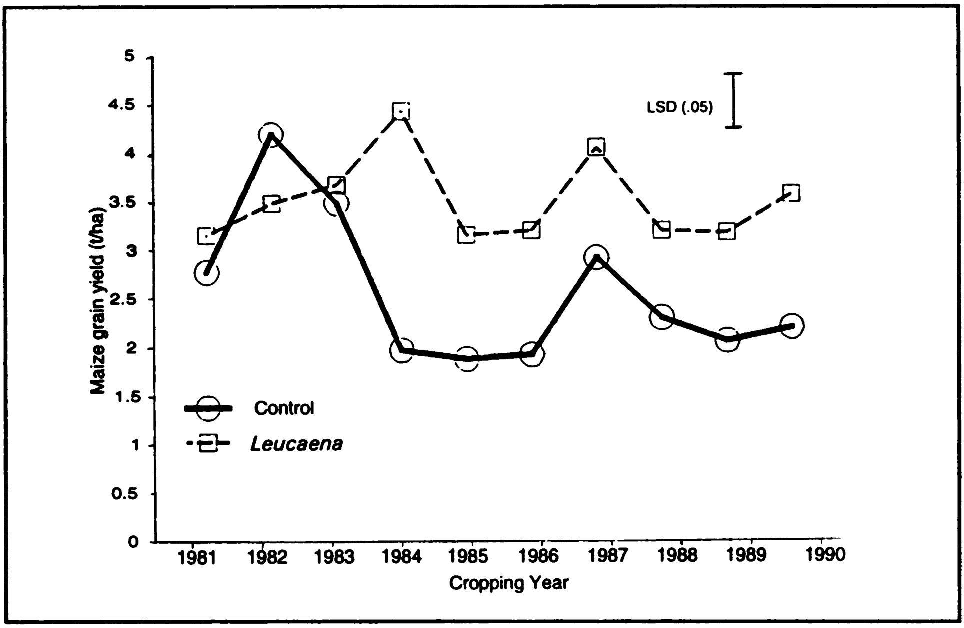

Figure 4. Effect of alley cropping with *Leucaena leucocephala* on grain yield of maize grown on degraded Oxic paleustalf compared to control (no tree) treatment for a period of ten years in southwestern Nigeria. (Fertilizer rate — years 1-3: 90N-40P-40K; years 4-10: 45N-12P-25K in kg h^{-1})

Source: BT Kang unpublished data.

5. Conclusions and Research Needs

It is recognized that the moist savanna zone is not homogeneous in terms of its biophysical and socio-economic conditions. Different driving forces influence the local farming systems and the degree of intensification. In the well-endowed areas with good market access and good technologies, intensification of agriculture with high input use is already taking place with maize and cotton, while in the less endowed areas with poor access and limited technology, traditional subsistence farming still prevails.

Ecologically the moist savanna zone has a high potential for food crop production. The NGS is well suited for short or medium-duration crops, such as maize, soybean, cotton, groundnut, etc., whereas the SGS is better suited to long duration crops like yam and cassava. However, crop yields under farmer conditions are still low, due to various soil and crop management factors and unfavorable socio-economic conditions. The research needs of each of the subzones of the lowland MSZ in West and Central Africa are shown in table 6. A favorable research environment and government policies that provide incentives to farmers are the necessary catalysts that will turn the MSZ into a veritable food basket for Africa.

Although the use of organic and chemical fertilizers is essential for intensive crop production, their availability in adequate amounts is a problem. The cost of inorganic fertilizer also limits its use in many parts of the MSZ. An integrated soil fertility management system which includes the use of organic and inorganic nutrient sources is, therefore, highly recommended for increasing and sustaining crop production. This integration is dependent on proper management of vegetation. In addition, the periodic addition of organic material to the soil is essential for maintaining soil productivity and for increasing the efficiency of fertilizer use.

Nitrogen fixing legumes have been shown to have a high potential for soil fertility maintenance and for weed and pest management. Niches need to be found for the inclusion of these legumes in existing production systems. In the well-endowed region of the NGS with intensive maize production, farmer's yield already reached over 50% of the experimental yield. Although further yield increase is possible, the main research needs is for discovering how to maintain the high yield level. The inclusion of legumes in relay cropping systems to control nematodes or reduce soil acidification arising from use of chemical fertilizer need to be explored. Similarly inclusion of legumes in rotation systems in the less endowed regions for soil fertility improvement and control of weeds (e.g., *Imperata, Striga*) and pests (nematodes) needs to be researched and included as part of an integrated pest management program.

The effective use of legumes requires further research on productivity, adaptation, chemical characteristics, fodder quality of potential herbaceous and woody species, and their suitability for inclusion in productive farming systems. Further research is also needed on the contribution of below ground/roots to soil fertility and SOM, particularly in the NGS where plant residue is continuously removed for feeding livestock.

The development of mixed farming systems for sustaining crop production in MSZ will be jointly explored with the International Livestock Research Institute (ILRI), Addis Ababa. The presence of livestock can increase farm productivity through better nutrient recycling and the provision of manure. The introduction of cattle will also provide more power for soil tillage.

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HIGHLIGHTS OF IITA RESEARCH ON MAIZE AND SOYBEAN IN NIGERIAN SAVANNAS

S.K. Kim[1], K. Dashiell[1], J. Kling[1], S.M. Osho[1], J. Fajemisin[1], C.N.B. Akem[2], R.C. Abaidoo[3]

[1]*Crop Improvement Division, International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria*
[2]*Plant Health Management Division, International Institute of Tropical Agriculture, PMB 5320, Ibadan, Nigeria*
[3]*Nitrogen Fixation by Tropical Agricultural Legumes (NIFTAL), University of Hawaii, USA*

Key words: maize, soybean, ecozone, maize streak virus, *Striga, Cercospora* leaf spot, red leaf blotch

Abstract: Research on maize and soybean in the savanna ecozone in Nigeria has been conducted at several experiment sites by International Institute of Tropical Agriculture (IITA) scientists in collaboration with national scientists. Maize research emphasized resistance breeding for maize streak virus (MSV) and Striga. High yielding open-pollinated (OP) varieties and hybrids were developed. Hybrids selected produce approximately 30% higher grain yield than the OP varieties under good management in the savanna. The development of hybrid maize stimulated the establishment of private seed industries. The companies produce and market seeds, not only for hybrid and OP maize varieties, but also for other food crops such as soybean, cowpea, rice and sorghum. Current research on maize emphasizes the development of higher yielding hybrids with a combined resistance to major biotic (Striga) and abiotic (drought, nitrogen) stresses. The development of Striga resistant OP varieties is another major objective.

In 1977, IITA decided to establish a comprehensive research program for soybean improvement aimed at developing technologies (varieties and agronomic practices) adapted for production in African environments because: (1) soybeans are capable of relatively high and stable yields, (2) the genetic variability exists to overcome biological constraints such as poor seed longevity and a requirement for specific rhizobial inoculants, (3) soybeans are an excellent source of quality protein and vegetable oil for humans and animals, and (4) national programs were showing keen interest in expanding soybean production. Our experience in the savanna for over a decade proves that this ecozone is very favorable for grain production. Maize-soybean intercropping or rotation appears to be an outstanding option for a sustainable cereal-legume cropping system.

1. Introduction

Maize (*Zea mays L.*) was introduced into Africa about 400 years ago and was grown mostly in the rainforest areas in West and Central Africa. It became an important food crop in the humid forest ecozone, grown in mixed cropping with cassava and other food crops. Average yield of maize in Africa is 1 ton/ha which is the lowest continental yield in the world. Poor agronomic practices, lack of high yielding varieties and resistance to biotic (diseases, insects and parasitic weeds) and abiotic (drought and nitrogen) stress are responsible for the low yield (Efron et al. 1989, Fajemisin et al. 1985). However, maize yield potential in the moist savanna belt in West Africa is high and this ecozone has a comparative advantage for maize grain production (Kassam et al. 1975, Kim et al. 1985, 1993, Fakorede et al. 1993). New maize varieties and production practices have enabled farmers in northern Nigeria to begin modernizing and to practice intensified farming (IITA 1990).

In 1978, IITA initiated soybean breeding efforts to improve two major qualities: seed longevity and nitrogen fixation. Considerable progress was made between 1978 and 1985 on the development of high yielding varieties for Africa that have superior seed longevity and the ability to nodulate with indigenous rhizobia, thereby circumventing the problem of inoculant production and inoculant distribution to farmers. In 1985, research was initiated on soybean utilization. The main objective has been to develop small-scale and home level food processing technologies that are appropriate for tropical Africa. This work will help to create a demand for soybean and should also help to improve the nutrition of the people. This work has received strong support from the International Development Research Center (IDRC) and Japan International Cooperation Agency (JICA). In September 1991, the IITA Grain Legume Improvement Program (GLIP) began collaborative research with the University of Hawaii on biological nitrogen fixation in soybean. This research is part of the Nitrogen Fixation by Tropical Agricultural Legumes (NIFTAL) project.

From 1986 through to 1992, there has been a rapid increase in production, industrial processing and home utilization of soybean in Nigeria and Zambia and modest increases in Ivory Coast, Ghana and the Republic of Benin. Also during this same period there was a remarkable increase in the incidence and severity of two diseases on soybean: *Cercospora* leaf spot (*Cercospora sojina*) and red lead blotch (*Pyrenochaeta glycines*).

This paper summarizes the results of IITA's research on maize and soybean and the experiences encountered in the technology transfer of the two crops to farmers during the last decade.

2. Maize Cultivation in the Moist Savanna

About three decades ago, maize cultivation was introduced to the savanna ecozone in Nigeria where sorghum and millet were the two dominant crops. The first variety recommended was TZB, a white grained, late maturing (120 days) maize population developed by scientists in IITA and the Institute for Agricultural Research and Training (IAR&T) in Ibadan. The Institute of Agricultural Research (IAR) of Ahmadu Bello University (ABU) developed a yellow variety, Samaru 123, and recommended it for the ecozone.

The first project for the promotion of maize production in the savanna was initiated in late 1970 by the Nigerian Federal Government and the World Bank through the Agricultural Development Projects (ADP). This project started with the Funtua, Gusau and Gombe ADPs, and was extended later to the Kano and Bauchi State ADPs. The Federal Government extension agencies, the National Accelerated Food Production Programme (NAFPP) and the National Agricultural Extension and Research Liaison Service (NAERLS), conducted over 3,000 minikit trials throughout the country.

3. Maize Research

Maize research in the savanna zone was initiated by IAR, and agronomic studies with different maize varieties were conducted. It was concluded that the savanna belt of Nigeria had a great potential for maize production (Kassam et al. 1975). The second program for the promotion of maize production in the savanna belt started in 1980 when IITA launched an intensive maize research project for this ecozone in collaboration with IAR, and Funtua and Gusau ADPs. From 1980 to 1993, maize trials and nurseries were established on over 400 ha in the selected areas in the savanna (table 1) and approximately 5000 different maize genotypes were tested annually throughout the testing sites (Kim et al. 1993). During the period between 1982 to 1986, one full time agronomist/breeder was assigned to the European Economic Commission (EEC) funded project in the savanna ecozone.

Table 1. Areas (ha) of IITA maize nurseries in the savanna ecology in Nigeria (1980-1993)

Year	Southern GS[a]		Northern GS[a]			Sudan Savanna			Mid-Alt/Sav.			Total
	Il	Mk	Ab	Kd	Sa	Fu	Gu	Ba	Mi	Sam	Za	
1980	-	2	-	-	-	2	1	-	-	-	-	5
1981	2	2	-	-	-	2	1	-	-	-	-	7
1982	3	3	-	-	5	5	4	-	-	-	-	20
1983	4	4	-	-	8	5	3	-	-	-	-	24
1984	4	6	-	-	8	5	2	-	-	-	-	25
1985	4	6	-	1	10	8	-	2	-	-	1	32
1986	8	12	-	2	8	5	-	2	-	-	1	38
1987	-	10	-	2	10	8	-	6	-	-	7	37
1988	-	10	-	-	12	8	-	6	-	-	2	38
1989	-	18	-	-	15	5	-	10	1	-	2	52
1990	-	15	-	-	15	-	-	5	2	-	2	39
1991	-	15	-	-	10	-	-	4	2	-	3	34
1992	-	13	8	8	-	-	-	4	1	6	-	40
1993	-	10	4	-	3	-	-	4	-	6	-	27
Total	25	128	12	13	104	53	11	43	5	12	12	417

Notes: a: GS = Guinea savanna, Il: Ilorin ADP, **Mk** = Mokwa National Grain Production Co., **Ab** = Abuja IITA Station, **Kd** = Kaduna Polytechnic, Allied Ranches and National Forest Research Institute (1992) **Sa** = Samaru IAR, ICRISAT Station, **Fu**= Funtua, Alhaji Ammani's Farm, **Gu**= Gusau, Sokoto State ADP, **Ba** = Bagauda Dantata Farm and ICRISAT Station, **Mi** = Minjibir, IITA/IAR Station, **Sa** = Saminaka, Alhaji Babangida Farm at Sigau, **Za** = Zal-Zalete, BARC Farm.

3.1 Development of experimental varieties developed at IITA from TZB

Based on adaptation and yield trials, the population TZB was selected for improvement. TZB is a tropical maize population (*Tropical zea*) developed at IITA from Nigerian population 'B'. In 1981, the first experimental varieties of TZB were formed based on families selected from Mokwa, Niger State and Gusau, Sokoto State. Mean yield of ten selected families which were used to form Gusau 81 TZB semi-flint was 5.4 t/ha, 38% higher than the population mean (table 2). Average yield of TZB population in the farmers' fields which was promoted by the ADPs might be close to the population mean, 3.4 t/ha. Another check variety used was TZPB (*Tropical zea* Planta Baja from CIMMYT), a population selected for the forest zone in West Africa. TZB and its related or mixed varieties are being grown on over one million hectares in the savanna areas in Nigeria (Kim et al. 1993).

Table 2. Grain yields and agronomic traits of the selected TZB semi-flint maize families from Gusau, Sokoto State, 1981

Family	Grain yield (t/ha)	Yield index (%)	Rank in yield	Days silk	Ear height (cm)	Plants harv./plot	Grain moist (%)	Ear aspect (1-5)
16	6.6	168	3	64	107	16	26	1.9
50	5.7	144	6	61	95	15	30	2.1
86	6.8	173	1	65	117	16	21	1.8
99	5.2	133	13	62	92	17	28	2.0
102	4.5	115	56	63	83	14	29	1.9
103	5.2	133	12	62	90	14	20	2.0
119	5.4	138	9	61	98	17	31	2.2
135	5.0	128	25	66	82	17	26	1.9
144	5.0	127	29	62	100	14	26	1.8
166	4.7	121	41	61	85	18	23	1.8
Sel. mean	5.4	138	-	63	95	16	27	1.9
Pop. mean	3.9	100	-	64	93	12	26	2.2
Check TZPB	3.4	87	-	66	95	13	26	2.5
LSD.05	0.8	-	-	3.6	22.7	1.9	0.8	0.3

Notes: **Grain yield**: yield at 15% grain moisture; **Yield index**: calculated% yield from the population mean; **Rank in yield**: ranking in yield of the selected family among 250 half-sib families tested; **Ear aspect** (1-5): 1 = outstanding, 5 = poor

Source: *IITA Annual Report* 1981, p 84.

The result of subsequent years of testing in Nigeria and five African countries showed that Gusau 81 TZB semi-flint was the top yielding variety across 10 locations (5.3 t/ha) and it was 18% higher yielding than the mean (4.5 t/ha) of two local checks used by the national programs (table 3). Seed multiplication of Gusau TZB was initiated at the Sokoto State ADP farm in Gusau in 1982. Over 200 tons of seed were produced. In subsequent years, the Nigerian National Seed Service (NSS) and all ADPs participated in their own seed multiplication program. Over 5,000 tons of seeds, called 'Agric Maize' were produced.

Table 3. Average grain yields in an international experimental trial of IITA maize varieties in Africa, 1982

Entries	Benin	Cameroon		Ghana	Kenya	Liberia	Nigeria				Mean
	Ni	Nt	Nj	Ny	Ki	Su	Ib	Ik	Il	Sa	
Gusau TZB	4.6	6.5	4.8	7.0	2.2	3.8	5.2	5.9	7.2	5.7	5.3
Sua TZPB	5.3	5.9	5.1	7.1	2.3	4.0	5.0	6.5	6.1	4.5	5.2
Mokwa TZB	4.5	4.9	4.4	6.7	2.4	3.6	5.4	5.7	7.6	4.3	4.9
Onne TZPB	4.6	6.0	4.4	6.3	1.8	4.1	5.1	6.4	6.1	3.2	4.8
Check 1	4.0	5.4	4.9	5.8	2.0	3.7	4.5	5.5	6.0	4.7	4.6
Check 2	2.9	5.0	4.5	5.3	1.8	3.6	4.5	5.3	5.3	4.3	4.2
LSD .05	0.7	1.0	NS	1.8	0.7	NS	1.3	1.0	1.6	1.7	

Notes: Testing sites: Benin — Niaouli, Cameroon — Ntui and Njombe, Ghana — Nyankpala, Kenya — Kikambala, Liberia — Suakoko, Nigeria — Ibadan, Ikenne, Ilorin and Samaru

Source: *IITA Annual Report* 1982, p 20.

3.2 Development of streak resistance (SR) maize varieties

The popularity of TZB in the savanna suffered a setback when maize streak virus (MSV) attacked susceptible local and TZB varieties. Under MSV infestation, streak resistant (SR) varieties outyielded TZB by over 100%, depending on the level of infestation (table 4).

Table 4. Grain yields and agronomic traits of streak resistant (SR) varieties under streak infested and free environments, 1985-1986

Variety	SR level	Grain yield (t/ha)		Ear height (cm)		Plant asp. (cm)	
	MSV	MSV	Free	MSV	Free	MSV	Free
Streak resistant varieties							
TZSR-W-1	1.3	5.0	5.7	105	117	3.5	3.0
TZSR-Y-1	1.2	4.7	5.5	102	108	3.5	2.9
EV 22-SR BC4	1.7	5.6	5.5	91	102	3.1	2.5
EV 28-SR BC4	1.2	4.7	5.6	88	106	2.7	2.6
EV 43 SR BC4	2.1	5.2	6.0	95	110	3.0	2.7
Streak susceptible varieties							
EV 22	4.5	0.7	5.8	55	101	5.0	2.7
EV 28	3.9	1.5	5.4	61	103	5.0	2.8
EV 43	3.8	2.7	5.6	81	106	5.0	2.8

Notes: Values: Mean of five environments in 2 years and 4 locations, SR level (1-5): 1= resistant, 5=susceptible, Plant aspect (1-5): 1 = good, 5= poor.

Source: Efron et al. 1989, p 22.

In collaboration with Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT) and African national programs, IITA developed over 100 different SR varieties with a range of maturities (90-120 days), grain colors (white and yellow), grain textures (dent, flint, semi-flint, floury), and ecological adaptations (forest, savanna and mid-altitude) (Efron et al. 1989, Fajemisin et al. 1985). Although the TZB is still grown widely in the savanna belt of Nigeria, most varieties called 'local' or Agric Maize are mixtures of TZB and IITA's SR varieties. Other varieties selected at Gusau were Gusau TZESR-W, and TZESR-Y (Efron et al. 1989). The European Economic Commission (EEC) supported IITA's high yielding variety development program from 1982 to 1986. Major germplasm tested in the savanna were streak resistant, open-pollinated varieties and hybrids.

3.4 Hybrid maize development

The third project for the promotion of maize in the savanna ecozone started when IITA and Nigerian institutions, with financial support from the Federal Government of Nigeria, launched a hybrid maize program in 1982. The primary objective of the hybrid maize project was to develop disease resistant and high yielding varieties for the savanna (Kim et al. 1985). Selected hybrids from over 500 experimental hybrids yielded 30% more than the open pollinated varieties under the same level of fertilization and crop husbandry (table 5). The highest experimental yield record established in 1983 with hybrid 8324-18 was 12.1 t/ha at 15% grain moisture.

Table 5. Grain yield and yield index of selected maize hybrids for moist savanna areas in Nigeria, 1993

Maturity	Grain Color	Hybrid	Grain yield (t/ha)	Yield ranges (t/ha)	Yield index (t/ha)
Late	White	8324-18	8.9	6.8-12.1	141
		8321-18	8.6	5.8-11.1	128
		8321-21	8.5	6.4-10.0	+128
Late	Yellow	8330-16	7.4	5.7-8.4	137
		8329-23	7.9	6.2-10.4	134
Intermediate	White	8338-4	8.3	7.0-10.4	164
		8338-2	7.3	5.1-8.9	149
Intermediate	Yellow	8341-6	8.1	7.5-9.1	148
		8340-21	7.0	5.0-8.0	146

Note: Average of two OP checks was used to calculate the yield index for a better comparison between hybrids of different sets.

Source: *IITA Research Highlights, 1981-1984.* Maize Improvement Program, p 22.

Selected hybrids were tested under farmers conditions and these results were also highly encouraging (table 6). Hybrids produced 7 t/ha under farmers' conditions, approximately 1.5 to 2 tons more grain than the two widely grown OP varieties, TZSR-W-1 and TZB. In addition, hybrids showed more tolerance to drought and better resistance to *Striga*.

Table 6. Grain yields of selected maize hybrids compared with improved open-pollinated varieties in on-farm demonstrations in the savanna zones of Nigeria, 1984

Variety	Maize grain yield (t/ha)	Range (t/ha)	No. of locations
Hybrid			
8322-13	8.8	6.9-11.8	6
8321-21	7.9	6.1-11.1	12
8321-18	7.3	4.9-10.3	11
Open-pollinated			
TZSR-W-1	5.6	3.6-7.7	15
TZB	4.1	1.9-5.1	15

Although the current commercial hybrids yield an average of 25% more in the savanna than the OP varieties, more effort should be directed to developing superior hybrids for yield and resistance to biotic and abiotic stress. The results of new hybrids selected in 1992 showed that a significant yield increase would be possible within the next few years. A new record yield of approximately 14.7 t/ha was obtained from the hybrid, 9205-15 (table 7). The shelling percentage (grain over the cob weight) of this hybrid was 87. Four other new hybrids yielded over 10 t/ha.

Table 7. Grain yields and agronomic traits of selected maize hybrids in Saminaka (800 m altitude) in Nigeria, 1992

Entry No.	Grain yield (t/ha)	% mean yield	Days silk	Plant height (cm)	Root lodging (1-9)[a]	Ear aspect (1-9)[b]
9205-15	14.7	132	62	260	3.3	1.0
9205-18	13.5	122	63	253	5.7	2.7
Check	10.5	94	64	243	6.7	3.0
9227-12	10.2	127	65	267	3.3	2.7
Check	7.3	92	66	238	5.3	3.3
9233-8	10.5	128	63	245	5.3	2.5
Check	8.1	99	64	240	4.8	2.0
9234-17	11.5	132	63	263	2.5	1.8
Check	8.5	97	65	244	4.3	2.8

Note: [a] Root lodging (1-9) 1 = resistant, 9 = susceptible
[b] Ear aspect (1-9) 1 = outstanding, 9 = poor.

3.4 Recent progress in the development of open-pollinated varieties

In the late 1980s, the best breeding populations were consolidated into one set of late composites (TZL Comp. 3 and TZL Comp. 4) and one set of early composites (TZE Comp. 3 and TZE Comp. 4). These composites were formed on the basis of heterotic patterns and are being improved through reciprocal recurrent selection. The objectives of this approach are:

a. to improve breeding efficiency by consolidating elite germplasm into a few broad-based populations
b. to enhance the heterosis between populations in order to maintain and improve the performance of variety crosses and the potential for extraction of superior inbred lines and hybrids
c. to harmonize breeding activities at IITA directed toward the development of open-pollinated varieties with those of the hybrid program and national agricultural research systems (NARS) breeding programs in the region

In a comparison of 25 early-maturing varieties in Nigeria, Burkina Faso and Côte d'Ivoire in 1991 and 1992, TZE Comp. 3 C1 ranked first and TZE Comp. 3 x 4 C1 ranked second for yield across sites in both years. TZE Comp. 4 C2 outyielded the Cl of both of the early composites in multilocational trials conducted in 1993. These populations perform well in northern savannas, yet have the necessary resistance to foliar diseases and ear rot, required for adaptation in the forest zone. In multilocational trials comparing 25 elite late-maturing varieties conducted in 1993, TZL Comp. 4 C0 ranked first and TZL Comp. 3 Cl ranked third based on an index of desired characteristics (table 8).

Table 8. Means across site for the most promising new varieties from the preliminary late variety trial, 1993

Entry	Days to midsilk	Plant height cm	Ear height cm	Ear rot ratings	Rust rating§	Ear aspect rating	Yield t/ha	Husk rating¶	Index
Hybrid checks									
8321-18	60.1	213	111	2.5	3.3	2.2	5.6	2.9	11.8
8644-27	60.1	201	102	2.3	3.2	2.2	5.1	2.7	11.4
New varieties									
TZL Comp 4 C0	61.2	223	117	2.2	2.8	2.6	5.0	2.6	7.0
Ikenne 9129 SR	60.2	212	108	2.2	3.0	2.7	4.8	2.4	6.0
TZL Comp 3 C1	60.0	216	115	2.5	2.8	2.5	5.1	2.9	5.8
Acr 91 Suwan 1-SR	60.2	220	116	2.7	2.9	2.4	5.0	3.1	4.3
Pop 29-SR C2	60.1	222	113	2.6	3.1	2.7	4.7	2.5	2.4
TZL Comp 3 C0	59.4	224	118	2.8	2.9	2.7	5.0	2.8	2.0
Ikenne 91 TZL Comp 3	59.3	214	113	3.1	2.9	2.6	5.1	3.2	1.3
Acr 9022-SR	61.1	211	109	2.3	2.6	2.9	4.6	3.0	1.1
Mokwa 91 TZL Comp 3	59.9	222	119	3.1	2.8	2.6	5.0	3.0	0.9
Acr 90 DMR-LSRW	60.7	219	114	2.9	3.0	2.7	4.4	2.1	0.4
Older varieties									
EV 8722-SR	59.3	211	105	2.9	3.2	2.8	5.0	3.0	1.2
Pop 29-SR C1	60.4	218	113	3.0	3.1	2.8	4.7	2.8	-1.6
DMR-LSRW	60.8	218	115	2.7	3.0	3.0	4.3	2.2	-2.6
Suwan 1-SR	59.5	213	112	3.1	2.9	2.9	4.1	3.1	-7.3
MEAN (25 entries)	60.2	216	113	2.7	3.0	2.7	4.7	2.8	0.0
LSD (.05)	1.08	7.98	6.67	0.56	0.44	0.27	0.24	0.49	
Weight in index	0	-.25	-0.5	-1.5	-0.5	-2	3	-1	

Notes: Trials conducted in Sinématiale, Côte d'Ivoire; Ikenne, Mokwa, and Samaru, Nigeria.
All ratings taken on a scale of 1-5, where 1 = outstanding; 5 = poor
§ Means for Ikenne only; ¶ Means for Mokwa only

TZL Comp. 3 C1 showed improvement over TZL Comp. 3 C0. Comp. 4 was advanced to the C1 in 1994, which is presently under evaluation. The performance of the population cross (TZL Comp. 3 x 4 C0) is also being assessed to determine the extent of heterosis between populations.

3.5 Development of *Striga* resistant varieties

Striga is one of the major biotic constraints to maize production in the savanna ecozone of West Africa. Among the several species occurring in Africa, *Striga hermonthica* (Del.) Benth is the most widespread. In 1982 scientists at IITA launched a breeding program to develop maize varieties resistant to *Striga*. Sources for tolerance/resistance were found among the hybrid maize and parental lines previously developed. These had been selected without prior knowledge of the presence of genes resistant to *Striga*. In 1988, scientists at IITA developed an artificial infestation technique for *Striga* in which different maize genotypes could be selected for resistance under a uniform challenge of *Striga* infestation (Kim 1991). The results of experiments conducted from 1984 to 1989 showed that *Striga* reduced average maize yield by 66% under moderate and high levels of infestation (table 9). Under a high level of *Striga* infestation, resistant hybrids produced an average of 2.5 times more grain than susceptible varieties (Kim 1991).

Table 9. A summary of grain yield reduction of maize varieties under *Striga hermonthica* infestation in the savanna zone of West Africa

Year	Materials	Grain yield (t/ha)		Yield reduction	Place
		Control	Infested by *Striga*	%	
1984	100 hyb	6.2	2.0	73	Mokwa
1984	2 OP	6.1	1.7	73	Mokwa
1984	2 hyb, 1 OP	3.9	1.3	67	Mokwa
1985	1 sus hyb	7.7	0.7	91	Mokwa
1988	1 res, 2 sus	4.8	1.9	60	IITA (SH)
1988	1 res, 1 sus	6.4	2.4	62	IITA (SH)
1988	2 res, 1 sus	3.9	2.2	56	Farmers
1985	2 sus	5.1	3.0	41	Cameroon
1989	3 sus	2.9	0.7	76	Benin
Average		5.3	1.7	66	

Notes: OP - open pollinated variety, hyb - hybrid, res - resistant, sus - susceptible, SH - screen house

Studies were conducted to understand the genetics of resistance to *Striga* and the influence of some factors such as N levels and *Striga* seed quantity on *Striga* growth and reproduction. Several hybrids with moderate levels of tolerance and resistance have been developed (Kim 1991, Kim and Winslow 1992). Some OP varieties are being improved for resistance (table 10). National programs have tested these materials in Africa. At the moment, hybrids show better levels of resistance than the OP varieties, apparently because the period of resistance breeding was longer. Current emphasis is directed at developing OP varieties with levels of resistance similar to the hybrids. The tolerant\resistant varieties support less *Striga* emergence per maize plant and also yield significantly more than susceptible varieties under *Striga* infestation. More emphasis is now being placed on developing maize varieties and hybrids which significantly reduce the number of emerged striga.

Table 10. List of *Striga* tolerant/resistant (STR) varieties and populations of maize developed by IITA scientists

Type	Variety	Stage	Grain Color	Grain Texture	Maturity
Hybrid	8425-8STR	Sx	yellow	dent	intermed.
	9044-31STR	Sx	yellow	dent	intermed.
	8434-11STR	Sx	yellow	dent/fl	intermed.
	8329-15STR	Sx	yellow	flint	early
	9044-27STR	Sx	yellow	flint	intermed.
	8322-13STR	Sx	white	fl/dent	intermed.
	8505-3STR	3x	white	fl/dent	intermed.
	9022-13STR	Sx	white	fl/dent	intermed.
	9021-18STR	Sx	white	fl/dent	intermed.
Open-pollin.	TZ Syn-W STR	C2	white	flint	intermed.
	TZ Syn-Y STR	C4	yellow	dent	intermed.
	TZ Syn-W/Y STR	-	white/yellow	fl/dent	intermed.
	Syn TZSR-Y-1 STR	C3	yellow	fl/dent	late
	Syn TZB STR	-	white	flint	late
	TZL Comp. 1	C3	white/yellow	fl/dent	late
	Acr 93 TZL Comp.1	-	white	fl/dent	late
	TZE Comp. 5	C4	white/yellow	fl/dent	early
	Acr 92 TZE Comp.5	-	white	fl/dent	early

Notes: Stage: Sx = single cross, 3x = three way cross; Grain texture: fl = flint; Maturity: early = < 105 days, intermediate = 105-115 days, late = > 120 days.

3.6 Response of new maize varieties to nitrogen

The lack of nitrogen is an important limiting factor to maize yield in the savanna. The general belief is that hybrid maize requires more N than the OP varieties. Four maize varieties — three hybrids and one popular OP variety — were tested under five different levels of N in three ecological zones of Nigeria during 1988 and 1989. The results of this study showed that the highest level of nitrogen use efficiency (NUE) was obtained from the application of 60 kg/ha of N (table 11). All three hybrids had significantly higher NUE and showed higher maize grain production per kg applied N. The capability of hybrids for high NUE and grain yield were consistent throughout all three ecological zones.

Table 11. Effects of N-rates and maize varieties on nitrogen use efficiency in three ecological zones of Nigeria, 1988 and 1989

Items	Forest		Southern GS	Northern GS
	Ikenne A	Ikenne B	Mokwa	Samaru
N rates (kg/ha)				
60	62.8a	55.4a	84.6a	77.9a
120	32.2b	29.2b	47.0b	45.9b
180	21.9c	19.8c	33.5c	31.9c
240	16.3d	14.1d	29.4d	22.9d
Mean	33.3	29.6	47.5	44.6
Variety				
8425-8	35.5a	28.4bc	47.4b	46.2a
8505-13	34.8a	30.3a	50.0ab	46.6a
8605-18	34.5a	30.4a	53.1a	47.1a
TZSR-Y-1	28.4b	26.4c	39.4c	38.5b

Notes: Values with the same letter in the same column are not significantly different at $p = 0.05$; GS = Guinea savanna; Ikenne A = first season (April-July), B = second season (August-Nov.) Nitrogen use efficiency (NUE) at each N rate and for each variety was determined by:

$$\text{NUE} = \frac{\text{GWT (grain weight)}}{\text{NS (fertilizer-N supplied)}}$$

Source: Akintunde et al. 1993.

Grain yields at 60 kg/ha of N were significantly higher than those at the zero N level (table 12). Yield differences were detected between 60 and 120 kg/ha levels of N in the savanna. The differences were not significant in the forest. Again, the three hybrids produced significantly higher grain yield than the OP variety tested.

3.7 Seed industry establishment for sustainable supply

Technical assistance from IITA has played a key role in establishing and maintaining the seed industry in Nigeria. The first seed company established was Agricultural Seeds Ltd. (Efron et al. 1993), which had both market and research components. After eight years of operation this company joined the US Pioneer Hybrid Seeds, Nigeria. Another company, Obasanjo Seeds, also joined Pioneer. Two other independent seed companies which have been very active in Nigeria are UAC Seeds, operating with PANNAR from South Africa and the Plant Breeding Institute in UK and UTC Seeds of Swiss origin. The companies produce and market, not only maize seeds, but also seeds of cowpea, soybean, sorghum, rice and vegetables. Approximately 1000 tons of hybrid maize seeds and 200 tons of OP varieties are produced per year and sold to farmers in Nigeria.

The environmental conditions in the savanna ecozone of Nigeria are very suitable for seed production for West Africa. The establishment of private seed companies

may be the most sustainable way of establishing a seed industry for enhancing seed supply in the region (Kim 1992).

Table 12. Effects of N rates and varieties on grain yields of maize in three ecological zones of Nigeria, 1988 and 1989

Items	Forest		Southern GS	Northern GS
	Ikenne A	Ikenne B	Mokwa	Samaru
N rates (Kg/ha)				
0	3.5a	2.6a	3.9a	3.3a
60	3.8b	3.3b	5.1b	4.7b
120	3.9b	3.4bc	5.6c	5.5c
180	3.9b	3.5c	6.0c	5.8c
240	4.0b	3.4c	6.0c	5.4c
Mean	3.8	3.3	5.3	4.9
Varieties				
8425-8	4.0a	3.2a	5.2b	4.9a
8505-13	4.0a	3.3a	5.7a	5.2a
8605-18	3.9a	3.6b	5.9a	5.3a
TZSR-Y-1	3.3b	2.9c	4.5c	4.3b
Mean	3.8	3.3	5.3	4.9

Note: Values with the same letter in the same column are not significantly different at $P = 0.05$.
Source: Akintunde et al. 1993.

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Progress by maize seed companies in Nigeria has been slow for many reasons. The prime factors appear to be the lack of a sound government policy for the support of input supply, especially fertilizers, poor backing for research and extension (Adenola and Akinwumi 1993), traditional preference for free seeds, e.g., OP varieties, the lack of understanding of the value of hybrid maize by some farmers, scientists and extension staff and poor market development. The history of hybrid maize in West Africa is still very recent, only 15 years, compared to the approximately half a century used for the improvement of the OP population.

4. Soybean Research

4.1 Priority setting

4.1.1 *Ecology*

The identification of the objectives of a breeding program is one of its most challenging and important activities. They must be relevant to the production, marketing and utilization of the crop in the ecozone where it is grown. A breeding objective that is not relevant to the production, marketing or utilization of the crop will waste resources.

One important step in determining the breeding objectives is to prioritize the various ecozones for which breeding is being planned.

In 1988, the IITA project put medium priority on breeding for the savanna and rainforest ecozones and low priority on breeding for the mid-altitude zone. By 1992, the savanna was top priority, the mid-altitude savanna, medium, and the rainforest, low (table 13). The major reasons for these changes were:

a. From 1988 through 1990 there was rapid expansion of soybean production in the savanna ecozone of Nigeria.
b. Considerable efforts were made by national programs in Nigeria to increase soybean production and utilization in the rainforest and the rainforest/savanna transition zones. There was very little adoption of soybean production by farmers, but soybean utilization was well accepted.
c. The Cassava Based System Research Group in collaboration with the University of Nigeria, Nsukka conducted a survey from 1988 to 1989 in Ohosu. This area is in the humid ecozone in southern Nigeria. One of the major findings of this study was the high incidence of human malnutrition associated with high cassava consumption. The introduction of legumes into the diet seemed to be the best way to increase the protein quality and quantity in the diet and this led to the implementation of a research program in Ohosu which, after three years (1987-89) demonstrated that the humid zone was a marginal environment for soybean production.
d. The Maize Based System Research Group conducted on-farm research from 1985 to 1989 on soybean in two locations in Nigeria (Ayepe and Alabata)

in the rainforest and transition ecozones respectively. Although there was little or no adoption of the crop for production, there was some adoption for utilization.

e. There has been an increase in soybean production in Benin Republic, Ghana and Ivory Coast from 1988 to 1992 and almost all of the increase was in the savanna ecozone.

f. From 1989 to 1992 a series of soybean/sorghum intercropping trials were conducted with the International Center for Research on Semi-arid Tropics (ICRISAT) at Zaria and Bagauda in the northern Guinea Savanna. The research showed that sorghum yield is not reduced when intercropped with soybean. The sorghum mean yield was about 2500 kg/ha in both sole and intercropping and the soybean yield of about 800 kg/ha proved to be a bonus to the farmers. When this research was started there was no soybean production within 200 km of Bagauda. The research trials were shown to Kano State Agricultural Development Project staff by the ICRISAT agronomist and they began introducing soybean as a sole crop and as an intercrop in southern Kano State.

At present, soybean production can be seen on many farms in the area around Bagauda.

It was observed that soybean was consistently adopted by farmers in the savanna zone but not in the rainforest zone. This led to the decision that research efforts should focus on the savanna where the present production systems of the farmers make it easy for them to adopt soybean production. Conversely efforts to develop soybean specifically for the rainforest zone were reduced.

It was heartening that the home utilization of soybean was adopted by people in the rainforest who did not grow the crop. This should improve the health and nutrition of people whose diets are low in protein.

4.2 Goals and objectives

4.2.1 *Overview*

The goals of soybean breeding from 1988 to 1992 are presented in table 13. The change in priorities for the ecozones from 1988 to 1992 (table 14) had a direct effect on the priority of several specific breeding objectives. High and stable grain yield was and still is a top priority. Recognizing that farmers use little or no capital input for most of their crops, especially legumes, led to the use of a testing environment similar to that of the farmers.

Table 13. Major goals of the Soybean Improvement Program from 1988 through 1992

Goals	Year				
	1988	1989	1990	1991	1992
High and stable grain yield	1*	1	1	1	1
Resistance to pod shattering	1	1	1	1	1
Seed longevity	1	1	2	2	3
Uniform cream seed color	4	2	2	2	2
Resistance to red lead Blotch	4	4	4	3	1
Resistance to *Cercospora* leaf spot	1	1	1	1	1
Resistance to bacterial pustule	2	2	2	2	3
Resistance to bacterial blight	4	3	3	3	3
Promiscuous nodulation	1	1	1	1	2
Increased nitrogen fixation	4	4	4	3	2
Resistance to pod sucking bugs	3	3	3	2	2
Resistance to defoliating insects	4	3	3	3	2
Nil-Lipoxygenase	4	4	3	3	3

Note: *1 - Top priority, 2 - Medium priority, 3 - Low priority, 4 - Not an objective

Table 14. Priority ranking of the ecological zones for soybean breeding

Goals	Year				
	1988	1989	1990	1991	1992
Breeding varieties for the savanna ecozone	2	2	1	1	1
Breeding varieties for the rain forest ecozone	2	2	2	3	3
Breeding varieties for the mid-altitude savanna ecozone	3	3	3	3	2

Note: *1 - Top priority, 2 - Medium priority, 3 - Low priority, 4 - Not an objective

4.2.2 *Pod shattering*

A survey was conducted in Benue State, Nigeria in 1989 and 1990 by IITA staff of the Resources and Crops Management Division (RCMD) and the Grain Legume Improvement Program (GLIP) (Smith et al. 1993). The major complaint of farmers was about soybean pod shattering. They complained that if they did not harvest the crop as soon as possible after it matured they risked losing all or a major part of the harvest. If they had planted a large area of soybean, harvesting all of it before the pod shattered was difficult. This information strengthened the opinion that resistance to pod shattering should be made a top priority of the breeding project.

4.2.3 *Seed longevity and color*

During the Benue State survey it was surprising that no soybean farmer complained that soybean germination was a problem. When asked whether they faced any difficulties in soybean germination or stand establishment, again 100% of the farmers reported that they found no problems In July and August seed samples were taken from the seeds stored by farmers from their previous harvest in October and November. All of the samples showed above 80% germination. This information along with lowering of the priority for working in the rainforest ecozone caused the priority of seed longevity to drop from high to low. However, it is important that the present levels of seed longevity be maintained.

In 1989, soybean processing industries and wholesale and retail traders, through the Nigerian Soybean Association, complained that when soybean seeds were not the normal cream color they were either rejected or the price offered was reduced since most buyers felt they were damaged or inferior. Thus the achievement of uniform cream seed color became one of the objectives of the improvement program in 1989, and by 1990 it received medium priority.

4.2.4 *Disease*

A major change in the objectives occurred when a new soybean disease, red leaf blotch, was identified on the Jos Plateau in Nigeria in 1990 and spread in 1991 and 1992 to soybean farms near, but not on the Jos Plateau. Research in Zambia has shown that this disease can reduce grain yields by 30-50% (Hartman et al. 1987). Some breeding lines with a moderate level of tolerance to the disease have been identified in Zimbabwe. This disease is now receiving top priority.

In 1988, breeding for resistance to *Cercospora* leaf spot was a top priority and it remains so. Many varieties that were resistant to the disease in breeding trials in 1988, became highly susceptible in subsequent years. Preliminary evidence from collaborative work with the IITA Plant Health Management Division (PHMD) indicates that the 'breakdown' in resistance is because of strain variation that occurs in the pathogen *Cercospora sojina*. Studies conducted in Nigeria by GLIP in 1989 (Dashiell and Akem 1991) found that *Cercospora* leaf spot on susceptible varieties can reduce grain yield by 40-65%. The breeding program continues to screen varieties for resistance to bacterial pustule, but this is a maintenance activity. At present, bacterial blight is not a major problem and highly susceptible breeding lines are discarded.

Recent research in collaboration with NIFTAL has shown that it may be possible to increase the biological nitrogen fixation of the soybean lines that already have promiscuous nodulation. Emphasis on screening for an increase in nodulation rating has been reduced more emphasis is now being placed on traits such as improved per cent effective nodules, total nitrogen accumulation and the proportion of this that is derived from nitrogen fixation.

4.2.5 *Insect pests*
While there are a few problems at present with insect pests; germplasm which is known to be resistant to pod sucking bugs and/or defoliating insects is being used as parent plants. Insect resistance is not a top priority at present.

4.2.6 *Organoleptic properties*
There is, among soybean germplasm, variability in organoleptic properties. The 'beany flavor' of soybean, which many people dislike, is caused by lipoxygenase. Efforts were and are still being made to develop improved varieties that have greatly reduced levels or no lipoxygenase.

4.3 Yearly work plan
During the trials, crop management practices which attempt to simulate the conditions on farmers' fields were used. The same crop management practices were used for testing all breeding lines and segregating populations. Fertilizer was applied before planting and incorporated into the soil. In 1988 and 1989, the rate was 100 kg/ha of 15-15-15 and 200 kg/ha of single superphosphate. Results of a survey of soybean growers in Nigeria in 1989 revealed that they used little or no fertilizer (Smith et al. 1993). Accordingly fertilizer was reduced to only 50 kg/ha of 15-15-15 and 100 kg of superphosphate from 1990 to 1992. Weeds were controlled by using herbicides or weeding with a hoe. No fungicides, insecticides or other chemicals or *rhizobia* inoculum are used.

The pedigree breeding method was used and two generations were advanced each year. Selection in the F_2 and F_3 was usually restricted to selecting good plant types and discarding single plants and progeny rows that were highly susceptible to bacterial pustule or *Cercospora* leaf spot. In the F_4 and F_5 generations progeny rows were discarded if they were highly or moderately susceptible to *Cercospora* leaf spot or bacterial pustule, or if they had poor seed color or plant type. The final single plant selections (SPS) were usually made in the F_6 and F_7 generation during the rainy season. The seeds of the F_6 or F_7 SPS were multiplied during the dry season and screened for resistance to pod shattering (using a laboratory method), seed size (10-13 g per 100 seeds was acceptable) and seed color (cream). The progeny rows that passed this screening were harvested in bulk, grouped by maturity and put into preliminary trails. The best lines in a preliminary trial were advanced to the advanced trial and all other lines were discarded. The best lines in an advanced trial were advanced to the uniform trial and all other lines discarded (see table 15). The locations where these trials were conducted from 1988-1992 and their ecology and major pest pressure are listed in table 16.

Table 15. Average characteristics of the uniform, advanced and preliminary breeding trials between 1988 and 1992

Trial	Plot size	Entries	Trials	No. of locations	Replication per location
Uniform	6m x 3m (4 rows)	14	3	5	4.0
Advanced	6m x 1.5m (2 rows)	16	3	5	3.0
Preliminary	6m x 1.5m (2 rows)	27	6	5	2.4

Table 16. The ecology and major pest pressure of locations where soybean variety evaluation trials were conducted from 1988 through 1992

Location	Ecozone+	Pest pressure*	Year				
			1988	1989	1990	1991	1992
Ibadan	T		✓	✓	✓	✓	✓
Abeokuta	T				✓	✓	
Egbe	SGS	CLS	✓				
Abuja	SGS	CLS				✓	✓
Zonkwa	SGS	PSB	✓	✓	✓	✓	✓
Mokwa	SGS	BP	✓	✓	✓	✓	✓
Zaria	NGS	BP	✓	✓	✓	✓	✓
Bagauda	NGS	CLS			✓	✓	✓
Jos	MA	RLB	✓	✓	✓	✓	

Notes: +SGS - Southern Guinea savanna, NGS - Northern Guinea savanna, T - Transition rainforest/savanna, MA - Mid-altitude. *CLS - *Cercospora* leaf spot, RLB - Red leaf blotch, PSB - Pod sucking bugs, BP - Bacterial pustule

Lines that did well in the uniform trial were sent to collaborators in countries outside Nigeria in the international trials. Within Nigeria, the best lines are nominated for entry in the national soybean variety trials that are part of the National Coordinated Research Projects on Soybean.

4.4 Progress and output

In 1988, the two best medium maturing breeding lines were TGx 923-2E and TGx 995-22E. The major advantage of both of these lines over SAMSOY-2 was resistance to bacterial pustule and *Cercospora* leaf spot (table 17).

Table 17. Comparison of the best medium maturing varieties tested in 1988 and 1992 with Samsoy-2, the most popular soybean variety in Kaduna State, Nigeria

	1988 Trial*						
	Yield	Nod.	Pust.	*Cerc.*	Field shat.	Seed color	Maturity
1988							
No. of location	4	3	3	2	4	5	4
SAMSOY-2	1745	3.0	3.1	2.6	1.9	6.5	116
TGx 923-2E	1736	2.8	2.2	1.3	1.7	6.0	118
TGx 995-22E	1642	2.3	1.8	1.2	1.4	2.5	114
1992							
No. of locations	3	3	3	3	3	3	4
SAMSOY-2	1213	3.2	2.3	2.2	1.9	2.6	106
TGx 1440-1E	1629	2.8	1.2	1.4	1.1	5.0	111
TGx 1448-2E	1558	2.8	1.2	1.3	1.0	2.1	110

Notes: *Heading descriptions: **Yield** - clean grain yield (kg/ha) at about 10% moisture; **Nod.** - nodulation scores: 1 - no nodules seen, 3 - good nodulation, 5 - nodulation comparable to inoculation; **Pust.** - bacterial pustule scores: 1 - no lesion seen, 5 - heavy lesions; ***Cerc.*** - *Cercospora* leaf spot scores: 1 - no lesion seen, 5 - heavy lesions; **Field shat.** - field shattering: 1 - highly resistant, 5 - highly susceptible; **Seed color** - the value is the percentage of seed that has the undesirable green seed color; **Maturity** - number of days from planting to R8

In 1992, the three most promising medium maturing breeding lines continued to have the advantages of resistance to bacterial pustule and *Cercospora* leaf spot, and, in addition, they had greatly improved resistance to pod shattering. The trial in 1992 did not show a statistically significant yield advantage of the improved breeding lines over SAMSOY-2. However, in the Nigerian national soybean variety trials, these varieties consistently had significantly high yields relative to SAMSOY-2 (table 18).

Table 18. Seed yield (kg/ha) from Nigerian national soybean trials with three replications per location

Entry	Year			Mean	Percentage of SAMSOY-2
	1990	1991	1992		
No. of location	15	13	13	41	
SAMSOY-2	1504	1540	1443	1496	100
TGx 1448-2E	1821*	1901*	1765*	1829*	122
TGx 1440-1E	1734	1826*	1771*	1777*	119

Note: *Indicates that yield is significantly higher at 0.05 level than SAMSOY-2.

The major improvements of soybean varieties between 1987 and 1992 were to increase grain yield by about 20%, improve resistance to pod shattering and to maintain the level of all other traits. This was accomplished at a time when many varieties that were resistant to *Cercospora* leaf spot were becoming highly susceptible.

5. Discussion and Conclusion

Research programs for maize and soybean improvement in the savanna ecozone in Nigeria span more than a decade. The prime objectives in the improvement programs were breeding for disease and *Striga* resistance in maize; and improving seed longevity, promiscuous nodulation, resistance to shattering and *Cercospora* and bacterial pustule diseases in soybean. Selected varieties of maize and soybean offer yield stability by their resistance to biotic and abiotic stress. The results of the research in maize and soybean conducted separately have shown that these crops are well-suited as a cereal-legume intercrop or rotation crop for the savanna ecozone in West Africa. An agronomic practice to promote the two crops as a sustainable cropping system would be desirable. These two crops could help to solve the food shortage in sub-Saharan Africa and at the same time provide a trap crop to reduce *Striga* seed population in the savanna (Parkinson et al. 1989).

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INLAND SWAMP RICE-BASED DEVELOPMENT IN AFRICA

D.V. Tran, C. Ofori and O. Berney

Food and Agriculture Organization, Rome, Italy

Abstract: *About 10-20 million ha of inland swamps are in West Africa. Inland valley swamp (IVS) development offers immense potential for increasing food production in this area; however, a great heterogeneity is found in inland swamps with respect to topography, water regime, soil types, depth and stratification. Hence appropriate location-specific technologies are required.*

Full development of swamps for cultivation generally consists of land clearing, tree felling, destumping, construction of plot earth bunds, land levelling, construction of head works including the spillway, construction of drains and irrigation canals with water control structures. The comprehensive development of inland valley swamps should include preparation of data on geographical characteristics, physical and biological environments and a socio-economic analysis of exploitable resources.

From an agronomic viewpoint, the utilized IVS are usually classified into three types: traditional, partially developed and developed. Inland valley swamp development programs should actively involve farmers at all stages of planning and implementation and should have strong government policy support for input supply, credit, processing, marketing, research, and extension activities. A coherent approach is essential for a sustainable productive system, which is environmentally sound, economically viable and socially acceptable by small farmers.

1. Introduction

In Africa, most food crops are cultivated under upland conditions. Only a few crops, such as rice and fonio, are grown frequently in the wetlands. Flooded rice is a productive crop, yielding from 2 to 5-6 t/ha per season, depending on the level of land development. The importance of rice in Africa is steadily increasing. The amount of imported rice has increased by more than three times in the last two decades, from 0.81 mt in 1970 to 2.9 mt of milled rice in 1990. Per capita consumption of rice doubled from 12 to 24 kg in West Africa in the same period (WARDA 1988). Africa produced 14 mt of paddy or 2.7% of the total world rice production on 6.9 million ha in 1992. The average yield was very low, around 2 t/ha. Wetlands, especially swamplands, may provide an environmentally sustainable and economically sound base for increased rice-based production in Africa. They could also serve as a rational alternative ecology for some annual food crops in the dry season.

A review and assessment of the present situation of inland valley swamp development and exploitation in Africa, including moist lowland savanna, and identification of constraints encountered for further investigation are discussed in this paper.

2. The Importance of Swamp Rice-based Cropping Systems in Africa

Soil degradation is a common and serious problem in the tropics. Asian farmers solved this problem by converting the humid zone tropical soils into bunded paddy fields. African farmers, on the other hand, because of lack of animal traction as well as the prevalence of diseases such as trypanosomiasis, have stayed away from the lowlands and have concentrated more on uplands. About 60% of the total rice area in Africa is upland rice under traditional shifting cultivation. Subsistence farmers clear forests by the slash-and-burn method and grow upland rice and other crops to meet their own demands. The rotational bush-fallow system, which is a relic of the pre-fertilizer era, is one of the major factors contributing to deforestation, soil erosion, desertification, and climate change, particularly when upland soils are not allowed sufficient fallow periods to rejuvenate soil productivity.

Wetland farming is more stable and productive than upland cultivation. In developed swamps, farmers can grow double, triple or multiple crops depending on water availability. In the wet season, even rice can give double or triple yields with appropriate technologies (improved varieties, cultural practices, etc.), which can then be followed by vegetable crops and cereals in the dry season (Tran and Ton That 1986). Swamps also provide fodder and water for cattle, particularly in the dry season. Hence, to increase food crop production, certain crops could be grown in the swampland, and upland could be used for more economic and environmentally sustainable crops, such as fruit trees, and for sustainable production methods such as agroforestry.

Inland swamps have great potential in all agroecologies of sub-Saharan Africa. Various names, such as *bas-fond, marais, petit vallée* or *marigot* are given in French while some local names: *fadama, vlei, dambo, boli, mbuga*, etc. are also used. In a FAO land use inventory based on a growing period of 150 days or more, about 138 million ha of wetlands, which are suitable for the cultivation of bunded rainfed lowland rice in tropical Africa are not being utilized (Ton That 1982). About 1.7 million ha or more than one per cent of such lands, however, are actually cultivated with either rainfed lowland or irrigated rice. From 10 to 20 million ha of inland swamps are located in West Africa (Hekstra and Andriesse 1983).

Although swamps have been used, to some extent, for rice production in African traditional farming systems, they are not attractive to many African farmers. In some countries, they are considered inferior or only of second priority to upland farming because of: (a) the more difficult working conditions, (b) low profitability due to low average yields under the traditional cultivation method (500 to 1500 kg per ha), and

(c) health hazards due to various diseases, for example, schistosomiasis, river blindness and malaria. Nevertheless, recent experience gained from inland swamp exploitation has demonstrated that it is not necessary to invest in heavy construction and costly management of swamps, but rather in small-scale development with a simple and less costly concept and execution. This may then enable farmers to manage and maintain their farms easily and at a much higher profit. Such a strategy would help many African governments to speed up future development projects of inland swamps. However, as great heterogeneity is to be found in any particular area of inland swamps, appropriate location-specific technologies are required for development.

3. Inland Valley Swamp Development

3.1 Classification of inland valley swamps

In inter-tropical Africa, inland valley swamps (IVS) are flat or slightly saucer-shaped areas of valleys which constitute a preferential drainage axis embedded within the alteration layers of the crystalline basement. They represent conveyance axes of runoff water, sub-surface flow and phreatic flow from alteration layers. IVS constitute an important part of the overall drainage networks of Africa. Their soils are saturated or submerged during a substantial part of the year. This is determined by the relative importance of surface and groundwater flows.

Hydrologic and geomorphic characteristics of swamps result from the combination of three main factors :

a. the relative position of the swamp along the valley
b. the rainfall and climatic characteristics of the area
c. the geology of the area

Four main types of IVS in Africa have been distinguished by Raunet (1985) and each is split into upstream and downstream:

i. Type I: Sudano-Sahelian, rainfall 800-1100 mm
ii. Type II: Sudano-Guinean, rainfall 1100-1500 mm
iii. Type III: dambos of East Africa, rainfall 1000- 1500 mm (high altitude)
iv. Type IV: swamps of humid regions, rainfall > 1400 mm.

Each of the four types has specific characteristics:

- soil type, depth and stratification
- the relative importance of each term of the water balance at the swamp level: (i) direct rainfall, (ii) surface runoff from embanking formations, (iii) overflow from the emissary, (iv) underflow within the swamp layers, (v) groundwater flow from the alteration layer of the embanking formations. The relative importance of the water contribution from each of these five

components determines the overall hydrology: average flow, magnitude of flood (if any), duration and timing of flooding, phreatic level in the swamp formation, and tendency to dry out.

3.2 Methods of swampland development for cultivation

Full development of swamps for cultivation consists of carrying out the following work:

a. land clearing of all vegetation including small diameter trees ($\leq$ 10 cm)
b. tree felling/destumping
c. construction of plot earth bunds
d. land levelling
e. construction of head works including spillway
f. construction of drains and irrigation canals including water control structures

Items (d) and/or (e) and/or (f) may be omitted, depending on the degree of development of the swamp that is envisaged,

The level of technology required for this work must take into consideration the constraints imposed by the farmers' capacity to exploit the swamp. The structural design to be adopted must, therefore, be easy to handle, adapted to local conditions and resources and capable of being maintained and hopefully reproduced at the village level.

Emphasis should be placed on utilization of the swamp from the start. This implies a progressive development over several years. The concept of total clearing and destumping of the swamp before any construction of water control structures should be replaced by a gradual process, with some initial destumping of the alignment of the structures and canals (head bund, main drain, peripheral canals, internal bunds, etc.) and the gradual destumping of the field plots at the farmers' pace for eventual field mechanization and land-levelling.

The objective of a water control system is twofold. It should prevent the swamp from being flooded, and control and direct water to the fields whenever required. Large floods should be safely evacuated through a floodway (main drain) and every field should have access to water supply and linked to the drainage system.

Preventing water from flooding the area is achieved by constructing a head dyke across the swamp on a suitable site. Two peripherical canals constructed along the edges of the swamp will supply water to all the fields through outlets. A drain excavated in the middle of the swamp will convey peak flows as described above and also the water draining from the cultivated fields.

3.2.1 *Land clearing and tree felling*

The traditional methods using simple hand tools make swampland clearing very tedious and require very high initial labor input. To provide both labor and time-saving opportunities, monkey winches for tree felling can be utilized and the complementary use of a power chain saw with the monkey winch considerably alleviates hand labor requirements. The use of skidding power take-off driven winches for the removal of felled trees from the swamp can also be employed with success.

3.2.2 *Head works*

The purpose of the head dyke is to prevent the swamp from flooding. It is the main component in the whole water control system and much care should be taken in the selection of the site of the head dyke, and particular attention paid to its design and construction. Many types of head dykes can be constructed, depending upon the specific local conditions. In most cases, an earth embankment with a concrete, masonry, or wooden flood spillway structure in the middle, is the most suitable.

The embankment both protects the area from flooding and forms a pool of water upstream which feeds the peripheral canals. The flood control structure overspills excess water during flooding into the main drain through regulation gates.

The following factors should be considered in selecting the best site for the construction of the head dyke:

a. *Area to be irrigated.* The head dyke must be in a position which will command a significant part of the swamp. The larger the command area, the lower the cost will be per unit area of developed swamp.
b. *Size of head dyke.* The size of the head dyke will depend mainly on the expected peak flows, the topography and the water level required to feed the canals. Suitable sites on narrow portions of the swamp are preferable. It should also be taken into consideration that the higher the water level needs to be raised, the heavier the work necessary for both the embankment and the flood control structures.
c. *Existing roads or paths.* If the valley is crossed by a road or a path the crossing may be combined with the head dyke.
d. *Area covered by water.* After constructing the head dyke a portion of the swamp lying upstream will come under water. Care should be taken to ensure that this area is as small as possible and will not consist of land suitable for development.
e. *Accessibility.* The site must be made accessible to machinery and equipment if they are required for construction work. Furthermore, access will be needed to transport material and to allow regular structure control.

3.2.3 *Main drain (floodway)*

The purpose of the main drain is to transport excess water in the main water course during floods and to take away drained water from the plots. It is usually located in the middle of the valley and follows the course and natural slope of the main stream. Its capacity must be designed to take care of the peak flows without overflowing. In the case of large swamps, secondary drains may be needed, as every field must be linked to a drainage channel.

The main drain, generally consists of the re-shaping of the main water course. If it is shallow, the typical cross-section should be rather large and shallow in order to avoid reaching a lower permeable strata of the swamp soil profile, and thus provoking excessive drainage of the water table. On the contrary, in rather steep swamps, the natural water course may be several meters deep, and the resulting high velocities may be erosive and make the bed unstable. Under these conditions, it may become necessary to stabilize the bed, reducing its natural slope by providing check-drop structures along the portion of the water course located inside the swamp development.

In swamps located in the upper watersheds where water shortages may occur, reuse of the drained water may be achieved by using check-drop structures to further raise the water level and feed secondary canals commanding the area downstream. It is thus possible to design systems that make maximum use of the available water. In this instance, the main drain serves both purposes, i.e., to collect water from the upper plots and supply water to the lower ones.

3.2.4 *Canals for water distribution*

Irrigation canals for water distribution to the plots are located at the periphery of the swamp, on a higher elevation than the fields to be irrigated. In wide swamps, secondary and field canals may be constructed for feeding all the plots.

The most important point is the starting bed level which has to be fixed in relation to the expected depth of water in the head dyke and diversion structure. In order to fix the bed level of the canal, the following points should be considered :

a. existing depth of the main stream
b. expected elevation of water retained behind the head dyke
c. elevation of the area to be commanded by the canal
d. the overall slope of the area along the proposed canal

In general, it is not recommended that water be raised too much behind the head dyke. High water levels would require an expensive structure and would generally flood large areas upstream. Whenever possible, it is advisable to keep the water level below one metre from the bed level in the stream.

The slope of the canal should be between 0.5% and 4% in order not to induce erosive velocity. If the general slope of the swamp exceeds this last value, check drop structures have to be built along the canal.

Under normal conditions in conventional irrigation schemes, a canal is designed to carry enough water to satisfy the irrigation water requirements. However, for swamp development, where the area is generally narrow, and plots poorly levelled with much fragmentation, the management losses are very high. Experience shows that it is generally advisable to double the canal capacity, which has been calculated on the basis of the irrigation requirements, taking into account factors such as the rapid growth of weeds and the consequent reduction of the discharge capacity and the interception of the flow, and seepage from the embankments of the canal.

3.2.5 *Water control structures in water supply canals*

Head regulator: At the beginning of the canal it is necessary to build a control structure which will prevent floods from entering and causing damage in the peripheral water supply canal.

Drop structures: In order to maintain a canal slope compatible with a non-erosive velocity of water flow, it is sometimes necessary to build drop structures. It is advisable to have several small falls of, for example, 0.50 m height, than to have a few high ones, which would require heavy structures and excessive earth moving.

Pipe outlets: Pipe outlets are the simplest and cheapest type of outlet. They can operate with a very small water head and are placed horizontally or sloping slightly towards the fields. The upstream end of the pipe should be placed at the elevation of the canal bed level, approximately every 30 m, in order to get water from the canal into the fields. This interval is not fixed but varies according to the topography of the swamp and to the field boundaries of individual plots. Steep, narrow swamps and fragmented areas will require more pipe outlets than large flat swamps. The main aim is to distribute water uniformly over the land. However, water distribution using this system limits control of water from one field to another. Once the water gets out of the canal through an outlet, it will go through several ownership plots, each with many basins, before reaching the drain. It is very difficult to match the outlet discharge with the water consumption demand of the command area. Where there is plenty of water, the losses to the drain are not a problem. However, for swamps in the upper watersheds, where the available flow is low, it is often difficult to meet irrigation requirements. Any water discharged to the drain can be used again in a lower area if downstream developments are present.

3.3 Valley swamp inventories

In many African countries, swampland is known to represent a great potential for new agricultural development. However, no reliable data are available to qualify and quantify these potential resources. Some spontaneous development has already taken place on the fringes of various swamps by individual farmers, where water control is relatively easy.

In order to categorize the various types of swamps with their associated soil types, hydrological regimes, and socio-economic potential, an inventory of swamps at the regional or country level is important: in some countries, due to rapid population increase with the consequent increasing pressure on the uplands (e.g., Rwanda, Burundi), swampland has become the last possible resource for the extension of cultivable land.

With the advent of personal computers, inventories are elaborated by using dedicated data base programs. By linking the inventory data base to a GIS graphic program it is possible to produce a set of maps showing swamps with common characteristics, based on a range of selected parameters.

When building a swamp inventory, some conceptual problems arise. For example, in many countries a local swamp name only denominates a part of a larger and/or longer swamp and is the portion assigned to the lands of a particular village or any other administrative unit. It is, thus, not bound to any hydrographic characteristics. Moreover, administrative limits are often marked by the emissaries of different governments, even though the same swamp extends through different administrative territories, and therefore two different names are often given to either side of the same swamp.

Geographically, an individual swamp has no proper meaning: in most watersheds, the entire hydrological watercourse network is bordered by continuous swamp strips. To derive a geographical notion of a swamp, these long strips of swampland must be conceptually split into numerous sections delimited by singular physical points such as confluence points, abrupt changes in slope or in width, or any distinguishable change in the swampland form. In order to characterize each section, a unique code is assigned.

Swamp inventories should record three broad categories of data:

- geographic features
- physical environment
- socio-economic characteristics

Each category is composed of one or several sets of particular data, some of which are generally available within the country and need only to be codified, quantified and elaborated in a form suitable for direct input into the data base program. Other data, on the contrary, such as actual cropped areas, swamp shape, etc. need to be reliably surveyed, which can be very costly. It is therefore of prime importance to state precisely for what purpose the inventory is to be set up and which type of question the database must be able to answer in order to allocate sufficient financial resources for its establishment.

a. *Geographical data:* Watershed and swamp code number, name, geographical coordinates, number on the national topographic map, administrative region, watershed area, altitude, swamp area length and width, slope, topology, name of the main emissary, etc.
b. *Physical environment*: Rainfall data and statistics, potential evapotranspiration, specific discharge, hydrological parameters (compactness index,

hydrographic network density, swamp index), soil series, lithology, agro-climatical zone, natural vegetation.

c. *Socio-economic data*: Local names, distance to road network, population (villages, density, etc.), present swampland use, crops, other human activities (fish farming, peat extraction, brick factories, playgrounds, etc.), markets, family incomes, existence of these studies and/or previous developments, etc.

The above data is certainly not exhaustive and more parameters can be taken into consideration.

The constitution of such a computerized inventory provides a valuable tool for categorizing swamps or parts of swamps, listing some common characteristics, e.g., agroecological zones with particular cropping capabilities, potential swamp development in high population density areas, categories of swamps with particular drainage problems, etc.

Consequently, the database would constitute the basic tool for elaborating a swamp development master plan, and thus would lead to the selection of decision-making criteria, making it possible for the government or potential donors to invest in the development and the future exploitation of certain categories of swamps.

4. Inland Valley Swamp Management

The soils of the wetlands can be broadly grouped under hydromorphic soils: including Gleysols, Fluvisols, Gleyic units of Acrisols, Luvisols, etc. in the drier slopes of the valley, for example, in the savanna areas. There are wide variations in the chemical properties of hydric soils and these depend largely on the mineral composition and the amount and quantity of organic material. The organic material plays an important role in the redox systems of these soils.

4.1 Soil fertility management

Soil management practices in rice-based cropping systems in the inland valley swamps and wetlands of Africa differ from one country to another; first, depending on the labor and energy input source and, second, on the resources available to farmers to purchase required inputs for soil fertility maintenance.

In countries where draught animals are available for the preparation of the land — ploughing, puddling and levelling — a higher quality land preparation is achieved than where human labor is the main energy input. In the latter, the simple implements employed, restrict adequate land preparation and other soil management practices such as the incorporation of rice-straw for organic matter maintenance, as well as green manuring practices.

Rice-straw has been by far the most readily available source of organic matter for lowland rice in tropical Asia and its incorporation into rice soils constitutes an effective recycling of organic material for soil fertility maintenance (Hideaki and Wittay 1988). An analysis of rice-straw (Hideaki and Wittay 1988) shows the following composition: 0.4-0.7% N, 0.1% P, 3% K and 8% Si. Jenkinson (1976) and Kai and Kawaguchi (1977) reported that the incorporation of rice-straw stimulated the mineralization of native soil organic matter. Most soils of inland valley swamps in West Africa are coarse textured and are of low fertility, with plant uptake ranging from 4 to 24 kg N/ha. Organic matter build-up to improve the structures of these soils as well as improve their fertility levels, constitutes one of the important management practices required to increase rice yield in these ecologies. Furthermore, the single grain structure of some of the inland valley bottom soils does not lend itself to puddling, a process necessary for efficient water as well as nutrient management in flooded rice production.

Soils of the flood plains are of alluvial origin. These soils, especially those from the basement complex, are more fertile than those in the inland valley swamps and have higher exchangeable Ca, Mg, K, ECEC and clay content.

In the bottomlands, Van Mensvoort et al. (1984) mentioned Al^{3+} toxicity, low inherent fertility, Fe^{3+} toxicity, and flooding as some of the main constraints to rice cultivation. Kyuma et al. (1986) summarizing the soil chemical properties in the wetlands of West Africa found that the pH exchange Ca, Mg and Na and ECEC increased from the equatorial forest zone to semi-arid Sudan and Sahel savanna zones. On the other hand, organic C, total N and exchangeable acidity decrease (table 1). Nutrient management for rice production in the inland valley swamps of both ecologies, therefore, must take these differences in soil chemical properties into account.

4.2 Alternating rice cultivation with upland crops

In most areas of the wetlands in Africa, rice cultivation is the predominant cropping system, but extensive areas also exist where the available water is inadequate to support two or three rice crops a year without additional irrigation. Residual moisture after flooding is utilized in the cultivation of dry upland crops such as maize, millet, sorghum and market garden crops. Soil management practices have to be tuned to match these cropping systems, starting from land preparation for the rice crop — puddling and levelling — to its preparation for rice sowing or transplanting, and crop residue management for the dry upland crops. In many areas of wetland cultivation, especially in flood plains and the *Bolilands* of West Africa, rice cultivation alternates with upland crops. Land preparation for rice differs from that for maize, sorghum or millet crops. Puddling in the case of the rice changes the physical characteristics of the soil and the rooting depth. Where animal or machine traction is available, adequate seedbed preparation can be achieved for good growth of the upland crop. On the other hand where the farmer has to depend solely on manual labor, seedbed preparation is poor, affecting crop stand density, and with subsequent reduction in yield.

In inland valley swamps, valley fringes and bottomlands where root and tuber crops such as cassava and sweet potatoes are cultivated in the dry periods, farmers

Table 1 General physico-chemical characteristics of top and sub-soils of flood plains and inland valley swamps in West Africa

	Site climate	pH	Org. C (%)	Total N (%)	Bray P_1 (ppm)	Exchangeable cations				Acidity	ECEC	Sand	Silt	Clay
						Ca	Mg	K	Na	--- (meq/100 g) ---		--------- (%) ---------		
						----------- (meq/100 g) -----------								
Flood Plain	Humid	4.59	1.96	0.207	4.3	1.74	1.40	0.36	0.10	3.32	6.85	30	38	33
	Sub-humid	5.88	0.52	0.075	2.8	5.92	2.39	0.24	0.53	0.28	9.36	47	28	25
	Semi-arid	5.69	0.63	0.075	1.7	7.64	4.28	0.57	2.39	0.29	15.27	52	18	30
Inland Valley Swamp	Humid	4.82	1.62	0.159	3.6	0.62	0.31	0.13	0.09	1.72	2.89	65	18	17
	Sub-humid	5.05	0.74	0.079	3.3	1.47	0.79	0.18	0.17	0.84	3.50	61	24	15
	Semi-arid	6.70	0.51	0.073	3.8	5.94	1.41	0.14	0.60	0.13	8.23	56	29	15

Source: K Kyuma, T Kosaki and ASR Juo (1986).

adopt soil management practices such as mounding, which increases rooting, overcomes excessive wetness and improves tuber development. The mounds are circular and are 30 to 50 cm high. Such management practices alleviate any possible oxygen deficiency that could occur when root crops are cultivated in the wet soils.Using green manure is beneficial under these cropping systems. However most small farmers are constrained by the lack of appropriate implements to alleviate the drudgery of this labor-intensive activity.

In Zimbabwe, a rice-based cropping system is practised on the *vlei* soils. The vlei is a grassland which is seasonally waterlogged and characterized by grasses and sedges and a general absence of woody species (Mharapara 1989). All vleis are wetlands with hydromorphic soils which range from sands to clays and the profiles may vary from undeveloped to highly developed.

Until legislation was passed that forbid vlei cultivation, rice and maize were invariably intercropped as an insurance against crop failure. Various land preparation methods were practiced including cultivation on the flat, rice was cultivated in the furrows which accumulated water. The present areas allocated to these crops are not typical vleis, but rather the fringes of the vleis, with the farmers practicing a rice-based cropping system. With the introduction of the ox-drawn plough to replace the hoe, land preparation has greatly improved, resulting in better crop establishment and higher plant populations. Farmyard manure is applied to maize as the rice varieties cultivated are more adapted to low fertility soils and barely respond to the application of fertilizer.

Similar to the vleis in Zimbabwe are the wetlands of Malawi and Zambia. These are large tracts of land of impeded drainage under the collective name of ***dambos***. The topography is normally of gentle slope (½-1°). The soils are usually heavy black hydromorphic soils which are well mottled: pale grey gleyed horizons with a prominent strong brown mottle. Texture ranges from sandy clay to heavy clay and the clay mineral being predominantly montmorillonite. The dambos are presently used mostly for communal grazing and vegetable cultivation. They are of high agricultural potential and could be developed for rice production.

4.3 Rice-based cropping systems in IVS

Agronomically, the utilised IVS are classified into three major groups: traditional IVS, partially developed IVS and developed IVS.

4.3.1 Traditional IVS: Farmers clear vegetation, then plant traditional *Oryza*, particularly *O. glaberrima* by either direct seeding or transplanting without chemical input and water control. Rice varieties are mostly photo-sensitive, having long growth durations ranging from 160 to 210 days. The average yield is from 1 to 1.5 t/ha and farmers grow one crop per year. In the northern equator, rice is sown on prepared soils at the onset of the rainy season or in May/June. Farmers also prepare rice in nurseries and transplant the seedlings about two months later when the fields are already flooded. The weeding and crop protection are done in IVS. Farmers will harvest the rice in December/January. The rice crop frequently suffers from drought and flash floods and yield is usually uncertain.

4.3.2 Partially developed IVS: These were originally traditional swamps which have been improved by farmers with or without government assistance through improving main drainage systems and introducing low-cost technologies such as improved varieties and some inputs (seeds and fertilizers). The yield obtained can be from 2 to 2.5 t/ha. A rice crop and off-season crops such as vegetables and maize are commonly cultivated wherever water exists. Flooding and dry spells also occur.

4.3.3 Developed IVS: These swamps have been completely developed with an effective water control system, good land levelling, and bunding. They are quasi-irrigated rice schemes, where cropping can be intensified and productive. Semi-dwarf and early maturing varieties of rice are used along with adequate inputs. The average yield of rice ranges from 3 to 6 t/ha. In many swamps, a double rice crop is grown, particularly in the humid tropical areas or existing irrigation perimeters. In Burkina Faso, farmers exploit the swamps intensively with two rice crops per year and an average yield of 4 t/ha per season. In some semi-arid countries, such as Tanzania and Mozambique, rice is only cultivated under irrigation schemes in the humid season, because of the water shortages in the dry season and poor management.

In the last three decades, rice technology has been developed with an emphasis on irrigated rice. However, rainfed lowland rice has not been forgotten. Farmers have adopted improved varieties and used some chemical inputs in partially developed and developed IVS. In the traditional swamps, farmers still rely on traditional cultivars. The Consulative Group for International Agriculture Research system's centers and national agricultural research systems (NARS) have made many contributions to a higher yield under relatively favourable conditions. Several improved varieties such as Suakoko 8, Mat Candu, CIAT 21528, C1322-28, and ITA 306 (Abifarin 1989) are tolerant to the iron toxicity which is prevalent in IVS cultivation. Some progress has also been made in improved farming practices for crop stand establishment, nutrient management, on-farm water collection and weed control (IRRI 1992); however, much more effort should be made concerning drougth tolerance and solving flood and soil problems under less favourable IVS conditions.

In the last several years, some international, intergovernmental and national agencies have directed their work towards understanding soil and hydrological conditions, national resource management and crop management in IVS agro-ecosystems. In 1990, the Food and Agriculture Organization regional office in Accra, Ghana, established a Technical Co-operation Network in Wetland Development and Management (WEDEM), aimed at promoting the environmentally-sound development and management of wetland resources for sustainable food production, and to exchange information. In the short term, the network aims to review and assess wetland potential, development technologies and management methods, and the experience gained by network members.

The International Institute of Tropical Agriculture (IITA), in its inland valley systems research program, strives to assess inland valley areas recently exploited, to classify different types of inland valleys, to review crop management and constraints encountered, and to develop appropriate technologies for inland valley agro-ecosystems in West and Central Africa (IITA 1990). Some French organizations, such as CIEH (le Comité Inter-gouvernemental d'Etude Hydraulique), IRAT (Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières) and CORAF (Réseau Riz de la Conférence des Responsables de Recherche Agronomique Africains) have worked on soil and hydrological problems, inventories and crop management in IVS in several French-speaking countries, such as Burkina Faso, Senegal, Benin, Madagascar, etc. In the last few years, the West African Rice Development Agency (WARDA) has focused on developing improved rice varieties, especially for iron toxicity tolerance, improved production and postharvest processing methods; it is also assessing the acceptability and impact of new technologies introduced into the upland/hydromorphic/inland swamp continuum in West Africa (WARDA 1988).

5. Constraints in Inland Swamp Rice Development and Exploitation

In recent years, many IVS rice projects in several African countries have attempted to improve effective water control in swamps, aiming to convert them into partially or completely irrigated rice fields, but such developmental work has encountered many difficulties. The major constraints encountered in swamp rice development are discussed below.

5.1 General development constraints

Feasibility studies on individual swamps are generally incomplete before development begins, due to the lack of experience in swamp rice development and inadequate skilled manpower. Some IVS development projects have suffered from the perceived need to achieve predetermined targets of developed swamp hectarages. In Sierra Leone for example, large areas swamp have been developed, but their quality has been low. Some developed swamps have also been abandoned after a few years of exploitation (Dingle 1984).

In addition, support activities for IVS development are inefficient. Credit inputs are inadequate and not available to farmers. Farm machinery and equipment are beyond the financial capability of small farmers. Undeveloped infrastructures do not encourage farmers to reclaim and develop new swamps which are often remote and isolated. Poor swamp maintenance, including water controlling systems, and inadequate machinery and equipment, have been observed in many projects. Government extension and training programs respond insufficiently to the scope of swamp development in quality and quantity.

5.2 Technical constraints

Great heterogeneity among swamps makes technology application in swamp rice development, particularly in the areas of engineering and agronomy, more difficult. Frequently, swamp rice development has been practised on a trial and error basis. In Sierra Leone, Mr. Thirugnanasambanthar (Dingle 1984) reported the following constraints in IVS development: (i) lack of comprehensive study and planning, (ii) shortage of skilled survey workers, (iii) excessive drainage, (iv) misplaced and inadequate head bunds and lack of control gates to control flash floods, (v) poor land levelling and insufficient interior bunds that do not respect the land contours.

With respect to agronomic practices, several constraints have been reported:

a. *Soil problems:* iron toxicities, organic acids, phosphorus, potassium and zinc deficiencies are found in swamps. Risks of erosion have been observed on the swamp slopes, but not at the swamp bottomlands
b. *Hydrology*: Inadequate water supplies occasionally occur in the early and late growing seasons and poor drainage in the mid-season. Many developed swamps have been abandoned in Sahelian and Sudano-Sahelian areas, where rainfall is uncertain.
c. *Pests and disease*: Insect pests: white and striped stem borers, stalk-eyed fly, rice gall midge locusts, etc.; Diseases: blast, glume discoloration, sheath rot, rhynchosporium, helmintho-sporium, xanthomonas, yellow mottle virus, etc. Other constraints include, weeds, rats and birds.
d. *Varieties*: Traditional varieties are widely used, but have a long growth duration (more than 150 days), suffer from lodging, low yields (0.5-2 t/ha), and susceptibility to soil problems, insect pests, disease and hydrological problems.
e. *Cultural methods*: The following cultural problems have been reported in IVS: inadequate land preparation, use of old seedlings, late planting, wide spacing, insufficient or no inputs, poor water control, inadequate weeding and pest control, and poor postharvest methods have been observed in swamp rice cultivation.

5.3 Social constraints

a. *Labor shortage:* IVS farming is labor-intensive, particularly during land preparation, seeding, transplanting, and weeding. These activities coincide with planting and weeding periods in upland farming and priority is given to the latter. In addition, the population density in some countries is not high enough to justify swamp rice cultivation.
b. *Women:* Women are frequently in charge of upland rice cultivation. They will lose power and recognition in the family if they move their work into the swamps. Many women who traditionally work in the swamps and will likely lose control of their farms once these swamps are developed.

c. *Land tenure system:* The land tenure system which was developed for upland crops does not guarantee farmers the continued ownership of developed swamps. In addition, many swamp owners do not become involved in swamp rice development, while the actual farmers have no swamps to grow rice in.
d. *Farmers' habits:* Farmers are used to traditional shifting cultivation on uplands. Inland swamp rice is a permanent cultivation system with a stricter cultural calendar. Moreover, swamp work means additional drudgery for farmers working working in a muddy environment. Consequently, there is a lack of enthusiasm for swamp rice development.

5.4 Economic constraints

High investment costs have been reported in many swamp rice development projects, especially for completely developed swamps. About 300-400 man-days/ha are needed for new land clearing and installing full water control systems, and costly inputs are required for improved rice cultivation (Dingle 1984). Furthermore, rice pricing policies have not favored swamp rice development in many African countries.

5.5 Health constraints

Farmers often complain of health hazards associated with working in swampy areas. These include malaria, rheumatism, hernia, bilharzia, river blindness and swollen feet. They are also exposed to leeches. A recent study on farmers' health in swamp development in Moyamba, Sierra Leone showed that there is no evidence that the IVS development project created niches for the breeding of vectors of any infectious diseases.

6. Case Study

Benin: Projects BEN/84/012 and BEN/91/002

Inventory, study and development of swamps in Benin

Government realized that its past irrigation development strategy, based on large-scale capital intensive schemes run by government agencies, had failed to a large extent because of their social inadequacy and lack of relevance to small farmers. The new strategy is based on small-scale farmer-operated irrigation systems developed in swamps.

The project has developed and tested a participatory methodology, in which local communities are considered as full partners and take all the main decisions in a negotiation process with local authorities and the project, which provides technical assistance and training. The communities, organized into farmers' associations, are responsible for the choice of design, implementation, operation and maintenance of their schemes, and for input supply and marketing of their products.

After an initial sensitization phase, which starts after a community has contacted the project for assistance, the farmers identify and analyze the physical, technical, social and economic problems they face, and organize themselves into a structure of their own choice, which will be the project's partner in the next phase, after a formal request for assistance has been made. Then the project prepares several variant designs differing in the degree of intensification and the cropping pattern to be presented to the swamp development project, and the association takes the final decision whether it will implement the project and what variant to select — the variants are gradual in the degree of development of the swamp and the farmers may decide to go step by step according to their investment capacity.

The chosen variant is then finalized, and the programming of implementation and determination of the inputs to be provided by the different partners are negotiated. A development contract is then signed.

During the implementation phase, the association is responsible for providing inputs and any problem is discussed with the project team. When the work is completed, an evaluation is made by the farmers, which may lead to further action. This monitoring and evaluation process of the functioning of the scheme and of crop production, associating the farmers and the project, continues during several seasons.

Rather than providing for all the needs of the farmers, the project team prefers to help associations identify and address local institutions for credit, marketing etc., in order to guarantee the sustainability of the operation and to increase the autonomy of the association.

7. Conclusion

Inland valley swamp development could contribute to increasing and stabilizing food production in many African countries, due to its assured water supply and relatively fertile soils. Swamp development would therefore, could contribute to the on-going efforts to promote household food security in sub-Saharan Africa. Increased swamp rice production in this region requires an integrated IVS development program, in which farmers have to be actively involved at all stages of planning and implementation, with strong government policy support for input supply, credit, processing, marketing, research, and extension activities. The inventory, characterization and classification of inland swamps are the first stages of their exploitation, followed by swamp feasibility studies, land development, and training in rice-based farming and postharvest activities. A coherent approach is essential to ensure a productive and sustainable production system, which is environmentally sound, economically viable and socially acceptable to small farmers.

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PART 4
Technology and Transfer

FROM CHARACTERIZATION TO TECHNOLOGY TESTING: Case Study of the Northern Guinea Savanna of Nigeria

V.M. Manyong and R.J. Carsky

International Institute of Tropical Agriculture (IITA), PMB 5320, Ibadan, Nigeria

Key words: characterization, dynamics of production systems, benchmark site, *Striga*, technology testing, northern Guinea savanna

Abstract: *Characterization studies conducted at both meso- and micro-levels in the northern Guinea savanna of Nigeria resulted in the development of a framework to study the dynamics of agricultural systems on the basis of specific determinants of agricultural intensification. These determinants include good access to markets, availability of ecological and socially adapted improved technologies, availability of inputs, and favorable government policy. Application of the framework at the macro-level resulted in the identification of four broad agricultural systems in West and Central Africa. Benchmark sites for technology testing should then be selected within the identified broad agricultural systems to address specific agronomic constraints such as Striga and soil fertility deficiencies identified by farmers and to create the opportunities for cropping system diversification.*

1. Statement of the Problem

The northern Guinea savanna (NGS) of Nigeria is characterized by a growing period of 151-180 days, a daily mean temperature during the growing period of more than 20°C and an altitude not exceeding 800m above sea level (IITA 1994).

Despite the apparent homogeneity of the bio-physical factors of the ecozone, production systems reveal tremendous differences in the use of resources, opportunities for resource management, and in results from farming activities (Norman et al. 1982). Moreover, production systems are not static and recent studies have shown dramatic changes during the last fifteen years (Smith et al. 1994).

This case study of the northern Guinea savanna of Nigeria illustrates the experiences of International Institute of Tropical Agriculture (IITA) researchers in addressing the issue of the heterogeneity of production systems during the process of technology development from characterization to technology testing.

Determinants of change in production systems are identified and the driving forces for agricultural intensification are highlighted. A framework to characterize the dynamics of the production systems is then derived from the characterization studies. The application of the above framework leads to the definition of the agricultural systems from which the benchmark sites for technology testing are selected. The methodology for technology testing and the analysis of agronomic problems and opportunities for the northern Guinea savanna of Nigeria are also discussed. A summary ends the paper.

2. Meso-level Characterization of Systems

A rapid rural appraisal survey was conducted in 27 randomly selected villages scattered across the NGS of Nigeria and covering parts of four states: northern Kaduna and southern Katsina State which are in the central part of the zone, south-eastern Sokoto State in the west, and Bauchi State in the east.

The NGS is remarkable for being one of the most intensified farming areas in Nigeria. In the last twenty years the farming system has undergone dramatic changes. The most striking change has been the increased importance of maize.

According to village interviews, the role of maize as a cash and food crop has increased dramatically (table 1). The importance of maize was found to be greatest in the central part of the zone where it was the most important food or cash crop in nearly all the villages. By contrast, in Bauchi and Sokoto states, maize was the most important food or cash crop in only two of the 12 villages.

Table 1. The increased importance of maize in the northern Guinea savanna, Nigeria: group interviews, 1989

	All villages	States			
		Northern Kaduna	Southern Katsina	Bauchi	Southeast Sokoto
No. of villages	27	10	5	9	3
		1989 (percentage of villages)			
Major food crop	96	100	100	89	100
Major cash crop	70	80	100	33	100
No. 1 food or cash crop	59	90	100	22	0
Improved maize grown	100	100	100	100	100
Minimal or no local varieties	52	60	100	22	33
		Mid-1970s (percentage of villages)			
Major food crop	33	30	20	33	67
Major cash crop	0	0	0	0	0
No. 1 food or cash crop	0	0	0	0	0
Improved maize grown	0	0	0	0	0
Minimal or no local varieties	0	0	0	0	0

Source: Smith et al. 1994

Village interviews also revealed dramatic changes in farmers's practices. Fallow periods were reported to have totally disappeared in 59% of the villages and to be declining in another 26%. The prevalence of continuous cultivation was highest in Katsina State, and lowest in Sokoto State (table 2). Fertilizer use increased dramatically over the period. Although fertilizer was introduced to the farmers of the NGS in Nigeria in the 1970s for the majority of the villages (fig. 1) in 1989, fertilizer was reported to be used by all farmers in all Kaduna and Katsina villages and by most farmers in half to two-thirds of villages in Bauchi and Sokoto States (fig. 2). Other changes observed more in villages in Kaduna-Katsina states than in Bauchi-Sokoto states included an increase in the adoption of animal traction, the development of a labor market and an incipient privatization of land-use rights. It was also observed that the *gandu* system, the local social organization of farming, is rapidly declining.

Table 2. Change in fallow periods: Northern Guinea savanna, Nigeria: Group interviews, 1989

	All villages	States			
		Northern Kaduna	Southern Katsina	Bauchi	South east Sokoto
No. of villages	27	10	5	9	3
			1989 (percentage of villages)		
No fallow	59	50	100	56	33
Fallow declining	26	50	0	22	0
No change	11	0	0	11	67
Fallow increasing	4	0	0	11	0
			Mid-1970s (percentage of villages)		
No fallow	30	40	20	33	0

Source: Smith J et al. 1994

3. Micro Level Studies

Intensive field monitoring was initiated in 1990 on 66 fields in 5 villages (3 in northern Kaduna State and 2 in southern Katsina State). In 1991, work continued in these 5 villages and was begun in i5 fields in one village in Bauchi state. The methodology was streamlined so that 185 fields in the original 5 villages could be visited.

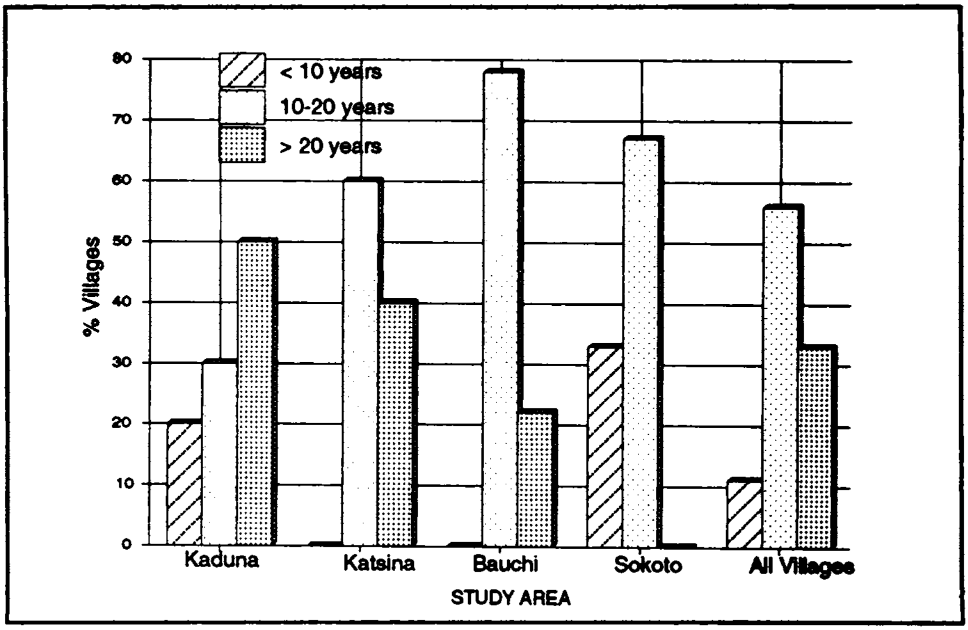

Figure 1. Introduction of fertilizers in NGS-Nigeria, 1989
Source: Smith et al. (1994)

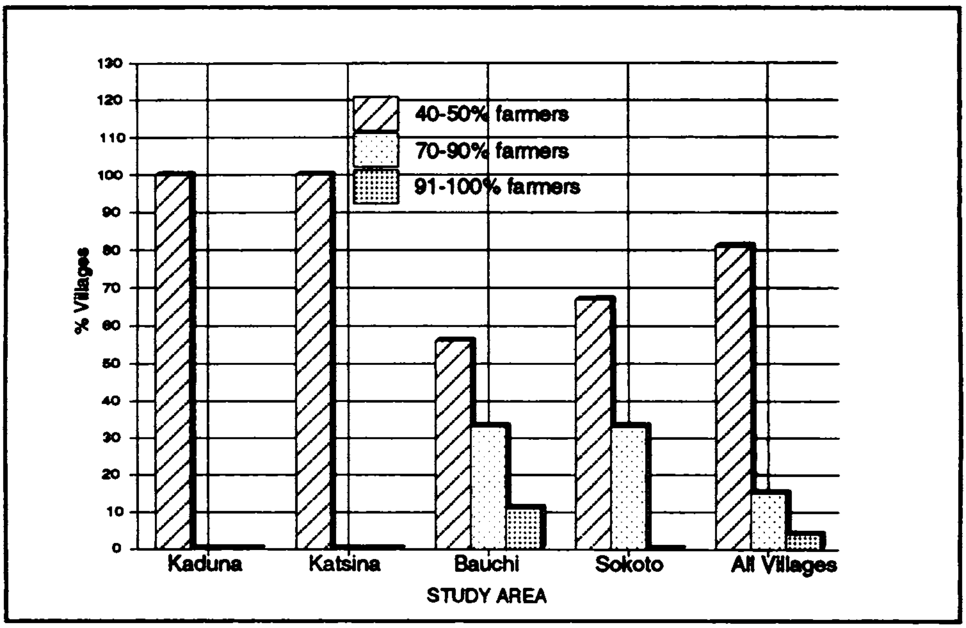

Figure 2. Adoption of fertilizers in NGS-Nigeria, 1989
Source: Smith et al. (1994)

In each village, the problem of *Striga* infestation of maize was discussed with farmers, and fields with a history of *Striga* occurrence were identified for monitoring. Field monitoring consisted of four visits in 1990, or three visits in 1991 during the cropping season, including a visit at harvest. Approximately 10 evaluation points were marked out in each field. Each evaluation point was about 5 m long and 2 rows of maize wide. These fixed evaluation points were used for all observations, and harvest data. All crops grown in association with maize were observed at the evaluation points.

Diagnostic trials were also conducted when an important constraint and/or solution was identified. The diagnostic trials conducted during 1990-1992 included:

a. *Striga*-tolerant maize varieties
b. legume rotations for *Striga* control
c. carbofuran for nematode control
d. legume rotations for nematode control
e. seed treatment for Fusarium control
f. zinc application for maize

Differences in the cropping systems were striking between the Katsina-Kaduna and Bauchi areas. Although cereal cropping was dominant, the frequency of maize cropping was 67% in the Katsina-Kaduna villages and 33% in the Bauchi village while the frequency of sorghum cropping was 58% in the Katsina-Kaduna villages and 63% in the Bauchi village. The frequency of integration of non-cereal crops, particularly grain legumes (groundnut and cowpea), was as high as 57% in Bauchi and about 26% in Katsina-Kaduna areas. The intensity of crop management and land use were also found to be different in the two areas (table 3).

Agronomic studies showed significant differences in bio-physical characteristics of the production systems of the two sub zones. Soils (table 4) were found to be more acidic, have lower organic carbon content (OC), lower total nitrogen (TN), higher phosphorus (P) content and greater Zinc (ZN) deficiency in farmers' fields in Katsina state than in Bauchi state.

Biotic constraints to maize production were studied in depth. It was found that in intensified cereal-based systems, symptoms of nematode damage and zinc deficiency are often mistaken for *Striga* damage by farmers (Weber et al. unpublished). Yield loss of maize was related to *Striga* damage score proposed by Kim (Kim 1991). Although *Striga* was found to be severe everywhere, the severity was higher in Bauchi than in Katsina-Kaduna (Weber et al., unpublished). Yield loss of maize was related to the *Striga* damage score reported by Kim (1991). Yield loss was also correlated to nematode damage scores on maize. Clusters of nematode genera were associated with differences in soil depth, soil texture and cropping (Weber et al. unpublished).

Table 3. Characteristics of production systems in cereal-based systems in Kaduna/Katsina and Bauchi States of Nigeria

Characteristics	Kaduna/Katsina States	Bauchi State
Land use intensity	high	mod-high
Intensity of crop management (weeding, ridging)	high	moderate
Use of purchased inputs (fertilizer)	mod-high	low
Frequency of maize cropping (% years with maize)	67	33
Frequence of sorghum cropping (% years with sorghum)	58	63
Frequency of non-cereals cropping (% years with non-cereal)	26	57

Source: Adapted from a. G Weber, J Smith and V M Manyong, unpublished.
b. VM Manyong, J Smith, G Weber and B Oyewole, unpublished.

Table 4. Characteristics of soils in farmers' fields in Katsina and Bauchi States, NGS of Nigeria

Variables	Katsina State[1]				Bauchi State[2]				P>F[3]
	N	Min	Mean	SD	N	Min	Mean	SD	
pH	75	4.5	5.8	0.65	52	5.0	6.43	0.54	**
OC(%)	75	0.09	0.47	0.18	52	0.19	0.83	0.52	**
TN(%)	74	0.01	0.04	0.01	52	0.02	0.07	0.04	**
P(ppm)	75	1.1	14.4	11.86	52	1.2	12.96	14.82	*
Zn(ppm)	40	1.64	3.75	1.75	22	1.94	6.32	6.57	*

Notes: [1] 15-20 years of fertilizer use under intensive, continuous cropping
[2] No or minor fertilizer use under intensive cropping with short fallow periods
[3] * and ** indicate significant differences between means for P < 5% and P < 1%, respectively
Source: G Weber, J Smith and MV Manyong, unpublished.

In general, nematode infestation was much more severe in Katsina-Kaduna than in Bauchi. Weed genera were also clustered into associations and regressed on bio-physical, management, and cropping history variables. Soil organic matter content and frequency of cereal cropping were the most important parameters for differentiating weed associations. Frequency of non-cereal cropping and soil cation exchange capacity were also important determinants (Weber et al. unpublished).

4. Determinants of Change

The above empirical results showed that a small number of driving forces were responsible for both spatial differences between the two environments and the dramatic changes that occurred within the last fifteen years.

Land pressure is not new in the northern Guinea savanna, since the population density in the area ranges from about 55 to 90 persons/km^2, which is moderately high by West African standards (Smith et al. 1994). The 1991 census figures in the recent analysis show that the population density of Katsina-Kaduna and Bauchi states are in the medium category (>51<100 persons/km^2) in comparison with highly populated areas (>100 persons/km^2) in the southern part of the country (Manyong et al. unpublished). Despite the fact that population estimates for Nigeria are often controversial (Tell 1992) the figures show that land pressure is as high in the 1990s as it was in the 1970s.

The agricultural intensification that resulted from the changes over time in the northern Guinea savanna of Nigeria may be explained by the interaction between 'market' internal changes and exogenous changes which occurred in this ecological zone.

4.1 Low cost of transportation

Transport became low in cost as a result of the improvement in the road systems and the subsidized fuel prices by the Nigeria government during and after the oil boom period of the 1970s. Big cities in the north were well connected by good paved roads to the major centers located in the south. Feeder roads were also improved and all the villages were reported to have good access to the wholesale markets in Katsina-Kaduna states; the proportion was less in Bauchi state (Manyong et al. unpublished). Fuel price was about 0.17 US$ per litre, one of the lowest in the world.

4.2 Improved and socially adapted technology

Sorghum and millet are the traditional crops in the NGS, while in the past, maize was grown in the compound. However, the IITA improved maize variety, TZB, released in the 1970s — which is well adapted to the ecological conditions of the NGS and met the consumer's requirements (white color and floury) — was rapidly adopted throughout the entire region.

4.3 Availability of inputs

The agricultural development projects (ADPs), strengthened by a World Bank funded project in the 1970s, greatly contributed to the expansion of the new maize variety. The ADPs convey an extension message to farmers in the form of a package that includes, in the case of maize, the improved variety, subsidized fertilizer and technical advice (Kaduna State ADP 1989). Despite the recent decline in the ADPs activities owing to the end of the World Bank funded project and the removal of fertilizer subsidies, maize has remained the most important food and cash crop in Katsina-Kaduna states (Kaduna State ADP). Private maize seed companies, such as Pioneer have been established in the area, and private fertilizer markets have sprung up, thus sustaining the regional maize production system.

These factors, in interaction with each other, constitute the determinants of change in Katsina-Kaduna states. By contrast, changes in Bauchi State were mainly driven by increased population density.

5. Market Versus Population-driven Forces for Agricultural Intensification

Two evolutionary pathways of agricultural intensification can be easily distinguished:

a. a population-driven pathway in which increase in population density is the main driving force for the evolution of the production system; and changes in production systems in Katsina and Kaduna States before the dramatic changes of the late 1970s and early 1980s are examples of population-driven changes. This still exists in many parts of Bauchi State
b. a market-driven pathway in which improved market opportunity is the main force behind the process of agricultural intensification, as in Katsina-Kaduna States.

Intensification induced by an increase in population density is well described by Boserup (1965) and by many other authors (Binswanger and McIntire 1987). According to these authors, the first step in this type of change is extensification, i.e., increasing the area under cultivation. When the land frontier is reached, the increased demand for land induces a reduction in fallow period. The changes first affect the proportion in which factors are combined, and thereafter, there are changes in technology as the productivity of different inputs changes.

Improved access to markets can also induce intensification (Binswanger and McIntire 1987). When market access improves, farmers have an incentive to increase the area under cultivation for cash crop production. Improved access to markets also increases returns to inputs and therefore provides an incentive to apply a higher level of inputs. By reducing marketing margins, improved access to markets increases cash availability, which provides the means to further intensify input use. Thus market-driven intensification changes factor proportions, and facilitates the adoption of land saving, input using technologies more than population-driven intensification.

The technology adds a new dimension to the intensification process. The rate can be substantially quickened if appropriate technologies are made available. However, an increase in the output/input price ratio induced by technology will not be large enough to give the region a comparative advantage in the production of a crop if access to market is poor. If, however, technological advances are accompanied by improved access to markets, the result can be a very dramatic increase in intensification (Smith et al. 1994) as in the Katsina-Kaduna study area. A government policy which subsidizes inputs or establishes a produce marketing board that increases the output/input price ratio, is likely to induce the same effect as technological change. Market access has been shown to influence crop diversification (Doyle Baker personal communication) which may quickly lead to crop specialization if a given crop has comparative advantage among feasible crops within the given zone. Access to markets and the availability of appropriate technology drive the system along the market pathway of intensification. Access to markets is a precondition, while the availability of an appropriate technology is a sufficient condition for a market-driven evolutionary pathway of intensification to occur.

6. Derivation of the Framework to Characterize the Dynamics of the Production Systems

Population versus market-driven systems constitute two broad categories of agricultural systems which affect the evolutionary process of agricultural intensification. Within each broad category, a distinction is made between intensification phases. The expansion phase occurs at low levels of land use intensity, in which farmers expand their production by opening up new land. When the land frontier is reached, only poor quality land or excessively distant land is available for further expansion. Thus, farmers move from an extensive to an intensive strategy and the production system enters the intensification phase (fig. 3). Transition from extensive to intensive agriculture is determined by several factors including those listed. Changes lie along a continuum but for analytical purposes, four systems are differentiated:

- Population-driven systems in the land expansion phase (PE) — feeding the family from farming is the *leitmotiv* of production. New land is opened up as population increases.
- Population-driven systems in the land intensification phase (PI) are similar to PE, but the land frontier has been reached and so fallow periods decrease.
- Market-driven systems in the land expansion phase (ME) — farmers have easy access to input and output markets. The level of production is largely determined by marketing opportunities for farm products.
- Market-driven systems in the land intensification phase (MI) are similar to ME, but the land frontier has been reached. Scarce land is of high value and farmers increase their investment in maintenance and the improvement of land productivity.

In summary, the framework characterizing the dynamics of systems stipulates that within a homogeneous bio-physical environment, the changes from extensive to intensive agriculture are mainly driven by either the increase in population density or by both market improved opportunities and the increase in population density.

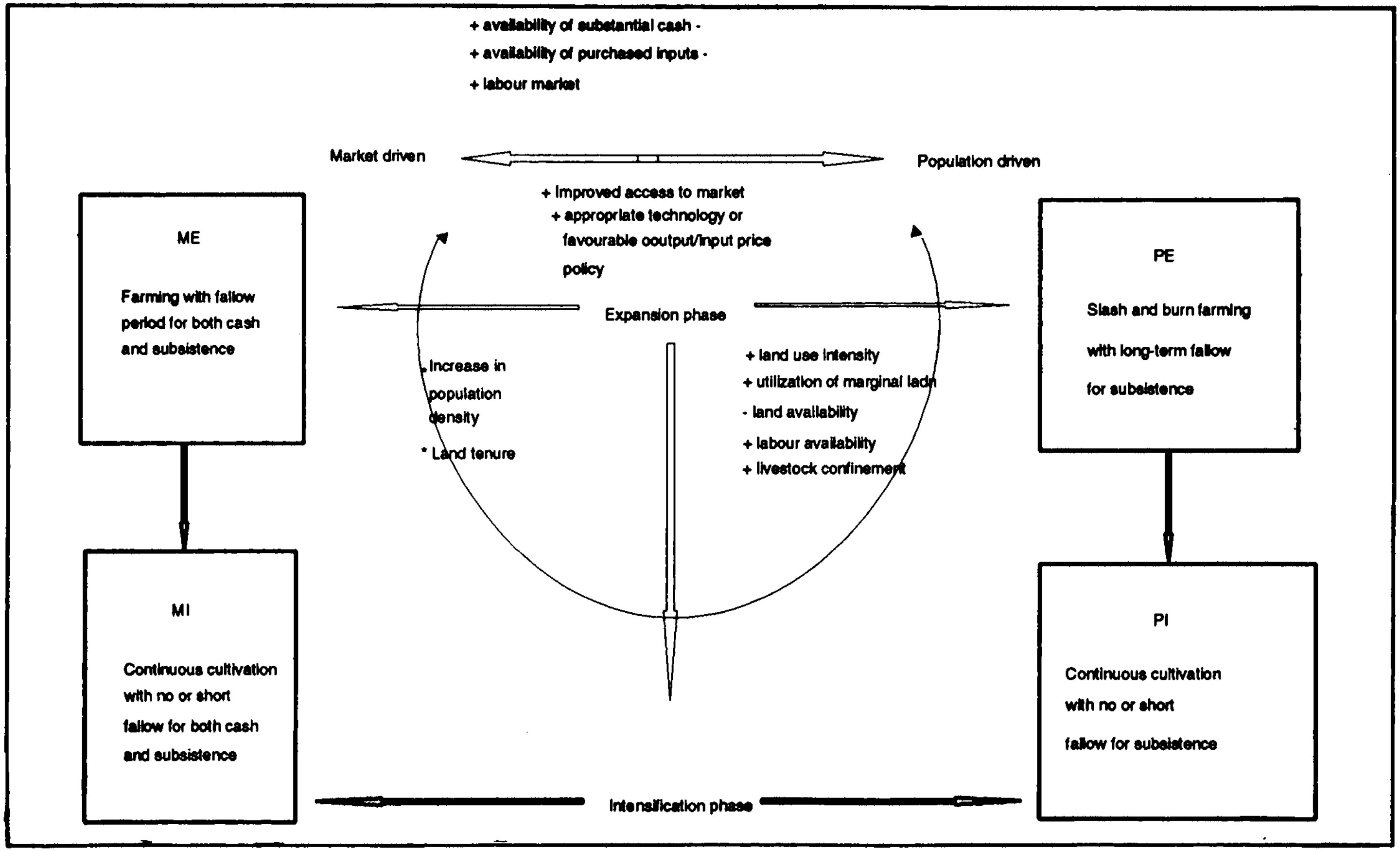

Figure 3. The dynamics of the production systems
Source: Adapted from G. Weber et al. (unpublished)

These two driving forces induce divergent agricultural intensification processes with correspondingly different resource degradation. Therefore, technologies required to address such issues need to take the requirements of the two systems into consideration.

7. Benchmark Sites for Technology Testing

The framework developed in section 6 was used to select benchmark sites for technology testing. Each benchmark site included one or more villages. The first criterion for selection of benchmark sites was the agroecological zone. In this case the northern Guinea savanna (with a growing period of 151 to 180 days) was the focus. Other factors such as population density and market access also influence the adoption of technology (Smith 1992). Population density determines the relative amount of production factors such as land and labor. Market access determines the output/input price ratio.

From a broad characterization of West and Central Africa, based on secondary data, two agricultural systems were identified in the NGS of Nigeria (Manyong et al. unpublished):

a. market-driven systems in the intensification phase represent 48% of the ecozone
b. population-driven systems in the intensification phase occupy 52% of the ecozones

The benchmark villages for the NGS were identified using two different approaches. For the population-driven agricultural system area, the 27 villages surveyed in 1989 constituted the frame for the selection of a first village. The village, Yamrat, is typical of the population-driven system with poor market access and little or no use of improved technology for the lead crops. In the same area, a second village was chosen with better market access, but with little or no use of improved technology for the lead crops, and the third village had poor market access like Yamrat, but lower land-use intensity (expansion phase) and strong outside intervention.

In the market-driven agricultural system area, a satellite image of uplands and inland valleys was used to locate inland valley areas of high potential ultilization in the NGS. Part of the image overlaps with the market-driven area identified through the broad characterization described earlier (Manyong et al. unpublished). One village, Kasuwan-Magani, was chosen as a benchmark site after a rapid survey of five. This village has good market access and strong indications of market-driven intensification. Selected characteristics of Yamrat and Kasuwan-Magani are presented in table 5. The villages are being further characterized as preparations are being made to test on-the-shelf technologies in them.

Table 5. Selected characteristics of the agricultural systems in 2 villages of the NGS of Nigeria

Characteristic	Agricultural systems	
	Population-driven intensification (PI)	Market-driven intensification (MI)
Village	Yamrat	Kasuwan-Magani
State	Bauchi	Kaduna
Access to market	Poor	Good
Lead crop	Maize, sorghum	Maize, sorghum
Purpose of maize cultivation	Food mainly	Cash and food
Niche crop	Millet, cowpea, groundnut	Rice, cowpea, vegetables
Regenerating crop	Groundnut, cowpea, fallow: less important	Less important but soybean, cowpea, groundnut
Fertilizer use	Scarce	Mod-high
Hired labor	Scarce	Abundant
Striga on maize	Very severe[1]	Severe[2]
SOM decline	Very severe	Severe
Soil acidification		Severe
Nitrogen	Severe	Severe/very severe

Remedies:
[1]Forage legumes for crop/livestock farmers, transplanted soybean/cassava in infested land (labor intensive).
[2]Tolerant hybrids, fertilizer soybean rotation or carbofuran for nematodes of maize (input intensive).

8. Technology Testing

8.1 Methodology for technology testing

It is common practice for researchers to ask farmers to test technologies without thorough discussion of their problems and possible solutions. The approach of this study was to discuss production problems and their causes with farmers in group interviews (Boserup 1965), discuss possible solutions to be tested, explain how to test each technology intended to solve the problem, and ask for volunteers.

This approach makes the farmer feel that he/she is part of the research team. Consequently, this ensures appropriate field selection, lessens the probability of trial abandonment, and increases the value of farmer observation/feedback. An important bonus of this approach is that researchers learn about farmers' criteria for judging the performance of a technology. Farmers may even propose other treatments or trial designs.

Farmers who are conducting the same trial are encouraged to interact with each other and with researchers during the growing season and at harvest (Versteeg and Koudokpon 1993). This helps to define the cause of the problem that the technology is meant to address and it also helps researchers to learn about farmers' criteria.

This approach to technology testing is impossible without a dedicated and mobile staff member living in or near the village. The sustainability of the system requires establishing a strong link with the local extension service.

8.2 Agronomic problems and opportunities in different NGS agricultural systems
Clearly, all of the chemical and biotic constraints to cereal production are more severe in intensified cropping systems. Areas with poor market access may have few alternatives for alleviating these constraints, while areas with good market access may have inputs such as fertilizers, fungicides, and even herbicides available. Also, a good market for produce can justify increased hired labor input. Thus, constraints and possible solutions depend on population density and market access: the basic driving forces of agricultural intensification. Technologies must be targeted to different zones based on their requirements for land, labor and purchased inputs (Smith 1992).

In sites with high population density and poor market access, the following technologies can be proposed (Weber et al. unpublished):

a. planting a forage legume for crop livestock farmers who want to avoid conflicts related to animal grazing
b. transplanting sorghum to escape *Striga*
c. planting cassava in *Striga* infested land

Striga is not a problem where land is allowed to lie fallow for at least as long as it is cropped. Thus it is not a severe constraint during the expansion phase. In intensified systems, frequent long cycle sorghum cropping increases *Striga* infestation. Maize may also promote increased *Striga* density if it is not weeded. Intensive management of maize, i.e., frequent weeding and remolding of ridges can reduce *Striga* incidence. Thus *Striga* might be expected to be more severe in population-driven than in market-driven intensification, as was found during the field monitoring study.

The proposed technologies often require additional labor. Fortunately, this is a production factor which should be available in a PI system. Labor-intensive technologies are being adopted in similar conditions. For example, *Mucuna* planted fallows are being used to improve soil fertility and control *Imperata cylindrica* in southern Benin (Versteeg and Koudokpon 1993). Alley cropping is also more likely to be adopted where labor is available and land is scarce (Smith 1992).

In sites with good market access, input requirements may be easily satisfied. Technologies with potential include; (i) hybrid maize with N fertilization, (ii) good quality seed and fungicide for Fusarium on maize, (iii) soybean rotation or carbofuran for nematode suppression on maize.

Since inland valleys are more likely to be utilized in either high population density areas or areas with good market access, improved rice varieties could be introduced as well as other crops for the dry season.

9. Summary

Characterization studies carried out in the northern Guinea savanna of Nigeria showed a divergent evolutionary path of production systems over time and space. This evolution was a result of an interaction between internal factors such as increase in population density and exogeneous factors such as improved access to markets, availability of a good technology and favorable government policy. These factors were responsible for the dramatic changes in food production in this NGS ecozone. A framework was derived to characterize the dynamics of the production system and it was used to select the benchmark sites for technology testing. For each benchmark site, multiple villages were used to assess differences in socio-economic characteristics of the systems.

Within a select village, technology testing started with a thorough discussion with the farmers on: agronomic production problems and the causes; the opportunities for addressing the problem; possible solutions; and the responsibilities of partners during field activities. This participatory approach made voluntary farmers feel part of the research and ensured their full involvement in the process of technology testing. Since the incidence of agronomic problems changes according to the type of agricultural system, the technology required for technology testing within a homogeneous bio-physical environment should be determined by the relative scarcity of the production factors and also by the output/input price ratio.

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METHODS FOR TECHNOLOGY TRANSFER FOR AGRICULTURAL DEVELOPMENT IN SUB-SAHARAN AFRICA

R.A. Yates
World Bank, Washington

Key words: Technology transfer, research and development, environmental degradation

Abstract: Increasing agricultural productivity in sub-Saharan Africa is feasible in most countries. However, it requires an enabling environment and continued generation and dissemination of improved technology. Research and development establishments must operate cost effectively by making full use of the capacities of the component groups (research, extension and farmers).

Considerable quantities of technical data, which cannot be ignored, are already 'on the shelf' for final adaptive testing and to guide new applied research. Research should be forward looking and not limited to immediate problems of farmers. Often, the adoption of improved technologies by farmers is dependent on their ability to understand the technology, its attractiveness and their access to the necessary inputs. Imposition of technologies is used mainly for practices which will be of long-term benefit to the community as a whole, rather than those which benefit the individual farmer. The sustainability of imposed technology requires the continuation of coercion, supported by some form of subsidy.

1. Introduction

1.1 The need for technology

The agricultural growth rate of sub-Saharan Africa (SSA) has failed to keep pace with the 3% rate of increase in population (table 1). Still less does it promise to meet the minimum 4% rate of increase in production required to provide a stimulus for economic development (World Bank 1989). Nevertheless, a closer examination of the data (Cleaver 1993) shows that the target is feasible. Table 2 lists six countries, which represent 40% of Africa's population, where agricultural production has equalled or exceeded population growth. Most of these six countries have reasonable climates and low population pressure (table 3). These conditions are not uncommon in SSA, so it should be possible for other countries (e.g., Zambia) to match these higher rates of growth of agricultural production. Countries which do have serious problems are the drought-prone Sahelian countries, and those with very high population pressure. Amongst the Sahelian countries, Chad (which features in table 2) is unusual in that it has exceptional irrigation potential. Nigeria is densely populated, but its problems are relatively minor compared to those of Rwanda.

Table 1. Average annual growth rate of agricultural production and population (% per annum) (Cleaver 1993)

	1965-73	1974-80	1981-85	1986-89	1990	1991
Agricultural production						
Sub-Saharan Africa (excluding S. Africa)	2.2	1.0	0.6	2.4	1.8	2.1
Sub-Saharan Africa (excluding Nigeria*)	2.1	2.1	0.2	1.9	1.1	1.0
	1965-80			1981-90		
Population						
Sub-Saharan Africa (excluding S. Africa)	2.7			3.1		

Note: *Represents almost 40% of the total agricultural production of SSA (not including South Africa)

Table 2. Individual rates of growth (% per annum) of agricultural production and population (Cleaver 1993, World Bank 1993)

Country*	Population growth rate		Agricultural growth rate		
Year	1991	1965-91	1986-89	1990	1991
Chad	5.8	2.2	6.1	8.9	20.0
Nigeria	99.0	3.0	4.3	4.1	5.0
Uganda	16.9	2.7	6.0	3.4	2.9
Kenya	25.0	3.8	4.3	3.5	-0.7
Tanzania	25.2	3.0	4.5	2.9	-
Burkina Faso	9.3	2.3	3.1	-3.4	4.7

Note: Countries with population of less than 5 million have not been included.

Much of the increased production in recent years can be attributed to the expansion of area under cultivation. In addition, yields of major crops have increased in many countries — yields of both cereals and root crops are reported to have increased in about twice as many countries as those that reported decreases over the 20-year period 1964-66 to 1984-86.

The need for yield-enhancing technologies is self-evident. During the 25 year period 1965-1990, the total population of the area doubled, and arable land area per capita decreased from 0.5 to 0.29 ha, in spite of an increase in the land area brought under cultivation. During the decade 1977/79 to 1987/89, there was a 4.4% increase, mainly at the expense of forest. Much of the intensification of production has been due to a reduction of the fallow period under traditional shifting cultivation systems (World Resources Institute et al. 1992, Stifel 1990). These changes are leading to soil degradation — the Global Assessment of Soil Degradation (GLASOD) project estimated that 71% of Africa's arable land and 31% of its pasture land has already been degraded (Oldeman et al. 1991). Some of the yield enhancing technologies available are destructive to the environment; others are not appropriate for use by peasant farmers; and many are of a temporary nature (e.g., varietal resistance to pests and diseases). It is essential, therefore, that additional appropriate technologies are continuously developed, popularized and implemented, both to increase unit yields, and to prevent environmental degradation

1.2 Constraints other than the development of technology

In addition to the availability of technology, numerous factors constrain the improvement of agricultural productivity. Cleaver (1993) provides an in-depth evaluation of these problems under five main headings: the policy environment, technological advancement, farmers' participation and empowerment, infrastructure, and natural resource conservation. These matters are not discussed in this paper, largely because researchers and extension workers can have little direct influence on their resolution.

2. Duties of the Research and Development (R & D) Establishment

In order to undertake its task efficiently, it is essential that each section of the R & D establishment has a clear understanding of its own responsibilities, and that it appreciates the capabilities and limitations of each of the other participants. Although research and extension workers have little direct influence on policy issues, they must be aware of the problems, and adapt their approach as appropriate. At the grassroots level, for example, farmers will not produce in excess of their personal needs if no market exists for excess production, or if there is no transport to take their products goods to the markets. The appropriate response for the researcher might be to promote another product. Similarly, farmers cannot adopt technology if the inputs required cannot be obtained, either because they are not available, or because the farmer has insufficient funds. For example, in a recent study in Kenya (Bindlish and Evenson 1993), more than two-thirds of the farmers in the sample survey stated that the lack of funds constrained their use of fertilizer. Here, the researcher must search for an alternative which the farmer can obtain, and can afford.

In brief, the direct responsibility of the R & D establishment is the production and dissemination of *appropriate* technology. This it must do at reasonable cost.

Table 3. Population and climatic characteristics of selected countries (Cleaver 1993, Pieri 1989)

	Population per sq. km arable land	Population % growth rate	Climate range
Chad	10	2.2	Desert to very drought susceptible
Zambia	21	3.3	Mainly very drought susceptible
Tanzania	55	3.0	Mainly very drought susceptible
Kenya	56	3.8	From marginal for farming to humid, and humid high-elevation farming.
Burkina Faso	65	2.3	Mainly very drought susceptible
Nigeria	129	3.0	From very drought susceptible to humid
Uganda	157	2.7	Mainly moderately susceptible to drought
Burundi	219	2.2	Mainly humid high-elevation farming
Rwanda	387	3.2	Mainly humid high-elevation farming

2.1 Production of technology

Researchers are responsible for ensuring that the technologies proposed are appropriate for the clientele (the farmers), that the farmers understand and appreciate them, and that they are convinced that the technologies will give them an attractive return. To achieve this, researchers must clearly comprehend the problems of farmers - but they must realize that the *farmer* is not some immutable stereotype. To quote the *Introduction* to the IITA Annual Report for 1987/88:

> [Our main clients are] the resource-poor farmers [who] require technologies that optimize productivity from low levels of purchased inputs, consistent with the requirements of sustainability; varieties resistant to diseases and insect pests and tolerant of adverse environmental factors; biological approaches that reduce the dependance on chemicals and that work with nature to solve farmers' problems; and management practices that save labor and raise productivity. [However, we must] also focus on . . . more advanced farm families who . . . can adopt improved technologies that will become the driving forces for change in Africa.

Table 4 attempts to condense into one page the full range of impact points of research. Basically, they comprise analysis of the environments (physical and socio-economic); development of genotypes better suited to those environments; control of pests and diseases (preferably through the use of some biological control mechanism, especially genetic resistance); and development of sustainable farming systems which are economically attractive to the client farmers.

Table 4. Agricultural research — Potential outputs

Economic and socio-economic environment	Understanding farmer motivation Long-term national/regional economic objectives Evaluation of research proposals and results	
Physical environment	Climate Soils and topography	
Plant genetic improvement	To obtain:	The desired edaphic adaptation Acceptability (social, edibility, storability) Pest/disease resistance
	For:	Food crops (cereals, grain legumes, roots, fruits) Industrial crops (beverage crops; oil palm, sugar, etc.) Pasture and other browse spp. (grass, legumes, trees) Trees (construction, fuel, shade, special purpose)
Animal genetic improvement	To obtain:	The desired climatic and social adaptation Acceptability (social, socio-economic) Pest/disease resistance
	For:	Draft animals Large ruminants (meat, milk) Small ruminants (meat, milk, wool) Other stock (mainly pigs, poultry)
Plant protection and animal health	Epidemiology (insects, diseases, parasites, nematodes) Control (chemical, biological, integrated pest management)	
Farming practices	Tillage systems (including minimum tillage) Plant nutrition (including low-input farming) Animal husbandry (grazing/other, fodder value, seasonal variability, feed mixes/supplements, housing, integrated crop with livestock farming systems) Soil, soil fertility and water conservation (sustainable farming systems, environmental protection)	

Researchers must guard against repetitive and pointless work; for example, they must appreciate that the labor constraints faced by all peasant farmers, and especially by women, will not be resolved by yet another trial which demonstrates that early planting gives better yields.

2.2 Cost efficiency

Research and extension in SSA is heavily dependant on donor-funding. A recent analysis of 23 major World Bank supported research projects revealed that only 40%

of the total investment (of more than $2 billion) was provided by the national treasuries. The net contribution of national treasuries approaches only about 20% when the suppoıt from other donors is taken into account. Maximum cost-efficiency must be achieved if research is to become sustainable. There are two main aspects that must be considered: the size of the research establishment, and the maximum use of available technology.

With respect to the *size of the research establishment*, it needs to be remembered that farmers are themselves researchers, that they will continue to make their own independent evaluations of new techniques, and that the R & D team need go no further than demonstrate that certain techniques justify this final evaluation. With this in mind, it is necessary to ask whether the massive increase in the research establishment over the last quarter-century has been necessary.

International Services for National Agricultural Researach (ISNAR) data (Pardey and Rosenboon 1989) from eight research systems familiar to the author, as shown in table 5, indicate a three-fold increase in professional staff over a period of two decades. Eicher (1989), using an earlier base date (1960) found that ten-fold staff increases were normal. There have been equivalent increases in infrastructure and other facilities.

Table 5. Number of professional staff in research establishments

	1965-69	mid-1980s
Malawi	26	92
Zambia	43	153
Burundi	14	57
Rwanda	7	43
Uganda	89	185
Sudan	52	248
Cameroon	81	245
Nigeria	306	986
Total	618	2009

The trend towards complex organizations for on-farm research (see section 4) has obvious implications for the demand for additional staff; close cooperation with extension is the obvious avenue for improving efficiency in the use of resources.

2.3 'On-the-shelf' technology

There is a great deal of accumulated data on most of the subjects listed in Table 4. In particular, there is a vast — but largely unused — bank of information relating to the conservation of soil and soil fertility (Yates and Kiss 1993), items which are of very special interest to the intensification of production and the protection of the environment.

Crop research in SSA started before the end of the 19th century — for example, in Nigeria, a botanical garden was set up in Lagos in 1893, and research at Moore Plantation started in 1899. In England, Rothamstead and Kew provided invaluable support to research for the whole of Anglophone Africa in the first half of the 20th century. The impressive presence of the Institut National d'Etudes Agronomique du Congo Belge (INEAC) in what is now Zaire, Rwanda and Burundi developed technology which is still of great value; for example, their upland rice variety OS 6 is still widely grown in West Africa (under many local names), and their work on oil palm was the basis of developments in Côte d'Ivoire. The various French research organizations, consolidated under the Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) since 1984, have made immense contributions to agriculture in Africa in at least the last four decades. Much of the earlier research is criticized because it concentrated excessively on *plantation* or *industrial* crops. There is some truth in this, but the criticisms are exaggerated (Eicher 1990). Though there was very little formal socio-economic research in pre-war years, the officers of the various administrative services usually had an in-depth knowledge of social, economic and cultural conditions; and the very numerous land resource studies of the '60s and '70s included detailed coverage of land-use and socio-economic factors (Young and Brown 1962, Mansfield 1975).

3. Methods of Technology Transfer

Technology may be transferred through authoritarian imposition on the farming community, or it may be adopted voluntarily. Voluntary adoption depends on effective methods of demonstration; it may be rapid, or relatively slow, through farmers gradually emulating the ideas of others. Unfortunately, there are also many examples of non-adoption — or discontinuation — of apparently attractive technologies.

3.1 Authoritarian

This is perhaps the quickest method of implementing technology, but it is often not permanent — once the coercion is relaxed, the practice tends to be discontinued. Typically, the practices are imposed because they are very important to society as a whole, but they may not have an immediate effect on the profit of individual farmers. For some reason or other, these practices do not seem to receive sufficient attention from extension services. The following examples relate to the conservation of soils and soil fertility; similar examples are common for the control of pests and diseases, especially in the field of animal health.

One excellent technology is the planting of Vetiver grass to control erosion. This technology was imposed by the Belgians on farmers in Rwanda and Burundi, and has been notably successful in the Prefectures of Gikongoro, Butare and Nyabisindo of Rwanda. But the use of Vetiver has never spread, not even, for example, to exactly similar terrain at Kayanza in Burundi, only some 40 km to the south. Worse still, the established Vetiver hedges are being allowed to deteriorate. Expensive terracing is being imposed by the present Government of Rwanda; one wonders whether it will be better maintained. Another example, currently very successful, of the adoption of a valuable technology depends on the personal authority of the President of Malawi. The President still makes an annual crop inspection tour; he insists on contour ridging, so virtually the whole country has contour ridging. In parts of W Africa, similar authority is exercised by the elders of villages in defining the cultivation cycle for the lands held under customary tenure; for example, in the vicinity of Jebba, Kwara State, Nigeria, the elders decide which part of the bush fallow should next be used under the slash and burn system.

3.2 Voluntary adoption

Two examples are drawn from Cameroon. The first is from near Bambui, NW Province, where one locality was notable for the outstanding quality of the (dominant) maize crop. The crop was grown in straight lines on well-formed ridges, and there was very little of the mixed cropping that was so common elsewhere in the region. Enquiries produced the explanation that the men had discovered that maize was a more profitable cash crop than coffee, so they had displaced the women from its culture, had introduced oxen for cultivation, and had applied fertilizer. In other words, they had adapted and adopted readily-available technology in response to a market signal. The second example was seen at Ngaoundere. An *adaptive researcher* proudly demonstrated his multiplication plots of new varieties of cassava, but was most annoyed that he could not show us similar plots for sweet potato because the farmers had stolen all of the haulms; he later pointed to tubers of this new variety being sold *illegally* in the market. Very simply, the farmers liked and wanted — and took the sweet potato, but not the cassava. The INEAC upland rice variety, OS 6 provides a similar example: it spread slowly throughout West Africa under a variety of local names, and remains, after many years, the major upland variety of the region.

More complex is the case of hybrid maize in Malawi: the earlier hybrids were excellent, but they did not have the flint grain required by the small farmers. Once flint hybrids were released, even the farmers in the poorest region (Blantyre, where 36% of households are headed by women) adopted the expensive technology of hybrid plus fertilizer. Table 6 gives some key data for two seasons; the severe drought nullified equivalent data for 1991/92, and the results for 1992/93 were distorted by the distribution of free seed of whatever variety that was available.

Table 6. Malawi, Maize: Farmer adoption characteristics in three ADD's

	Blantyre		Kasungu		Mzuzu	
	1989/90	1990/91	1989/90	1990/91	1989/90	1990/91
Farm size (ha)	0.8		1.4		1.5	
% in fallow	1		6		8	
% in maize	96	98	82	70	83	81
% in hybrid	6	11	13	23	22	19
% farmers using fert. on hybrid	71	93	97	96	97	100
Yields (t/ha)						
local, not fert.	0.7	0.8	0.9	1.2	0.6	0.9
local, fertilized	1.2	1.4	1.4	1.6	1.2	1.6
hybrid, fertilized	2.2	3.1	3.0	2.7	2.9	3.6

3.3 Emulation

The most pervasive form of the spread of new technology is through farmers copying techniques adopted successfully by their neighbors. Zambia provides an excellent example on a large-scale of the *trickle-down* of technology from large commercial farmers. Three major farm categories are defined by Government:

	Size (ha)	% cropped Area	% Farming families
Commercial	> 20	22	1
Emerging	5 - 20	17	9
Traditional	< 5	61	90

The main difference between the commercial and emerging farmers is that the larger farmers use tractors, whilst many emergent farmers rely on oxen; both use new varieties and fertilizer. Traditional farmers rely on hoe cultivation and use little fertilizer. Average yields of maize are of the order of 0.75 t/ha, 2.5 t/ha, and 6 t/ha for the traditional, emergent and commercial farmers, respectively (K McPhillips personal communication). Commercial and emergent farmers co-exist where access to markets is good; traditional farmers continue with their systems only in more remote locations.

The analysis in a recent detailed study of the impact of extension in Burkina Faso (Bindlish et al. 1993) 'tends to confirm that the effect of T & V is not confined to T & V contact group members, but extends to other farmers'; the contact group members are more likely to be large farmers, usually full-time and often of a younger age group; farm size and education levels were positively linked to awareness, testing and adoption of new technologies. A similar study in Kenya (Bindlish and Evenson 1993) specifically examined the spread of information from farmer to farmer: although 48% of all farmers reported that they had received advice direct from extension workers, two thirds said that they had learnt of the new techniques from other farmers. In addition, the Kenya study found that the rate of adoption of any technology depends on the farmers' comprehension of it, on his ability to purchase any inputs required, and on his assessment of the profit to be derived from implementing that technology. The uptakes of seven important practices were evaluated. Three items (spacing, timely planting and improved cultivars) were adopted by the majority of farmers, both men and women: they are easily understood and require little investment. One item (basal fertilizer) was widely adopted by men, but much less so by women: it was easy to understand, but required cash. Practices which are more difficult to evaluate and require cash (top-dressing with fertilizer and, especially, plant protection with chemicals and borer-control) are much less popular.

3.4 Failure to adopt

Researchers should realize that, if their technology is not adopted by farmers, then perhaps they, the researchers, have failed to understand the needs of those farmers.

Examples of failures to emulate good practices are common. In crowded countries such as Malawi, very large differences between adjacent peasant farms are easy to find — differences that often exceed the responses demonstrated in adaptive research trials. Many can be attributed to human limitations: for example, when the farmer's sole implement is a hoe, especially if the farmer is a woman and head of the household working without assistance, it is difficult to plant the whole farm at the beginning of the rains; or, if a field is abandoned to weeds after it has been planted, the most obvious explanation is that she, or one of her children, fell ill at a critical time. The impact of serious diseases such as AIDS cannot be ignored. Also common is the failure of farmers to emulate excellent farming systems used at prison farms — those at Ifakara (Kilombero valley, Tanzania) and Butare (Rwanda) come to mind as excellent demonstrations of sound farming techniques. Again, the explanation is probably the different levels of availability of labor.

Numerous examples can also be cited of the refusal of the farming population to adopt apparently attractive technology: as mentioned above, the adoption of hybrid maize in Malawi occurred only after flint varieties were released; and the cassava varieties being extended in Cameroon were not being taken up. Short-strawed varieties of sorghum have not been popular in Malawi and Cameroon; and the determinate varieties of cowpea have not proved popular with livestock owners in the Sahel.

Table 7. Percentage of farmers adopting practices by farm size and sex of household head (Bindlish and Evenson 1993)

	Spacing	Planting	Varieties	Basal fert.	Top dressing	Chemicals	Borer control
Small	68	73	70	50	21	9	9
Medium	74	79	77	79	29	12	12
Large	71	79	80	71	11	10	13
Male	75	78	75	75	25	10	11
Female	65	73	73	44	18	11	10

4. Forms of Verification and Demonstration

Effective verification and demonstration are fundamental to the voluntary transfer of technology. Where the technology fits the requirements of the farmer, and is effectively demonstrated, then adoption will take place. If it is not adopted, then the researcher and extension worker should confirm that they have correctly understood the problems of the farmer, and that they have properly verified and demonstrated their proposals.

These tasks must be accomplished at reasonable cost. In recent years, much effort has been expended in the development of methodologies to improve the transfer of technology (a two-way transfer inclusive of obtaining feed-back from the farmers). The methods developed were expensive, have often given disappointing results, and are falling out of favor with many donors; some major donors have withdrawn, or are expecting to withdraw their support in view of generally negative evaluations after about a decade of operation. There are four main reasons for the adverse evaluations: the output from the farming systems research (FSR) teams has been disappointing; the cost has been very high; in many countries, it has proved impossible to retain good quality national staff; and there is a tendency for FSR groups to work as separate enclaves, without sufficient cooperation with farmers, extension and research departments — indeed, FSR teams are frequently blamed for forming a barrier between researchers and farmers, rather than a bridge (see, for example, the recent evaluations by World Bank personnel in Venkatesan and Schwartz 1992). The trend today is to accept that effective and cost-efficient R & D must depend on researchers maintaining contact with farmers, and on the improvement of research-extension cooperation. Nigeria is the only example known to the writer in the publicly-funded[1] research sector in Africa where this latter approach has been in operation for sufficiently long to allow some evaluation of its degree of success.

[1] The integration of research and extension, and thus direct researcher-farmer linkages are normal in the private sector.

4.1 Farming systems research

There is unanimity in agreeing that researchers must understand the motivation of farmers, and it seems self-evident that a researcher can understand the farmer only if he regularly visits and communicates with him. To quote Coulter (1989):

> The involvement of farmers at an early stage . . . is an excellent way of preventing expenditure of time and money on technology that has no chance of acceptance . . . An understanding of how farmers perceive benefits must be an essential part of research.

However:

> the idea of cooperative research with farmers has engendered extreme enthusiasm to the extent that some would regard farmers as the main source of ideas for new technologies and that research scientists have a subordinate role . . . It must be recognized that, however important today's problems are for farmers, researchers must also try to define and answer tomorrow's problems. IRRI's rice research would not have made the impact it did, had it looked entirely at today's problems; short-strawed, nitrogen responsive varieties would not have been identified by farmers as a high priority.

Similarly, the staple starchy foods of Africa (maize and cassava) did not begin to be cultivated in Africa because the farmers demanded them; without doubt, research should today broaden its perspective and promote (along with other fruit trees) bread-fruit and jack-fruit, the starchy staples of other countries which are far less likely to fail because of drought or flood.

In the early 1980s, great faith was placed in what was originally called 'farming systems research'. Various donors modified the detail of the methodology, but the essentials — the use of multi-disciplinary teams to identify the constraints of the farmer, and to adapt technology to the needs of each individual group — remained unchanged. Multi-disciplinary teams proliferated through most of Africa under names such as OFAR (on-farm adaptive research) in Nigeria, ART or ARPT (adaptive research/planning teams) in Malawi and Zambia, EMSP (Etude du Milieu et Systemes de Production) in Rwanda, Ateliers in Burundi, and, of course, FSR in Cameroon and elsewhere. Simmonds (1991) suggests that individual researchers should adopt a farming systems perspective, rather than rely on complex, multi-disciplinary teams; this solution would certainly reduce costs and, in the view of the writer, would be more effective. The basic concepts have been further developed in some instances. For example, the Village Test Program at Tcholelovogo in northern Côte d'Ivoire is a participative R & D program financed by the extension services but led by the R & D unit of the research service (Institut des Savanes—IDESSA), supervised by two full-time IDESSA staff, and operated in conjunction with technical experts from other ministries. It embraces components ranging from statistically analyzable trials to large-scale demonstrations on soil and water conservation, and the installation of wood-lots. There are few replicates. Dutch financed R & D work in Zambia follows a similar intensive approach — but again (because of the high unit cost) at few sites. In Ghana, then in Togo, the concept of farmer participation was developed further through the use of confidential ballots — so that meetings with farmers would not be excessively influenced by a few dominant personalities.

4.2 The Nigerian experience

The research-extension-farmer liaison system operating in Nigeria is the largest and most highly developed in Africa; it is the major component of the ADP (Agricultural Development Project) system, which covers the whole country. The ADP system is an asset which has been built up over a long time (since 1974) at considerable cost (about US$ 1.2 billion). They started as enclave IRDP projects which relied excessively on expatriate management and have developed to state-wide projects (in all 30 states) which concentrate almost exclusively on the development and delivery of technical messages to the farming community and which rely almost entirely on nationals for their management. The extension services touch an estimated six to seven million farm families (comprising about 80% of the rural population) where, as a result of their efforts, there has been widespread (80%) acceptance of an improved cassava-maize inter-cropping technique, 35% adoption of the use of mini-setts for planting yams, 25% adoption of improved upland rice varieties, and 20% adoption of rabbit rearing. Yet, evolution of the system is not complete; in particular, it is accepted that on-farm adaptive research is still relatively undeveloped and needs to be built up (Singh and Joyce 1994). The adaptive research component includes the formation, in each of five regional research institutes which were selected to represent the five major agro-ecological zones, special farming systems research (FSR) groups which liaise through monthly technology review meetings with the subject matter specialists of each ADP. The resource persons in the FSR teams comprise experts from local universities and other institutions, in addition to the members of the institute responsible for FSR in that region. Linkages continue with the front-line extension staff through the standard fortnightly training sessions and technical *messages* are passed down the line, and feedback obtained. The program of on-farm trials is planned and reviewed in annual workshops held at each regional center with occasional national workshops to reinforce the regional workshops. The off-station trials are implemented through the cooperative efforts of the FSR team and the extension staff. The system has proved effective in verifying and popularizing available technologies that have proved to be appropriate (such as those mentioned above), but it has not succeeded in tackling more complex, longer-term issues such as soil fertility conservation; it has integrated the efforts of the FSR researchers into the real world of practical farming, but has had little effect on the bulk of institute-bound researchers.

4.3 Improving research-extension-farmer linkages

The researcher must visit the fields of the farmer, and the farmer must visit the experiment station; the extension worker, with his responsibility for acting as a bridge, must be in both camps. This basic concept can be sub-divided into five distinct components which are currently being adapted to the specific requirements of individual countries during the preparation of World Bank projects. These concepts build on the Nigerian OFAR experience, with items (b) and (d) making significant additions.

a. Representative researchers participate in regularly scheduled extension meetings, to help in defining technical messages, to receive *feed-back*, and to commence arrangements for on-farm trials.
b. On-farm trials are an integral part of the work of all researchers (*all* researchers, not just the FSR researchers) in which all interested persons — researchers, extension workers and farmers participate; they include complex *researcher-managed* trials, more simple *extension-managed* trials, and *farmer-managed* demonstrations.
c. Work at research stations is opened to the examination and comment of farmers and extension workers at least once per year.
d. The totality of the research program (not just the OFAR program) is subjected to joint evaluation and planning by national economic planners, researchers, extension workers, and farmers.
e. Adequate reporting is essential. Publications must be produced regularly and promptly. They will include (amongst others): annual research reports suitable for senior extension personnel, and regular revisions of extension leaflets.

Maximum improvement of research-extension cooperation requires both the informal desire to cooperate, and formal agreements. For example, research and extension technicians in Burundi cooperated enthusiastically; but formal agreements were also required, as only in this way could the extension staff justify to their supervisors the time spent on, and the expenses of, their research.

4.4 Technical and financial discipline

A recent World Bank workshop (Venkatesan and Schwartz 1992) discussed at length the use of budgetary control systems to ensure that research is properly directed. The Workshop concluded that extension should handle the budget for OFAR trials, and research should hold the budget for all other trials. Concern was expressed, however, that researchers would spend a disproportionate amount of resources on single-commodity research, and neglect research on agricultural practices (such as mixed cropping). It was argued (but not agreed) that extension should control some of the research budget, and so *force* research to undertake such work.

In the opinion of the present writer, strict budgetary control is essential — but not in the form discussed at the workshop. It must take its place alongside other aspects of the re-introduction of discipline into the preparation of research proposals, and making researchers accountable for their results. This discipline falls under three headings.

4.4.1 *Concept and justification*

The proposal must be consistent with the national research master plan; it must be fully justified in relation to identified constraints; it must fully take into account the existing knowledge base — within the country, within the region, and elsewhere; and it must be justified on economic grounds in the sense of comparing the complete (see 4.4.3 below) cost of the program with the anticipated benefit at farm level.

4.4.2 *Work-Plan*

The work plan upon which the budget is based must be comprehensive in the sense of covering all stages of the research, from laboratory and on-station research to on-farm trials; it must demonstrate cost-efficient planning through, for example, *sharing* specialist support in multi-disciplinary studies, and through obtaining effective cooperation with other bodies, both up-stream (e.g., with IARCs for the supply of genetic material) and down-stream (e.g., with extension services for on-farm trials); and it must list target numbers of trials of each type (laboratory, green-house, on-station, off-station), and give *verifiable indicators* such as target dates for the release of progeny from a breeding program, or completion dates for the various stages of research on soil fertility.

4.4.3 *Budget estimates*

Budgets must be complete and include, in addition to direct costs related to individual experiments, all costs including total employment costs (salaries for all employees including fringe benefits) and overheads including provision for maintenance and replacements. The total costs of all approved research programs must lie within the expenditure ceiling for the total national agricultural research system, and the component parts must reflect the relative priorities set in the national research master plan.

4.4.4 *National research master (or strategy) plans*

The concept of national research master (or strategy) plans is relatively new: most countries have now prepared such plans but, so far, very little use has been made of them to guide the work of researchers, or to coordinate the activities of donors. The concept of researcher accountability, from laboratory to farm, and for efficient operation, is only now beginning to be accepted in Africa; the first (and still imperfect) steps are currently being implemented in Malawi, Rwanda and Mali. The concept of an overall limit (the ceiling) for total research expenditure is even more recent and, in the experience of the writer, has been the greatest obstacle which delaying the development of effective and efficient research strategies.

4.5 Maximizing cost-efficiency

The limited availability of total funds is well known by everyone engaged in research and extension. But there is little appreciation of the inevitable: the necessity for making maximum use of all available resources — notably of staff and their support services. In the experience of the writer, there is a serious underutilization of the capacity in national staff. Both professional and technical support staff. Professional staff are well trained, but are isolated from others with similar specialties. They need guidance about their priorities and work plans and respond positively to constructive discussion. Technical support staff (research) are, typically, very reliable and carry out their instructions meticulously. Yet many of them could — and wish to — do more; many of them have also never worked with extension staff, nor with farmers, but would like to do so. Similarly, extension staff are usually interested in what happens on the research plots, and respond eagerly to invitations to help.

Finally, the R & D establishment must always keep in mind that the farmer himself is the most committed of all researchers — he has more at stake than any of his salaried partners, and will undertake his own evaluation of all proposed technologies. His techniques may not satisfy the biometrician, but they are valid. Of special importance is the fact that the farmer will undertake the final adaptation of any technology to the innumerable micro-environments. This is not the duty of the research establishment — though the researchers must be satisfied that their technology is sufficiently robust to accept such adaptations.

5. Conclusions

Increasing agricultural productivity in SSA is feasible in most countries, but it will require an appropriate enabling environment plus the continued generation and dissemination of improved technology. The technological aspects are clearly the responsibility of the R & D establishment which, to be sustainable, must operate at a high level of cost efficiency.

To attain cost efficiency, the R & D establishment must first clearly identify the responsibilities of each group of participants (research, extension, and farmer), and ensure that full use is made of their capacities. With respect to the research section, some observers (notably Eicher 1989, 1990) consider that research establishments have already been over-extended: it is clearly difficult to reduce the existing units, but there is much to be said for resisting any further recruitment until the productivity of the researchers is demonstrably improved. The reasonable demands of extension that more research be carried to the farms is one obvious use for surplus resources.

Second, the R & D establishment must make maximum use of existing data. Considerable quantities of technical data are already *on the shelf* for the final *adaptive* stages of research and/or to guide new *applied* research — it is totally unacceptable that such data be ignored. Third, research must be forward-looking, and not limit itself to responding to the immediate problems of the farmer. Unfortunately, these facts have been distorted in recent years, leading to the development of a range of solutions based on unacceptably expensive forms of multi-disciplinarity. Alternative solutions have not been in place for sufficiently long to evaluate their results.

The cost-effective solution now being promoted by the World Bank is to ensure that each researcher spends sufficient time in the field with the farmer, that he cooperates fully with other sections of the R & D establishment (notably his extension colleagues), and that both farmers and extension workers participate in the planning and evaluation of research programs. Also, the *client* (either farmer or extension worker) must avoid making unrealistic demands: notably they must not ask researchers to address each individual, minor variant of a problem, but they must realize that the farmer should carry out the final evaluation of all technologies. The R & D establishment must limit itself to ensuring that it recognizes the problems, that its recommendations are appropriate and properly verified, and effectively demonstrated.

Farmers will voluntarily adopt improved technologies once they are convinced that these practices are beneficial to them. However, it is their livelihood at stake so, even after they have seen convincing demonstrations — either on neighboring farms, or in demonstration plots — they will test them cautiously, using their own research methodology, before adopting them over the whole farm. The rate of adoption will be influenced by the ability of farmers to understand the technology concerned, and by their access to the necessary inputs. Farmers will not adopt technology that they find unattractive, and researchers must carefully re-evaluate all technologies that are rejected: they have probably failed to understand the farmers' problems.

The imposition of technologies by some authoritarian means is used mainly for practices (such as soil conservation and the control of contagious diseases) which will be of long-term benefit to the community as a whole, rather than practices which will immediately benefit the individual farmer; sustainability usually demands the continuation of coercion, supported by some form of subsidy.

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TESTING AND ADOPTION OF TECHNOLOGY: Methods for Coping with Agricultural Diversity in the Moist Savannas of Francophone Africa

Pierre Rebuffel, Yves Bigot and Patrick Bisson[1]

Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)
BP 5035, 34032 Montpellier, France

Key words: agricultural diversity, zoning, typology, cropping system, farming system, francophone sub-Saharan Africa

Abstract: One of the constraints to the creation and diffusion of new technologies in the savanna zones in sub-Saharan Africa is the absence of strong links between effective technologies, geographical setting and the socioeconomic context. The diversity of the agricultural environment has been responsible for the failure of many development schemes as the same technologies cannot be applied across diverse agro-ecological zones. Agronomists in CIRAD have used several methods to handle this diversity. The first part of this presentation covers the major factors in agricultural diversification in sub-Saharan savanna zones. This is followed by a discussion of how diversity is handled at the regional, farm, cropping system and crop management level. The components of diversity have been analyzed and the major variables identified. This analysis has resulted in a categorization into zones where the patterns of diversity can be mapped and typologies, where it cannot be mapped.

1. Introduction

Agricultural innovations with a strong potential for adoption are rare. The success of cotton production with animal traction in sub-humid francophone Africa, has been varied, selective and limited to certain zones and farm categories. The failure of many development schemes and research projects is based on the erroneous idea that technologies can be transferred successfully across various environments.

2. Major Factors in the Agricultural Diversity in the Savanna Zone

Agricultural diversity in the savanna zone in sub-Saharan Africa is related to the physical features (mountain ranges, the basins of large rivers, inland-valleys, etc.) and essentially to differences in the amount and distribution of the rainfall and variability

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[1]Responsibility for the interpretations and any errors or omissions, lies solely with the authors. The views expressed do not necessarily reflect those of CIRAD.

in soil types. This physical diversity is also reflected in the history of human migration patterns. The inequitable distribution of equipment, communication infrastructures, access to markets, credit and agricultural services are factors that can create very strong heterogeneity within short distances. Farms in the same village are far from being homogeneous. The social position of the farmer, the manpower capacity, the age, the motivation and origin of the farmers, the duration of stay by immigrants, the ethnic group, the equipment, the role of animal husbandry, the obligations dictated by customs are all potential factors in differentiation between farms.

The emergence of commercial crops has increased the differentiation according to the farmers' capacity to integrate cash crops into the farming system[2] (Faure 1991). This differentiation was further accentuated by the fact that these new crops were being adopted by the farms that had already accumulated a certain amount of capital and labor, and had acquired, for example, animal traction and motorization (Bigot and Raymond 1991).

In the early 1960s, the agricultural sector in sub-Saharan Africa was strongly supported by national governments, through subsidized inputs, price support, development projects, technical extension, organization of credit and crop collection. The economic downturn since the 1980s, has resulted in the withdrawal of state support and a fall in the prices of some commodities, which has had serious repercussions on farmer production strategies (Yung et al. 1992).

The development of any new technology must take into account the diversity of the agro-ecological environment at the regional and local levels. The development of appropriate technologies for the numerous agroecological farming systems in Africa would be difficult. It is impossible to give individual advice for each farm and to take the case of each field into account. Therefore, regional diversity must be solved for a limited number of *recommendation domains*. The components of these diverse ecozones — crop patterns, soil types, rainfall — should be analyzed in such a way as to identify the major variables to be taken into account to reveal the pattern of organization.

The results of such analyses are *zonings* when the pattern of the diversity factors can be mapped, and *typologies* when it cannot be mapped.

3. Agricultural Zoning

Agricultural zoning results in a cartographic model of the diversity of a region with respect to one or more of the criteria which influence agricultural productivity such as soil, climate, demography and social customs.

[2]Farming system is used here for the French concept of 'système de production'. The farming system is the combination of the factors of production (land, labor, capital) and the enterprises in a farm (Sebillote 1982).

The number of basic criteria used in a zoning operation and the degree of aggregation obtained by combining the criteria chosen, depend on the target problem and the use to be made of the results. The number of categories in a zoning operation should be limited for operational reasons. In fact, the correspondence to administrative units or development zones is often a practical necessity. Data processing tools can be used in the practical elaboration of zoning. In this case it is preferable to talk in terms of the probabilistic definition of agricultural regions. This definition of regions is based on the possibility of occurrence of certain criteria that are increasingly easy to examine as the capacity for the storage and processing of information increases.

It should be remembered that the first step is to choose the variables to be used. However, the larger the number of variables, the greater the possiblity of error, unless sufficiently reliable and significant data are obtained. Obtaining reliable data can be a very expensive activity.

3.1 Zoning of agro-climatic parameters

The potential of any ecosystem in the savanna zone in Africa is closely dependent on rainfall. Even where rainfall is ample, part of the rainwater which reaches the soil may be lost to the crop through evapotranspiration, runoff or erosion. Rainfall, however, is not the sole determinant of crop yield.

In many models of crop yield build-up, transpiration from the crop is clearly related to yield (Jallas 1986). On this basis, CIRAD agro-climatologists have developed methods and software to identify the agro-climatic capabilities of a region.

An evaluation of the duration of the rainy season and water holding capacity of the soil enables the calculation of optimal sowing dates, cycle lengths and the potential yield of crops. The results of those calculations are then mappable.

The method has been applied in Africa on many occasions since the 1970s. It resulted in the zoning of the climatic capability for cereals in Senegal, Mali, Burkina Faso, Niger, Côte d'Ivoire, Togo and Chad (Cretenet 1987). The zoning of agro-climatic capability based on frequential analysis of the terms of the water balance is a valuable technique. Breeders can thereby obtain a map of ideotypes based on the criteria of cycle duration and of the length of developmental stages (Sanogo 1991). Agronomists possess information on the probability of obtaining a certain level of production for a crop or a crop combination.

3.2 The probabilistic approach to agricultural regions from census and statistics

The classification of regions into agro-ecological zones facilitates the siting of regional surveys or experimental facilities and helps to determine the geographical domain of research results.

An anyalsis of this type was implemented in Togo. The criteria chosen were (a) rainfall, (b) population density, (c) the crops grown, (d) the existing outlets for commercial crops (Faure 1990, Kleene 1989).

Soil was not selected as a variable, as it was not proved that the pedological characteristics of land were a major element at the regional level of the current agricultural situation in Togo. Regions were defined using an aggregation of statistical observation units which were defined by the heterogeneity between two units. The use of data analysis methods such as automatic classification facilitates this stage. The number of regions will vary according to the accuracy at which the users wish to work. In the case of Togo, the probabilistic approach to agricultural regions made it possible to make a reasoned choice of survey villages. It showed research sites in a regional context and refined the validity of the results. The results were used to enhance the regionalization of the Société Togolaise du Coton's extension system and to define the stratification of the area prior to socioeconomic surveys.

The probabilistic approach to agricultural regions enables a closer view of the discontinuities that may occur between adjacent units (Faure 1991). This concerns both physical factors and large differences in population densities and the organization of the infrastructure and markets (Sebillotte 1974).

It can be seen, for example, that cotton production is sited in a limited part of the savanna and the boundary is generally well defined. Cotton production is less in zones where population densities are very low or very high; where the markets are limited or in zones which are very dry or very wet. It is extremely interesting to perform chronological comparisons of the same zones. For example, when climatic conditions are favorable, certain crops are observed to spread into former hunting grounds, but later abandoned with drought or changes in soil quality.

4. Taking Non-mappable Factors of Diversity into Account: Typologies

Typology is used for non-mappable representation of diversity using one or more criteria. Themes showing variability for short distances are used. As in the case of zoning, the subjects of typologies can be varied and data analysis methods can be applied.

The first stage in elaboration is the search for discriminatory criteria. The latter must meet conditions of reliability, be relatively inexpensive to collect and be significant. The typologies with most potential for agronomists are those of farms, cropping systems[3] and crop management sequences.[4] In all cases, prior zoning of the

[3] *Cropping system* is used here for the French concept of *système de culture* which is the whole of the cultivation techniques used on a group of identically managed fields. Each cropping system is clearly defined by: (i) the nature of the crops and their order of succession; and (ii) the crop management sequences applied to the different crops, which include the varietal choices (Sebillotte 1982).

study area enables definition of the limits of validity of the typologies. A few examples are given here.

4.1 Farm typologies identified for recommending equipment

The use of animal traction has increased significantly in the past twenty years in certain areas of sub-Saharan Africa. However, the switch to animal traction increases costs, changes crop management sequences, and affects the management of labor and work calendars. Appropriate advice is needed to help farms achieve a new balance and benefit from the new production capacities.

The formulation of advice is based on the identification of groups of farms in terms of production constraints. The most relevant and easily accessible variables are then identified to develop a classification key for use by field advisers (Lendres 1982).

After the positive results from using animal traction in Mali, it appeared beneficial to use the same method to advise farmers concerning the use of motorized equipment for cotton farms in Burkina Faso. Analysis of the data collected over the years on 300 farms was then used to establish a classification based on structure and farming accounts. The categories reflect the technical and economic performances of the farms, their structure and their changes (Faure 1993). These results and previous findings were used to refine the management advice method with regard to both the identification of groups and the formulation of the advice (Forest and Lidon 1984, Schwartz 1985).

4.2 Typologies of fields as a tool for advising on fertilizer use

There is a considerable gap between farmers' practices and the recommmended use of inputs in most of the cotton growing zones in sub-Saharan Africa. It was necessary to obtain more information on farmers' practices in order to understand the problem and maximize the benefits gained from inputs (Pichot et al. 1981).

Experimental studies on the response of cotton to fertilizer application showed that the variability observed can be explained by two factors:

a. physical factors, related to plant water supply, soil, climate and sowing date, formalized with a water supply model
b. factors related to crop management and mainly weed management, sowing date and the crop sequence on the cotton plots (Cretenet 1990)

Soil resource maps and bioclimatic data can be used for soil and climate zoning. However, the diversity of cultivation practices has necessitated the development of

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[4] *Crop management sequence* is used here for the French concept of *itinéraire technique* which is an orderly succession of cultivation techniques applied by the farmer to the plant community, on a given field, in order to reach a given production target (Sebillotte 1974).

methods for establishing typologies of crop management sequences and plot fertility levels.

These methods enable the use of simple criteria to classify cotton fields into three categories:

i. soils with high capability — where the problem is maintenance of fertility
ii. soils with medium capability — where the problem is improvement of fertility
iii. degraded soils — that are abandoned and require regeneration (Faure 1984, Yung et al. 1992)

This criteria was used to develop a typology of scenarios that were subsequently used to set up tables for fertilization advice on a given site, sowing date and weed control. Another table was set up to aid decision-making and to specify expected yields, the corresponding mineral balance, the cost of inputs and the expected gross margin.

Using these tables in the 1984-85 season in Côte d'Ivoire resulted in an estimated saving of 5350 tonnes of fertilizer (worth 770 million CFA francs) and a 1620-tonne increase in national cotton production; taking the benefit of the operation for all growers to nearly a thousand million CFA francs (Cretenet 1990).

4.3 Typologies of cropping systems for environmental preservation

The decrease in land reserves in the savanna zones in sub-Saharan Africa is leading to the expansion of permanent agricultural settlements. This must be accompanied by the implementation of sustainable cropping systems which can protect the environment (Poisson and Doumbia 1987). Optimization of each crop management sequence in a cropping system, in accordance with the objectives set by the farmer, does not necessarily ensure the sustainability of the system. It is necessary to identify the major trends/changes in the cropping systems currently used.

It is possible, through surveys, to draw up typologies of cropping systems using a method similar to that used for classifying crop management sequences (Suzor 1991). The development of a table for appraising cropping system sustainability requires taking into account the dynamics of change in the components of soil fertility on a time-scale that is not compatible with on-farm trials. CIRAD agronomists have set up long-term experiments, taking different types of cropping systems into account, to develop tables for the appraisal of cropping system sustainability and to propose stable alternatives (Pieri 1989, Siband 1972 and Faure 1984).

However, these approaches are limited if they are not situated within the context of the farm so that the strategies used by the producers and other economic actors are taken into account. Strategies that are developed outside the on-farm context may lead farmers to use practices that are incompatible with sustainable management of natural resources (Capillon 1993).

One of the crucial problems encountered in cropping system development involves recognizing the importance of the larger picture in the management of diversity. An approach which starts with general observations and moves to the particular has long been recommended, but has rarely been used. However, such an approach is essential for reaching practical conclusions. Examination of crop management sequences related to the effective use of insecticides, fertilizers and herbicides on cotton is being initiated, beginning with attention being paid to ecozones and farm and cropping system typologies before individual fields. This should help to make methods concerning crop management sequences more operational with regard to achieving practical results.

5. Conclusion

In managing diversity, it is necessary to identify situations which have similar constraints. The zones and typologies which are similar can be grouped together and practical answers can be provided to such questions, as choice of crops, equipment and the use of fertilizer.

Data which are reliable, inexpensive to collect and significant are required for the success of this approach. The degree of significance to be awarded to any variable will then depend on the demonstration of its importance. A field of activity using operational zoning and typology procedures must therefore be complemented by a field research concentrated on the identification of the dynamics that may emerge. These would include all the effects of urban growth and population increase on new activities such as firewood gathering, vegetable growing and small-scale animal husbandry.

This assumes that the institutions interested in diversity should not specialize solely in one commodity. It also assumes that if higher levels of diversity are beneficial, the areas under investigation could be broadened. These two institutional conditions rarely coincide: Research activities in programs with practical objectives do not usually concentrate on a specific commodity; where programs have a sufficient number of independent disciplines, these are seldom coordinated.

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SOCIO-ECONOMIC CONSTRAINTS TO SUSTAINABLE AGRICULTURE IN THE MOIST SAVANNAS OF SUB-SAHARAN AFRICA

N.B. Mijindadi[1], G.O. Olaniyan[2], Eyo Ita[3], S.S. Cheema[1], O.O. Oyebanji[1]

[1]*Federal Agricultural Coordinating Unit (FACU), Abuja, Nigeria*
[2]*National Cereals Research Institute (NCRI), Badegi, Nigeria*
[3]*National Fresh Water Fisheries Research Institute, New Bussa, Nigeria*

Abstract: *The moist savannas of sub-Saharan Africa have the potential to produce surplus food because the growing period in the region is suitable for the growth of annual crops of medium duration. However, the long-term impact of improved farming practices such as the use of agro-chemicals and other intensive cultivation methods can degrade the natural soil resource base. There is, therefore, a need to identify and encourage production methods which enrich the soil.*

This paper identifies some sustainable cropping systems practiced in the moist savanna ecological zones in Nigeria. It also provides brief discussions on the dominant crop mixtures, key cultural practices, production problems and socio-economic constraints experienced by farmers.

Future policy directions that could contribute to sustainable agriculture in the region are suggested.

1. Introduction

When the first set of countries in sub-Saharan Africa (SSA) became newly independent in the late fifties and early sixties, little did the world imagine that after three decades, a large proportion of the nations, and indeed their citizens would be worse off than they were at the time of their political independence.

In 1993, 32 of the 47 nations listed as poor by the United Nations were found on the African continent. The African population growth rate of over 3% continues to out-pace the agricultural growth rate of about 2%. Food imports are increasing at about 7% per annum. The percentage of the population classified as food insecure is over 30% for a number of countries including Chad, Burkina Faso, Central Africa Republic and Zaire. The high degree of degradation of natural resources due to the heavy dependence on wood for both fuel and building combined with the high population growth rate, has resulted in extensive deforestation. For example, sub-Saharan Africa's forest cover estimated at 6.6 million km^2 is disappearing at the rate of 32 thousand km^2 per annum. The need for sustainable agricultural systems in SSA is therefore self evident. There are a number of viewpoints on the sustainability of agriculture. Economists view sustainability from the perspective of ensuring a pricing system that does not create distortions in the markets for agricultural inputs and outputs, or curtail the ability to meet recurrent costs of projects on a sustained basis. Management experts are concerned with how to ensure appropriate institutional and organizational capacities for effective agricultural project implementation over a long period.

The views held by agronomists and other natural scientists relate to the technical aspects; for example, the long-term impact of current farming practices such as agro-chemicals and other intensive cultivation methods which can degrade the environment and the natural resource base. Thus, the concern is to identify and encourage production methods which enrich the natural resource base while at the same time giving rise to high productivity.

A sustainable agricultural system has been defined as one which over the long term enhances environmental quality and the resource base on which agriculture depends; it provides basic human food needs and improves the quality of life of farmers and society as a whole (Kang and Chuman 1991). A critical aspect of the sustainability concept is the ability of the agricultural system, not only to meet prevailing needs, but also to be adaptable enough to meet future needs.

It would be of interest to identify why the moist savannas are important for the attainment of sustainable agriculture. An IITA (1992) publication indicates several reasons:

a. the moist savanna has high levels of insolation — which increase photosynthesis
b. the growing period is well suited to annual crops of medium duration
c. the area has the potential to produce surplus food
d. adoptable technologies in sustainable agriculture are likely to be more easily worked when leguminous crops are included in the cropping systems already established
e. the importance of livestock in the ecologies should facilitate the introduction of crop-livestock systems which tend to be more sustainable than either crop or livestock alone.

The objectives of this paper are to (i) identify some sustainable cropping systems practised in the moist savanna ecological zones; (ii) identify the major socio-economic constraints in the production of the cropping systems; and (iii) suggest some future policy directions that could contribute to a sustainable agricultural system. This paper will draw heavily on Nigerian agricultural experiences and practices.

2. Sustainable Cropping Systems

The moist savanna constitutes the major cereal and legume producing area of Nigeria. The area is also suitable for the production of tuber crops. Besides crop based systems, agricultural production based on livestock or fisheries is also practised.

The crop based systems may have sorghum, maize, rice, yam, or cassava as the major crop. The basic idea is that a legume crop has to be included in any sustainable system because of its ability to enrich the soil. Also, other soil enriching practices must be incorporated into the system. Table 1 summarizes information about common crop based systems which are practiced in the moist savannas. The following cropping systems are common in the MSZ.

2.1 Sorghum-based systems

They are common in the northern Guinea Savanna. Important crop mixtures are: sorghum/groundnut; sorghum/cowpea; sorghum/maize/cowpea; sorghum/millet/cowpea. Where millet is part of the mixture, it is often planted at the onset of the rains before the other crops.

The key production constraints of the sorghum based system are *Striga* infestation and the non-acceptance by farmers of improved sorghum varieties which tend to have short stems and spotted or cream colored grains. They also tend to be more susceptible to attack by birds. Farmers prefer long-stemmed varieties with red grains. With respect to cowpeas, the yields are low because farmers do not use insecticides, and continue to grow late maturing local varieties.

2.2 Maize-based systems

Maize-based systems are prevalent in southern Guinea. The most sustainable crop mixture include maize/cowpea. Maize is usually planted first on the ridges; cowpea is planted six weeks later on either side of the ridges or in the furrows. The maize is harvested around August leaving the cowpeas in the field. Maize production yields are again hindered by the parasitic weed *Striga*. The Institute for Agricultural Research, Samaru, and the National Cereal Research Institute, Badegi, both in Nigeria, have identified some promising lines of maize for *Striga* resistance. Several studies have also shown reduced severity of *Striga* with the increased use of nitrogen fertilizer (Olaniyan 1992).

2.3 Rice-based systems

Rice is usually grown as a sole crop in inland valley swamps. However, in upland areas, rice/cowpea or rice/groundnut mixtures may be grown. Rice is grown on flats about the middle of the rainy season. The key factor hindering high yields is late planting and low plant density. The National Cereal Research Institute has released up to 50 improved lowland and upland varieties that are being grown by farmers.

Table 1. Some sustainable cropping systems in the moist savannas in Nigeria

Crop based system	Sorghum-based system	Maize-based system	Yam-based system	Rice-based system
Ecological zone	Northern Guinea savanna	Southern Guinea savanna	Derived Guinea savanna	Inland valley savanna
Location/States	Kebbi, Niger, Kwara, Kaduna, Katsina, Plateau, Bauchi, Taraba and Adamawa	Kwara, Oyo, Kogi, Niger, FCT, Plateau, Kaduna, Benue and Taraba	Ondo, Oyo, Kwara, Osun, Plateau, Edo, Benue, Taraba, Enugu, Abia, Anambra, Imo and Cross River	Niger, Kogi, Kwara, Plateau, Taraba, Abia and Benue
Dominant/crop mixtures	Sorghum/groundnut Sorghum/cowpea Sorghum/maize/cowpea Sorghum/millet/cowpea	Maize/cowpea	Yam/sorghum/groundnut Yam/sorghum/cowpea	Rice/cowpea Rice/groundnut
Key cultural practices	Millet is often the first crop to be planted at the onset of rains before the other crops.	Maize is planted on ridges af the onset of rains and cowpea intercropped on either side of the ridges or in the furrow later.	The yam is planted when sorghum matures on mounds or ridges. Upon the harvest of sorghum, the stalks are used as trellises for yam vines.	Rice is planted on flat about the middle of the rainy season, after the legume has been planted.
Major constraints	1. Severe *Striga* infestation 2. Non-acceptance of improved sorghum varieties by farmers	1. *Striga* infestation 2. *Imperata* infestation	1. Lack of improved yam varieties 2. Low-acceptance of yam mini-sett technology 3. *Imperata* infestation	1. Poor water management technique 2. Intensive crop-weed competition 3. Iron toxicity

2.4 Yam-based systems

Yam based systems dominate the derived Guinea savannas. Although yam/sorghum is most common, bambara nut, groundnut, or cowpea may also be grown in the yam/sorghum mixture to give a more sustainable system. The yam is planted near the maturing time of sorghum on mounds or ridges. When the latter is harvested, the sorghum stalks are used as trellises for the yam vines.

The most limiting production constraint is the lack of soil fertility maintenance and the scarcity of staking materials. Farmers have also been reluctant to accept the yam minisett technology as they prefer to use whole tubers in order to get good sized warehouse yams. When they use minisetts it takes up to two seasons to produce sizeable yams from these setts. Work at the National Root Crops Research Institute and IITA have shown the value of staking in yam based systems. Average yield increases of up to 9 tonnes/ha have been obtained when yam was staked in the southern Guinea Savanna.

Two other systems with livestock and fish production are worth noting.

2.5 Livestock-based system

When crop production is properly managed there is abundant crop residue to supplement livestock feed in the MSZ. The high adoption rate for work bulls by smallholder farmers has also been enhanced by the relative ease of obtaining locally fabricated implements for bulls. One sustainable livestock based system which a few farmers practice in the northern guinea savanna is the animal traction based maize/cowpea production coupled in some cases with smallholder dairy production. Bulls for farm work have to be very carefully selected. Preferred animals are usually 2-3 years old, with a strong neck, straight back and normal straight legs. Identified constraints to animal traction include inadequate animal health care due to the high cost of drugs and inadequate feeding and livestock management practices.

2.6 Fisheries-based system

A fish culture/poultry/vegetable integrated system has been found to be sustainable by the National Fresh Water Fisheries Research Institute based at Kainji, Nigeria. The poultry provides manure used for feeding the fish in the pond. At fish harvest the nutrient rich pond mud or manured pond water is used as fertilizer in vegetable plots. Crop residue, weeds or rotten fruit from the vegetable plots could also be used to fertilize ponds. Other fish-based sustainable systems identified by the Institute are rice/fish and pig/fish using basically the same principles as above. The major production constraint is the shortage of fingerlings or the lack of a tradition of fish farming. There is also little awareness of the benefits of such an integrated fish-based system.

3. Socio-economic Constraints

Besides the technical production constraints indicated above, there are a number of socio-economic constraints which prevent the realization of the yield potential of the sustainable systems discussed above.

3.1 Inadequate input supply

There is a lot of uncertainty with respect to the availability of farm inputs. While the use of fertilizer, for example, has been generally accepted as farmers find it difficult to obtain when they require it, due in some cases to inadequate distribution arrangements. As a result, the rate of application tends to be less than optimal. The use of pesticides, including herbicides is not as widespread as that of fertilizers. But even where farmers are convinced of the need for pesticides they may find the cost prohibitive. With respect to seed, a number of improved varieties of maize, rice, cassava, cowpea, soybean have been introduced and adopted by some farmers. There is usually an inadequate supply of planting material and farmers often use unimproved planting material with its unreliable germination characteristics, which contributes to the below average yields obtained.

3.2 Labor shortage and low farm power base

Various studies in the moist savannas have shown that high seasonal labor shortages occur at periods for land preparation, weeding and harvest for cereal crops. For example, the average labor input for land preparation for rice planted in inland valley swamps could be as high as 230 person-hours per hectare (National Cereals Research Institute). Similarly in yam-based systems, the most laborious operations are heap making and staking. According to Nweke et al. (1991), of the 708 man days of labor spent on the farm in the 1984-85 season, about 80% was spent on yam production, and up to 30% of the labor for yam was hired. The farm labor shortage problem has resulted in high labor rates. In some cases, labor may be unavailable even if the farmer could afford it.

Closely related to the labor shortage constraint is the low farm power base of agricultural production in sub-Sàhara Africa in general. Farmers continue to rely on the use of hoes and cutlasses because the use of ox-drawn and tractor-mounted implements are not wide spread. Studies show that manual labor accounts for up to 80% of farm power in the moist savanna sub-zone while non-manual cultivation accounts for only 20%. Factors limiting the use of draught animals include the risk of livestock diseases and parasites, particularly in the SGS, and the absence of a livestock rearing culture in a large part of the region. With respect to the use of tractors and ploughs, the high cost of the equipment and the shortage of spare parts and repair services are a major handicap. Labor shortage coupled with a low farm power base limit the area under cultivation, delay farm operations, and reduce farm output.

3.3 Poor rural transportation

Most farmers in SSA operate smallholdings scattered over a wide area without a good rural road network — both for the delivery of farm inputs and for transporting farm output to consuming areas. These conditions have given rise to: (a) high transport costs; (b) the operation of traders who buy cheaply from farmers to make large profit margins in urban markets; and (c) heavy post-harvest losses in some years due to the delayed movement of farm products (e.g., tomatoes) from producing areas. The lack of effective on-farm storage structures tend to worsen the effect of the poor rural road system.

3.4 Poor rural marketing facilities

A lot of attention has been focused by SSA governments on improving the productivity level of agriculture through revitalized extension services. However, the extension services have paid less than adequate attention to a mechanism for the efficient marketing of farm products. Thus, despite the fact that production increases have been recorded in recent years for cassava, yam, maize, rice, and onion in the moist savanna areas, the benefits from such production successes have to some degree tended to be lost to both producers and retail markets in terms of support services and facilities. The markets are not usually well planned; they lack good drainage systems, have no stalls/stores; no cooling facilities for perishable products, and no adequate price information. The result is that the condition of retail markets poses health hazards to users and results in high produce losses and hence relatively higher prices to consumers. There is therefore a need to establish improved markets with appropriate facilities to sustain agricultural production initiatives.

3.5 Poor incentives for agriculture

There are very few incentives for farmers in SSA. Subsidies for such input as fertilizers hardly reach the peasant farmers who are the declared benefactors. This has been the main argument of donor agencies that argue for the removal of subsidies. In addition to making fertilizer available agriculture cannot be profitable without an appropriate package of incentives to enhance farmers' access to farm inputs including land acquisition, farm power, including machinery, implements and credit. The agricultural sector also needs incentives to make agricultural imports and exports contribute effectively to increased farm productivity.

Government in sub-Saharan African nations have tended to devise policies which have unintentionally discriminated against agriculture. Examples are the ban placed on exportation of staple food produce from Nigeria; and the operation of Government Marketing Boards in other countries. The barrier to agricultural exports effectively narrows the markets available to farmers, lowers farm product prices and leads to reduction in overall farm production. Similarly Nigeria's past experiences indicate that government controlled marketing boards tend to buy exportable farm produce at low prices only to sell at much higher international prices abroad, thus indirectly taxing local producers. Also the experience of Nigeria, when marketing boards were abolished in the early years of the Structural Adjustment Programme, showed clearly the positive impact which a liberalized marketing system can have on agriculture and farmers, in this case with respect to cocoa marketing and exports.

Related to an appropriate incentive environment for agricultural production are the frequent changes in government policies following instability in the political environment in sub-Saharan African countries. It is not unusual for a government to place a ban on the importation of a commodity, for example, in order to encourage local production and for the ban to be lifted by the same government a year later before farmers have had a chance to reap the gains of their investments based on the earlier policy. Such policy reversals do not make for sustained investment in agricultural production.

3.6 Under-investment in research

The national agricultural research systems (NARS) in SSA are grossly under-funded. In Nigeria, for example, the level of agricultural research funding is only 0.12% of the agricultural gross domestic product; as compared to the one per cent level recommended for developing countries (Shaib 1993). Lack of adequate funds has resulted in poorly developed infrastructural facilities, non-availability of books and journals needed for meaningful research work,and the exodus of a large number of scientists from research institutes to other sectors of the economy.

3.7 Farming systems research

Until recently, relatively little emphasis had been put on farming systems research. There has therefore been insufficient work on crop mixtures and sustainable cropping systems, some of which are indeed practiced by farmers. In such situations, farmers were reluctant to accept innovations based essentially on sole cropping experiments.

3.8 Inadequate extension work in non-crop enterprises

The extension services in a number of countries in the MSZ have improved in recent times due partly to the support received from donor agencies such as the World Bank, IFAD, FAO, and non governmental organizations. However, these have been relatively more in the crop sub-sector. The important role of livestock, fisheries, agroforestry and indeed the crop-legume interactions, all of which hold the key to sustainable farming systems, have not received as much attention from extension services. This situation is in part due to the poorly developed research system for the non-crop sub-sector and the poor linkages which exist between crop based research institutes and the non crop institutes. The introduction of the unified extension service in Nigeria is designed to address this problem. However, the underfunding of the extension service by state governments, and the frequent changes in key extension management staff have prevented the full realization of the benefits of the unified extension system.

3.9 Key policy imperatives

Below are highlighted a few areas of policy initiatives that would enhance sustainable agricultural systems in SSA.

3.9.1 *Encouraging farmer participation through group action*

The constraints imposed by factors such as timely availability of farm inputs, poor rural marketing facilities and other postharvest operations can be alleviated if genuine farmers' associations or cooperatives are effective. Unfortunately, cooperatives have been generally unsuccessful. Members are disloyal to their own societies and tend to deal with agencies and individuals outside their societies; similarly, cooperative officials have been known to defraud their societies, which they perceive as government bodies; in some instances, cooperatives members, who collect credit facilities refuse to repay.

Yet, community associations which have been formed voluntarily without government intervention have been known to thrive — they have built community schools, clinics and roads and provided other such public facilities. Thus it would be useful to identify and provide support for such voluntary associations and encourage them to get involved in input supply, farm production, ownership of bulky farm equipment, including those for processing, etc. Such farmers' associations formed along commodity lines, e.g., for milk and vegetable oil production and marketing have been found to work successfully in India. Such associations could also gain better access to farm credit through a mutual guarantee system. Group action is also beneficial to extension work. Nigeria's agricultural development projects' experiences with women in agriculture programs, for example, show that working through women farmers' groups provides more rapid dissemination of agricultural innovations when compared to working through individual farmers.

3.9.2 *Research and extension emphasis*

There is need for greater public investment in agricultural research and extension given the high rates of return known to exist in these areas. In particular, research is needed in the development of acceptable varieties of crops such as sorghum and grain legumes; as well as more work on sustainable crop mixtures and cultivation practices, which will support greater soil productivity

Similarly, the extension services in the region need to create greater awareness of those innovations and practices that will sustain soil fertility and productivity. These include the inclusion of leguminous crops in the cropping systems; the popularization of alley cropping with leguminous species and placing emphasis on the benefits of crop/livestock and crop/fishery systems. As earlier indicated, the fact that legumes and livestock already form part of the traditional farming systems in the MSZ should make extension work in these technologies relatively easier. In Nigeria, a new National Agricultural Technology Support Project (NATSP) with funding support from the World Bank is designed to address these issues.

3.9.3 *Improved farm power base*

The labor shortage problem could be ameliorated through a farm mechanization program with adequate public support and provision for private initiative. The policy should include programs for training local blacksmiths and artisans to be able to manufacture intermediate level farm implements at the village level with emphasis on ox-drawn equipment in the first instance. This can be done with assistance from research institutes, universities and the extension services. Graduates from such training centers could then be given credit support to establish their own workshops. The extension services would need to design and run appropriate training programs for farmers on how to use such equipment, including the use of oxen and ox-drawn implements. Such mechanization efforts would need to be tied to appropriate veterinary services for animals as well as extension advisory services on animal care and feeding.

4. Conclusion

Three issues need to be emphasized for sustainable agricultural growth.

First, work on farming systems shows that there is a need for greater attention to be paid to diagnostic surveys and for a thorough understanding of what has become known as *indigenous knowledge systems*. It is clear that farmers are not entirely unfamiliar with sustainable cropping systems. What needs to be done is to build on farmers' traditional practices rather than to introduce practices that they find difficult to identify with.

Second, agriculture must be made profitable even if it implies government support. A situation in which developing countries in Africa and elsewhere are being advised to remove agricultural subsidies while the more developed countries are heavily subsidizing their agriculture needs to be carefully examined. It is also essential to ensure that the subsidies reach intended beneficiaries.

Finally, the instability in the political climate in SSA countries has already introduced elements of instability into agricultural institutions. This should not be allowed to worsen given the differing agricultural extension strategies being promoted by different donor agencies. We believe that the emphasis should be on building on the implementation capacity of existing institutions rather than constantly replacing them.

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CROPPING PATTERNS IN THE SAVANNA OF WEST AFRICA: Risk Programming Analysis in Côte d'Ivoire

Akinwumi A. Adesina[1] **and André D. Ouattara**[2]

[1]*West Africa Rice Development Association, 01 BP 2551, Bouaké 01, Côte d'Ivoire*
[2]*University of Abidjan, Côte d'Ivoire*

Key words: cropping patterns, income risks, ecosystem

Abstract: *This paper examines the trade-offs between income and risk in cropping patterns in the savanna zone of Côte d'Ivoire using three villages as case studies. Farmer attitudes to risk and a risk analysis based on risk programming models developed for manual, oxen and tractor farms are used to derive the implications of crop technology development strategies in the moist savanna zone.*

The study shows that substantial increases in yield and reductions in income risks could be made by reallocating the existing crop mix. Maize is the most risk prone crop and requires greater yield stability to reduce farmers' risks. Increased price incentives for rice have led to the expansion of upland rice cultivation. Expansion of rice production in the lowlands is a viable option; but the supply of irrigated land is not readily expandable. As a result, research may need to concentrate on technologies that can reduce likely negative soil fertility effects of the continued expansion of upland rice cropping on the poor soils of the savanna zone.

1. Introduction

Uncertainty is a pervasive characteristic of agricultural production (Low 1974, Mapp et al. 1979). This uncertainty arises due to several bio-physical factors such as highly variable weather events, disease or pest infestations. Other factors such as the changing economic environment, the introduction of new crops or technologies, and uncertainties surrounding public institutions and their policy implementation, also combine with these natural factors to create a plethora of yield, price, and income risks for farmers (Anderson et al. 1985, Mapp et al. 1979, Heyers 1972, Adesina and Brorsen 1987).

The majority of agricultural producers in sub-Saharan Africa farm under a situation of acute risk. The low and highly erratic rainfall (Bunting et al. 1975, Nicholson 1983, Sivakumar 1988, Lamb 1983) and the absence of institutional innovations (e.g., crop insurance, disaster payments, emergency loans, etc.) to shift part of the risk from the private sector to the public sector, make risk-management a critical part of farmer decision making (Matlon 1991, Adesina and Sanders 1991, Shapiro et al. 1993). In the savanna regions of West Africa, the highly variable rainfall and poor soils have been shown to differentially affect the yield potential of various crops (Kassam and Kowal 1973). It is, therefore, important to examine the riskiness of various crops in the savanna zone of West Africa, the risk-efficiency of existing crop patterns, and the opportunities for re-allocating crop mix in order to guarantee a stable income for farmers.

The objectives of this paper are to determine the effects of farmers' risk attitudes on the cropping patterns in the savanna zone of Côte d'Ivoire, and to estimate normative acreage response and market supply elasticities for rice — a major crop in the savanna zone — whose relative profitability has increased due to the recent exchange rate policy readjustment (i.e., the devaluation of the CFA franc in francophone West Africa). The analysis is based on risk programming models developed for manual, oxen and tractor farms, and is used to determine implications for crop technology development strategies in the moist savanna zone of Côte d'Ivoire.

2. The Study Villages

The study was conducted in three villages in the moist savanna agroecological zone. One of the villages (Mbengue) is located in the Sudan zone, while the other two (Napie and Sirasso) are located in the higher potential sub-Sudan zone, which borders the limits of the Guinea savanna zone. The characteristics of the villages are shown in table 1. Mbengue and Sirasso villages both have low population densities and a relative abundance of land. In contrast, Napie is a land-scarce village, with a very high population density (51 persons/km^2). Both Napie and Sirasso have better water supplies than Mbengue due to the existence of neighboring dams that supply water for irrigated rice in the villages. Crops grown vary by village, but in the entire zone the major crops are cotton, upland rice, lowland rice, maize, and peanuts.

Table 1. Characteristics of the study villages in the savanna zone of Côte d'Ivoire

	Village		
	Mbengue	Napie	Sirasso
Agro-ecological zone	Sudan	Sub-Sudan	Sub-Sudan
Total area (km^2)	2364	288	1822
Total population	28039	14756	25266
Rural population	22912	14756	20860
Total population density (persons/km^2)	12	51	14
Rural population density (persons/km^2)	10	51	11
Land supply situation	Surplus	Limiting	Surplus
Presence of irrigation	None	Yes	Yes

For most of the farmers, cotton is the predominant cash crop. Three types of farms are found in the zone: manual, oxen and tractor farms. Field data for the study were collected from a representative sample of 85 farm-households in the three villages (manual: 39, oxen: 41 and tractor: 5). All production activities by farm type were monitored by field staff stationed in the villages throughout a 12-month period. This allowed the collection of data for second cycle irrigated rice in Napie and Sirasso. Data were collected on input-output coefficients for all crops by farm-type.

3. Empirical Model

Several approaches exist for incorporating risks in farm-programming models, including mean-variance (E-V) analysis using quadratic programming, stochastic programming (Adesina and Sanders 1991), or a linearized variation of the E-V approach (MOTAD) (Hazell 1979). The MOTAD approach is used in this analysis. The MOTAD model and its variants have been used in risk analysis of farmer decision making in Africa (Maleka 1993, Adesina et al. 1988). The variant of the MOTAD model applied in this study allows the integration of farmers' risk attitudes.

The empirical model used in the analysis is simplified below:

$$\text{Max } L(E,\sigma) = E(\pi) - \Phi\sigma(\pi)$$

ST

$$\Sigma_j\, a_{ij} X_j \le b_i \qquad \text{for all } i$$

$$\Sigma_j\, (c_{jt} - E[c_j])X_j + d_t \ge 0, \qquad \text{for all } t,\ t = 1,2\ldots T$$

$$\theta\Sigma_t d_t - \sigma(\pi) = 0$$

$$X_j \ge 0;\ E(\pi) \ge 0;\ \sigma(\pi) \ge 0$$

where:

- X_i is the area in crop $_j$ (ha)
- a_{ij} are the respective input-output coefficients that capture the level of use of resource $_i$ in the production of crop $_j$
- b_i is the available resource endowment for factor i
- c_{jt} is the revenue of crop $_j$ in year t ($t = 1, 2 \ldots T$)
- $E(c_j)$ is the sample mean revenue for the crop $_j$ across all of the T years
- d_t is the measure for the absolute value of negative deviations in total revenue
- $\theta = 2s/T$ is a constant, and $s = (T\pi/2(T-1))^{1/2}$ is the square root of Fisher's constant (Hazell and Norton 1986)
- $E(\pi)$ is the expected profit from the crop production plans
- Φ (the risk aversion parameter) measures the attitude of the farmer towards risk

$\sigma(\pi)$ is the MAD (i.e., mean absolute deviation) estimate of the variance of profits from crop production over the *T* years in the analysis

The objective function is the maximization of a utility function that depends on the expected profit discounted by the weighted standard deviation of profits, the weight being the risk aversion parameter for the decision maker.

The second set of equations, which are highly disaggregated, model the farm resource use patterns. Land type or ecosystem constraints were specified for each crop. For rice, this included upland, lowland and irrigated ecosystems. Irrigated land constraints were further sub-divided, based on the crop season, into first (March/April to August) and second season crop (August-December). Crop-specific upland ecosystem constraints were specified for each crop (i.e., maize, cotton and peanuts), based on the observed cropping patterns in the field data. Labor-use patterns (in man-days per ha) were modelled using monthly (intra-seasonal) labor constraints for crop cultivation. Both household and external labor were considered. Due to the existence of active labor markets during certain periods in the season, flexibility for monthly labor hiring activities was allowed (using transfer rows) for complementing available household labor in each period. The wage rate in each of these periods was set equal to the on-going wage rate paid for hired agricultural labor in each village.

In addition to manual labor, oxen and tractor availability, constraints were specified based on the number of hours these technologies could be used. Because oxen and tractors were available for rent, the model also took into account farmers who would be able to rent them. An annual cash constraint was used to model the trade-offs between own-liquidity and credit-use. Expenditure for purchased inputs (e.g., fertilizers, herbicides, insecticides) could be met from farmers' own liquidity, with or without complementary credit. Only official credit use (from the cotton company, CIDT[1]) was considered, as it was impossible to obtain reliable information from farmers on their use of informal credit: Islamic cultural norms, which predominate in the savanna zone, do not permit interest charges.

Several accounting or balance rows were used to ensure internal consistency for the total production of each crop. These accounting rows specified that the amount of the crop sold, plus the on-farm consumption requirements, should not exceed total production. Crop-specific subsistence requirements were specified to account for economies of scale in farm-household size. Based on the age and sex of household members, consumer adult-equivalent requirements (CAEU) were developed for each crop (Eponou 1983). These were then aggregated to the household level to determine the minimum consumption requirements for each crop. Additional provision above this minimum requirement was permitted to allow farm households to keep extra grain to finance the miscellaneous social obligations that often form an important part

[1] Compagnie Ivorienne des Textiles.

of the household expenditure. Other constraints in the models include use of external inputs, which were specified by crop and input-type based on the averages from the field data.

The third set of equations are the MOTAD constraints, which measure the deviation (i.e., d_t) of incomes in any given year from the mean incomes across all the years. Together with the fourth set of equations, these constraints are used to determine the mean absolute deviation of income returns over all crops in each of the T years considered. This involves the transformation of the sum of the income deviations into an estimate of standard deviation of income (i.e, σ) using the Fisher constant (Hazell and Norton 1986). The crop prices and yield trends collected from regional statistical reports[2] for the period 1986-91, complemented by the field data collected in the villages in 1992/93, were used to generate distribution of crop incomes for the seven years (i.e., $T = 7$) used in the risk analysis. Using this model, representative farm models for manual, oxen and tractor farms in the villages were developed.

4. Results

4.1 Initial base model validation

Model farms were developed using the averages of the input-output coefficients generated from the actual field data. Since averages were used, it is possible for the predicted results in the models to diverge from the averages of observed cropping patterns.

4.1.1 *Mbengue village*

Validation of the results indicated that the predicted cultivated areas in the calibrated base models closely approximates the observed cropping patterns (table 2). Motorized farms have the largest cultivated area (25 ha) compared to the oxen (7.4 ha) and manual farms (3.2 ha). Cropping patterns on the manual farms consist of maize, upland rice and cotton, with the largest share of total cultivated area being in cotton (56%), followed by upland rice (29%) and maize (15%). On the farms with oxen, the cropping patterns include, in addition to upland rice, cotton and maize, lowland rice and peanuts. The most important crops for the oxen farms are cotton (46% of cultivated area) and maize (29%), with the minor crops being upland rice (11%) and lowland rice (8%). Cotton is also the most important crop on the tractor farms (41% of total cultivated area), followed by maize (37%) and upland rice (15%); the minor crops are lowland rice (2.5%) and peanuts (3%).

[2] These data were collected from the statistical reports of the CIDT, the agency responsible for crop statistical data collection for the savanna region.

Table 2. Cultivated area on manual, oxen and tractor farms in Mbengue village, Sudan zone, (validation of base models)

Crops (ha)	Manual farms		Oxen farms		Tractor farms	
	Av. from field data	Base model	Av. from field data	Base model	Av. from field data	Base model
Maize	0.49	0.49	2.20	2.10	11	9
Upland rice	0.93	0.93	0.80	0.80	3.70	3.70
Lowland rice	-	-	0.60	0.60	0.64	0.64
Cotton	1.70	1.80	3.50	3.40	10	10
Peanuts	-	-	0.47	0.47	0.80	0.80
$E(\pi)$	n.a	155505		456788	n.a	1585288
$\sigma(\pi)$	n.a	138142		836165	n.a	3644814

On the oxen and motorized farms, labor was the greatest constraint because of additional hectares under cultivation. Farms having tractors used hired labor for seven months, compared to five and three months for the oxen tillage and manual farms respectively. The utilization of external inputs (table 3) is extremely low for the manual farms, with the only external input used being insecticides on cotton. Fertilizer, herbicide and insecticide use is more diversified on the oxen and motorized farms. The majority of input use is on cotton, followed by maize.

4.1.2 *Napie Village*

Validation of the models for the manual and oxen tillage farms (table 4) showed that the calibrated base model closely approximated the cultivated areas observed from the averages of the field data. The farm plans of the manual and oxen farms included similar crops (irrigated rice, lowland rice, upland rice, peanuts and cotton) with the differences being in the relative shares in each of the crops. Total cultivated area for the manual farms is 2.7 ha compared to 4.2 ha for the oxen farm. On the manual farms the most important crops were: cotton (40% of cultivated area) and irrigated rice (31%); with the minor crops, including peanuts (13%), upland rice (9%), and lowland rice (4%). For farms with oxen, the most important crops in the model results were cotton (51%), irrigated rice (20%) and peanuts (15%), with the minor crops being upland rice (10%), and lowland rice (4%).

Labor was a constraint to land preparation on the manual farms in March (irrigated rice, 1st cycle), June (land preparation for peanuts and cotton) and September (land preparation for second season irrigated crop). To cope with this labor constraint, a total of 116 hours of oxen traction was hired: 72 hours in June and 44 hours in August. For farms with oxen, the demand for labor was highest in June (for planting the 1st season irrigated rice and for the weeding of maize) and in November (for harvesting lowland rice and cotton). The use of external inputs varied across the two farm types in Napie (table 5). In general, the use of chemicals and fertilizers was higher for farms with oxen tillage, with cotton and irrigated rice receiving the greatest proportion of these inputs.

Table 3. Utilization of chemical input by crop on manual, oxen and tractor farms, Mbengue village, Sudan zone (base model results)

Input	Crop	Farm type					
		Manual		Oxen		Tractor	
		Quantity	Total %	Quantity	Total %	Quantity	Total %
NPK (kg)		-	-	903		2102	
	maize		-		46		20
	cotton				54		80
UREA (kg)		-	-	351		717	
	maize		-		46		20
	cotton				54		80
INSECTICIDE		38		116		192	
Furandan (L)	maize		100		23		0
	cotton		-		77		100
HERBICIDE		-	-	7		6	
Bellater (L)	maize				100		100
HERBICIDE		-	-	2		4	
Ronstar (L)	upland rice				100		100
HERBICIDE				15		26	
Cotodon (L)	cotton	-	-		100		100

Table 4. Cultivated area on manual and oxen farms in Napie village, sub-Sudan zone, Côte d'Ivoire (validation of base models)

Crops (ha)	Manual farms		Oxen farms	
	Av. from field data	Base model	Av. from field data	Base model
Irrigated rice (1st season)	0.43	0.43	0.45	0.45
Irrigated rice (2nd season)	0.43	0.43	0.45	0.39
Upland rice	0.25	0.25	0.40	0.40
Lowland rice	0.12	0.12	0.18	0.18
Peanuts	0.35	0.35	0.28	0.63
Cotton	1.07	1.07	2.50	2.20
$\hat{E}(\pi)$	n.a	193500	n.a	423218
$\sigma(\pi)$	n.a	287879	n.a	510418

Table 5. Utilization of chemical input by crop on manual and oxen arms, Napié, sub-Sudan zone (base model results)

		Type of farm			
		Manual		Oxen	
Input	Crop	Quantity	Total %	Quantity	Total %
NPK		428		591	
	Irrigated rice				
	(1st season)		17		11
	(2nd season)		10		10
	Lowland rice		4		3
	Upland rice		8		6
	Cotton		59		70
	Peanut		1		
Urea (kg)		177		230	
	Irrigated rice				
	(1st season)		16		11
	(2nd season)		16		10
	Lowland rice		4		3
	Upland rice		7		6
	Cotton		55		70
	Peanut		<1		-
Insecticide					
Furadan (L)		26		28	
	Irrigated rice				
	(1st season)		8		18
	(2nd season)		8		14
	Cotton		84		68
Herbicide					
Ronstar (L)		7		4	
	Irrigated rice				
	(1st season)		43		35
	(2nd season)		43		30
	Lowland		14		35
Herbicide					
Cotondon (L)		5		7	
	Cotton		100		94
	Peanut		-		6

4.1.3 *Sirasso village*

The results from the models for Sirasso are shown in table 6. The crops cultivated on the manual farms include maize, irrigated rice, upland rice, peanuts and cotton. Total area under cultivation is 3.14 ha per farm, with the relative share of each crop being: cotton (31%), upland rice (18%), peanuts (16%), maize (15%), and irrigated rice (10% for the first and second season crop, respectively). The average area under cultivation in the farms with oxen-tillage is 6.8 ha, nearly double that of the manual farms. On the oxen farms, cotton is the most important crop in terms of area under cultivation (37%). The remaining land is divided among the following crops: maize (16%), upland rice (15%), peanuts (13%), and irrigated rice (9% respectively, for the first and second season crop).

Table 6. Cultivated area on manual and oxen farms in Sirasso sub-Sudan zone (validation of base models)

Crops (ha)	Manual farms		Oxen farms	
	Av. from field data	Base model	Av. from field data	Base model
Irrigated rice (1st season)	0.31	0.31	0.62	0.62
Irrigated rice (2nd season)	0.31	0.31	0.62	0.62
Upland rice	0.55	0.55	1.03	1.03
Peanuts	0.51	0.51	0.86	0.86
Cotton	0.98	0.98	2.5	2.5
Maize	0.48	0.48	1.1	1.1

The highest demand for labor on manual farms was during June, July and October which resulted in the hiring of a total of 401 man-days of labor. In June, the farmers prepare the land for cotton and upland rice. July is the period when peanuts are planted, while the dry-land crops are harvested in October. On the oxen farms, the highest demand for labor was in October, during harvest. This suggests that the use of oxen traction principally for area expansion shifts the labor bottleneck to the harvesting period. The use of chemical inputs is much higher on the oxen farms than the manual farms (table 7). However, in contrast to Napie and Mbengue — where cotton is the major user of external inputs — most of the external inputs in Sirasso were used on irrigated rice.

4.2 Risk analysis

Risk-efficient crop plans were generated based on farmer risk-preferences and resource availabilities. The results are discussed below by village.

4.2.1 *Mbengue village*

The relative uncertainty of various crops in the village zone was determined using regional time series data on prices and yield. In terms of product prices, the majority of the crops (except maize and cotton, with coefficients of variation (cv) of 0.04 and 0.08, respectively), exhibited very high coefficients of variation (cv > 0.90). Analysis of temporal variations in yield show that the crops can be categorized into 3 groups: high yield/risk (maize: cv = 0.61), medium yield/risk (lowland rice: cv = 0.22; peanuts: cv = 0.29; and upland rice: cv = 0.29), and low yield/risk (cotton: cv = 0.09). When yield and price variability are jointly considered, the risk associated with various crops can be categorized as follows: high returns/risk (maize: cv = 0.63), medium returns/risk (lowland rice: cv = 0.25; peanuts: cv = 0.35), and low returns/risk (cotton: cv = 0.14; upland rice: cv = 0.13).

Table 7. Utilization of chemical input by crop in manual and oxen farms, Sirasso, sub-Sudan zone (base model results)

		Type of farms			
		Oxen		Manual	
Input	Crop	Quantity	% Total	Quantity	% Total
NPK (kg)		708		440	
	Irrigated rice:				
	(1st season)		26		20
	(2nd season)		26		20
	Maize		48		38
	Cotton		<1		12
	Peanut				10
UREA (kg)		276		172	
	Irrigated rice:				
	(1st season)		26		20
	(2nd season)		26		20
	Maize		48		38
	Cotton		<1		12
	Peanut		0		10
INSECTICIDE		24		15.6	
Furadan (L)	Irrigated rice:				
	(1st season)		25		33
	(2nd season)		25		33
	Cotton		50		33
HERBICIDE		53.4		10	
Ronstar (L)	Irrigated rice:				
	(1st season)		34		41
	(2nd season)		34		41
	Cotton		32		0
	Lowland rice		0		18
HERBICIDE		16		5.96	
Cotodon (L)	Cotton		100		57
	Peanut		0		43

a. *Manual farms*

In the risk-efficient model the area cultivated to maize was less when compared to on-farm data, regardless of the level of risk aversion. However, as the level of risk aversion increases, the risk-efficient crop mix shows a decline in the area of upland rice, and an increase in the area cultivated to cotton. It is important to note that while upland rice and cotton have low/return risks, cotton has higher returns per ha than upland rice. The observed greater area of cotton cultivated by risk averse farmers indicates that cotton is used as a hedge against income loss. Marketed surplus for rice and cotton follow the same pattern as area under cultivation.

Table 8. Risk-efficient crop plans for manual, oxen and tractor farms in Mbengue, Sudan zone

Crops (ha)	Type of farm					
	Manual		Oxen		Tractor	
	$\Phi=0$	$\Phi=1.5$	$\Phi=0$	$\Phi=1.5$	$\Phi=0$	$\Phi=1.5$
Maize	0.35	0.35	0.52	0.52	6.30	0.19
Upland rice	2.80	1.73	4.50	3.60	3.70	3.70
Lowland rice	-	-	-	-	0.80	-
Cotton	0.14	1.22	1.64	2.56	12	13
Peanuts	-	-	0.21	0.21	0.24	0.24
Rice sales (kg)	2172	1199	8227	6342	6029	4689
$\hat{E}(\pi)$	192407	182119	646932	634076	1669996	1535026
$\sigma(\pi)$	150545	107666	190203	173627	2458301	416070

b. *Oxen farms*

On oxen-tillage farms, the area cultivated to maize (a high risk crop) in the risk-efficient model declined to 0.52 ha (table 8), which was substantially lower than the 2+ ha which obtained in farmers' cropping patterns, regardless of level of risk aversion. The area in upland rice was significantly increased in the risk-efficient model, compared to the existing crop plan. Other changes in the risk-efficient model involved the elimination of lowland rice from the optimal farm plan and marginal area expansion of peanuts. Projected incomes from the risk-efficient crop models are significantly higher than from farmers' actual cropping patterns, indicating that farmers can significantly increase farm income and lower their risks.

In the risk-efficient solutions, the area in upland rice declines from 4.5 ha for the farm plan of the risk-neutral farmer, to 3.6 ha for the farm plan of the highly risk averse farmer ($\Phi=1.5$). However, the area in cotton expands with increasing level of Φ. Regardless of the level of risk aversion, the volume of marketed output for rice and cotton on the oxen farms is substantially higher than for manual farms.

c. *Tractor farms*

The risk-efficient crop plan for the tractor farms (see table 8) shows the largest decline is in area under maize, compared to the farmers' crop plan. Apart from the risk neutral farmers' cropping plan (where maize area was reduced to 6.3 ha from 9.3 ha in the existing crop plan), a substantial decline in area under maize occurs for each of the risk aversion levels. It is important to note that the income risk associated with the farm plan of the risk neutral farmer is also substantially higher than for the risk averse farmers. As the level of farmers' risk aversion increases, the area of maize in the risk-efficient solution declines from 6.3 ha for Φ=0 to 0.19 ha for all Φ>0. This indicates that risk averse farmers can reduce their risks by reducing the area of cropped maize.

4.2.2 *Napie village*
In terms of yield risk, the crops can be divided into three groups: those with low yield risk (cotton: cv = 0.09), medium yield risk (upland rice: cv = 0.28; irrigated rice: cv = 0.21; and peanuts: cv = 0.29), and high yield risk (maize: cv = 0.61). Three price risk groupings have also been identified: low price risk (cotton: cv = 0.008; maize: cv = 0.04) and medium price risk (upland rice: cv = 0.21; irrigated rice: cv = 0.21; peanuts: c.v = 031). Classification by level of income risk produces the following groupings: low income risk (cotton : cv = 0.15; upland rice: cv = 0.13), medium income risk (irrigated rice: cv = 0.24; peanuts cv = 0.35), and high income risk (maize: cv = 0.64).

a. *Manual farms*
The risk-efficient crop plans for the manual farms did not include the production of maize, which has the highest income variability (table 9). The results show that at high levels of risk aversion (Φ > 0.5) the area in the second-season irrigated rice crop declines sharply as the yield risk of the second-season irrigated rice crop is much higher. Rainfall in the zone is mono-modal and the cultivation of the second-season irrigated rice crop occurs in the dry season. The dam used by farmers in Napie village is the smallest of the dams in the savanna area, with a watershed area of 5.4 km^2 and a reservoir capacity of only 1.7 million m^3. Thus, water level is generally low during the dry season posing significant problems of water distribution to paddy rice. Yield of the second rice crop is relatively lower than the main crop and is more variable. In general, the results show that expected income and income risks follow an inverse pattern as the level of risk aversion increases. This indicates that risk averse farmers can select crop mixtures that carry lower income risks, by trading-off higher expected profits.

b. *Oxen farms*
The risk-efficient crop plan for the oxen farms (table 9) shows that the area in main-season irrigated rice is largely stable across the various levels of risk aversion. However, the area in the second-season irrigated rice crop declines sharply at higher levels of risk aversion, and drops out of the optimal risk-efficient solution for the highly risk averse farmer. This result, when taken together with that of the manual farms, suggests that farmers currently cultivating the second-season irrigated rice crop in the zone are likely to be either risk neutral or moderately risk averse.

The model results show that the variability of incomes from the risk-efficient farm plan is substantially lower than that from the existing crop plan. This suggests that if farmers consider the reduction of income risks as relatively more important than higher expected income, a reallocation of the existing crop plan to the risk-efficient crop mix would be preferred.

Table 9. Risk-efficient crop plans for manual and oxen farms in Napie, sub-Sudan zone

Crops (ha)	Manual		Oxen	
	$\Phi = 0$	$\Phi = 1.5$	$\Phi = 0$	$\Phi = 1.5$
Irrigated rice (1st season)	0.43	0.43	0.45	0.15
Irrigated rice (2nd season	0.43	0.15	0.45	-
Upland rice	0.10	-	-	1.81
Lowland rice	0.03	-	-	0.18
Peanuts	0.24	0.9	0.63	0.73
Cotton	1.25	-	2.55	0.27
Rice sales (kg)	1424	746	1039	2708
$E(\pi)$	215,000	90,000	492,000	195,000
$\sigma(\pi)$	318,000	41,000	585,000	127,000

4.2.3 *Sirasso village*

In terms of variability in yield risk, the crops can be divided into high risk (maize: cv = 0.62), medium risk (upland rice: cv = 0.42; peanuts: cv = 0.29; and irrigated rice: cv = 0.22), and low risk (cotton, cv = 0.13). Using price variability, it was observed that maize has the least variation in price. When both price and yield risks are considered together to determine income risk, the crops in the village can be divided into three major groups: (a) high-income risk (maize: cv = 0.64), (b) medium -income risk (irrigated rice: cv = 0.25; upland rice, cv = 0.31; and peanuts, cv = 0.35;) and (c) low-income risk (cotton, cv = 0.19).

a. *Manual farms*

The risk-efficient model results (table 10) indicate that the crop mix selected at various levels of risk aversion closely mirrors the risk patterns of the crops. For maize, the cultivated area declines substantially for highly risk averse farmers: declining from 0.96 for the risk neutral and moderately risk averse farmers, to 0.18 for the highly risk averse farmer. However, area in cotton (with low income risk) increases as the level of Φ rises. In contrast to the situation at Napie, the cultivated area in irrigated rice for both the first and second seasons remained constant regardless of the level of risk aversion. The explanation for this is given later, after the results for the oxen farms are discussed.

Table 10. Risk-efficient crop plans for manual and oxen farms in Sirasso, sub-Sudan zone

Crops (ha)	Manual		Oxen	
	$\Phi = 0$	$\Phi = 1.5$	$\Phi = 0$	$\Phi = 1.5$
Irrigated rice (1st season)	0.31.	0.31	0.62	0.62
Irrigated rice (2nd season	0.31	0.31	0.62	0.62
Upland rice	0.53	0.24	-	1.85
Lowland rice	0.96	0.18	5.22	0.34
Peanuts	0.24	0.90	0.20	0.80
Cotton	-	1.42	-	2.5
Rice sales (kg)	2749	2287	6389	10,183
$E(\pi)$	440,000	352,000	2,186,000	955,000
$\sigma(\pi)$	384,000	87,000	1,693,000	185,000

b. *Oxen farms*

Risk-efficient crop mixtures for oxen farms (table 10) show that at low to moderate levels of risk aversion, maize is the predominant crop. However, at high levels of risk aversion (Φ=1.5), the area in maize is substantially reduced. For the highly risk averse farmer, both cotton and upland rice enter the optimal solution and form an important share of the total area cultivated. As was observed for the manual farms, the area of the main-season and second-season irrigated rice crop was not affected by the level of risk aversion. This result has an important implication when compared with the situation in the Napie: the dam that supplies the irrigation water to the Sirasso farms is the largest in the entire savanna, with a watershed area of 144 km^2 and a reservoir capacity of 60 million m^3 (DCGTX 1992). Water reserves from the dam are adequate for a successful second-season of irrigated rice crop.

These results have important implications for efforts to increase rice production via double-cropping in the savanna region. Given the mono-modal rainfall pattern in the region, it can be expected that in areas where dams exist with sufficient water reserve capacity for a second-season rice crop, farmers (regardless of their risk attitudes) will plant a second crop of irrigated rice.

4.3 Rice production and farmer response to economic incentives

With the devaluation of the FCFA in 1994, the relative profitability of rice in the cropping systems of the savanna zone has increased. The responsiveness of farmers to this new economic incentive varies by type of ecosystem and farm (Jaegar 1992). An understanding of the nature of this response is critical for rice technology development strategies in the savanna region.

Due to high variability in resource endowments across farm-types and different risk attitudes of farmers, supply response analysis using aggregate data (Bond 1983, Gunjal and Sed-Elmi 1994, Binswanger et al. 1987) is inappropriate, as it cannot capture these important elements. Normative supply response functions developed from farm-level models (Hazell and Norton 1986) are, therefore, used in this analysis.

Using the risk-efficient model for each of the farms in the three villages, we examined the responsiveness of farmers to increased opportunities for rice cultivation by conducting a sensitivity analysis on the relative price of paddy. Three levels of paddy prices were considered: PO (base price in each village), P1 (135 CFA/kg), and P2 (160 CFA/kg); 3 levels of risk aversion (i.e., $\Phi = 0$, 0.5 and 1.5) were also considered.

4.3.1 *Response by rice ecosystem*

In Mbengue village, manual farms (table 11) responded by expanding the area of upland rice and reducing the area under cotton. It was found in an earlier study that rice and cotton compete for land in manual farms (Eponou 1983). On the oxen farms, a very major expansion of upland rice was observed (table 12). In addition, lowland rice now enters the farm plan as the price for rice is increased. However, due to the highly inelastic supply of available lowlands, it was not possible for the farms to further expand cultivation in this ecosystem. These findings suggest that the response to the price incentive by oxen farms would result primarily in the extensification of upland rice area. For the tractor farms, response was not sensitive to changes in the price of paddy. This may be due to the reliance of these farms on very large areas of cotton and very low product substitution between cotton and rice.

Table 11. Simulation of the effects of changes in paddy prices* on cropping patterns — manual farms, Mbengue village, Sudan zone

Crops (ha)	Risk aversion level								
	Φ=0			Φ=0.5			Φ=1.5		
	PO	P1	P2	PO	P1	P2	PO	P1	P2
Maize	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Upland rice	2.80	3.00	3.00	1.80	2.80	3.00	1.70	2.80	2.80
Cotton	0.14	-	-	1.20	0.14	-	1.20	0.14	0.14
Market supply of paddy	2171	2310	2310	1199	2172	2310	1149	2172	2172
Expected profit [E(π)]	192407	311878	369634	182627	311865	369634	182119	311865	366164

*In each of the simulations, PO is the current base price in each village, and P1 is 135 CFA/kg and P2 is 160 CFA/kg.

Table 12. Simulation of the effects of changes in paddy prices on cropping patterns — Oxen farms, Mbengue village

Crops (ha)	Risk aversion level								
	$\Phi=0$			$\Phi=0.5$			$\Phi=1.5$		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
Maize	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Upland rice	4.50	6.20	6.20	4.50	6.20	6.20	3.60	6.20	6.20
Lowland rice	-	0.61	0.61	-	0.61	0.61	-	0.02	0.61
Cotton	1.64	-	-	1.64	-	-	2.56	-	-
Peanut	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Market supply of paddy	8227	12601	12601	8227	12601	12601	6342	11605	126011
Expected profit [E(π)]	646932	1316476	1631511	646932	1316476	1631511	634076	1280706	16315111

Results for the manual farms in Napie village (table 13) indicate that most of the rice acreage response came again from the upland ecosystem. Lowland rice also comes into the optimal solution, but the inelastic supply of land limits further expansion. The area in irrigated rice remained unchanged as the price of paddy changed, due possibly to the perfectly inelastic short supply of irrigated land. Increases in the area of upland rice are accompanied by a decline in the cultivated area of cotton. A similar pattern was observed in the oxen farms, although the absolute area under upland rice is substantially higher in the oxen-tillage farms than in the manual farms (table 14).

For Sirasso village, the results show that the response of both manual and oxen farms to the increased economic incentive is to bring substantial areas of uplands into cultivation (table 15 and table 16). The level of upland rice expansion is very substantial for the oxen farms due to the ability of oxen to extend cultivated area. No changes were observed in the area of irrigated rice, reflecting the perfectly inelastic supply of land.

4.3.2 *Normative acreage response and marketed supply response-elasticities*
Using the results for the above analysis, normative market supply and acreage response elasticities were estimated for each farm type in the three villages. Our results provide disaggregated elasticities by type of farm and by agro-ecological zone. Such disaggregated estimates, useful in understanding production possibilities, have not been estimated by previous economic studies in the savannas of West Africa (Delgado 1977, Eponou 1983, Smith et al. 1993, Ogungbile 1980).

In general, acreage response elasticities are higher for the oxen farms compared to the manual farms[3] (table 17). The only exception is in Napie village, where the acreage response elasticity for the manual farms is higher than for oxen farms. In Napie, land is scarce (the population density is high), while in Sirasso land is relatively abundant (the population pressure is low). Therefore, the oxen farms in Sirasso face a relatively more elastic land supply than those in Napie, and this is reflected in the lower acreage response elasticity for the oxen farms in Napie. This model result is supported by findings in previous studies in Africa showing that the potential for the use of oxen for area expansion is most limited in areas with high population pressure and land scarcity (Pingali et al. 1987, McIntire et al. 1992, Sargeant et al. 1981).

When the averages of the two villages in the sub-Sudan zone are used, the results indicate that farms in the sub-Sudan zone have higher rice acreage response elasticity than farms in the lower-potential Sudan zone. For the manual farms in the Sudan zone, the elasticity estimate is 0.64 compared to 1.1 for the villages in the sub-Sudan zone. Estimates for oxen farms are 1.4 in the Sudan zone and 1.5 in the sub-Sudan zone. This is likely due to the higher rainfall in the sub-Sudan which reduces the risk of upland rice cultivation, compared to the Sudan zone.

Estimates of the market supply elasticities show higher farmer response in the sub-Sudan zone villages (i.e., Napie and Sirasso). The market supply response of the oxen farms is higher than the manual farms in two of the three study villages. This largely reflects the larger areas cultivated by oxen farms, as there is no significant yield-effect from oxen use. In both Mbengue and Sirasso villages, the estimates of the market supply elasticities are lower than the acreage response elasticities. This suggests that while rice production in these zones could be expanded by bringing larger areas of upland rice into cultivation, the output effect of such a process on market supply is likely to be highly mitigated by low yields in the uplands.

[3]Estimates could not be obtained for the tractor farms in Mbengue as their crop plan was not sensitive to paddy prices changes.

Table 13. Simulation of the effects of changes in paddy prices on cropping patterns — manual farms, Napie village

Crops (ha)	Risk aversion level								
	$\Phi=0$			$\Phi=0.5$			$\Phi=1.5$		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
Irrigated rice (1st season)	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Irrigated rice (2nd season)	0.43	0.43	0.43	0.39	0.43	0.43	0.15	0.43	0.43
Upland rice	0.09	0.39	0.39	-	1.39	1.42	-	1.39	1.42
Lowland rice	0.12	0.12	0.12	-	-	0.12	-	-	0.12
Peanut	0.24	0.24	0.24	0.94	0.24	0.24	0.88	0.28	0.24
Cotton	1.25	1.03	1.03	0.05	0.03	-	-	-	-
Market supply of paddy	1499	1994	1994	1180	3656	3701	746	3046	3701
Expected profit ($E(\pi)$)	215609	285261	398687	109834	111266	390799	900054	286556	390799

Table 14. Simulation of the effects of changes in paddy prices on cropping patterns — oxen farms, Napie village

Crops (ha)	Risk aversion level								
	Φ=0			Φ=0.5			Φ=1.5		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
Irrigated rice (1st season)	0.45	0.45	0.45	0.45	0.45	0.45	0.15	0.45	0.45
Irrigated rice (2nd season)	0.45	0.45	0.45	0.40	0.45	0.45	-	0.45	0.29
Upland rice	-	0.76	2.08	0.76	2.08	2.08	1.81	2.08	2.08
Lowland rice	-	0.13	0.18	-	0.18	0.18	0.18	0.18	0.16
Peanut	0.63	0.63	0.63	0.63	0.63	0.63	0.73	0.63	0.63
Cotton	2.55	0.78	-	1.78	0.25	-	0.27	0.25	-
Market supply of paddy	1039	2307	4211	2039	4211	4211	2708	3986	4190
Expected profit [E(π)]	491712	597962	659935	418637	536088	659935	195276	536088	658921

Table 15. Simulation of the effects of changes in paddy prices on cropping patterns — manual farms, Sirasso village

Crops (ha)	Risk aversion level								
	$\Phi=0$			$\Phi=0.5$			$\Phi=1.5$		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
Maize	0.96	0.96	0.96	0.18	0.10	0.10	0.18	0.10	0.10
Upland rice	0.53	1.41	1.41	0.20	2.05	2.27	0.24	1.31	2.26
Irrigated rice (1st season)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Irrigated rice (2nd season)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
Peanut	1.02	0.15	0.15	0.70	0.15	0.15	0.66	0.15	0.15
Cotton	-	-	-	1.42	0.21	-	1.42	0.95	0.01
Market supply of paddy	2749	4131	4131	2232	5154	5492	2287	3979	5475
Expected profit [$E(\pi)$]	439899	684604	787890	353012	570800	711371	322415	552170	710787

Table 16. Simulation of the effects of changes in paddy prices on cropping patterns — oxen farms, Sirraso village

Crop (ha)	$\Phi=0$			$\Phi=0.5$			$\Phi=1.5$		
	P0	P1	P2	P0	P1	P2	P0	P1	P2
Maize	5.22	0.08	0.08	5.22	0.08	0.08	0.38	0.17	0.08
Upland rice	-	5.14	5.14	-	5.14	5.14	2.39	5.05	5.14
Irrigated rice (1st season)	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Irrigated rice (2nd season)	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
Peanut	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Cotton	-	-	-	-	-	-	2.45	-	-
Market supply of paddy	6389	21084	21084	6389	21084	21084	13234	20805	21084
Expected profit [$E(\pi)$]	2169289	2769593	3296707	2169289	2769593	3296707	1131541	2766714	3296707

5. Conclusion

This paper has analyzed the cropping systems of three villages in the Sudan and sub-Sudan zone of the savanna of Côte d'Ivoire. The analysis shows that risk-efficient cropping patterns varied by farm type (i.e., manual, oxen and tractor farms) and by the risk attitude of the farmer.

The model results show that existing cropping patterns of farmers in the study villages are not risk-efficient, and that substantial reductions in income risks (and increased income gains) can be made by re-allocating the existing crop mix. In particular, the results show that maize is the crop with highest risk in the two zones and that risk averse farmers should reduce their area under maize in a risk-efficient crop plan. The relatively high risk of maize in the Sudan zone is due largely to its high yield variability. Technology development strategies to expand the maize area in the zone may need to focus more on yield stability in order to lower the risks that farmers face. The relatively higher success of maize in the Guinea savanna zone may be due to the higher rainfall and lower yield risks in this zone compared to the Sudan zone (Smith et al. 1993, Lawson and Juo, n.d.).

Table 17. Normative marketed rice supply and rice acreage response elasticities in three villages of the savanna zone of Côte d'Ivoire

	Sudan zone			sub-Sudan zone			
	Mbengue			Napie		Sirasso	
	Manual	Oxen	Tractor	Manual	Oxen	Manual	Oxen
Acreage response elasticity	0.64	1.37	n.a	0.79	0.62	1.40	2.30
Marketed supply response elasticity	0.62	0.68	n.a	1.02	0.75	0.85	1.30

The model results have implications for strategies to increase rice production in the savanna zone. Rice cultivation in the zone is mainly dependent on upland rice. Available estimates in Côte d'Ivoire (Becker and Diallo 1992) indicate that rice area in the savanna zone is about 117,500 ha, which is about 34% of the total rice area in Côte d'Ivoire. Upland rice systems account for 66% of the rice area in the savanna zone, while irrigated rice represents 8%. Floodplains and lowlands account for 11% and 9% respectively. Model analysis of the response of rice farms in the zone to output price changes indicate that normative acreage response elasticities vary by village location and by farm-type. In general, increased economic incentives for rice production will lead to a significant expansion of cultivated rice area. However, the results from the model indicate a potential danger: The majority respond by expanding the upland rice area. The inelastic supply of land in the lowlands limits production extensification, however, the introduction of intensive land-use technologies could significantly raise yield per unit area. The perfectly inelastic supply of irrigated land (for double cropping of rice) in the zone severely constrains the potential for increasing rice output in response to economic incentives.

Despite the possibilities for expanding the area under rice in the abundant uplands of the savanna zone, the effect of such a land extensification strategy on marketed output is likely to be limited, due largely to low yields. Our results suggest that new technologies for increasing land productivity of upland rice are urgently needed in the Sudan zone, as this is likely to be the ecosystem where price incentives will result in area expansion under rice. Under such conditions, research efforts may need to concentrate on technologies that can reduce the likely negative soil fertility effects of the continued expansion of upland rice on the poor soils of the Sudan savanna.

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TECHNOLOGY DEVELOPMENT, TESTING AND TRANSFER: An Overview of ICRISAT's Experience in Semi-arid Africa

S.V.R. Shetty[1], S.K. Debrah[2] and C. Renard[1]

[1]*International Crops Research Institute for the Semi-arid Tropics (ICRISAT) Sahelian Center, Niamey, Niger*

[2]*West African Sorghum Improvement Program, Bamako, Mali*

Key words: ICRISAT, semi-arid tropics, sorghum, millet, groundnuts, networks, NARS

Abstract: The International Crops Research Institute for the Semi-arid Tropics (ICRISAT) has a mandate to improve the productivity and stability of six major crops basic to life and to develop sustainable farming systems in the semi-arid tropics (SAT). This paper presents an overview of ICRISAT's operations with particular reference to its experience in technology development and transfer activities in sub-Saharan Africa. The agroclimatic and socio-economic characteristics of the semi-arid tropics are first described. ICRISAT's initial intervention in selected countries of West Africa is summarized and examples of achievements in strengthening national programs cited. The present structure of centers, teams and networks which was built on the initial experience is highlighted. The progress made in generating improved cultivars and developing component technologies through resource management research is outlined and examples given. Technology transfer activities including networking and human resource development are also described.

The features of ICRISAT's analytically rigorous future plan and the criteria used to develop research themes are highlighted. For the mid-term plan, biotic constraints under crop improvement programs, rain water management and soil conservation were given top priority. Finally, the paper recognizes the need for collaborative research with IITA and national agricultural research systems (NARS) in the wet/dry SAT in the northern Guinea zone of West Africa where the cropping systems involve ICRISAT's mandate crops.

1. Introduction

The mandate of ICRISAT is to improve the productivity and stability of the six major crops basic to life in the semi-arid tropics (SAT) and to develop improved and sustainable farming systems that will make optimum use of resources. The mandate crops include sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.), finger millet (*Eleusine coracana* L.), pigeon pea (*Cicer arietinum* L.), chickpea (*Cajanus cajan*) and groundnut (*Arachis hypogaea* L.). The SAT areas are spread over nearly 20 million square kilometers and cover all or parts of 50 nations on five continents.

The International Crops Research Institute for the Semi-arid Tropics has its headquarters at Patancheru, India, but a significant number of its research activities are based in Africa. The two main research centers in Africa are the ICRISAT-Sahelian Center near Niamey, Niger and the SADC/ICRISAT Southern Africa program near Bulawayo, Zimbabwe. In addition, scientists are also based in other locations: in Kano, Nigeria; in Samanko, Mali in the West African Sorghum Improvement Program (WASIP); and in Nairobi, Kenya in the Eastern Africa Cereals and Legume Research Program (EARCAL). In addition there is a Southern Africa Regional Groundnut Program based in Lilongwe, Malawi.

This paper presents a brief summary of ICRISAT's activities and some examples of its achievements in semi-arid tropical (SAT) Africa. The resource base of the SAT of Africa and ICRISAT's approach in addressing the constraints to improved productivity and sustainability are described. ICRISAT's future plans for the medium term are outlined in the last section. As this workshop's major objective was to prioritize research and development needs in the moist savanna, the paper also indicates some possible areas for cooperative research in the northern Guinean zone of West Africa.

2. The Semi-arid Tropics in Africa

According to the classification given by Troll (1965) the SAT are the areas located in the seasonally dry tropical climates where the mean annual temperature exceeds 18° C and the rainfall exceeds potential evapotranspiration for only 2 to 4.5 months (dry SAT) and for 4 to 7 months (wet/dry SAT). The coefficient variability of rainfall in the SAT is high, ranging from 20 to 40%. The SAT area in Africa, based on this classification, is shown in figure 1. Most of Africa's western, eastern and southern regions fall under SAT.

In West Africa, the mean annual rainfall varies from 250 to 1250 mm. The rainfall isohyets run parallel with the equator with southern bands receiving more rainfall. The variability of the annual rainfall increases with aridity from south to north. Monthly mean rainfall increases gradually from the beginning of the rainy season in early summer to a maximum in August.

In East Africa the rainfall zones are more complex because of the presence of highlands with altitudes of 3000-5000 m. The mean annual rainfall for two-thirds of the stations is between 600 and 1200 mm, the rest receiving amounts in excess of 1200 mm. The highlands receive more rainfall than adjoining lowlands. In East Africa it is not possible to forecast annual rainfall in terms of geographical coordinates (Sivakumar and Virmani 1981). Rainfall variability in Southern Africa is also fairly large. However, as one moves upwards to the equator the rainfall tends to increase. The rainfall data show that moisture availability is difficult to predict, particularly in the later part of crop cycles in the African semi-arid tropics. The length of the growing period ranges from 80 days in the Sahelian boundary to 270 days in the southern regions of Ghana, Nigeria and Sudan. South of the equator, the season in parts of Namibia, Botswana, Zimbabwe and Mozambique is again reduced to 80 days.

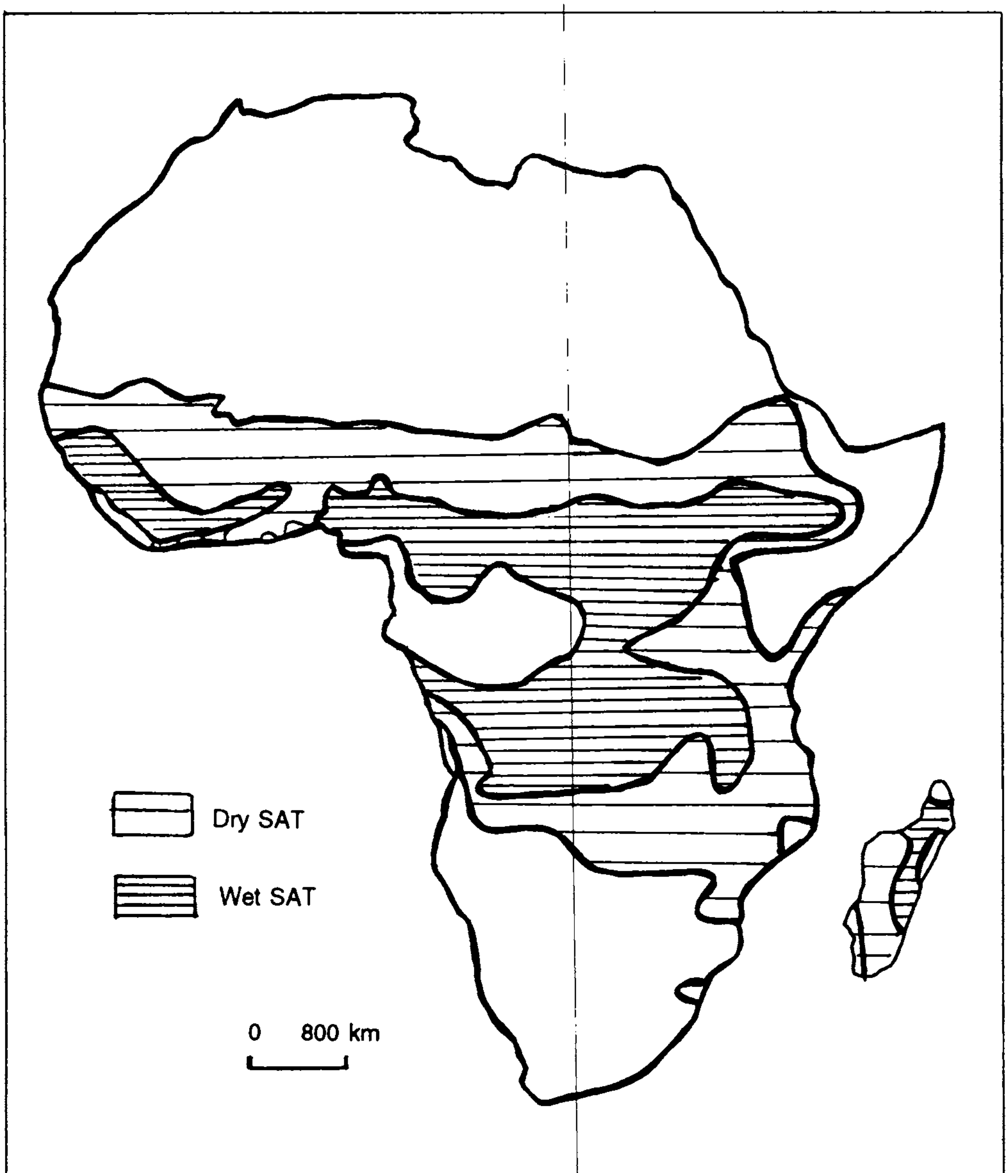

Figure 1. Semi-arid tropics in Africa
Source: Progress report of climatology (ICRISAT 1980-81)

In the sorghum and millet growing areas of semi-arid Africa the major soil zones identified are Arenosols, Luvisols, Ferralsols, Vertisols and complex soils. Arenosols are sandy soils that occur in the northern boundary of West Africa and along the southern boundary of Mozambique, Zimbabwe and Zambia. Luvisols occur in the more moist climates of the Sudanian ecological zone in West Africa. Ferralsols are the most weathered soils, situated towards the wet boundary of the SAT. Vertisols cover large areas in Sudan and Ethiopia. The complex soils include Nitosols, Lithosols, Cambisols and Ferralsols found in most of Tanzania, Kenya and parts of Southern Africa. Most of these soils are poor in natural fertility and susceptible to water and wind erosion. They lack buffering capacity because of low soil organic matter and tend to be acidic in nature. They have poor structure and low moisture-holding capacity.

Agricultural production is the major occupation of the inhabitants of semi-arid Africa where about 70% of the population live in rural areas. The socio-economic environment is characterized by high population growth rates, rapid urbanization, declining food production and slow economic growth. The human population of sub-Saharan Africa in 1990 was 489 million and it is growing at an annual rate of 3.2%. It is projected to reach 1294 million by 2035 (Bulatao et al. 1990). The urban population, which currently stands at 29% of the total population and is growing at a rate of 5.7%, is projected to represent 54% of the total population by the year 2025 (United Nations 1985). Per capita food production in sub-Saharan Africa has meanwhile been declining. Over the period 1962-1983, per capita production of the principal crops decreased at -1.6% (Jayne et al. 1989). During the eighties, the gross domestic product grew at one per cent per year, compared with 4.3% in developing countries. However, as a result of the rapid population growth, per capita incomes decreased at an annual rate of 2.2% in the mid to late 1980s, but are predicted to grow at 0.5% per annum in the 1990s (World Bank 1990).

Based on these projections, per capita coarse grain consumption is expected to grow at an annual rate of 2.2% up to the year 2005, and at 3.2% per annum between 2005 and 2030 (Crosson and Anderson 1992). The projected rate of growth in consumption is considerably greater than the growth in food grain production, and unless food grain production keeps pace, we can expect to see increases in the relative prices of coarse grains, that could adversely affect the absolute poor who depend directly on these grains for subsistence. It is against this background that ICRISAT, in collaboration with its partners in sub-Saharan Africa (SSA), have focussed attention on agricultural productivity over the last 15 years.

3. ICRISAT's Intervention

Prior to the establishment of the regional research focus in the early 1980s, ICRISAT staff were only posted out to a few individual national agricultural research systems (NARS) in the West African semi-arid tropics (WASAT). The principal objective of those outreach programs was to strengthen the capacity of NARS in conducting research on sorghum and millet. Institutional strengthening by collaborative research and infrastructure development and training were the major objectives in those early years. Staff based in Burkina Faso, Mali, Senegal, Nigeria and Niger were also able to identify common constraints to agricultural production in the region.

The similar nature of the constraints and the limited number of qualified personnel available to conduct appropriate research provided the impetus for the establishment of regional research centers. Such a regional approach involving a 'critical mass' of scientists achieves economies of scale and efficiency, avoids duplication of effort, provides the synergistic effect of exchanging information and combines the collective experience of professionals.

Presently, the regional research teams based in sub-Saharan Africa include:

a. the ICRISAT Sahelian Center (ISC) in Niger, where strategic and applied research in resource management and crop improvement research in millet and groundnut are conducted
b. the West African Sorghum Improvement Program (WASIP) with teams based at Kano, Nigeria and Samanko, Mali
c. the Southern African Development Community (SADC) ICRISAT program on sorghum and millet at Mataphos, Zimbabwe and on groundnut at Lilongwe, Malawi
d. the Eastern African Cereal and Legumes (EARCAL) team based in Nairobi, Kenya, where research is conducted on sorghum, millet and pigeon pea

At the Sahelian Center, Niamey, ICRISAT scientists in the Resource Management Program cover agroclimatology, agroforestry, agronomy, soil and water management and economics. It was soon realized that the complexity of the production systems required the expertise of scientists from other disciplines not part of ICRISAT mandate, and researchers from other centers and institutions are associated in the following collaborative programs:

International Livestock Research Institute (ILRI) (formerly ILCA) — animal nutrition, animal traction, livestock economics and manure management

International Plant Genetic Resource Institute (IPGRI) (formerly IBPGR) — genetics resources

International Centre for Research in Agroforestry (ICRAF) — agroforestry genetics

International Food Policy Research Institute (IFPRI) — food policy cowpea agronomy

International Fertilizer Development Center (IFDC) (University of Wageningen) — soil chemistry and soil physics

This arrangement has led to a well-structured multi-disciplinary team able to cover a much broader field of resource management research. Similarly, in the Pearl Millet Program, genetics aspects are covered by the Office de la Recherche Scientifique et

Technique d'Outre-mer (ORSTOM). The Sorghum Program, based in Mali, is reinforced by a team of scientists from Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD).

The ICRISAT research teams located in these regions provide bases for strategic and applied research and contribute to improving germplasm, components of technologies, training of national scientists and disseminating information. They also provide the technical core for regional networks and training programs. Networks, along with research teams, assist national scientists and enhance their participation in cooperative research. The foundation for the concept of organization by centers, teams and networks was built on the experience acquired by ICRISAT from research activities in West Africa from 1976.

In the early years it was believed that similarities in the constraints that limit the production of pearl millet and sorghum in India and Africa would facilitate the transfer of improved genetic material from India to West Africa. However, the first phase of research in West Africa indicated that such direct transfer was not possible. The major factors that hindered the adaptation included:

a. vulnerability to high temperatures at seedling emergence and sand blasting, resulting in few plant stands and reduced vigor and development
b. poor adaptation to low fertility conditions
c. susceptibility to diseases, insect pests and *Striga*
d. inappropriate length of time from emergence to maturity and morphological traits

In view of these factors, efforts by the regional teams were later directed towards promoting adaptation by incorporating local germplasm into the breeding material *in situ*. These efforts have resulted in the development of several improved varieties (table 1).

The early phase of ICRISAT's intervention in WASAT also helped build a good sorghum and millet research base in the national programs of the region. Prior to the 1970s these two crops had received little research attention. Infrastructures in terms of research facilities and trained manpower were lacking. The experience of the ICRISAT-Mali cooperative program is a good example of such an institutional building approach followed from the start. The program helped in developing facilities and qualified personnel for the sorghum and millet programs of Mali. The establishment of the Cinzana research station, the construction of a food technology laboratory in Bamako, the long-term training of 11 senior Malian researchers, the short-term training of 59 middle-level researchers and technicians, the training of 67 agricultural college students in sorghum and millet research through internship, and the establishment of strong links between the Mali national program and other regional and international programs have resulted in Mali's Institut d'Economie Rurale (IER) being generally considered as the leading sorghum and millet research institution in West Africa (Shetty et al. 1992).

Table 1. ICRISAT materials released for use in the national agricultural research systems in sub-Saharan Africa by December, 1991

ICRISAT name	Released name	Country of release	Year	Remarks
Sorghum				
Hageen Durra 1	Hageen Durra 1	Sudan	1982	Hybrid
ICSV 2	ZSV 1	Zambia	1983	Cultivar
IS 9302	ESIP 11	Ethiopia	1984	Cultivar
IS 9323	ESIP 12	Ethiopia	1984	Cultivar
ICSV 1	SPV 351	Malawi	1989	Cultivar
ICSV 112	SV 1	Zimbabwe	1987	Cultivar
ICSV 88060	SV 2	Zimbabwe	1987	Cultivar
SDS 3220	Macia	Mozambique	1989	Cultivar
IS 8571	Mamonhe	Mozambique	1989	Cultivar
WSV 387	Kuyuma	Zambia	1989	Cultivar
WSV 187	Sima	Zambia	1989	Cultivar
IS 2391	SDS 1513	Swaziland	1989	Cultivar
IS 3693	SDS 1594-1	Swaziland	1989	Cultivar
ICSV 1007 HV	Mugawin Buda 1	Sudan	1991	*Striga* res. cultivar
IS 9830	Mugawin Buda 2	Sudan	1991	*Striga* res. cultivar
Pearl Millet				
Serere composite 2	Uganda	Sudan	1991	Dev. in Uganda
ICMV 1	WC-C75	Zambia	1987	Cultivar
ICMV 5	ITMV 8001	Niger	1985	Cultivar
ICMV 6	ITMV 8092	Niger	1985	Cultivar
ICMV 7	ITMV 8304	Niger	1985	Cultivar
ICTP 8203	Okashana 1	Namibia	1989	Cultivar
ICMV 82132	Kaufela	Zambia	1989	Cultivar
IKMV 8201	IKMV 8201	Burkina Faso	1991	Cultivar
L.Backup Composite	Lubasi	Zambia	1991	Cultivar
IE 2929	Lima	Zambia	1989	Finger millet
Groundnut				
Sel.Robust 33-1	Johari	Tanzania	1985	Cultivar
ICG 7794	Roba	Ethiopia	1988	Cultivar
ICGMS 42	CG 7	Malawi	1990	Cultivar
	MGS 4	Zambia	1990	Cultivar
ICGV 86194	Sinkarzei	Ghana	1989	Cultivar

Source: ICRISAT (1992) semi-arid tropical rainfed agriculture: Opportunities and challenges. A report presented to the World Bank, Washington, DC.

Similar activities in other countries have also resulted in the development of a research infrastructure. In 1975, necessary physical facilities were established at Kamboinsé in Burkina Faso. In Niger, the Institut National de Recherche Agronomique du Niger (INRAN) has been assisted to develop the physical facilities for a research station at Tara in southern Niger, where there is a good potential for improving crop productivity in the Sudan zone. In Nigeria, a new research station at

Bagauda has been developed and completed while the national scientists from the Institute of Agricultural Research (IAR) will share the use of laboratories at Kadawa.

4. Progress in Research, Technology Development and Transfer

As indicated above, early interventions by ICRISAT have enabled scientists to identify the principal constraints to agricultural production in the SAT of Africa. Table 2 gives examples of constraints to cereal production in the WASAT and the strategies adopted by ICRISAT and collaborating NARS in the region to address them. The research process consists of combining elements of crop improvement such as genetics, breeding, crop physiology and crop protection, with those of resource management — soils, climate, agronomy, socio-economics, etc. — to produce such intermediate products as germplasm and/or such final products as varieties, techniques and technologies.

Table 2. Strategies to overcome major on-farm constraints to sorghum and millet production in West Africa

Constraint	Factors	Strategies
Stand establishment	Moisture, temperature, sand storms	Superior varieties, tillage, ridging, crop residues
Moisture stress (drought)	Drought during crop establishment and grain filling	Timely planting, correct planting densities, soil management, early and drought-tolerant varieties, tailoring cultivars
Nutrient stress (soil fertility)	Low inherent fertility	Timely planting, fertilization, rotation, intercropping, efficient nutrient use, manure, genotypes
Insects	Stem borers, panicle insects	Host-plant resistances, cultural practices, integrated pest management (IPM)
Diseases	Downy mildew, smut etc.	Genetic resistance, IPM
Weeds	*Striga*, and other annual and perennial weeds	Cultural practices, genetic resistance, IPM
Traditional cultivars	Susceptible to stresses	Adapted and high yielding varieties with stability of production
Traditional management	No tillage, local varieties, low densities, minimal inputs	Improved management techniques, Improved varieties
Consumer acceptance	Grain quality	Improved varieties with ease of dehulling acceptable for local products

It should be noted, however, that the research process is collaborative in nature, not only within the institute but also among the NARS of the region. The crop research networks provide excellent vehicles for interaction with NARS in developing and testing improved cultivars and technologies.

It is out of the scope of this paper to list in detail the products of ICRISAT's research and development activities. Some examples of the products of research, with particular reference to the West African semi-arid tropics, are given below.

4.1 Varietal development

Table 2 lists some ICRISAT materials that have been released in sub-Saharan Africa by 1991. A large number of ICRISAT's materials are also currently in various stages of use in different NARS. The research networks provide excellent vehicles for the exchange of ICRISAT and NARS germplasm in the sub-region. In a recent survey of the 17 West and Central African sorghum research network member countries, roughly 83% of the 206 varieties tested in the network's regional trials between 1988 and 1992 were being used in farmers' fields, in multi-locational tests, in pre-release stages or had been released in the various countries. Notable varieties coming out óf this network are Nagawhite, ICSV 111 IN, S-35, ICSV 1078 BF, Malisor-84-1, ICSV 1089 BF and ICSV 1063 BF, with yield potential greater than 3 tons ha^{-1}. These yields are about four times higher than the average yields of the local varieties used as controls in the regional trials. Similarly, through the auspices of the West and Central African Millet Research Network, several varieties of pearl millet are being grown by farmers, and multiplied and evaluated on-farm and on-station in nine countries.

4.2 The development of techniques and cereal technologies

4.2.1 *Climatic data analysis and cropping strategies*

The relationship between the onset of the rains and the length of the growing season has been used by ICRISAT scientists to predict rainy season potential. This serves as an early warning and also helps farmers to adopt cropping strategies accordingly. The Institute, with other agencies such as AGRHYMET, predicted that the 1987 rainy season in the Sahel would be short, with crop yields probably falling below average. This information helped the authorities make provision for the shortfall at the national level, as pearl millet yields were indeed significantly below the 1986 yield level. At ISC, scientists have also demonstrated that in years when the rains are early, a second crop of cowpea can be relay planted for hay after a first crop of millet.

4.2.2 *Land and water management technologies*

Vertisol management, as well as improved land and water management practices to alleviate water-logging developed at the ICRISAT center are now being applied successfully in Ethiopia. The ICRISAT-Burkina Faso program showed that a combination of permeable rock bunds (a water harvesting technique) and tied ridges (a soil management technique) increased sorghum and millet yields by roughly 55%. At ISC, the introduction of *Andropogon gayanus* into the farming system, not only served to create wind barriers to protect pearl millet seedlings, but have also resulted in higher economic gains with additional stover yields from *A. gayanus*.

4.2.3 *Labor-saving technologies*

Scientists at the ICRISAT Center for Vertisol Management have developed different types of animal-drawn equipment, such as the wheeled tool carrier (tropicultor or nikart). These are being evaluated on Vertisols in Ethiopia. In West Africa, donkey-drawn equipment has been developed and is being used for land preparation, weeding and other activities, making them less laborious, as was done in Burkina Faso, where tied ridges were constructed with donkey-traction. In the WASIP-Mali program, scientists are testing, with farmer participation, the herbicide 2-4 D for *Striga hermonthica* control on a large scale. If it is found economical and is adopted, labor used for hand-pulling the parasitic weed could be released for other activities.

4.2.4 *Techniques to improve productivity: Fertilization, intercropping and crop management*

Techniques, combining the use of selected varieties, fertilization, spatial arrangements, planting dates and rotation, have led to several promising technologies. At ISC, results of tests on various components have shown that in the millet-based cropping system, applications of small quantities of P (13 kg ha^{-1}); the use of the improved millet variety, ICMV5, and the cowpea variety, TVX3236, at higher densities; ridging with first rains and sowing on ridges; use of animal traction for ridging and weeding; and crop rotation, have combined to give yield advantage, amounting to more than 100%, in both good and bad years. In Burkina Faso, the technological packages using various combinations of variety, fertilizer and irrigation gave sorghum and millet yields ranging from 400 to 4500 kg ha^{-1}. The ICRISAT-Mali bilateral program has also developed sorghum-cowpea, millet-cowpea and millet-maize intercropping systems that have resulted in yield increases of between 30% and 40% over those produced in the corresponding traditional systems.

4.2.5 *Cereal demand and utilization enhancing technologies*

At the Ahmadu Bello University in Zaria, the West and Central Africa sorghum research network is conducting studies on the sorghum-wheat composite flour technology for bread and confectionery. Using the white sorghum variety SK 9212 to supply 50% of the composite flour, acceptable and less expensive bread which is within the reach of poor consumers has been produced. Also in Nigeria, the technical feasibility of using 100% sorghum for beer brewing has been demonstrated, though only 2.5% of the total domestic production of sorghum is currently being used for beer. In Mali, the food technology laboratory research on cereal-cereal and cereal-legume combinations has led to the development of simple weaning food recipes that are widely used in the rural areas. Similar studies by SADC/ICRISAT on alternative utilization of sorghum and millet are also generating useful results.

4.3 Technology transfer

The spread and adoption of the products of research are conditioned by policy changes, market availability, infrastructure and resources in the countries of use. The visible impact of ICRISAT's cereal research has mainly been in the provision of elite genetic material and improved varieties to the crop improvement programs of NARS. Specialized training has also been provided to NARS in hybrid seed production and advanced research techniques and methodologies. At the farm level, data obtained so far from some NARS show that the utilization of new varieties is limited. This may be explained by the length of time necessary for the effective diffusion of available varieties, in view of the weak links of the technology transfer infrastructure in most countries of West Africa. Important prerequisites for the effective transfer of technologies to farmers in many countries in the region include the establishment of operational seed multiplication units to support the diffusion of improved varieties, and operational extension services and input supply infrastructure to help the adoption of improved agronomic techniques.

Climate analysis, intercropping systems research, screening methods for biological and physical stress and statistical methods for experimental data analysis are receiving increased attention from NARS scientists. Two crop networks in the WASAT, coordinated from ISC (pearl millet) and WASIP-Mali (sorghum) have provided useful vehicles for transferring these research methodologies and using them for human resource development and for strengthening national agricultural systems. These networks, though coordinated from ICRISAT locations, are managed by NARS representatives, who determine priorities and allocate donor funding for activities. They emphasize the exchange of improved technologies and cover annual planning meetings, workshops to develop activity plans and tours for monitoring activities. Approved projects assign part of their funds towards training extension workers and farmers. At present, four projects are being implemented by the West African pearl millet network:

Project 1. The provision of early varieties of seeds to farmers in the Sahelian zone and adapted varieties in other millet growing zones is in operation in Burkina Faso, Cameroon, Côte d'Ivoire, Mauritania, Niger and Nigeria. This project includes on-farm trials with improved varieties. The trials are conducted by the NARS in close collaboration with their respective extension and development agencies.

Project 2. The integrated control of millet head insect pests is active in Benin, Gambia, Ghana, Guinea Bissau, Nigeria and Togo.

Project 3. The improvement of the control methods for downy mildew in pearl millet has been initiated in Burkina Faso, Ghana, Mali, Niger, Nigeria and Senegal.

Project 4. The improvement of millet production systems has been initiated in Niger, Burkina Faso, Mali, Senegal and Côte d'Ivoire to develop and evaluate alternative, more productive and sustainable millet production systems.

4.3.1 *Human resource development*

Human resource development is the key to developing strong national programs in the SAT. Considerable emphasis has, therefore, been placed on in-service and graduate training of national staff. Table 3 provides a summary of African participants in the human resource development program at the ICRISAT Center. The program is funded by many donor agencies.

Table 3. Participants in the human resource development programs at ICRISAT Center, 1974-1992

Region	Total	Post-doctorate	Senior research fellow	Research fellow	Research scholar	National scientists	6-month partici-pants
West Africa	500	3	2	29	7	33	425
East Africa	371	3	6	47	29	56	230
Southern Africa	231	1	1	11	4	30	184

Between 1984 and 1991, 41 international, regional and national workshops and conferences were also organized (table 4). In recent years, participation in network organized workshops and meetings has been increasing. Training programs, workshops and conferences are also organized to provide an opportunity for interacting with NARS scientists and establishing contacts for future collaborative research.

5. Future Plans

The Institute has just developed a medium-term plan for the period 1994-98, based on a detailed analysis of the economic consequences of the various constraints encountered in the semi-arid tropics. The features of this plan are that it is analytically rigorous, transparent in the process and criteria used to make choices, draws on extensive agro-climatic and socio-economic data bases and involves all scientists in ICRISAT and the major NARS in an interactive process. The choices of research themes were based on four criteria:

a. efficiency — as measured by the net benefit/cost ratio
b. equity — as measured by the number of absolutely poor people and the number of female illiterates
c. internationality — as measured by the Simpson Index of diversity
d. sustainability — as measured by the likely contribution to the conservation of the natural resource base

Table 4. Workshops, monitoring/study tours, meetings, and training courses, organized by ICRISAT and its networks in Africa

	International	Regional	National	Total
West Africa (total)	6	30	5	41
Millet	-	14	-	14
Groundnut	-	2'	-	2
Resource Management	3	2	1	6
West African Sorghum Program	-	10	-	10
ICRISAT/Mali	-	-	4	4
Others	2	1	-	3
East Africa (total)	-	8	-	8
Sorghum and millet improvement	-	7	-	7
Pigeon pea	-	1		1
Southern Africa (total)	5	37	1	43
Sorghum	2	6	-	8
Pearl millet	2	7	-	9
Finger and small millet	1	2	-	3
Resource management	-	4	1	5
Forage	-	5	-	5
Groundnut	-	9	-	9
Pigeon pea	-	1	-	1
Others	-	3	-	3

In developing protocols for potential research themes, considerable attention was given to the delineation of appropriate research domains where the various constraints were identified. The crop improvement programs used production systems and yield constraints as the primary criteria for defining their domains or zones of adaptability. The resource management program found that the most appropriate method for reviewing research opportunities was by using soil and climate-based research domains. In prioritizing research themes, biotic constraints received high priority under crop improvement programs, while abiotic constraints and the conservation of natural resources were considered important under resource management. Since soil fertility and water are the two major constraints to increased and stable agricultural production in the SAT, rain water management and soil conservation research were given top priority in the mid-term plan.

Future plans illustrate the increasingly strategic focus of ICRISAT's research portfolio in recognition of the growing strength of many of its NARS partners. However, in SAT-Africa, ICRISAT hopes to maintain a proper balance between strategic and applied research, and in collaboration with NARS, achieve an effective impact on agricultural research in Africa. This increasingly collaborative nature of the research with NARS will require that future assessments of socio-economic impacts should be based on the joint rather than on the separate impacts of NARS and ICRISAT. It is also hoped that the joint collaboration between national and international agricultural research will achieve the goals of increased agricultural productivity, alleviation of poverty and sustainable agricultural development.

5.1 ICRISAT's plans for the moist savanna

The wet/dry SAT in West Africa include a substantial area of the north Guinean zone. The cropping systems of this zone also include ICRISAT mandate crops; sorghum, pearl millet and groundnut. Though, in the past, ICRISAT did not have a specific research program in this zone it now believes that this area deserves its attention, particularly from the resource management point of view. ICRISAT could collaborate with IITA in characterizing the production environment and could, in collaboration with NARS, develop and test sorghum and groundnut-based cropping systems in the zone.

The longer growing season in this area of high potential provides greater opportunities for system manipulation with appropriate genotypes and management. Limited past studies in Mali and Nigeria have shown that when improved genotypes are planted at a more appropriate time in the rainy season they could not only bring stability to production, but also could provide more time and opportunity for the establishment of associated crops such as maize, sorghum, pearl millet, groundnut and cowpea. With appropriate genotypes and dates of planting and harvest, and better resource management, more productivity could be achieved through inter, relay, ratoon and sequential cropping systems. Such systems to improve cropping intensity can serve, not only as a biological approach to resource management, but also help limit the area brought under cultivation. A few leading NARS, IITA, and ICRISAT could jointly elaborate an appropriate research proposal to work on common cropping systems at a few selected benchmark sites in the moist savanna.

Looking ahead, ICRISAT has realized that the challenge for agricultural research in the SAT transcends the 'food first' imperatives of the sixties and seventies. In the nineties and beyond, the objectives are threefold: increased agricultural productivity, poverty alleviation and sustainable agricultural development. To meet these objectives, which cannot be addressed by commodity-based programs only, a multi-disciplinary team of researchers is better armed for operating in a given eco-region.

The impact of agricultural research will be assessed by its contribution to the restoration of resources, sustainability of production systems, and welfare of the populations. This broad field of activities requires more collaboration than in the past between the different actors operating in the region: IARCs, NARS and universities.

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AGRICULTURAL INNOVATION IN THE COTTON ZONE OF FRANCOPHONE WEST AND CENTRAL AFRICA

Pierre-Marie Bosc and Ellen Hanak Freud

Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) 42, rue Scheffer, 75116 Paris, France

Key words: innovation, cotton, maize, sorghum, vertical integration, input credit, soil fertility, West and Central Africa

Abstract: This paper examines the adoption of improved technologies in the cotton-cereal based farming systems of the francophone savanna zones of West and Central Africa, in the context of the large cotton development projects which have long characterized these zones. Overall, the record on technology transfer is very good, with widespread adoption of improved varieties, mineral fertilizers, phytosanitary treatments and animal traction for cotton, and, to some extent for maize, when market outlets have been assured for the latter. These innovations have been facilitated by the particular institutional context of a well-managed, vertically integrated cotton subsector, notably comprising: (1) close research-extension-farmer links, (2) the provision of input credit, and (3) guaranteed marketing outlets, via which credit is repaid. Cotton also appears to function as a lead crop for the intensification of cereals. The existing challenges are both institutional and technical in nature. First, how, under the current wave of privatization measures, to maintain the minimum level of services needed for the integrity of the input credit system? Second, how to introduce economically viable combinations of organic and inorganic fertilizers into the cropping systems for the maintenance of soil fertility under continuous cultivation?

1. Introduction: Why focus on the cotton zone?

A situation peculiar to the moist lowland savanna of francophone Africa — and more specifically of the former French colonies which are members of the CFA franc zone — is the continued presence of a special pre-independence model of development for commercial promotion of smallholder cotton cultivation (maps 1 and 2).[1]

[1] In Central Africa, this includes Cameroon, the Central African Republic (CAR) and Chad, and in West Africa, Benin Republic, Burkina Faso, Côte d'Ivoire, Mali, Senegal, and Togo. Niger, which is sometimes included in this grouping, is excluded from consideration in the present study in view of the very small quantity of cotton produced (6000 tonnes of seed cotton), and the considerably drier climate conditions, which require irrigation. For Mali, the data presented concerns only the zone covered by the Compagnie Malienne du (continued...)

The basic model consists of tightly run projects, which oversee the entire range of activities within the cotton sub-sector: farmer recruitment and supervision, input and credit supply, and the various stages of output marketing, including ginning activities. Institutional responsibility for project management within individual countries lies with national cotton development companies. The similarity of the model across the countries stems from the close, long-term association of these companies with two institutions operating on a regional scale: the French-based Compagnie Française du Développement des Fibres Textiles (CFDT), which, in addition to providing the export outlet, has furnished management and technical support; and the network of cotton research institutes linking the French-based CIRAD (Cooperation Internationale en Recherche Agronomique pour le Développment; formerly IRCT — Institut de Recherche du Coton et des Textiles Exotiques) with the national agricultural research institutes within the zone.

For several reasons, the experience of the cotton zone is central to an understanding of the dynamics of technology transfer in the moist lowland savanna of francophone West and Central Africa. First, by virtue of their sheer size and longevity, the cotton projects have dominated the institutional landscape of the francophone savanna. The participation rates of rural households within the zone range from roughly one-quarter in Côte d'Ivoire, whose cotton zone reaches far enough south to include areas well-suited to other commercial crops to three-quarters in Mali. The leading role of these projects is even more apparent when one recognizes that since the early 1970s, as part of the general movement to focus on food security issues and basic needs, they have promoted intensification of the production of food crops, and especially coarse grains, as part of a rotational cycle with cotton. In some countries (Côte d'Ivoire, Mali, Cameroon, and Senegal), the cotton companies have actually had the official mandate for providing extension for the food crops in the zones in which they operate.

Secondly, this development model has had a relatively high degree of success. Cotton production over the entire zone doubled in the first decade after independence, and has more than tripled over the past 25 years (figure 1). As such, it provides one of the rare cases in Africa of increasing world market share (moving from 4 to 9 % of world exports between the 1979/81 average and 1992/93 — CIRAD 1993). Output growth has been accompanied by impressive productivity gains. In the field, the introduction of animal traction and yield-increasing input packages has brought estimated average yields of seed cotton from under 500 kg/ha to over 1000 kg/ha in the past 25 years (figure 2). These are average levels for rainfed cotton worldwide, and well above those in most sub-Saharan African countries. In the ginnery, fiber

(continued...)
Développement des Textiles (CMDT); a small amount of cotton (10,000 t.) is produced in the zone under the Office de Haute Vallée (OHV).

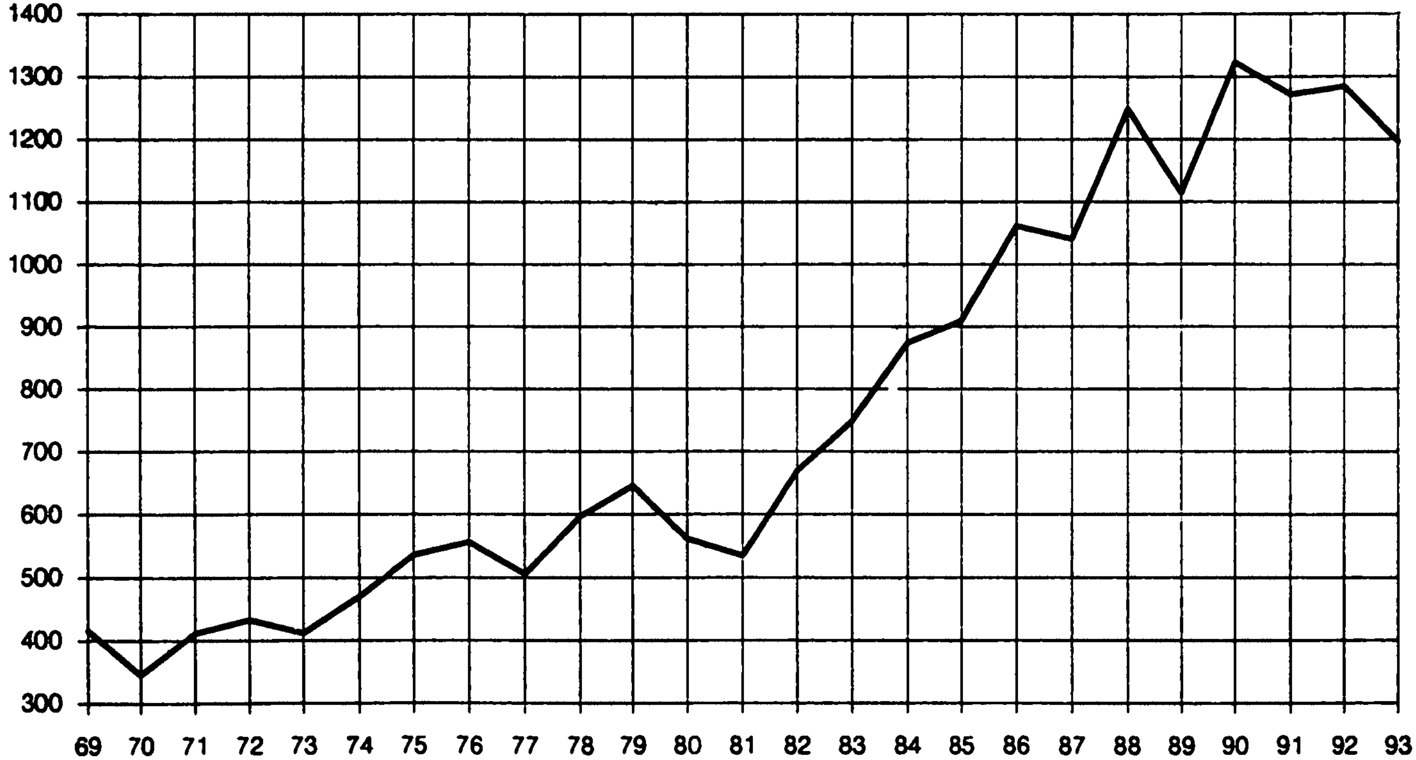
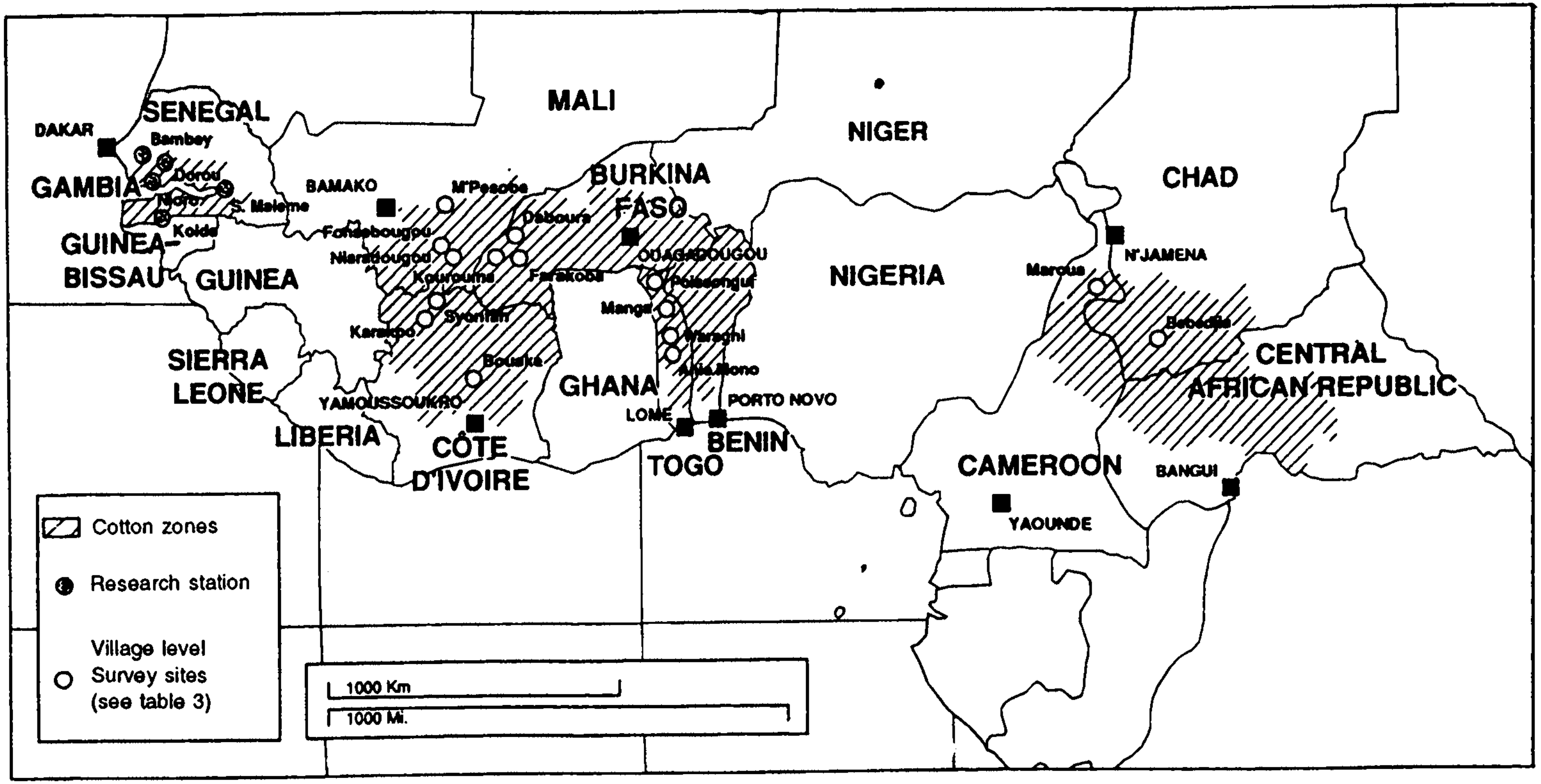
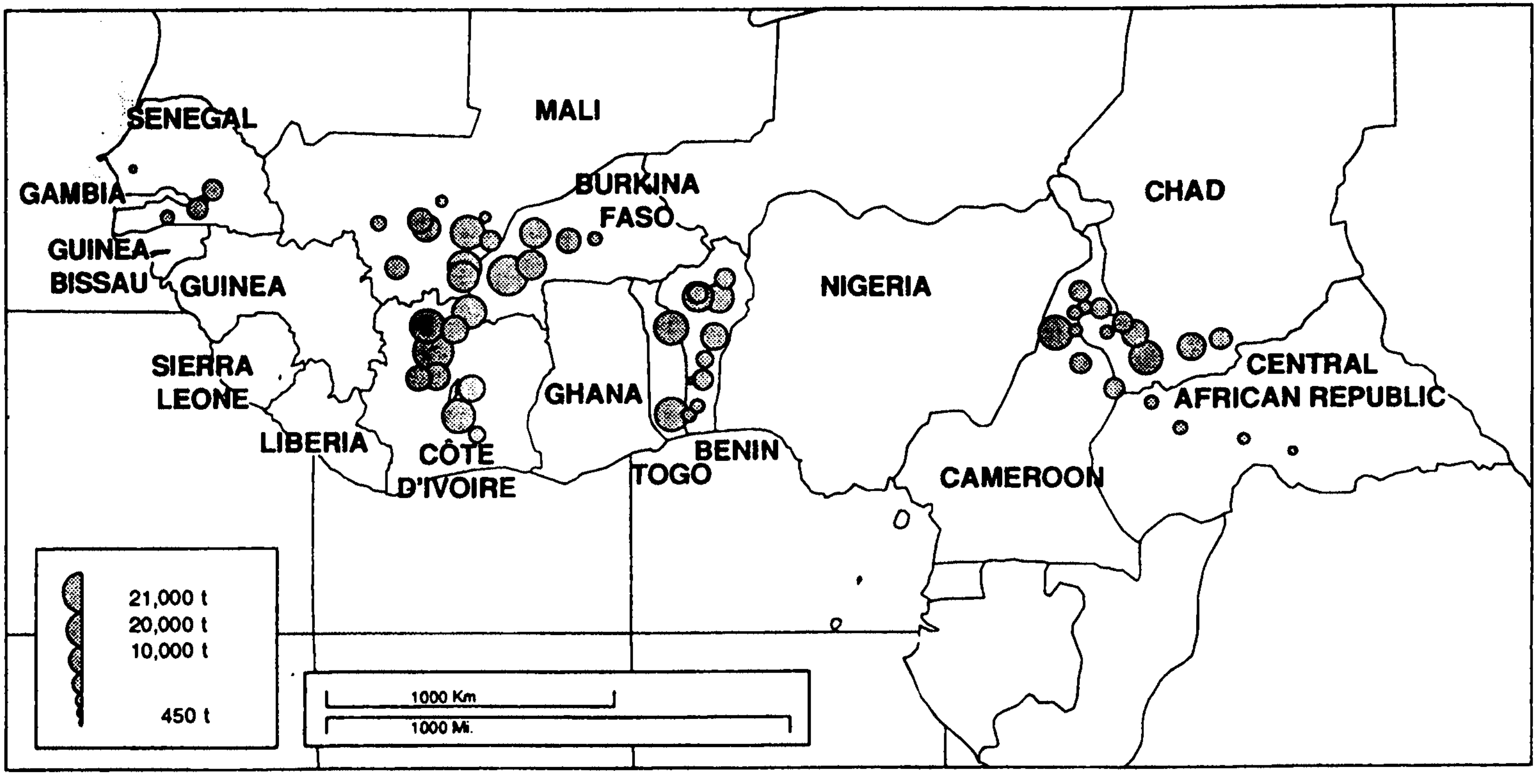


Figure 1. Seed cotton production in the franc zone countries ('000t)



Map 1. Cotton zones of West and Central Africa (CFA countries)
Source: Ministère de la Coopération (1991)



Map 2. Cotton fiber production by ginning sites (1992 1993)
Source: Compagnie Française du Développement des Fibres Textiles (CFDT)

extraction rates have moved from 35% in the early 1960s to over 40%, among the highest levels in the world.

For the national economies, cotton is an important source of export earnings.[2] At the local level, cotton has been the vehicle for monetizing the savanna economies, which, in contrast to the humid forest zones of the coastal countries, have had few alternatives for income generation in agriculture (Bosc and Hanak Freud 1995).

In food crops, the main innovation in the zone has been the expansion of maize cultivation, in some cases from initially minimal levels, and generally at the expense of the area under sorghum/millet. As a corollary to this there has been very limited adoption of improved sorghum varieties. For maize, the acreage expansion has been accompanied by varying degrees of productivity-enhancing measures. Cotton appears to function as a lead crop in encouraging technical innovations in the coarse grains.

For both cotton and food crops, the economic and technical challenges require responses from the research system and from the policy environment. The cotton subsectors have gone through two economic crises over the past decade, as a result of unfavorable price shocks on the international market, from mid-1984 to mid-1986, and again from mid-1991 to mid-1993. These shocks provoked a search for lower cost techniques, and called into question the institutional forms of the development model, including the degree to which the national cotton company should ensure the provision of its various functions both upstream (inputs and credit supply) and downstream (guaranteeing a producer price). The longer term economic viability of cotton is also linked to the technical challenge of ensuring the maintenance and improvement of soil fertility in these zones which, by African standards, receive relatively high doses of fertilizers, but which are nevertheless showing signs of ecological degradation.

If, for sorghum, the main challenge at present appears to be the technical one of finding suitable higher-yielding varieties, the main challenge for maize is economic, finding sufficient market outlets to make intensification profitable. As with cotton, there are, however, also important questions concerning the ability of the new, more liberalized, institutional environment to provide necessary support to farmers, particularly for credit and the supply of inputs (seed, chemicals, equipment). It is also important to assess the ability of the traditional 'cotton infrastructure' to achieve the successful development of agricultural intensification and, for the diversification of revenue from agriculture in this zone.

[2] Only in Côte d'Ivoire, Cameroon and Senegal, countries with important export agricultural activities in other agro-ecological zones, did cotton's share in total agricultural export revenues fall below 25% in the 1980s (Satyanarayan et al. 1993).

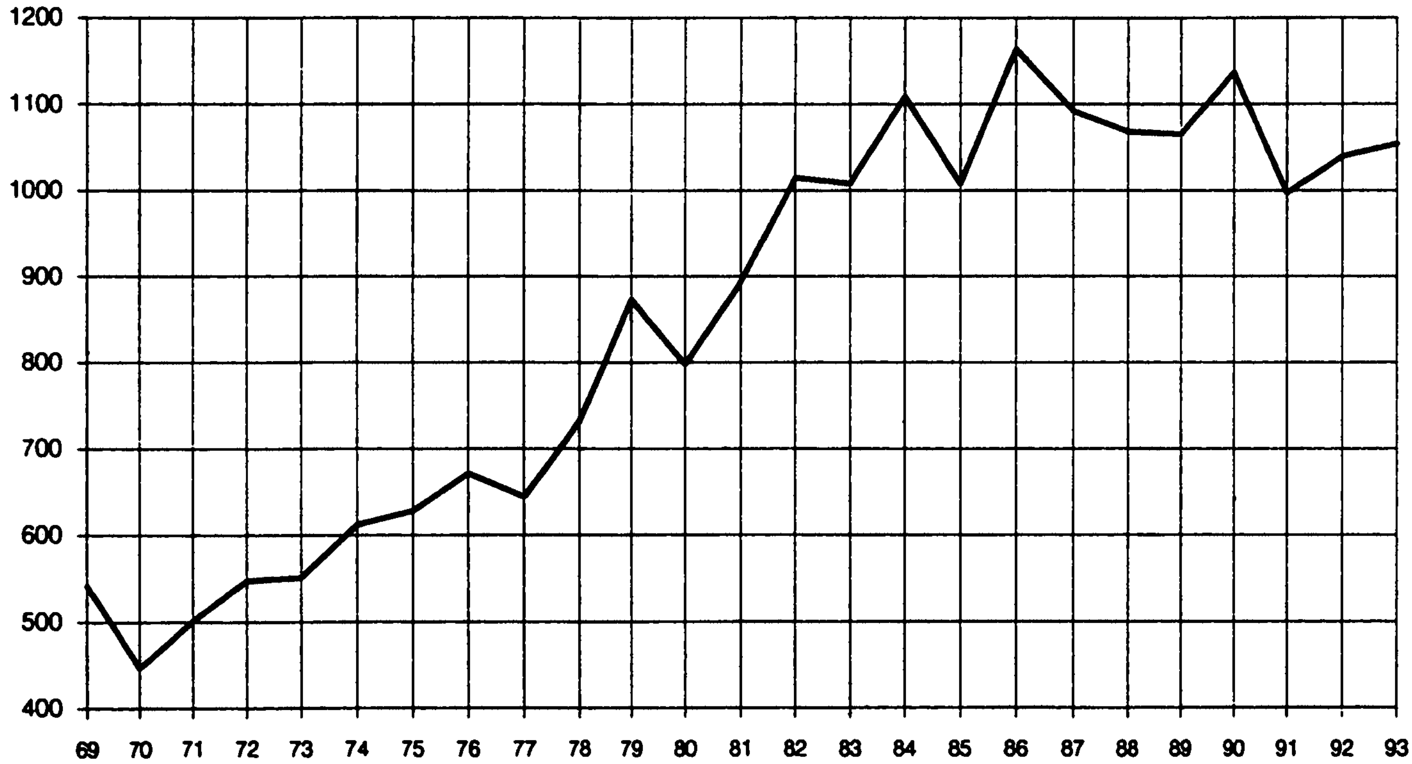


Figure 2. Seed cotton yields in the franc zone countries (kg per capita)

This paper starts with an overview of the process of innovation up to the present, then highlights the nature of the challenges which lie ahead. Given the breadth of the zone covered, this review is necessarily general, and provides details of individual cases only by way of illustration. The reader wishing additional information on particular countries or locations is referred to the bibliography. Such information is particularly rich for cotton, which has been the subject of considerable research on technology transfer over the years.

2. Overview of the Agricultural Dynamics in the Cotton Zone

2.1 Global trends

Against the general trends of output and yield growth for cotton, there are some striking regional differences within the zone. Cotton has a much longer commercial history in the Central African countries. When African countries began to gain their independence, there were already relatively large areas under cotton in Chad (300,000 ha), Central African Republic (CAR) (129,000 ha) and Cameroon (64,000 ha), which together produced over 130,000 tonnes of seed cotton output (table 1). The projects in the pre-independence period were known for their coercive nature: cotton was typically imposed as a commercial crop, and farmers were subject to sanction for refusing to grow it (Gide 1930, Fok 1993). At a technical level, cotton-growing in that era bore little resemblence to the methods that characterize the zone today: manual labor techniques were the norm, and the use of fertilizer rare, resulting in very low yields (between 200 and 400 kg/ha of seed cotton).

Developments in the six West African countries date mainly from their independence. During the 1960s, commercial production jumped from negligible levels to over 170,000 tonnes, and estimated yield levels generally double those of the Central African zone. Technical progress and acreage expansion combined over the following 15 years, achieving output levels of 700,000 tonnes by the mid-1980s, with estimated average yields of over 1200 kg/ha. In Central Africa, only Cameroon achieved an increase of this magnitude in better-watered lands to the south of the original cotton areas of the Extrême Nord Province. Chad and especially the CAR have lagged behind in terms of both output and yield growth.

Concerning food crops, one must distinguish between at least two broad climatic regions within the cotton zone. In the better-watered areas of northern Côte d'Ivoire, Benin, Togo, southern CAR, and the southern limits of the cotton zone in Cameroon, staple food crops include not only the coarse grains and legumes such as cowpeas and groundnuts, but also the roots and tubers, and, in Côte d'Ivoire, upland rice. Among the coarse grains, maize has traditionally played an important role in these systems, in some cases (Côte d'Ivoire) to the practical exclusion of sorghum and millet. In northern Côte d'Ivoire, as well as in Benin and Togo, maize has long been a dominant part of the diet. An important difference among these countries is the diet of urban dwellers, who for the most part live near the coast. Whereas maize has traditionally been a key staple food in southern Benin and Togo (as in the Accra region of neighboring Ghana), urban dwellers of southern Côte d'Ivoire are more apt to consume the staples of the forest zone: cassava, yam, plantain and rice, which are also imported in large quantities.[3]

As one moves further north into the Sahelian countries and northern Cameroon, coarse grains dominate the mix of staple foods, supplemented by legumes. Maize has traditionally played a minor role — either as a 'garden' crop in the well-manured fields near the house, or in association with other coarse grains (e.g., southern Mali). Rural and urban diets in these countries have had little tradition of maize consumption. An exception is urban areas of southern Cameroon, owing to a long tradition of maize cultivation in the humid plateau areas of the southwest (Western and Northwestern Provinces) (Fusillier 1993).[4]

Trends in food crop output in the zone are less readily discerned than cotton, given greater difficulties of data collection. For the countries which also have humid zones that produce maize, roots and tubers (Côte d'Ivoire and Cameroon), generalizations concerning trends in the moist savanna, based on national data, are even more unreliable.

The overall production trends estimated by the FAO for roots and tubers, suggest some growth in per capita output in Benin since the late 1970s, whereas other countries in the zone experienced a decline (Côte d'Ivoire, Cameroon, Togo, and especially CAR). Observers suggest that production of cassava is moving northward, as has happened in Nigeria.[5] However, the countries of this zone have not yet been able to benefit in any significant way from varietal improvements in cassava along the lines of the Nigerian experience (Nweke et al. 1992).

The issues at stake concern research (to determine varieties more suitable for organoleptic or agronomic reasons), and a supporting environment for multiplying and distributing improved cassava cuttings. The Nigerian model, whereby a major public effort went into on-farm demonstration and the distribution of cuttings, provide a useful reference point.

The other main dynamic would appear to be the rise of the importance of maize in the mix of coarse grains. This is partly borne out in the aggregate data on estimated per capita output for maize and sorghum (table 2). Although substitution can occur between maize and either sorghum or the millets, the comparison using

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[3] Consumption studies from the late 1980s showed urban dwellers in the Republic of Benin consumed roughly 70 kg/year of maize (Bricas et al. 1994), whereas their counterparts in Abidjan consumed less than 10 kg/year (Fusillier, 1991). In other urban areas, in the savanna (such as Bouaké), the level reached 30 kg/year

[4] In these provinces, maize and beans form the basis of the diet, and per capita consumption of maize is estimated at roughly 100 kg/year (Fusillier, 1993).

[5] For Nigeria, see Carr (1989); for northern Cameroon, personal communication from J Pichot (CIRAD).

Table 1. Seed cotton production and yields

	Production ('000t)				Yields (kg per ha)				Fiber extraction rate	
Period	1959-61[a]	1969-71	1984-86	1991-93[b]	1959-61	1969-71	1984-86	1991-93	1961	1988
West African Zone										
Benin	2	36	103	176	705	844	1,314	1,168	39.3	40.5
Burkina Faso	2	29	124	158	94	368	1,210	844	34.3	40.7
Côte d'Ivoire	4	36	205	226	693	908	1,343	1,083	34.8	44.1
Mali	6	53.7	168	279	213	753	1,262	1,279	34.8	39.3
Senegal	0	15.3	34	48	846[a]	1,064	924	1,118	39.5[d]	40
Togo	6	4	66	93		730	1,155	1,157	35.7	41.9
Central African Zone										
Cameroon	25	57	112	122	436	552	1,308	1,249	35.3	41.4
Central African Rep.	31	53	35	18	204	404	459	500	36.1	40.7
Chad	82[c]	106	95	132	266[c]	358	691	651	36.8	38.2
Period	**1959-61**	**1969-71**	**1979-81**	**1990-92**	**1959-61**	**1969-71**	**1979-81**	**1990-92**	**1968-71**	**1990-92**
Anglophone Countries										
Ghana	-	0	7	20.6	-	540	627	1,103	-	32.4
Nigeria	-	186	92	271	-	458	190	624	33	19.6

Source: FAO production yearbooks (for Ghana and Nigeria), Ministere de la Cooperation (1991) national data is perhaps more significant when millet is excluded, since these are grown mainly in zones too dry for maize. Of the four Sahelian countries where very little maize was consumed 20 years ago, Chad is the only country where farmers show little interest in growing maize. Senegal, Mali, and Burkina Faso have experienced significant growth in maize output, with per capita consumption levels now estimated at 17, 23 and 30 kg/year, respectively.

Among traditional maize-eating countries, only Côte d'Ivoire appears to have had relatively constant production over the period, while Togo and CAR experienced a pattern similar to Nigeria and Ghana, i.e., a drop in production around 1980, followed by a recovery to earlier levels. In Benin, where production initially rose to high levels in response to import demand from Nigeria, the dramatic drop around 1989-91, if true, may be due to the political disruptions at that time; more recent (1992) estimates show that production has returned to 1970 per capita levels. Only in Cameroon do the data suggest an apparent long-term decline.[6] But this trend masks the rise of maize in the northern areas, and particularly the Northern Province, which is similar in character to the Sahelian moist savanna. According to national agricultural statistics, production in the north moved from roughly one-tenth to one-quarter of the total between 1975 and 1990 (Silvestre 1994, Fusillier 1993).

The rise of maize production in the areas where maize is not traditionally grown, is also seen in the statistics recorded by those cotton companies providing food crop extension services. In Mali, the reported maize area of participating farmers (defined, by the CMDT, as maize area prepared with animal traction) increased from just over 20,000 ha in 1980 to over 100,000 ha by the early 1990s (Fusillier, 1994). In Senegal, the area under maize rose from 6,000 to 18,000 ha over the same period. In northern Cameroon, the figure jumped from some 7,000 ha in 1982 to nearly 35,000 ha (SODECOTON annual reports). For the cotton zone of Côte d'Ivoire, a traditional maize-growing region, the area under maize is reported to have more than doubled from 40,000 to over 90,000 ha. Since the area under cotton also nearly doubled over this period, this is likely to reflect a more comprehensive sample of farmers at the end of the decade, rather than major increases in area under maize in the zone itself.

Meanwhile, FAO data on estimated sorghum output per capita show substantial growth only in Mali and Burkina Faso, where it continues to outweigh maize by a factor of three to one. In other countries there has been a tendency for either modest growth (Togo, Benin) or stagnation (table 2).

[6] An alternative source (DEAPA, Min. of Agriculture) reports stagnation of total output (and hence per capita decline) over the decade beginning in the late 1970s. But this series then indicates a dramatic jump in output of nearly 40% in 1990, sustained in the subsequent two seasons. Fusillier (1993) hypothesizes that this could be attributed in part to a renewed concentration on maize in the traditional coffee-areas of west Cameroon in response to a fall in coffee price. If this data is correct, aggregate per capita output would have recently recovered to roughly 45 kg/ha.

Table 2. Maize and sorghum production per capita (kg per capita)

	MAIZE			SORGHUM		
	1969-71	1979-81	1989-91	1969-71	1979-81	1989-91
West African Zone						
Benin	75	84	49	19	17	22
Burkina Faso	11	16	30	95	89	106
Côte d'Ivoire	47	43	41	3	3	2
Mali	12	9	23	-	50	72
Senegal	10	12	17	-	24	16
Togo	79	57	76	-	33	36
Central African Zone						
Cameroon	54	48	34	-	35	31
Central African Republic	24	17	29	-	17	13
Chad	3	6	6	-	47	53
Anglophone Countries						
Ghana	48	35	50	17	13	13
Nigeria	21	9	22	64	47	52

Note: a) in 1992, maize returns to a level of 75 kg per capita
Source: FAO Production Yearbooks

2.2 Micro-level trends

Data from micro-level studies compiled by Fusillier (1994) confirm these trends in the evolution of agriculture in the cotton zone since the early 1970s. These studies, recorded information on land-use patterns at intervals from between 6 to 20 years, and provide a clear picture of the expanding role of cotton in the farming systems (table 3). In the locations studied in northern Côte d'Ivoire, western Burkina Faşo, and southern Mali, the area under cotton increased by 25 to 50%, and at the end of the 1980s represented from 20 to 45% of the total. (see map 1 for locations). In Togo, the share of cotton is generally lower (from 10 to 17%), and of three locations has only increased in the southern site.

Although its absolute share of the farming area only expanded to a limited extent (in part through a replacement of intercropped maize by single-stand maize), the share of maize in the total food crop area expanded more noticeably. This did not occur in the two northern sites in Togo, an area known for poor soil quality. In Côte d'Ivoire, where sorghum levels are negligible, one also notes a significant role of other food crops, which account for over half of the area cultivated. In the other countries, sorghum and millet area does decline in the total devoted to food crops, but less dramatically than one might have expected.

Table 3. Maize and sorghum production estimates ('000 tonnes)

	MAIZE			SORGHUM		
	1969 - 71	1979 - 81	1989 - 91	1969 - 71	1979 - 81	1989 - 91
West Africa Zone						
Benin	201	289	228	52	59	104
Burkina Faso	60	108	270	528	620	952
Côte d'Ivoire	257	352	491	14	24	26
Mali	67	61	216	-	341	664
Senegal	42	66	123	-	131	120
Togo	160	150	269	-	87	125
Central Africa Zone						
Cameroon	355	418	400	-	301	364
Central African Rep	44	40	87	-	39	39
Chad	12	27	31	-	210	294
Anglophone						
Countries						197
Ghana	417	380	745	147	140	4,605
Nigeria	1,215	599	1,955	3,632	3,284	

Source: FAO, Production Yearbooks

In the non-traditional maize areas, these grains remain far more important than maize. Since maize yields in these systems are likely to be higher than those for the other coarse grains, owing to greater efforts at intensification, maize's share in total output is relatively higher when compared to the area under cultivation.

Survey data from 346 households in the Northern Province of Cameroon for the 1990-91 season suggest a similar pattern of expansion of maize within a cotton-based system (Silvestre 1994). With cotton at 41% of total area, maize and sorghum occupied roughly equal amounts of the food crop area of over 40% (table 4). Although nearly all of the sample households grew maize in the 1990-91 season, only one-fifth of them had begun growing it before 1980. Because of much higher yields (1800 kg/ha versus just over 1000 kg/ha for the sorghum), maize accounted for two-thirds of cereals output.

In the context of the micro-level data, it is appropriate to touch briefly upon a subject which has been the source of some debate: does cotton cultivation come at the expense of the rural family's food balance? To answer this question properly, it would be necessary to have information on both food production and purchases by cotton and non cotton households, as well, ideally, of consumption data for different types of household members. The studies to which we have found reference, for Togo, Chad and Mali, are more partial in nature, examining only food production across households with and without cotton (Min. de la Coopération 1991). The

Table 4. Evolution of land use patterns in the cotton zone

Country	Site	Date	Share of cotton in total area %	Share in maize %	Food crop area sorghum/millet %
N. Côte d'Iviore	Syonfan	1975-89	32 - 47	30 - 43	5 - 0
W. Burkina Faso	Karakpo	1975-89	20 - 25	25 - 35	0 - 0
S. Mali	Kourouma	1984-90	30 - 40	53 - 66	21 - 18
	Daboura	1970-90	24 - 35	1 - 14	72 - 65
S. Togo	Fonse bougou	1982-90	34 - 43	6 - 15	73 - 73
N. Togo	Niara dougou	1977-87	28 - 36	11 - 20	88 - 66
	Waragni	1985-90	11 - 17	12 - 18	41 -41
	Manga	1985-90	16 - 17	23 - 23	31 -32
	Poissongui	1985-90	13 - 10	0 - 0	76 -79
N. Cameroon	Northern Province	1990-91	41	46	43

Source: Fusillier (1994), using studies by ORSTOM (Côte d'Ivoire), INERE (Burkina Faso), IER (Mali) and IRCT (Togo). Silvestre (1994) for N. Cameroon.

overall conclusion of these surveys, carried out by the respective national cotton companies, was that cotton households produced at least as great an amount of cereals as non cotton households.

Disaggregated data from such a study in Mali for the 1991/92 season revealed, however, that among smaller, less endowed households (those owning fewer than two sets of draught equipment, representing slightly over half of the total), cereal production per capita was higher for the non cotton households (Campagne and Raymond, forthcoming). These differences showed up as surplus after accounting for home consumption, seeds and losses; on average, even the least well-equipped cotton households (owning no equipment) were able to grow their entire household cereal needs (estimated at 212 kg/person/year). Even where cotton is dominant, it does not surpass half of the land under cultivation, which reflects the need to provide household food needs.

3. Innovation Processes: The technical dimensions

The different dimensions of the technical progress that has been made in cotton production and the coarse grains in the zone, including an appreciation of the agro-technical factors which have facilitated adoption are reviewed in this section. Adoption or its absence is of course intimately linked to the economic interest farmers may have in the technologies, which are influenced by the organization of extension, input delivery systems and output markets. These factors are reviewed in the subsequent section.

3.1 Cotton

Cotton is well-suited to the climatic conditions of the moist savanna, and even to the dryer regions of this agro-ecological zone, since its characteristic of multiple flowering renders it relatively robust to periodic dry spells, although it requires high nutrient levels to thrive. Unfertilized cotton (the norm elsewhere in sub-Saharan Africa), not only produces low initial yields, it also requires frequent displacement of cultivation sites. Whether or not the continuous cultivation of cotton is possible in the moist savanna under fertilized conditions is a question which is addressed below. Cotton also is subject to a number of pests, which, if untreated, can have a more important negative impact on yield than failing to fertilize. Yields also depend critically on the degree to which the *crop calendar* is followed: in particular, soil preparation, early planting, and timely weeding. Fiber extraction rates, which have a direct impact on the final value of the seed cotton, depend both on the cotton variety and on timely evacuation and ginning of the harvest.

Technical progress in the field has been achieved on virtually all of these fronts, through a combination of genetic improvement and introduction of better husbandry practices. In the first respect, the seed stock has been continually upgraded through releases of varieties exhibiting the following characteristics (Min. de la Coopération

1991): (i) more adapted to local conditions;[7] (ii) exhibiting higher levels of tolerance to pests and diseases (bacteriosis, jassides); (iii) with higher fiber content — especially in Côte d'Ivoire, Togo and Cameroon (see table 1); and (iv) with improved fiber length and higher average fiber quality. The nature of the cotton projects, whereby all farmers growing the crop are registered, ensures that improved seed (provided free of charge) is sure to cover most, if not the entire, area under cotton.

With respect to crop husbandry, the most comprehensive statistics relate to share of cotton area receiving three types of cultural practices: mechanized soil preparation, inorganic fertilizers, and pesticides. Similar information is also available for herbicides in a subset of the countries where they have been promoted. These data, while instructive, do have some limitations. As with cotton area itself, these numbers are collected based on declarations of farmers participating in the projects. Inaccuracies can result, probably less because of farmer error of assessing size of individual cotton parcels than because farmers may have an incentive to report different values than the actuals, owing to the nature of input distribution. That is, farmers declaring intent to fertilize and/or apply pesticides on a certain area are thereby eligible to obtain these elements of the *package* on credit, in quantities based on recommended dosages.

One type of misdeclaration has long been presumed to exist: that farmers *underdose* their declared cotton areas, channeling part of their chemical inputs to their food crops (or selling a portion when the chemical can be sold for a higher price on the market or when the farmer needs cash). In terms of the statistics, the effect of such a practice would simply be that declared areas are treated at some diluted rate in relation to the norms. A second type of misdeclaration, noted by Cousinié (1993) in Togo, has the effect of calling into question the area data themselves. In four regions of the country, at two points in time, he found evidence of farmers systematically underdeclaring total cotton area, and using the inputs obtained for the declared area not only for other purposes, but also to conduct more extensive farming strategies on cotton than would be permitted by the *package*. The percentage of cotton fertilizer *missing* due to diversion to other uses was in most cases at or below 6%, while that due to acreage underdeclaration ranged from 15 to 60%. In relation to recommended doses of 200 kg/ha, this meant that farmers were actually applying anywhere from 76 to 161 k0g/ha. For insecticides, the overall percentage *missing* was the same, but diversion to other uses was more important (from 10% to 23% of total). On average, cotton area was underreported by nearly 20% of the farmers in 1985, increasing to 37% in 1991. Cousinié reports a similar phenomenon of under-declaration in the cotton area of Guinea. To the extent that the problem is widespread

[7] For instance, in Senegal and the eastern part of the cotton zone in Burkina-Faso, areas with greater rainfall risk, research has developed shorter cycle, more flexible varieties.

in other countries, this suggests not only (an unknown rate of) dilution of input doses actually applied on reported areas, but also an upward bias in average reported yields.

Figure 3 provides an overview of the trends in the use of fertilizer, pesticide, and animal traction for the zone as a whole, and table 5 provides data over time for individual countries. The data reveal the importance of the two chemical inputs in the cotton farming systems. On average, the percentage of area receiving pesticide treatments rose quickly following independence, moving from virtually negligible levels to over a third of area under treatment by 1970. By the early 1980s, only three countries (Burkina Faso, Chad and CAR) had substantial areas untreated. The adoption of treatments has been facilitated by the introduction of ultra-low-volume sprayers beginning in 1970, which both reduce the drudgery of spraying, and the amount of water that needed to be transported to the fields for the mixtures.

Overall, inorganic fertilizer use, the principal means by which plant nutrition is promoted in the projects, grew in tandem with pesticide use. By the early 1980s there were generally very high reported levels of use (over 80% of total declared area) in all but the two Central African countries in which yield levels have remained low (Chad and CAR).

Although weeding is an important determinant of cotton yields, use of herbicides, by contrast, have remained fairly minor in importance (figure 4). Only Ivorian farmers showed a steadily growing interest in their application up to the late 1980s, bringing the area treated to over 30%. The apparent lower interest by farmers in Mali and Cameroon may be explained at least in part by differences in weed pressure, and, in particular, by the development of mechanized alternatives for weeding. In Mali herbicides have also benefitted least from subsidies among the various chemical inputs (personal communication, M. Fok, CIRAD). In Senegal, adoption has been highly sensitive to subsidy and credit policy changes (personal communication, B. Diop, SODEFITEX).

The major non chemical innovation in the cotton-growing zone is the increase in area under animal traction. Insofar as its use is readily extended to the cultivation of other crops in the farming system, animal traction is perhaps the most profound innovation accompanying the *white revolution*. If less complete than the adoption of pesticides and fertilizers, the growth in use has nevertheless been impressive, with an average of roughly half of cotton areas under animal traction. The important differences in adoption rates among countries result in large part from more favorable initial conditions in the dryer, trypano-free areas, where cattle are more abundant. In such places (Mali, Chad, northern Cameroon, Senegal) one finds the vast majority of area mechanized. The spread has also been facilitated, in some of these areas (southern Mali, parts of Burkina Faso), by the availability of cleared land or grassy fallows, less difficult to plow mechanically than land cleared directly after savanna bushlands (Pingali et al. 1987, Bosc et al. 1990).

Mechanization has been applied progressively not only for plowing, but also for weeding and sowing, with the result that only harvesting remains entirely manual. As such, it remains a brake on labor productivity, but ensures better cotton quality than that attained by countries which have mechanized this operation, such as the United States. Animal-drawn carts, also forming part of the equipment of many mechanized households, facilitate local transportation, especially between village and field. By easing the labor constraint for these various tasks, mechanization has thus made it possible for farmers to extend their cultivated area. Since there is a minimum threshold of labor required to apply mechanized techniques well (in particular, because the expansion of area requires more labor for harvesting), the advantages of this labor-saver have, ironically, been able to be reaped more easily by large households (Bigot and Raymond 1991).

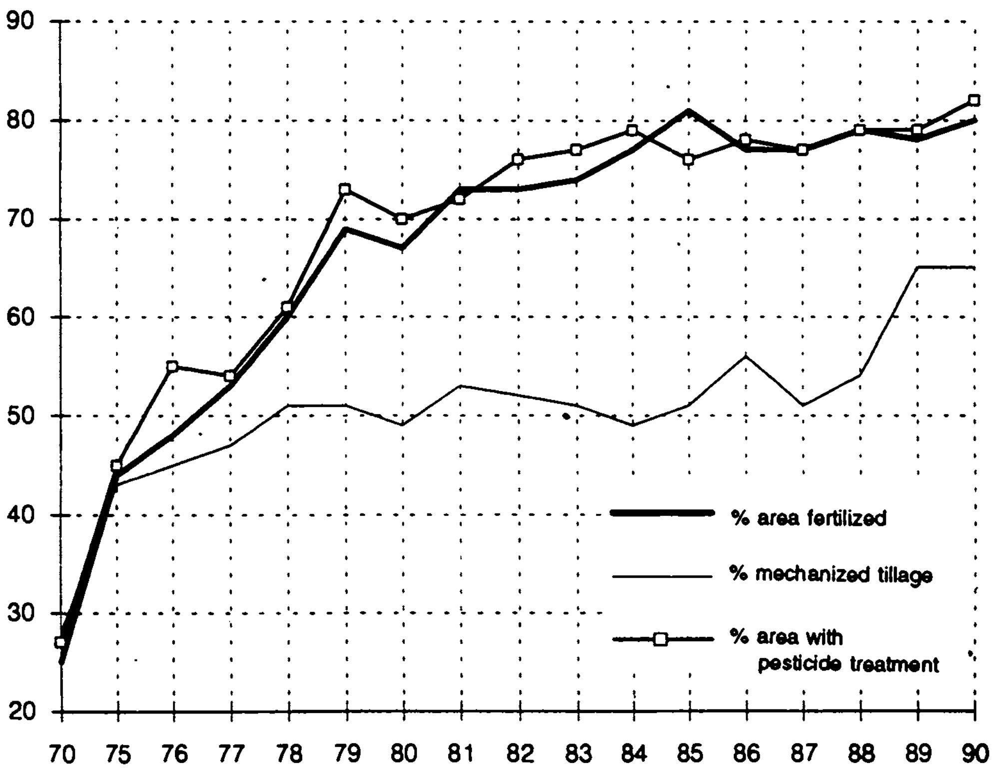

Figure 3. Diffusion of technical innovation in cotton areas of the francophone countries

Table 5. Area under cotton and diffusion of technical innovation

	1960 - 1961				1970 - 71				1988 - 89			
	Area ('000 ha)	% Animal traction	% Fertilizer	% Pesticide	Area ('000 ha)	% Animal traction	% Fertilizer	% Pesticide	Area ('000 ha)	% Animal traction	% Fertilizer	% Pesticide
West African Zone												
Benin	-	-	-	-	39	3.2	68.3		-	-	-	-
Burkina Faso	21	-	-	-	81	12.9	16.4		170[a]	37.0	77.6	56.7
Côte d'Ivoire	-	-	-	-	36	4.4	86.2		213	33.7	83.8	100.0
Mali	34	0	0.5	1.1	66	45.3	52.8		180	91.2	88.0	84.4
Senegal	0	-	-	-	14	66.4	100.0		39	60.5	81.5	87.1
Togo	-	-	-	-	4	16.1	42.9		68[a]	8.4	99.0	99.4
Central African Zone									112	73.0	93.0	93.7
Cameroon	64[b]	7.7	2.3	0.8	102	34.1	21.1					
Central African									53	26.2	38.0	63.3
Republic	129[b]	0	0.8	0.8	126	4.0	21.6		199	96.4	43.9	43.8
Chad	300[b]	-	1.2	1.1	302[c]	36.6	13.9					

Notes: a) 1987 - 88; b) 1961 - 62; c) 1971 - 72
Source: Ministère de la Coopération (1991)

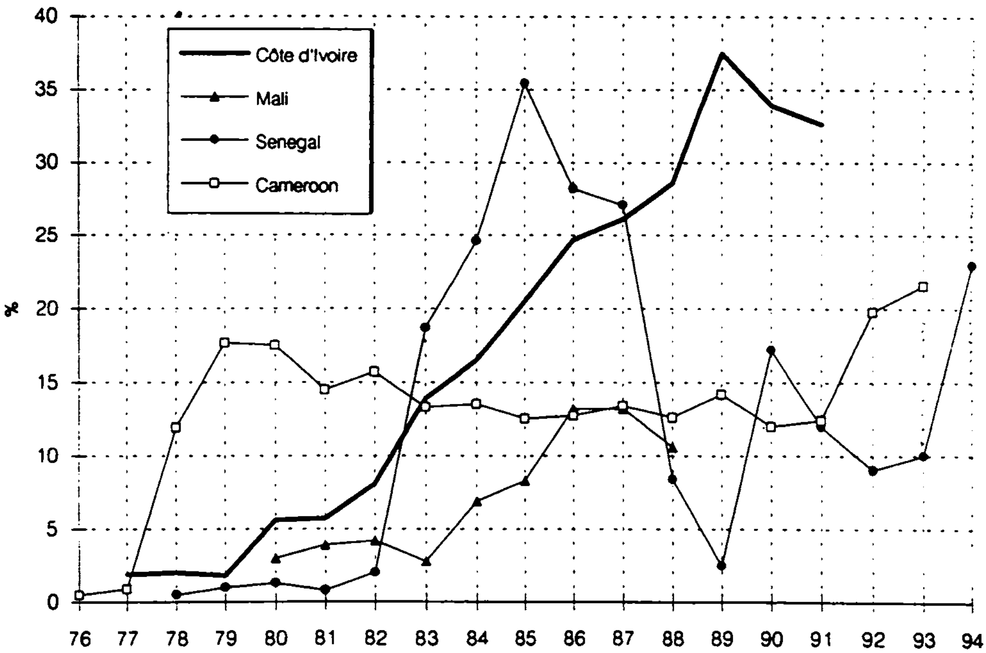

Figure 4. Evolution of area treated with herbicide as percentage of total cotton area

There have been attempts at taking the process a step further, through motorization, in Burkina Faso, Mali and Côte d'Ivoire, in the 1980s. These experiments, in each case with several hundred households, confirmed the anticipated rise in labor productivity, and hence possibilities of expanding farmed area. Since the cost of farm operations under this model have proven prohibitive, in part because of difficulties in food crop marketing, the use of tractors has been discontinued (Losch 1986, Lecomte 1989, Faure 1994).

The improvement in yield levels registered over the past few decades also results from some general improvements in the adherence to the crop calendar (particularly early sowing and earlier and more frequent weeding). There is conflicting evidence concerning the extent to which mechanized farmers are better able to apply these practices. Bigot and Raymond (1991), based on data from Côte d'Ivoire, conclude that mechanized farmers do not plant earlier than their non-mechanized counterparts. For southern Mali, surveys by Niang and Giraudy found that the proportion of cotton area planted early depends critically on the adoption of mechanization, and on the number of harnesses available to the household (Giraudy 1993a). With respect to the number of weedings, however, there were not significant differences between the two types of households.

The cloud on the horizon for innovation in cotton production appeared in the second half of the 1980s. For the zone as a whole, the data on reported yield levels suggest an abrupt brake in progress (figure 2). Since then, significant drops have been registered in several of the countries with the highest yields (Benin, Côte d'Ivoire, Burkina Faso), with smaller declines or stagnation in most other countries in the zone (table 2). If Cousinié's findings of increasing underreporting of cotton area are generalizable beyond Togo, yields may have actually declined more than was estimated. There are two alternative, though not necessarily conflicting, interpretations of this phenomenon. The first, consistent with Cousinié's data, is that farmers have shifted to more extensive farming techniques in response to the unfavorable changes in input and output prices provoked by the cotton crisis. The second is that the zone is witnessing a yield crisis provoked by depleted soil fertility, due mainly to insufficient application of organic nutrients. These issues, which constitute the major technical challenge for cotton's future, are discussed in concluding section of the paper.

3.2 Coarse grains

The sorghum and millet varieties indigenous to the region have several basic technical advantages in relation to maize. First, like cotton, they are relatively robust to rainfall failures.[8] Second, they have good storage properties. Third, they require less labor for manual food preparation (husking and pounding) (Bricas et. al., 1994), and may also require less cooking time (and hence less fuel) than maize. Finally, and not least, they are, by virtue of their traditional dominance of the cropping patterns, the preferred staples for preparation of local dishes.

In comparison, maize has two main characteristics in its favor. First, being of shorter cycle, it can be harvested earlier in the season, thereby filling the food gap during the traditional *hungry season*. Second, it responds well to fertilizer, in sharp contrast to the local sorghum varieties, whose high photosensibility leads to greater stem and leaf growth.[9] If maize has been gaining on the traditional coarse grains in cropping patterns, this would appear in no small way linked to the obstacles

[8] The rise of maize, more sensitive to drought, has been favored by relatively good rains in the region since the mid-1980s.

[9] A third factor sometimes cited is its superior characteristics as a rotation crop with cotton, since sorghum leaves toxins in the soil.

encountered by research in its search for higher yielding sorghums that retain the organoleptic and storage qualities of the local varieties.[10]

The initial improvement strategy was to work with East African varieties (*Sorghum caudatum*) which respond better to fertilizer. Despite higher yield potential, these varieties encountered farmer resistance because of their color (reddish in contrast to local white), grain quality (mealiness, lending itself poorly to preparation of local dishes such as tô), and problems of moldiness during storage resulting from grain bunches insufficiently exposed to the air (which, in addition to causing losses, leads to lower germination rates of grain stored for seed). Although some progress has been made in cross-breeding strategies (the color problem has been resolved), research continues to search for a successful combination of characteristics, including the use of molecular genetics (personal communication, J.L. Marchand, CIRAD).

In the meantime, a number of improved open pollinated varieties of maize have become available through the national research systems, based on a combination of massive selection among local varieties (*Tiemantié* in Mali, *Massayomba* or *Jaune Flint de Saria* in Burkina Faso, *Blanc-Violet de Bouaké* in Côte d'Ivoire) and introductions of genetic material from international research centers (Centro Internacional de Mejoramiento Maíz y Trigo (CIMMYT) and the Internatinoal Institute of Tropical Agriculture (IITA).[11] In relation to the selected local varieties, well-suited to local conditions and performing well under low or medium intensification strategies (1.5 to 2 tonnes/ha with relatively small quantities of fertilizer — 50 to 100 kg/ha), the main advantage of the varieties introduced into the region have been two-fold: higher yield potential for farmers wishing to pursue more intensive strategies, and resistance to certain pests and diseases, the most important being maize streak virus (MSV). In Burkina Faso, the MSV-resistant variety has been appreciated because it also responds well to intensification efforts (personal communication, J.L. Marchand, CIRAD).

The most comprehensive quantitative indicators of the spread of technical innovations for the coarse grains are those made available by the four cotton companies with the mandate for food crop extension (Côte d'Ivoire, Cameroon, Mali, and Senegal).[12] A surprising statistic concerns the diffusion of improved maize seed, which is quite low in relation to reported area under maize within the projects. In

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[10] For millets, the main varietal improvement effort has been devoted to the short-cycle varieties most prevalent in the semi-arid zones of the Sahel (Bosc and Garin 1993). Relatively little work has been done on the long-cycle millets grown more commonly in the moist savanna, since research placed more hopes on the potential of sorghum for this zone (personal communication, P. Garin, CIRAD).

[11] See Bosc et al. (1990) for an overview of research achievements in the zone; Boughton and Henry de Frahan (1992) for southern Mali; and Silvestre (1994) for Cameroon.

[12] Unless otherwise indicated, data on diffusion in these countries are drawn from Fusillier (1994).

Mali, average annual deliveries amounted to less than 100 tonnes, which should cover less than a tenth of the total project area. In Cameroon, with slightly higher deliveries (and lower reported area), the proportion rose to roughly a quarter of the total. Of the four, only Côte d'Ivoire had an aggressive diffusion strategy, releasing enough seed annually to cover roughly 25,000 ha, or a third of the total project area, from the early 1980s to 1988.

The main interest in improved maize varieties, apart from maize streak resistance, is the higher yields obtained under fertilizer application. It is perhaps more valid therefore, to gauge the quantities of seed distributed in relation to area receiving fertilizer. In this case, one finds that both Côte d'Ivoire and Cameroon were able to fully cover their *intensive* maize areas with improved seed: The share of fertilized maize in relation to the total is reported to be quite low in these countries, especially in comparison with fertilized cotton. In Côte d'Ivoire, fertilized maize area hovers around 10 to 15,000 ha throughout the 1980s, or roughly 15% of the total. In Cameroon's cotton zone, reported area under intensive maize does not exceed a fourth of the total.[13]

The Malian experience stands out in contrast to these two cases. Here, areas receiving inorganic fertilizer have expanded steadily throughout the 1980s, moving to over 70% of the recorded area of 100,000 ha by 1992. Since, in addition, 45% of the area is cited as receiving organic fertilizers, it is possible that the proportion of maize receiving one or the other of these treatments is even higher. In relation to this volume, the amount of improved seed distributed in Mali remains adequate to cover only a small fraction.

Data from Mali also point to the relatively low recourse farmers have to fertilizer for their sorghum and millet fields. In Niang and Giraudy's survey, roughly the same proportions of inorganic and organic fertilizer were applied on maize as indicated by CMDT's global figures (Giraudy 1993b). Meanwhile, slightly over a tenth of the fields planted to the other course grains received these treatments.

In contrast to the fertilizer evidence, animal traction appears to be adopted for the coarse grains in roughly the same proportions as for cotton — close to complete adoption in Mali, between 30 to 40% in Côte d'Ivoire. For maize, which has more onerous soil preparation requirements than sorghum, the move to animal traction is particularly attractive as a labor-saving device. As with cotton, draught equipment is also used by some farmers for weeding and sowing. Simulation exercises suggest that mechanization of cereal cultivation in this zone can enable important efficiency gains, particularly in the context of rainfall constraints, by permitting earlier sowing and better root growth (Reyniers and Forest 1989, ESPACE 1987, 1988).

[13] Silvestre's finding, that 70% of cotton farmers surveyed in the Northern Province used fertilizer on at least some of their maize, suggests that SODECOTON's data may underestimate the actual area receiving fertilizer. The fact that inexpensive fertilizer from Nigeria is readily available in this region may help to explain the discrepancy.

Concerning the weed problem, herbicide use on maize in Mali has taken off to a far greater extent than for cotton, covering over a third of the recorded area in 1992. The other country where this product is important is Côte d'Ivoire, in roughly the same proportion as for cotton.

Owing to differences in data collection, it is not possible to make straightforward comparisons of maize yields using the various intensification measures noted above. Cross-country comparisons conform to the expected ordering. The data for Cameroon, which estimate average yields on intensive maize area only (improved seed and fertilizer), show average levels during the 1980s at about 2.5 t/ha. For Mali, with roughly three-fourths of the area fertilized, and using mainly uncertified seed, recorded yields are around 2 t/ha. Côte d'Ivoire, with a small and decreasing share of area fertilized (falling from 25 to 15% of an increasing total maize area over the 1980s), predictably registers a downward trend, with an average over the decade of roughly 1.5 t/ha. In each case these figures substantially outweigh estimated national averages as appearing in FAO series.

4. Innovation Processes: The role of price and institutional factors

4.1 Cotton

Although price factors have been fairly important in the increase in smallholder cotton production, it seems certain that the institutional environment has been the driving factor. The structures created for cotton development have left little to chance, from the upstream activities of technology development to the final sale of cotton fiber for export. As such, this model is the antithesis of the current market-driven approach to agricultural development which has replaced earlier economic models which favored some sort of price subsidy or protection. In light of these changing economic ideas, to which the cotton sub-sectors themselves have not been immune, it is important to recognize the elements of the model which appear to have been key to success. There are numerous parallels with other agricultural development projects in sub-Saharan Africa, many of which have been less fortunate.[14] One of the distinctive characteristics of the cotton projects is that the cotton companies have been able to maintain the high level of professionalism needed to translate the objectives into action. How some of these features might be reproduced in the context of other institutional forms is a matter subject to some debate.

4.1.1 *Close research/extension/farmer linkages*

There are few, if any, cases of smallholder agriculture in Africa where there has been such a direct link between research and the farming community. Project structure has facilitated this process. Research has been a central actor in the projects, charged with

[14] This includes cotton development elsewhere in Africa. For a description of the contrasts with performance in some anglophone cotton-growing countries, see Lele et al. (1989).

finding technical solutions to problems encountered in the field. Its direct links with the extension service have permitted frequent modifications of technical messages. The nature of the extension-farmer linkage has, in turn, ensured that new research results have not only been widely communicated, but also tested relatively quickly. Farmer contact has been pervasive, because extension in the cotton projects has also been responsible supplying seed and taking farmers' orders for purchased inputs.

4.1.2 *Credit facilities*

Farmers have been able to purchase both seasonal inputs and draft equipment on a large scale, because of their access to seasonal and medium-term credit facilities. In contrast to so many other experiences in sub-Saharan Africa, the credit system in the cotton projects has had good repayment rates. Repayment is ensured via another link in the vertical chain of the sub-sector: money due is directly deducted from the proceeds of cotton sales.

4.1.3 *Guaranteed output marketing*

Such a repayment system can only work when there is some assurance that farmers will sell their produce through the structure to which they owe money. This has worked well for cotton because the crop lends itself to a monopsonistic primary output marketing system: apart from the local ginneries, which form part of the integrated structure, there are no viable outlets for large quantities of seed cotton. The set-up of the marketing system has also been important in two other respects. For one, fiber quality and extraction rates have benefitted from close coordination between the field and the ginneries, whose locations and capacities have been increased in tandem with the rise in cotton output (map 2). Secondly, the system has permitted the timely payment of a guaranteed producer price. The view is widely held that this certainty has been instrumental to the intensification process, by providing farmers some assurance of the net revenues they would earn after purchase of seasonal inputs.

Output prices have generally been fairly modest, (before from the crisis years), averaging about a third or less of the world price of cotton fiber. This has been counterbalanced by varying degrees of input subsidies, which project management considered necessary to encourage intensification. Whether or not intensification would have occurred at the same pace with higher output prices and fully-costed inputs is a matter for historical debate. In the 1980s, this was, inadvertently, what happened to pricing policy — first producer prices were raised substantially in response to favorable world market conditions in the early 1980s, and then subsidies were progressively withdrawn as part of the adjustment strategy when world prices plummeted. By this time, most farmers had already adopted input use, and the relevant question is what level of intensification will be maintained.

Even when at relatively modest levels, the price offered for cotton has been adequate to stimulate rapid output growth in most countries in the region. The exceptions have been those few areas where farmers have had more remunerative alternatives. The Central African Republic is one case in point. Here, extremely low rural population densities have made it possible for both hunting and food crops sold in Bangui to compete successfully with cotton, even after the price rises of the 1980s (Yung 1989). By contrast, in both Togo and Benin, where food crop specialization for the Nigerian market had served as a lucrative alternative (Cousinié 1993, Raymond forthcoming), cotton production took off in response to the price increases (which coincided with the closing of Nigerian borders), more than tripling in the space of a few years. The other country where the price hike has had dramatic effects is Burkina Faso. Here, the absolute component of the response is likely to be more important, since alternatives in commercial agriculture have been limited. Also, since the mid-1980s, the possibilities for earning money via migration to the cocoa/coffee growing areas of Côte d'Ivoire have slowed down considerably, given the decrease in new forest lands available for farming and the decline in the producer prices for both products.

4.2 Maize

Because of its potential yield advantage in comparison with the traditional coarse grains, maize has been the primary beneficiary of targeted institutional support to food crop production in the zone. In comparison with cotton, this support has been light, confined mostly to the classic *upstream* activities of seed dissemination and extension advice. Two central elements of the cotton formula — seasonal credit and guaranteed output marketing — have been absent, apart from brief experiments in some countries where the cotton companies have been involved (notably Mali).

Differences in the nature of the product do not make this formula suitable to maize. Credit reimbursement against output sales is more difficult to ensure, since maize can be eaten or sold through other channels. Government guaranteed output markets for local foodstuffs are also difficult to manage cost-effectively, given competition from private traders who can respond with greater flexibility to price variations and to consumer demands for quality. The record on maize innovation suggests, nevertheless, that both credit and, especially, marketing issues are crucial. Problems in both areas have led, ironically, to a situation where the institutional mechanisms supporting cotton have become key for maize as well.

The problem with markets has been their limited size and distance from production locations. In the areas where maize has not been the traditional staple, farmers themselves appear to have been less reluctant to switch to maize consumption than their urban counterparts. The competition with maize comes not only from the traditional coarse grains, but from rice, available through imports or local irrigation schemes (Delgado and Reardon 1987, Reardon 1993). As a result, maize remains a minor consumer item in the urban areas.

In Mali, the government attempted to shelter farmers from the limited demand by guaranteeing an attractive purchase price for maize in the early years of the intensification program.[15] This policy which was implemented by the cotton company and which led to considerable losses, was discontinued in 1986 with the liberalization of grain marketing. Since then, maize prices have been highly unstable, and generally at a discount in relation to millet. The main demand for maize is seasonal, during the period before the longer cycle traditional grains become available (Boughton and Henry de Frahan 1994). Although the maize area reported as receiving fertilizer has continued to increase in subsequent years, signs of extensification are also present. One is a return to the traditional practice of intercropping with millet in some areas (Boughton and Henry de Frahan 1994). Observers also report an apparent reduction of fertilizer doses (Fusillier 1994). Farmers surveyed by the Institut d'Economie Rurale (IER) repeatedly indicated that the absence of a guaranteed price for maize was a disincentive to fertilizer purchases (Boughton et al. 1994). (table 6.)

Table 6. Fertilizer sale price

Year	Burkina Faso	Côte d'Ivoire	Mali	Cameroon	Chad
77	35	71	61	-	79
78	35	72	61	-	93
79	35	76	66	-	105
80	40	80	71	-	120
81	55	79	105	-	140
82	55	83	105	-	160
83	62	87	105	100	160
84	76	126	105	112	152
85	88	141	105	120	175
86	86	117	143	156	182
87	88	104	153	156	155
88	88	104	153	156	155
89	-	114	153	118	155
90	-	134	116	118	155
91	108	113	116	118	152
92	122	106	116	116	151
93	95	104	116	108	11

Even in the coastal countries where there is a higher urban demand for maize, marketing has posed problems for farmers of the cotton zone because of locational

[15] In the early 1980s, these purchases ranged from 5 to 8,000 tonnes. If as much as 20% of participating farmers' production was mrketed (a 1992 CMDT survey estimated this value for Koutiala, a relatively commercialized area), these purchasaes represented a significant amount of total sales (one-half to a third).

disadvantages. In Côte d'Ivoire, it was farmers in the cocoa-growing areas of the Central-West region who were able to take advantage of the government's import substitution policy for maize for the poultry industry in the mid-1980s (Fusillier 1991). Cotton zone farmers, further from Abidjan, where the trading network was not as well organized, barely partook in this new market opportunity, despite the fact that it coincided with the period when intensive maize production was being promoted. Similarly, maize supplies for southern Cameroonian cities come mainly from the western plateau, rather than the more distant cotton zone (Fusillier 1993). In both countries, agro-industrial demand for maize (for breweries as well as animal feed) has declined sharply since the onset of the recession of the late 1980s.

In the absence of credit and reliable maize markets, cotton's role in encouraging innovation has been three-fold. First, most directly, it provides the possibility for diverting cotton inputs obtained on credit to maize fields. How important this is quantitatively appears to vary from place to place, and across time. Of the two Togolese maize-growing villages noted in table 3, the amount was only important (21% of cotton fertilizer) in Manga for one of the two years observed (Cousinié 1993). In Western Burkina Faso, surveys for the Technology for Soil Moisture Management Project found that one of farmers' key interests in cotton input credit is the possibility for diversion to maize (personal communication, D. Deybe, CIRAD). Although these studies did not estimate the magnitude of the diversion, some indication may be gleaned from the following data: while farmers report using on average 100 kg/ha of the cotton complex on their cotton fields, SOFITEX reports distributing an average of 150 kg/ha of cotton farmed (figure 5a). Cotton insecticides are also reported to be important for treating maize seeds (Cousinié 1993).

A second area of support is the spillover effect on maize from cotton technology. One clear area where this has occurred is with animal traction purchased on credit. There is a debate concerning the existence of another type of spillover effect on maize: whether or not fertilizer residuals boost yields of maize following cotton in the rotational cycle. In theory, there should be no spillover if the farmer follows the recommended crop calendar (early sowing, timely application of fertilizer). That many farmers report evidence of an effect may be linked to lateness in either of these practices, which prevents the cotton from using up all the nutrients provided by the fertilizer (P and K). Wybrecht (1992) documents this phenomenon for southern Togo.

Farmers ability to finance such equipment points to cotton's third role in maize innovation: providing an assured source of cash income. In the absence of reliable marketing outlets for the maize itself, the availability of a reliable marketing outlet for cotton can permit farmers to cover the costs of maize inputs. An assured, alternative source of revenue can be important when farmers have uncertainty concerning the price they will get for the maize sold. It is essential to have another source of revenue when intensification is destined for home consumption, as would appear to be the case for a large proportion of maize area in Mali.

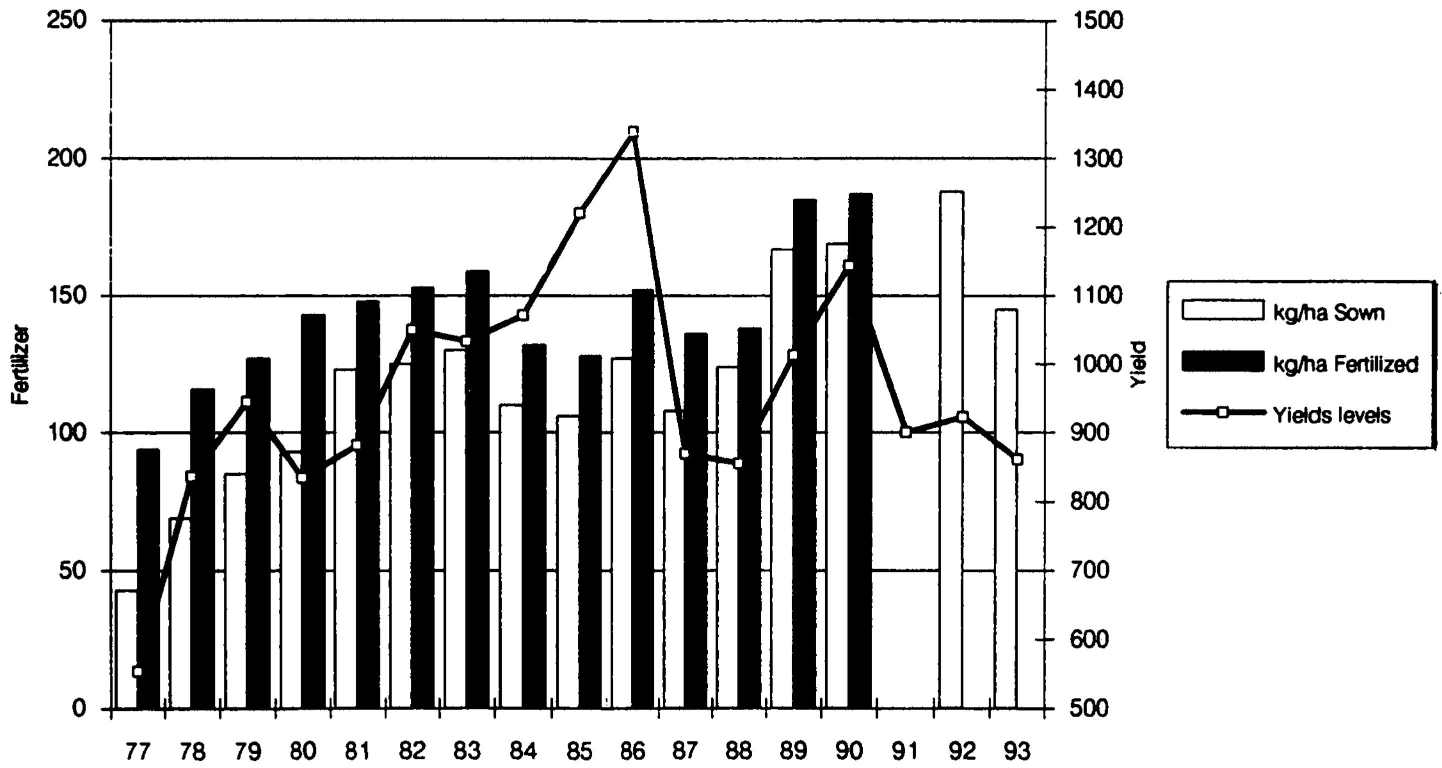

Figure 5a. Burkina Faso

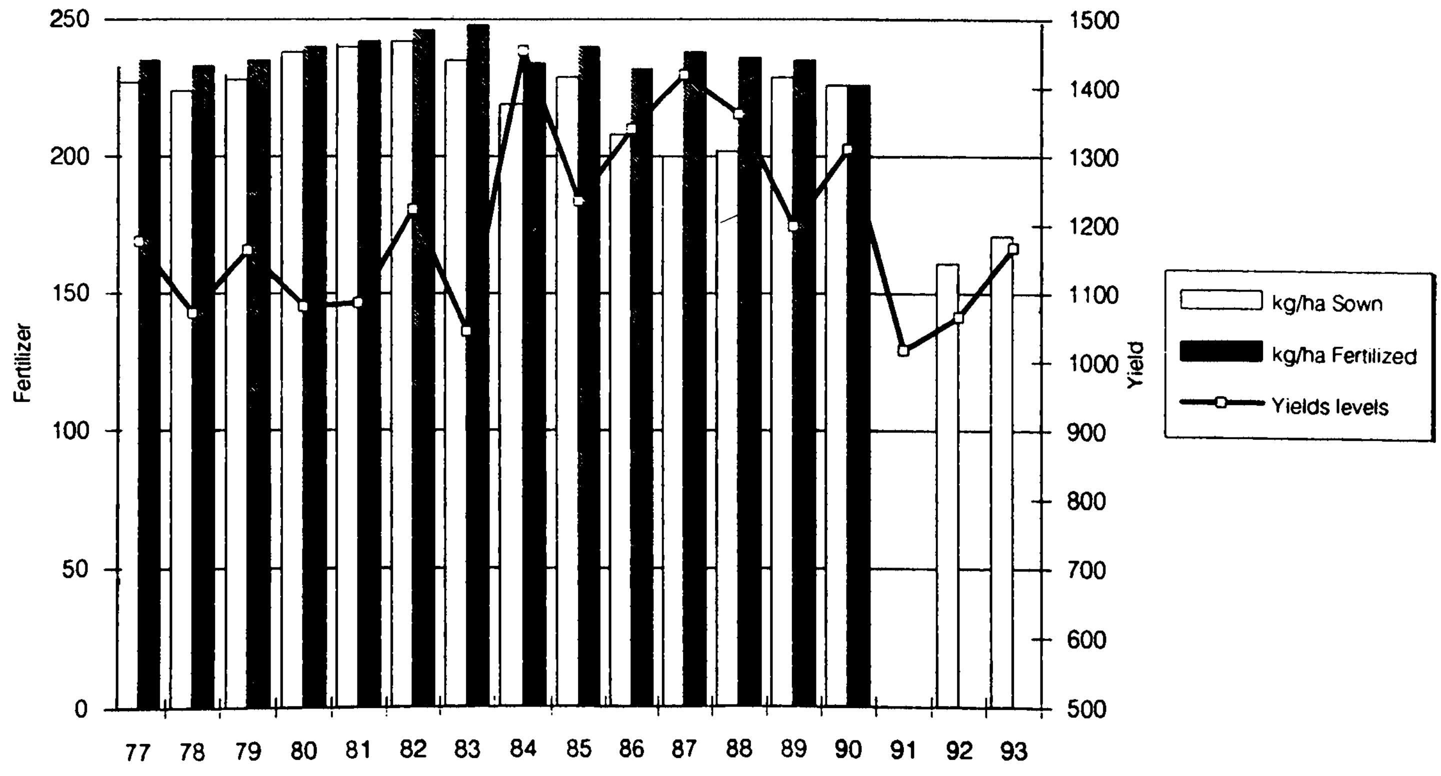

Figure 5b. Côte d'Ivoire

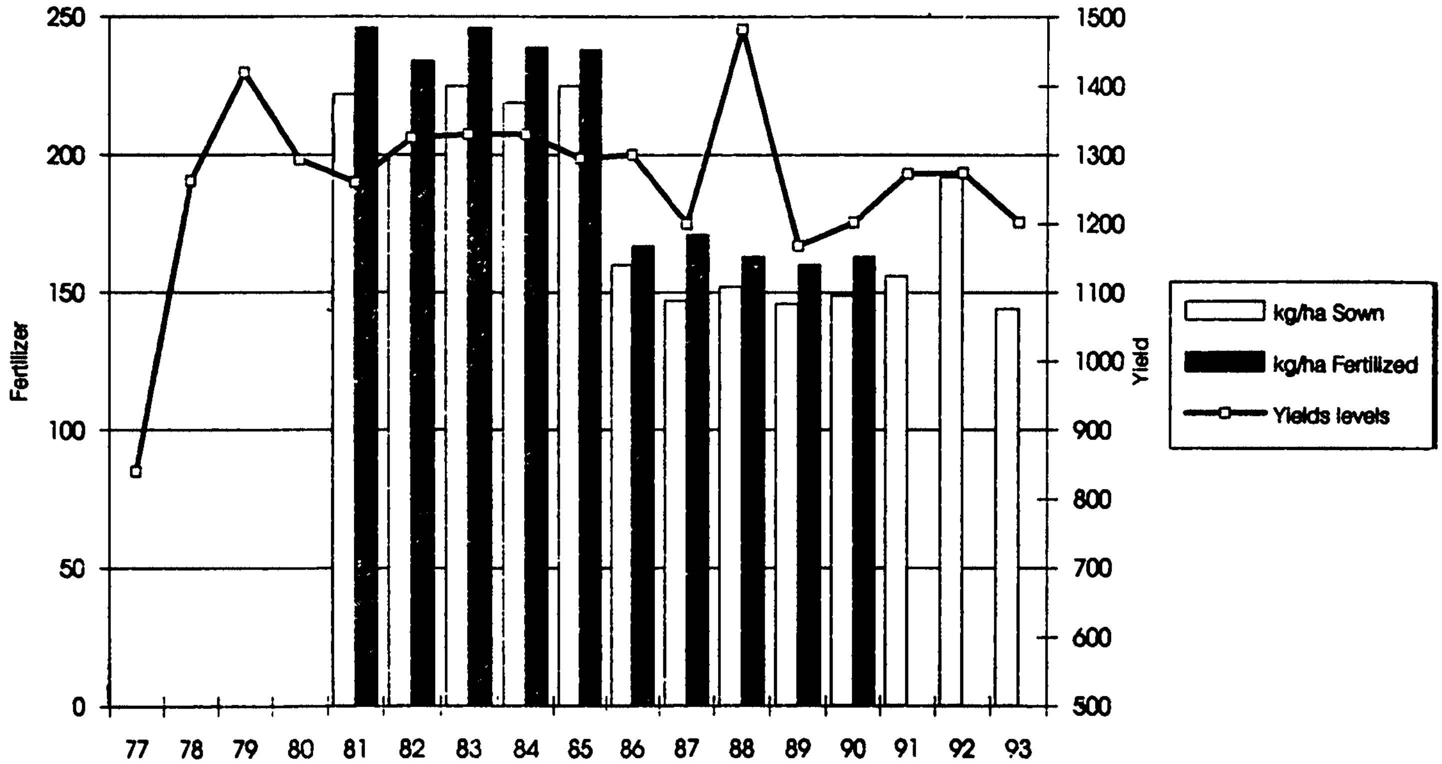

Figure 5c. Cameroon

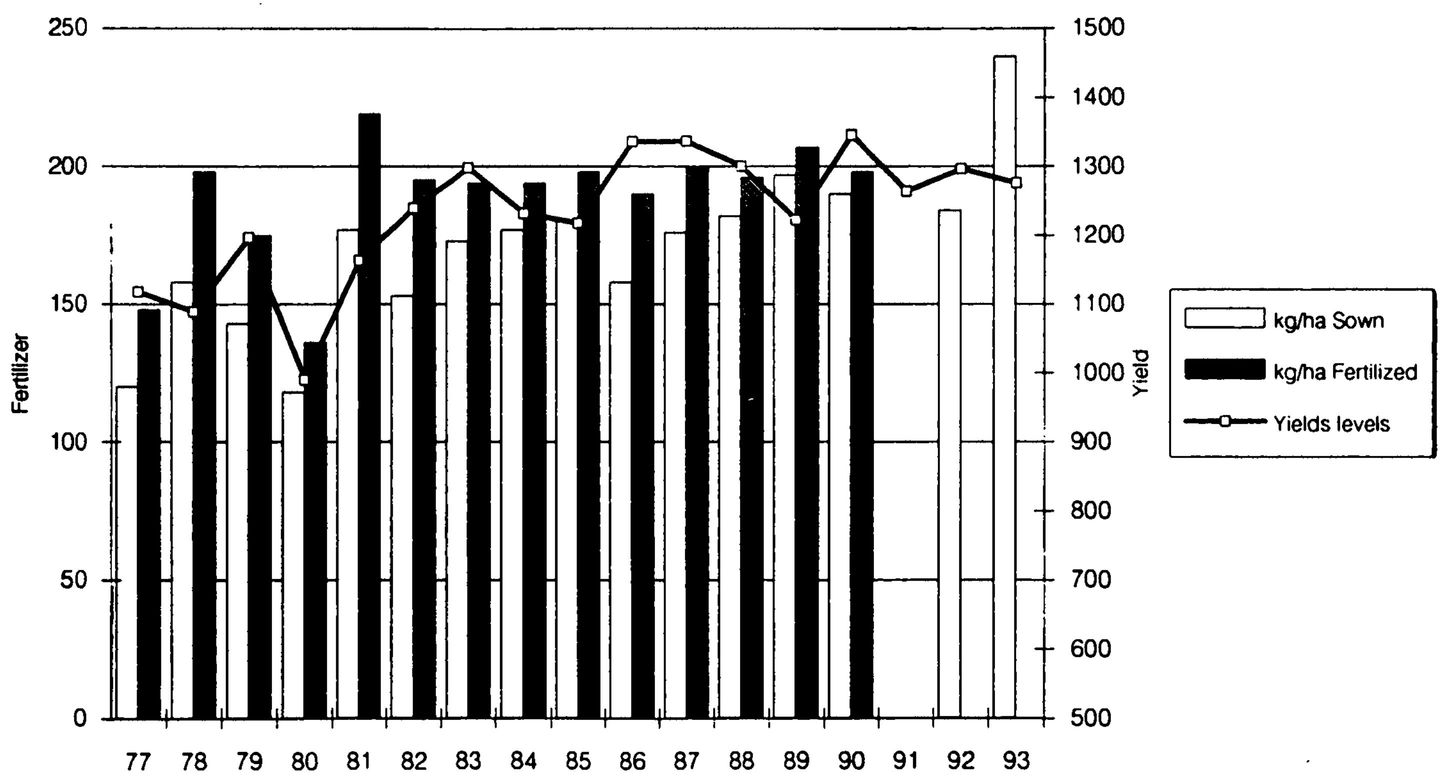

Figure 5d. Mali

Niang and Giraudy's survey data provide indirect evidence of cotton's role as a lead crop for maize (Giraudy 1993b). Both fertilizer and herbicide use on maize were positively correlated with farm size and number of sets of draught animal equipment. The link with cotton lies in the fact that larger farms are also those which devote the largest areas to cotton, and hence have the highest cotton receipts. In Burkina Faso, indirect evidence of a different type is available, based on Wey's (unpublished) survey of maize varieties used by cotton and non cotton farmers. The proportion of improved seed, mainly of interest under intensification strategies, was noticeably higher on the cotton farmers' plots. This is all the more noteworthy since the cotton company has had no responsibility for maize extension in this country. Using case studies in Burkina Faso, Mali and Côte d'Ivoire, Bigot and Raymond (1991) found that savings from cotton earnings were a key determinant of farm households' ability to purchase their first draught equipment.

The apparent dependence of maize intensification on the cotton infrastructure contrasts with the experience of the northern guinea savanna of Nigeria since the late 1970s. Here, maize itself was able to function as a lead crop, generating revenue to support the spread of animal traction (Gilbert et al. 1993). While the support from the agricultural development projects, in the form of improved seed and heavily subsidized fertilizer, certainly played its part in this transformation, the availability of lucrative markets has been crucial. The much larger urban markets in Nigeria, including large cities in the north, present a definite advantage to the development of commercial food farming in the savanna zones, compared to the rest of the region (Bosc and Hanak Freud 1993).

5. Crisis, Adjustments, and Challenges Ahead

5.1 The challenges of markets and institutional reform

The first cotton crisis began with the fall in world prices in mid-1984. Whereas cotton had been generating substantial tax revenues in the early 1980s, the 60% drop in price over the next two years (from 15 FF/kg of fiber to 6 FF/kg)[16] produced a situation where none of the countries in the zone could maintain their cotton sub-sectors without recourse to substantial budgetary support. In exchange for the subsidies, the cotton companies agreed to undertake a major cost-cutting exercise (Min. of Coopération 1991). The only area to be spared from the cuts, was the producer price level, which had just been increased under the favorable world market of the early 1980s.

The reform process which ensued brought costs down by one-quarter to one-third. A prime casualty was the range of ancillary activities which the cotton companies had been funding in the good years: dispensaries, roads, and subsidies to food crop

[16] In the early 1980s, the high value of the dollar against the FF ($1.00 to 10.00FF) meant, their income in terms of dollars declined. Since 1986, the French franc has averaged at roughly 5.75 FF to US$1.00.

promotion. Although the producer price was left intact, input subsidies were removed on fertilizers and pesticides, sometimes abruptly, sometimes more gradually. To counterbalance this effect, research has attempted to seek lower cost combinations of purchased inputs, but so far with limited success.[17] A challenge for the future will be to move from standard extension messages toward more individualized advice, taking into account the diversity of agro-ecological conditions at the local level and of farmers' individual management constraints. This could permit more efficient (cost-reducing) use of chemical inputs.[18]

Rationalization exercises were undertaken to bring down margins for cotton marketing and processing operations, for instance through cost-cutting at the ginneries and better coordination of transport for input haulage and cotton evacuation. Under the heading of rationalization, reforms were also set in motion to shed the cotton companies of some of their functions. Most notably, this began with increasing reliance on producers' associations for the organization of purchasing operations at the village level.

This activity was already being handled by producers' associations in Mali already by the mid-1970s, as an outcome of negotiations between the cotton company and farmers, who were disatisfied with the grading and weighing services provided by the official buying agents. To resolve the crisis of confidence, it was decided to transfer record-keeping to the villages themselves, and support was provided to improve villagers' literacy and bookkeeping skills (Fok 1993). Given the links between output sales and credit repayment, the responsibility for recording sales implied, in addition, the recordkeeping for credit. In Mali this transfer has worked well, with repayment rates remaining at high levels. Similar movements to transfer responsibility for these functions were launched in the 1970s in some other countries in the zone (notably Côte d'Ivoire, where the system has also worked well). With the onset of the crisis, the movement was speeded up[19] and generalized to other countries.

By the time the crisis subsided in mid-1986, the reforms had gone far enough to restore financial balance at the new international sales price of 10 FF/kg. But the success proved short-lived; .when the price dropped again in 1991 (to 7 FF/kg), there

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[17] For pesticides, recommended doses were reduced by about 20%, corresponding more closely to the levels farmers had actually applied in the past. For fertilizers, attempts to regulate quantities based on date of sowing have met with farmer resistance in test cases in Côte d'Ivoire (Bosc and Hanak Freud 1993).

[18] It could be worthwhile, in this context, to consider enlarging upon the current very limited varietal diversity in cotton within any given region. While this would require modification of seed production and diffusion procedures, it could permit farmers who sow at different periods to come closer to optimal levels of input response (personal communication, H. Manichon, CIRAD).

[19] In Côte d'Ivoire, for instance, the share of the GVCs (Groupement à Vocation Coopérative) in primary purchasing moved from one-half to 100% over the 1980s.

was little fat left to cut. Producer prices were no longer spared. The process of scaling back on operations has continued, but this time with less certainty that ability of the system to work effectively was left intact.

One particularly disquieting tendency has been the mounting pressure on producer associations throughout the zone to take on additional functions, such as input purchases and the associated credit risks. Even in Mali, where the producer associations have become increasingly well organized,[20] there has been strong producer resistance to taking on these risks (Berthomé and Mercoiret 1993). In countries where the associations are more recent, and/or result from administrative decrees rather than a grassroots movement, problems still need to be resolved at the level of recordkeeping for cotton sales. For instance, in Cameroon in the 1992/93 season, 11% of the villages had their marketing privileges withdrawn, and another 17% did not receive the marketing bonus because of unsatisfactory management of these operations (Raymond et al. 1994).

Whether on a presumption of cost effectiveness or simply as a matter of principle, governments have also been under pressure to break up the cotton companies. One target is the ginneries, which are to be privatized as separate entities. Another target is cotton extension, which would be (and in some countries already has been) merged with the national, all-purpose service.

There is certainly nothing sacrosanct about the institutional framework. Neither privatization nor voluntary increases in responsibility by producer associations, are in themselves inherent problems. The private sector has shown itself quite capable of contracting transportation services, for instance, and associations are able to keep records at point of purchase. This can be a very positive move, bringing the associations into a more active position in decision-making within the subsector—e.g., negotiations on input and output pricing terms, on the research agenda, and on cost-cutting reforms (Fok forthcoming).[21] The problems arise if the reforms either push associations into responsibilities for which they are not ready, or break up the links within the sub-sector which allow it to perform vital functions such as input credit. If ginning is privatized, this jeopardizes the repayment system which has worked so well. Private sector alternatives for input credit do not exist, and without a well-functioning credit system, input supply itself becomes an endeavor too risky to attract many private operators (Upton 1992, Fontaine and Sindzingre 1991).

The second cotton crisis ended in late 1993, and solvency was restored. Yet these two successive shocks have exposed the vulnerability of West and Central African

[20] The associations took advantage of the new, more liberal political climate to form a union, Syndicat des Cotoniers et Vivriers du Mali Sud (SYCOV) in the early 1990s.

[21] This process is most advanced in Mali; to work well, it implies that producers have access to the necessary information to act as full participants (information on world markets trends, futures markets, cost structure of the sub-sector, etc).

cotton, and the farming systems that are built around it, to world market fluctuations. It is the vulnerability of small, export-oriented producers in a market where major producing countries (USA, Pakistan, China), whose cotton is mainly destined for domestic textile industries, regularly pay their farmers support prices (World Bank 1992). Although progress has been made in reducing costs in the francophone cotton zone, the institutional reforms now underway are not likely to provide the necessary buffer from losses under a future shock of such magnitude. It will be a challenge to find ways to implement the reforms without undermining the viability of the system under normal times.

The reduced profitability of cotton-growing, especially since the second shock, has renewed farmer interest in diversifying their sources of revenue. If traditional coarse grains are to play a bigger role, suitable varieties which produce higher yields will have to be developed. For maize, it will be necessary to resolve the problem of limited demand. Policy measures may be able to help, if governments are willing to reduce the availability of cheap imports of alternative staple grains.[22] The market challenge for maize can be seen, as well, as a technical challenge. Research in Mali suggests that the reduction of both production and especially processing costs could allow this product to move beyond its niche position in the local market (Boughton and Henry de Frahan 1994, Boughton et al. 1994).[23] As with cotton, the reduction of production costs in maize will come via techniques which allow a more efficient use of inputs and rainfall, in diverse agro-ecological and management situations (Forest et al. 1991). When considering such diversification options, policymakers should bear in mind the key role that the cotton infrastructure has played in intensification strategies up to the present.

5.2 The soil fertility challenge

Because it has been accompanied by an abrupt halt in yield growth, the cotton crisis has also highlighted the ecological vulnerability of the cotton-based farming systems. Given the changes in input : output price ratios, one likely explanation is a reduction in input use levels, and a return to more extensive farming practices. To examine this question carefully, it would be necessary to record actual farm situations over a long

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[22] The devaluation of the CFA in January 1994 could favor local grain production for urban markets (rice as well as coarse grains), if governments let the full effect of increased import prices be passed on to the consumers (So far, there has been some reluctance to do so). The effects are not likely to be equal among local cereals. Simulation exercises holding the price of other cereals and urban incomes constant found that the devaluation would lead to a considerable loss in the demand for maize products in Bamako, as a consequence of higher maize prices (due to high production and processing costs) (Boughton et al. 1994). The actual effects on maize demand will depend on what happens to the prices of the other staples, and maize's relative position among them.

[23] For detailed information on the maize subsector in this country, see the studies done by the commodity research unit of the Institut d'Economie Rurale (IER) e.g. Teme and Boughton, 1992.

enough period to establish the trends in input use and yield levels. The responses are not always immediate, particularly if farmers are able to compensate for declines in fertilizer use by other practices, including crop rotation, opening up new land and changing the management of organic matter (personal communication, P. Garin, CIRAD).

Available data at the country level on yields and average fertilizer sales on a per hectare basis only partly confirm the hypothesis of yield declines linked to input reductions (figures 5a-d). Mali, one of the few countries where the producer price has not been cut, has maintained both yields and average fertilizer purchases. In Cameroon, there has been a dramatic drop in inputs, but only a modest decline in yields, a phenomenon which may be due to the relative ease of changing cultivation sites in this land-abundant region. In Côte d'Ivoire, meanwhile, the declining trend in yield preceded the fall in fertilizer sales. Burkina Faso, in turn, registered yield declines, despite fertilizer increases. However, the apparent decline in the efficiency of inputs in these two countries may merely reflect an increasing diversion of cotton inputs to food crops. This could also be a more worrisome sign for the long-term viability of intensive cropping systems in this zone.

Concern over the possibility of a long-term decline in yield in the cotton-based systems has led to a considerable body of research on the determinants of soil fertility in this zone. There appears to be a consensus on the following points:

a. Cultivation causes the soil surface to suffer serious loss of organic matter, which makes the soil structure fragile, causing pulverance, crusting, run-off and top-soil erosion. Although the role of chemical degradation in the reversal of the soil's productive potential should not be underestimated, weed invasion, loss of soil structure, and acidification of the growing layers are the main factors at play (Pieri 1989).

b. Traditional farming methods based on long periods of fallow followed by short periods of cultivation can maintain soil fertility at moderate degrees of crop intensification. The fallow favors the development of two fertility-restoring effects, in what one might consider the *live* phase of the soils: rooting, which spreads organic matter throughout the profile, facilitates water and gas circulation, and contributes to soil fixation; and biological activity of both the soil's fauna and its micro-organisms, which contribute respectively to humification and mineralization of the soil (Pieri 1989).

c. The progressive reduction of fallow lands poses a major technical challenge for reproduction of fertility conditions (Garin 1993). Fallow-based methods of fertility reconstitution require land held in reserve to be three to four times the amount of land being cropped at any given time (Pieri 1989).

d. Although inorganic fertilizer have been a key component of high-yielding agriculture in this zone, chemical fertilizers cannot solve the problem of long-term soil fertility decline. If used exclusively, they contribute to acidification of the soils, regardless of the cropping system. Mineral fertilizer-based mono-cropped systems using cotton/cereals rotations have been shown to require rapidly increasing amounts of fertilizer applications (by a factor of 4 or 5!) to maintain stable yields (Hien et al. 1984).

e. The combination of inorganic fertilizers and manure-based organic fertilizers, less easily degradable than organic fertilizers of plant origin, can maintain long-term productive capacity of the savanna soils under continuous cultivation (Pieri 1989). The required quantities of organic fertilizers are vast: on average, 2 t/ha/year of mixtures consisting of 30-40% manure and the remainder of broken-up plant residue.

f. Although technical proposals exist for household-level production of fertilizers in line with such recommendations (Berger et al. 1987, Berger 1990), there are legitimate questions concerning both the technical and socio-economic feasibility of their implementation on a large scale (César and Coulibaly 1990, Landais et al. 1990). In particular, the capacity for producing and spreading manure-based fertilizer is limited by three interdependent constraints: the availability of plant residues;[24] the quantity of cattle available (nearly 2 head of cattle are needed per hectare), as well as its distribution and the capacity of the farming population to manage the herds effectively for manure production; the labor costs associated with both production and transport of these fertilizers to the fields. It is, therefore, not surprising to find that average quantities of organic fertilizers applied by farmers fall well below recommended levels. Surveys in both Mali and Togo found average levels of 300-350 kg/ha, with concentration on a relatively small percentage of fields located at close distance to farmers' homes (Berger 1991, Raymond et al. 1991).

g. In recognition of these constraints, alternative fertility reconstitution methods have been sought, including the introduction of improved fallows and permanent grazing lands associating grasses and leguminous plants. Although good technical results can be obtained with these strategies, their effective implementation would require some modification of current management

[24] For this purpose, sorghum presents a solid advantage over maize, producing 4 t/ha of straw versus only 2 t/ha.

practices for both individual and communal lands (César and Coulibaly 1990).

Progress in fertility management in this zone will require two types of research at the agronomic level: diagnosis of environment-technique interactions in actual farming situations, associated with monitoring and evaluation of fertility components as they evolve under farmers' conditions in significant agro-ecological and demographic situations. These agronomic programs will need to be incorporated in larger, multi-disciplinary programs in order to achieve a better understanding of the constraints to resource management at the individual and communal level, so that a proposal of viable alternatives can be made (Garin 1993).

The challenges of soil fertility maintenance and reconstitution are obviously not limited to the cotton-based systems described in this paper. As population growth leads to a reduction of fallows, and increasing sedentarization of agriculture, these same issues face the moist lowland savanna lands more generally. Inasmuch as the farmers in the cotton projects are already operating at a relatively high degree of intensification,[25] their experiences with soil management may provide a useful reference point for agriculture elsewhere in this agro-ecological zone.

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Part 5
Research and Development in the Moist Savannas of South America

RESEARCH AND DEVELOPMENT EXPERIENCES IN THE MOIST SAVANNAS OF COLOMBIA

M.A. Ayarza

Tropical Lowlands Program, Centro Internacional de Agricultura Tropical, Cali, Colombia

Key words: germplasm, agroecosystems, soil fertility, biotic and abiotic constraints

Abstract: *Neotropical savannas offer the best alternative for expanding agricultural frontiers in the tropics of Latin America. However, there are a number of biotic and abiotic constraints to the development of sustainable production systems.*

This paper summarizes the main achievements of the Centro Internacional de Agricultura Tropical (CIAT) in its efforts to develop input efficient production systems in the savannas of Colombia. Acid tolerant crop and pasture species grown alone or as components of integrated production systems have the potential to increase agricultural productivity and enhance soil fertility in areas with limited supply of external inputs. Farmer participation in the selection and testing of improved germplasm is essential to the adoption process.

The new focus of CIAT on better understanding of the biophysical and socio-economic factors driving agricultural systems in these areas will permit successful intensification of agriculture.

1. Introduction

Recent estimates indicate that agricultural output in Latin America is not sufficient to meet population food demand (Vera et al. 1993). This situation will worsen in the coming decades if population continues to grow at the current rate and agricultural production does not increase significantly.

There are two options for increasing agricultural production in the region: (a) intensification of production in areas already under exploitation, and (b) expansion of the agricultural frontier to more fragile areas such as the savannas, hilly lands and forest margins. Both options imply a risk of resource degradation under conventional management systems, especially in the more fragile environments.

The neotropical savannas offer the best opportunity for expanding livestock and crop production in the frontier regions of Latin America. They constitute a significant area in Brazil (220 million ha), Colombia (17 million ha), Venezuela (28 million ha) and Bolivia (4 million ha). In some areas of Brazil where fertilizer supply is good and government support has been strong, rapid intensification of agriculture has been possible with the use of conventional management technologies (Mueller 1992). However, in large areas of the savanna, limited availability and high cost of external inputs (such as lime and fertilizers) and lack of infrastructure and/or distance to markets result in marginal economic development. In these areas, alternative production systems are needed to enhance input use efficiency, increase agricultural output and avoid degradation as can be achieved with the use of conventional management systems.

This paper describes the potential for and the constraints to agricultural expansion and intensification in Latin American savannas with emphasis on the well drained savannas of Colombia. Since 1969, CIAT has been working at the Carimagua Research Station in close collaboration with the Instituto Colombiano Agropecuario (ICA) on the development of input efficient systems. Achievements on germplasm improvement and the design of improved crop and management systems will be discussed. In addition, future research challenges for the savannas are described within the context of CIAT's new strategy.

2. Agroecological Characterization of the Colombian Savannas

The Colombian savanna, known as 'Llanos Orientales' occupies approximately 25% of the total area of the country. It is located between the Andean mountains and the Orinoco river (figure 1). The eroded sediments deposited during the Pleistocene age make up the parent material of the soil (FAO 1965). Three different landscapes characterize the region: the high plains (Altillanura), the dissected plains (Serranía) on the right margin of the Meta river, and the poorly drained savannas on the left margin of the same river. The first two landscapes are well drained and have a number of similar characteristics which differ from the third landscape (Sanchez and Cochrane 1985).

The mean annual precipitation is about 1800 mm distributed from April to November followed by a severe but relatively short dry season from December to March. The mean annual temperature is about 26° C and is uniform throughout the year.

The soils of the well drained areas are mostly Oxisols characterized by a pH-H_2O less than 4.5, kaolinitic clay and abundant iron and aluminum oxides (Guerrero 1971). Most of the cation exchange complex is occupied by aluminum and phosphorus availability is very low (table 1).

The savanna vegetation is dominated by grasses such as *Axonopus, Leptocoriphyum, Andropogon* and *Trachypogon,* (Fisher et al. 1992) which are used for extensive cattle production. Burning is practiced in the upland areas before the start of the rains and after the rains in the lower areas (Fisher at al. 1992). The objective of this practice is to improve the quality of the animal diet while maintaining the dominance of grasses over woody species. Current stocking rates on farms in the Llanos range between 6.0 and 9.0 ha/AU. Continuous grazing is the most common management system. With burning and low stocking rates, average animal liveweight gain is 90 kg/head/year (Rivera 1988).

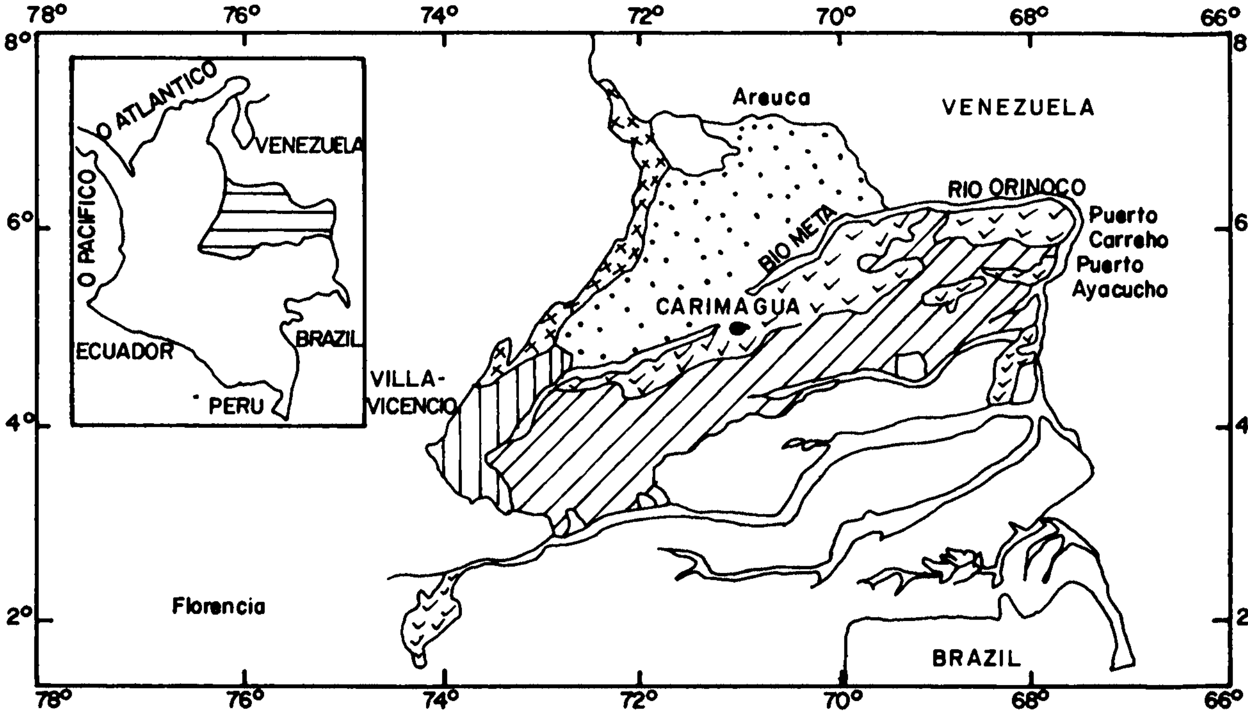

Figure 1. Landscape distribution in the Llanos Orientales of Colombia

Table 1. Soil chemical and physical properties of the well drained soils in the Colombian Llanos

Landscape unit	Depth (cm)	Text. class	pH-H_2O	Org. C (%)	Extr. P (µg/g)	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Al	Al sat %
						meq/100g				
High plains	0-20	Clay loam	4.5	3.7	1.6	0.10	0.02	0.08	2.8	93
Dissected plains	0-40	Sandy loam	4.9	1.4	0.6	0.05	0.04	0.01	2.8	97
Serrania	0-25	Sandy	4.7	0.6	0.8	0.05	0.07	0.02	1.9	93
Piedmont	0-11	Clay loam	4.7	1.3	4.2	0.39	0.30	0.17	1.3	58
	11-31	Clay loam	4.0	0.8	1.9	1.15	0.32	0.14	1.9	52

During the last 25 years there has been a rapid expansion of agriculture in the Llanos due to extra revenue from increased oil exploitation, and the availability of technology. The price of land is increasing (US$ 100-200/ha) and agricultural intensification is taking place; crop production and integrated crop livestock systems are replacing extensive pasture land in areas near the main cities. At present, these areas account for most of the rice production in the country and contribute 30% of total beef production (Spain 1990).

In more remote areas, where infrastructure is limited, the cost of land is low (US$ 40-50/ha) and there is little management input. Ranchers in these areas maximize animal production per head (Fisher et al. 1992).

Population density close to the piedmont areas (Villavicencio and Puerto Lopez) and along the Andean foothills is generally high, but very low in areas where infrastructure is limited.

3. Potential and Limitations of the Colombian Savannas

The well drained savannas of Colombia and similar savanna areas in Venezuela and Brazil have a number of important advantages but also have severe limitations. Soils are generally deep and well structured, with little or no physical barriers to root development. Rainfall provides adequate to excess moisture during six to eight months of the year and topography ranges from very low relief to gently rolling landscapes which are easy to mechanize for intensive cropping. These areas are easily accessible and the cost of building roads is low compared to that of most humid tropical regions (Fisher et al. 1992).

Among the limitations, the most severe is the prevalence of acid and infertile soils with high levels of Al in the exchange complex. All major nutrients are deficient and P fixation is high due to the abundance of Fe and Al oxides. Despite the low relief, soil erosion is a problem, even in the native savanna systems, because of regular burning and grazing. Erosion hazards increase when soils are plowed or disk harrowed to plant crops and pastures (Restrepo and Navas 1982). Conventional land preparation destroys the macrostructure and leads to surface sealing and compaction, resulting in severe runoff and soil loss during the rainy season.

The low productivity of the savannas in animal production, in spite of low stocking rates, is due to the poor nutritive value of the savanna species (Paladines and Leal 1979). Calving rates are low (< 50%) with high rates of abortion and losses through mortality losses (Rivera 1988). During the dry season forage quality and quantity is poorer, leading to extreme nutritional stress for grazing anima's, especially cows with suckling calves.

Crops grown in the savannas are also subject to extreme biotic stresses, e.g., rice blast, which is more difficult to control under savanna conditions than elsewhere (Spain and Ayarza 1992). Anthrachnose (*Colletotrichum*) is more damaging to the legume *Stylosanthes guayanensis* in the savannas than in humid forests. Leaf cutter ants and other insects are also hazardous to crops and pastures, especially during the establishment phase.

The lack of local sources of lime and fertilizers, the long distance to markets and the cost of transportation have limited the use of conventional external-input based management technologies in most of these regions.

4. Research Strategies

The main research strategy adopted by CIAT to overcome the major limitations in these areas has been to identify input efficient crop and pasture species with high yield potential and low demand for external inputs. Efforts were concentrated on the collection, evaluation and selection of pasture and crop germplasm resistant or tolerant to pests and diseases and well adapted to acid soil conditions (Al toxicity, P deficiency and low nutrient availability). Most of the work for the past 20 years has been conducted at the Carimagua Experiment Station located in the eastern plains of Colombia. This site is representative of the well drained areas of the Llanos. During the last decade, evaluation work has been extended to other more intensively used areas which are closer to the piedmont regions of the Llanos.

4.1 Germplasm development

More than one thousand grass and legume accessions were collected by CIAT agronomonists from the tropics of Asia, Africa and Latin America and tested for adaptation to soil and environmental constraints at Carimagua. After more than 10 years of evaluation, several promising materials have been identified and further tested under a broad range of conditions in the savanna ecosystem through the International Network for Pasture Evaluation (RIEPT). The result of this effort is the release of superior grass and legume accessions by national institutions in several Latin American countries (table 2). Most of these materials have excellent edaphic adaptation to low fertility soils, high seed yield and good forage quality (Miles and Lapoint 1992). Some of them also have the capacity to respond to increased soil fertility.

Table 2. Forage grasses and legumes evaluated at RIEPT and released in different countries, 1986-1991 (Miles and Lapoint 1992)

Species	CIAT No.	Cultivar	Year	Country
Grasses				
Andropogon gayanus	621	Llanero	1986	Mexico
		Andropogon	1988	Cuba
		Veranero	1989	Costa Rica
		Otonero	1989	Honduras
		Gamba	1989	Nicaragua
Brachiaria brizantha	26646	La Libertad	1987	Colombia
Brachiaria brizantha	6780	Brizantha	1987	Cuba
		Cigante	1989	Venezuela
		Insurgente	1989	Mexico
Brachiaria decumbens	606	Brizantha	1988-87	Cuba
		Chontalpo	1989	Mexico
		Sehal	1989	Panama
		Pasto Peludo	1991	Costa Rica
Branchiaria dictyoneura	6133	Llanero	1987	Colombia
Brachiaria humidicola	679	Aguja	1989	Venezuela
		Humidicola	1989	Panama
		Chetumal	1990	Mexico
		Humidicola	1990	Colombia
Panicum maximum		Vancedor	1990	Brazil
		Tanzania-1	1990	Brazil
Legumes				
Centrosema acutilofium	5277	Vichada	1987	Colombia
Stylosanthes guianensis	184	Zhuhuacao	1987	China
Desmodium ovalifolium	350	Itabela	1989	Brazil
Pueraria phaseoloides	9900	Jarocha	1989	Mexico
Clitoria ternatea		Thehuana	1988	Mexico
		Clitoria	1990	Honduras
Centrosema pubescens	438	Centrosema	1990	Honduras
Arachis pintoi	17434	Amarilo	1990	Australia

The Cassava Program of CIAT has developed high yielding materials and identified management practices to increase cassava production in the region (fig. 2). The Rice Program recently developed an outstanding, upland rice variety which is tolerant to soil acidity, has a high yield potential and an improved grain quality. This variety has already been released in Colombia as 'Oryzica Savanna 6'. Several new lines are showing higher yield potential (3-5 t/ha) and superior resistance to blast disease (table 3). The irrigated rice sector has also benefited from the development of new varieties by CIAT and national programs.

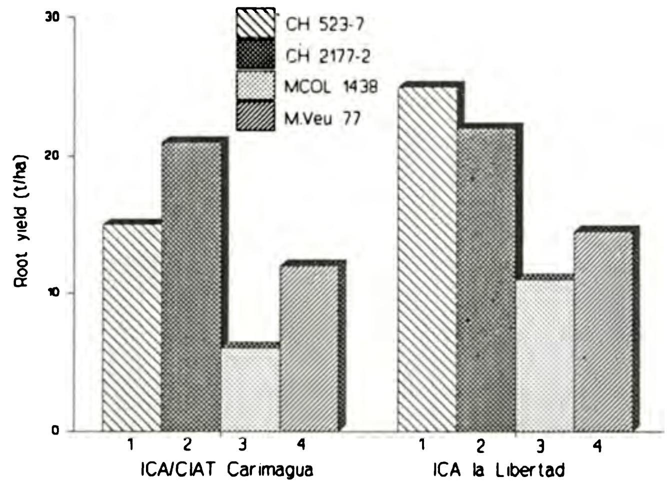

Figure 2. Average root yields of two new cassava clones (CH 523-7 and CH 2177-2) and two control cultivars (M Col 1438 and M Veu 77) grown at two locations in the Llanos Orientales, Colombia

Table 3. Average mean grain yield of seven breeding lines of rice in semi-commercial plots, Nova Olimpia, Mato Grosso, Brazil, 1988 - 1989 (CIAT 1990)

Line	Yield (kg/ha)
Mean of seven lines	5139
Local checks:	
Araguaia	3269
Cuiabana	2625
IAC 47	2031

Carimagua has also been used as a major screening site for plant resistance to pests and diseases. Several *Brachiaria* pasture ecotypes have been selected for resistance to spittle bug which causes severe reduction in plant vigor and limits forage production of most of the commercial varieties available in tropical America (Lapoint and Miles 1992). For cassava and rice, numerous crosses have been tested for resistance to major pests and diseases. During the evaluation process, genetic sources for resistance to pests and diseases have been identified and incorporated in advanced breeding lines.

4.2 Development of improved management systems

4.2.1 *Savanna-based production systems*

Researchers at CIAT found that the main constraint to animal production in the savannas of Colombia is energy (Alvarez and Lascano 1987). Mean digestibility of neotropical savanna grasses is <40%, even in young plant parts after burning. To overcome this limitation small areas of improved grasses (energy banks) or grass/legume mixtures were tested. Animal liveweight gains increased significantly when animals had access to a small paddock of *Andropogon gayanus,* compared to the savanna based systems (Lascano and Plazas 1990). Even higher animal responses were observed with banks of grass/legume mixtures (table 4). The introduction of forage legumes into the savanna to improve the quality of animal diet has been tested with limited success because of problems of persistence of the legume under this system (Fisher et al. 1992).

Table 4. Effect of the introduction of *A. Gayanus** + *S. Capitata* in improved pastures planted in a commercial farm in the Llanos of Colombia, on animal production

Year	No of cows	Stocking rate (AU ha^{-1})	Cow weights (kg)	Conception (%)	Weaning weight (kg)
1979	330	0.08	233	50	109
1980	328	0.13	292	64	119
1981	390	0.15	303	62	118
1982	427	0.16	301	76	142
1983	446	0.19	332	53	148
1984	485	0.19	328	60	143

Note: 5.5% of farm area was planted with improved pastures (*Andropogon gayanus/Stylosanthes capitata*).

The strategy of supplementing animal diet with salt licks containing 6% P has improved reproductive performance markedly, reduced the abortions and calf mortality during the first month after birth (Vere and Seré 1990). In addition, fertilizer applications significantly increased forage dry matter content and quality of the native savanna species (Fisher et al. 1992).

4.2.2 *Legume-based pastures system*

Even on poor savanna soils, legume-based pastures have shown potential for increased animal performance. Animal gains increased two-fold and gains per hectare ten-fold when animals grazed on a grass/legume mixture compared to gains from traditional production systems (fig. 3). Impressive improvements in reproductive performance were also made using the grass-legume technology (Thomas et al. 1993). In this system the legume is the key component. The nitrogen fixed by the legume improves the nutritive value of the forage and increases the overall productivity of the pasture with time. Results of a long-term grazing trial comparing a mixture of *B. decumbens* + *P. phaseoloides* with a pure *Brachiaria* pasture showed that the legume produced an increase of only 5% during the first rainy season. However, after four years, the advantage of the association over the pure grass was linear and increased by 65% (fig. 4).

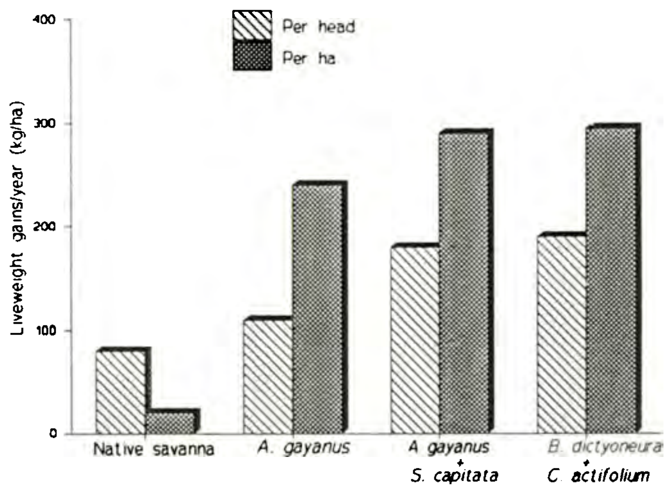

Figure 3. Potential animal productivity of native savanna and improved pastures in Carimagua, Columbian Llanos

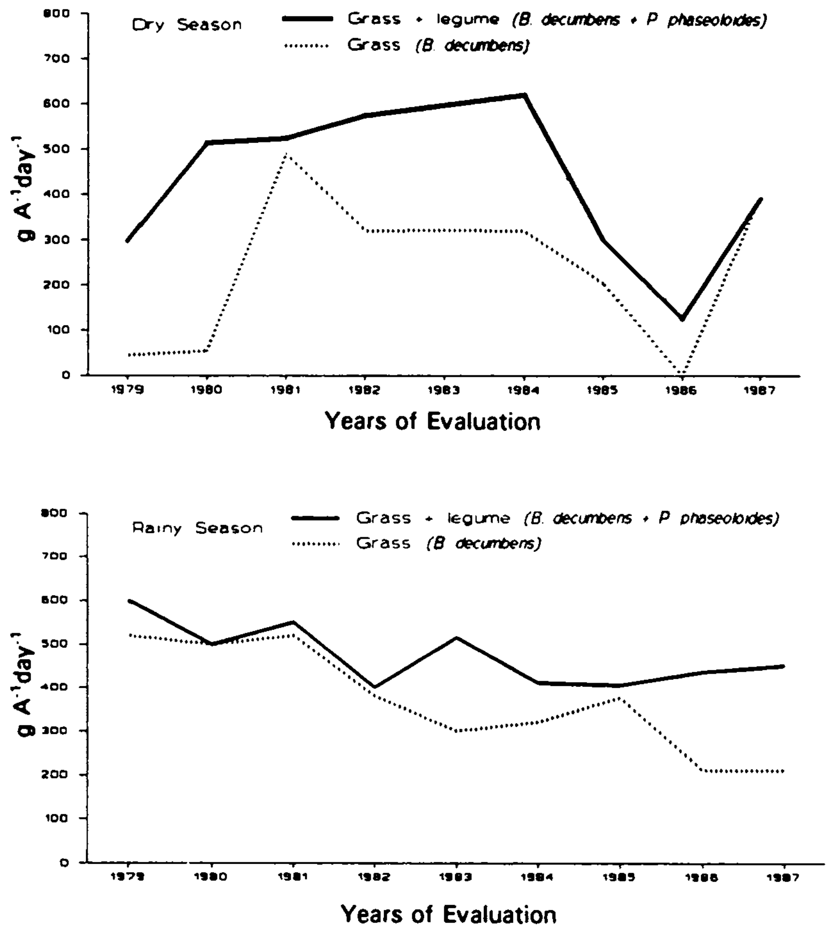

Figure 4. Liveweight gains in a pasture of *B. decumbens* alone and in association with *P. phaseoloides*, evaluated for nine years during the raining and the dry seasons in an Oxisol at Carimagua, Colombia

Legume-based pastures not only improve animal diet and performance but also improve soil chemical and physical properties. Recent work using the ^{13}C isotope showed that the legume contributed 29% of the total soil carbon found in the top 2 cm of a pasture of *B. decumbens* + *Pueraria phaseoloides* (fig. 5). The contribution of the legume decreased gradually down the soil profile (Rao et al. 1992). There was also a larger proportion of water stable soil aggregates > 0.5 mm in the 0-20 cm topsoil of the grass-legume mixture than in the pure grass and the savanna pastures. These qualitative differences were accompanied by higher potential rates of N mineralization in soil from grass/legume pastures than only grass pastures (table 5).

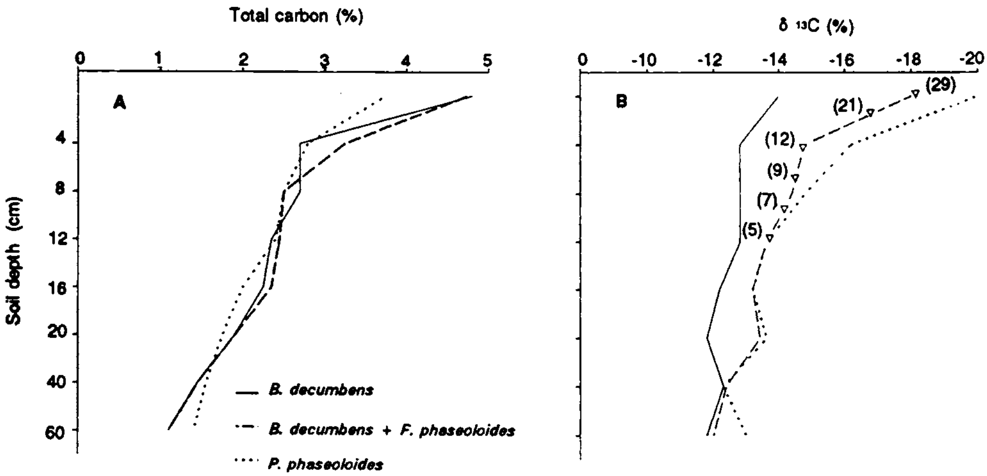

Figure 5. Distribution of total carbon content and ^{13}C natural abundance in relation to soil depth in different pastures. (Values in parentheses represent % of carbon derived from legume in a grass + legume association)

Based on information generated from a mixture of *Brachiaria dicytoneura* and *Arachis pintoi* pasture, it has been estimated that the amounts of legume required to balance the N cycle without involving a net change in soil organic N reserves should vary between 20 and 45% of the total DM herbage, depending on the pasture utilization intensity (Vera 1990).

Table 5. Potential N mineralization rates under *Braocheri C. Decumbens* + *Paerarid* pasture measured by two methods (R.Y. Thomas, unpublished data)

Method	g N / g soil/day	
	B. decumbens	*B. decumbens* + *Kudzu*
Incubation in pots in glasshouse for 4 weeks	0.519 + 0.085	0.913 + 0.116
Anaerobic incubation at 40 C for 7 days	3.86 + 1.33	6.84 + 1.69

4.2.3 *Agropastoral systems*

The development of improved rice varieties and legume-based pastures tolerant to soil acidity made it possible in 1988 for the Rice and Tropical Pasture Programs to begin a joint research project on a rice-pastures system for the Colombian Eastern Plains. Field trials conducted at Carimagua and at several farms in the Llanos showed that the average production of rice planted simultaneously with pasture species was similar to that obtained when it was planted in monoculture (table 6). In addition, the residual effect of fertilizer applied to the rice was so great that pastures were fully established three months after the rice was harvested. Economic analysis of the operation showed the feasibility of this technology. The system has also been used to reclaim degraded pastures (CIAT 1990).

Table 6. Estimated grain and biomass production of rice planted in monoculture and in association with a grass-legume pasture on an Oxisol in the eastern plains of Colombia (CIAT 1990)

System	Rice (t/ha)	Weeds	Grass	Legume
		---Dry matter (kg/ha)---		
Rice in monoculture	1.89 - 2.50	280 - 1118	-	-
Rice + B_t d + C_t a	1.95 - 2.3	542 - 898	609 - 1962	149 - 314
Rice + A_2 g + S_t c	1.74 - 2.4	292 - 658	1464 - 2103	437 - 448

Notes: B_t d = *Brachiaria dictyoneura* (cv. Llanero)
C_t a = *Centrosema acutirolium* (cv. Vichada)
A_t g = *Andropogon gayanus* (cv. Carimagua 1)
S_t c = *Stylosanthes capitata* (cv. Vichada)

Improved pastures also have a positive residual effect on subsequent crops. The results of a trial conducted at Carimagua showed that rice planted after ten years of grazing of a *B. decumbens* + *Kudzu* pasture produced an extra 1.7 ton/ha of rice compared to plots with only grass pasture (Vera 1990).

Corn, soybean and pasture varieties which have shown promise are under development through collaborative projects between CIAT, CIMMYT and INSORMIL. The objective of this work is to broaden the options for improving agropastoral systems in the Llanos.

4.2.4 *Improved crop production systems*

The initial focus of CIAT's Rice and Cassava Programs on the development of germplasm tolerant to acid soil conditions has been complemented with the development of integrated production systems. Technologies for processing and conserving fresh cassava have improved its market potential (Weathey and Isquierdo 1991). The Integrated Pest Management Program has allowed a reduction in pesticide applications to control rice blast and other pests. Results of preliminary surveys indicate that the percentage of farmers who do not use pesticides has increased from 22.7% to 42.8% in the 1990s (CIAT 1991).

5. Experiences at the Interface Between Research and Development

High yields and pest resistance do not always guarantee adoption of the new varieties by farmers. For this reason, in the early 80s, CIAT started the exposure of selected crop and pasture components to farm conditions. In 1985, the Tropical Forages Program, in collaboration with the ICA technology transfer project (CRECED), promoted the use of legume-based pastures among cattle producers. The project selected some farms in the Llanos and jointly established pastures and seed plots of *Stylosanthes capitata* c.v Capica and *A. Gayanus* c.v. Carimagua 1. After four years of work, 60 farmers planted 3000 ha of the pasture and produced 14 tons of *Capica* seed (Ferguson 1992). The project was expanded to involve 250 farmers who planted a total of 10,000 ha of the improved pasture.

In spite of the potential of legume-based pastures to improve animal performance and soil fertility, adoption by farmers in the Llanos is still incipient. Lack of awareness and limited seed availability are still major barriers (Ferguson 1992). Nevertheless, the adoption of grasses has been easier than legumes with the exception of *Stylosanthes capitata* cv. *capica*. These onfarm experiences have led to the awareness of the need for increased farmer participation and the involvement of a wider range of institutions.

The Cassava Program has recently incorporated farmer participation in the evaluation of its germplasm. The objective is to incorporate farmers requirements in the selection process (Hernandez 1991). The new strategy has led to the early adoption of improved cultivars.

The Rice Program has collaborated closely with ICA and the rice growers' association, FEDEARROZ, in the on-farm testing and production of seeds of new upland rice lines. Most of the seed multiplication and testing at a commercial scale has been conducted by local institutions in Colombia, Venezuela and Brazil.

7. CIAT Strategies to Meet Future Challenges

CIAT recognizes the need to complement its traditional commodity research with research on natural resource management if food production and economic growth are to increase without jeopardizing the environment. Research on germplasm is directed toward the understanding of the physiological and biochemical bases for adaptation to acid soil conditions and the use of biotechnology to incorporate desirable traits such as resistance to pests and diseases, herbicide tolerance, etc. Although screening will continue under severe stress conditions, germplasm testing will be broadened to evaluate multipurpose options such as crop pasture rotation, cover crops, and green manure.

CIAT's research on germplasm development will be complemented with the characterization of the resource base in order to develop sustainable agricultural systems for the savanna, the hillsides and forest margins of tropical America. Characterization studies on biophysical and socio-economic factors are underway in the Agroecological Studies Unit of CIAT. The information generated will be used to develop improved production systems and to measure their impact at representative sites within each of the agroecosystems. This will permit a rapid extrapolation of results to similar environments.

Relevant research on savanna ecosystems is underway in the areas of nutrient cycling, organic matter dynamics and modelling. The objective is to understand the principles of input efficient systems and to examine the potential impact of different management scenarios on the sustainability of improved systems.

8. Conclusions

Information presented in this review supports the general hypothesis that it is possible to increase savanna productivity with minimum risk of resource degradation. A fundamental component of this technology is the use of high yielding crop varieties and pasture species tolerant to soil acidity, and which are able to utilize and recycle nutrients efficiently.

The strategic use of acid-tolerant pasture species has the potential to substantially improve animal productivity in savanna-based production systems with low levels of intensification. In areas with higher levels of intensification the replacement of savanna vegetation with adapted crop and pasture species can increase animal performance and crop productivity substantially even with the modest use of external inputs. The combination of rice with pastures in space and time has proven to be biologically and economically feasible for reclaiming degraded pastures. However, more work is needed to broaden the crop and pasture germplasm options for different levels of intensification. Recent reductions in subsidies for agriculture inputs have greatly increased the relevance of crop-pasture integration.

The strategic research on germplasm development and resource management by CIAT should, in the coming decade, contribute substantially to the development of highly productive and sustainable systems for the neotropical savanna ecosystems. A better understanding of the biophysical and socioeconomic factors driving agricultural development in these areas will ensure successful intensification of agriculture and will help to relieve the pressure on other fragile areas such as the rainforests.

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DEVELOPING SUSTAINABLE CROPPING SYSTEMS FOR THE BRAZILIAN SAVANNAS

C.R. Spehar and P.I.M. Souza

Empresa Brasileira de Pesquisa Agropeuária-Centro de Pesquisa Agropecuária dos Cerrados (EMBRAPA-CPAC), C. Postal 08223, 73301 970 Planaltina, DF, Brazil

Key words: land occupation, tillage methods, soil fertility and conservation, organic matter, crop adaptability and rotation, sustainability

Abstract: *The Brazilian savannas (cerrados) cover an area of 200 million ha. and were on the fringe of agriculture in the country until two decades ago. This extensive low input upland rice and pasture system has been replaced by modern soybean production. Late maturing and aluminum tolerance have expanded soybean adaptability in this environment, supplying 50% of the national production. Breeding work on other traditionally cultivated plants is also reviewed and their potential in the production systems is discussed. Research on improving soil fertility, land development and tillage are discussed in relation to soil conservation and organic matter maintenance. Alternative cropping systems which enhance soil fertility are also presented.*

1. Introduction

The Brazilian savannas (cerrados) occupy one quarter of the country. The vegetation, which shifts gradually from open fields to dense woods, resembles that of the African savannas in many respects. Unlike the African savannas, the cerrados are dominated by acid soils devoid of nutrients, and has high levels of available aluminum and low moisture-holding capacity. This has greatly limited the expansion of modern agriculture in this region. Recent achievements in soil research and the concomitant improvement of crops and forestry have contributed to the expansion of modern agriculture in this area (EMBRAPA-CPAC 1980, 1981). This paper focuses on the historical background of the cerrados and particularly on the problems which originated with the rapid change from low input traditional cropping systems to modern farming.

2. Physiographic Background

The cerrados, which are situated between the Atlantic and the Amazon forests, (figure 1) cover an area of about 200 million hectares (EMBRAPA-CPAC 1979). Traditionally, this immense area of plateaux, has been exploited for beef cattle, with low input and low production efficiency.

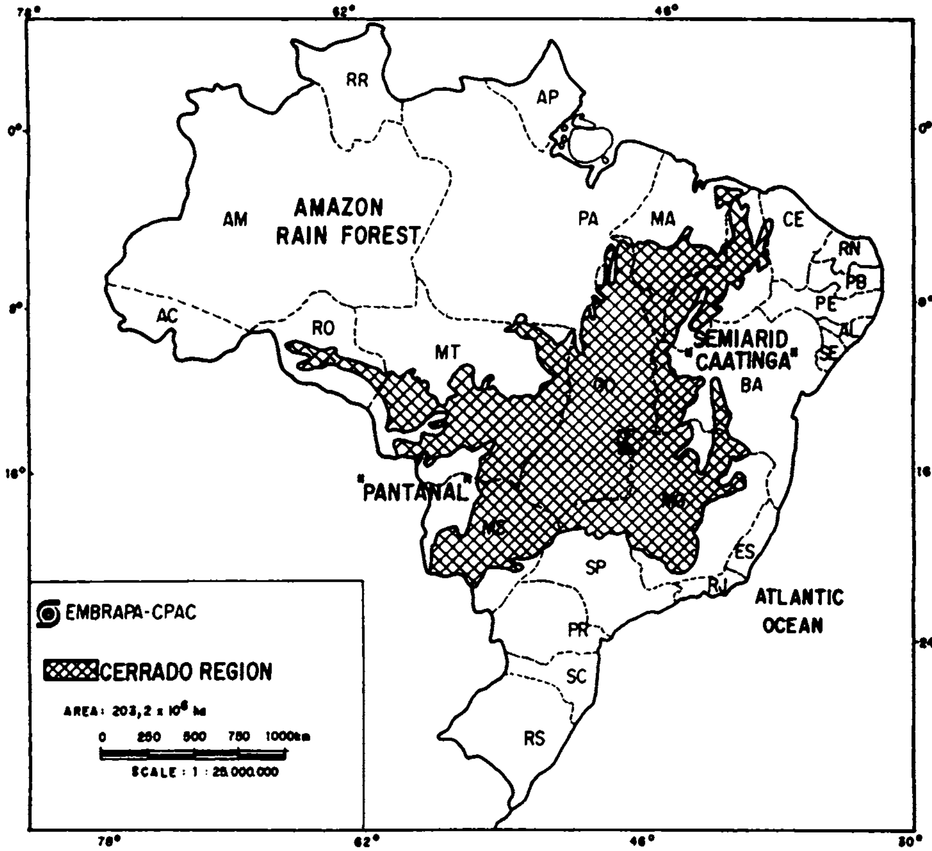

Figure 1. Cerrado region of Brazil

2.1 Climate

The climate of the cerrados has two moisture regimes: the rainy and the dry season. The average yearly precipitation is concentrated between September and May and varies between 1000 and 2000 mm depending upon the region (figures 2 & 3). Only 15% of the rainfall occurs in the dry season and this limits cultivation of annual crops. However, the streams and tributaries of three of the great river basins of South America provide water for irrigated cultivation into the dry season.

The average daily solar radiation in the cerrados ranges between 475 and 500 Langleys (cal/cm^2/day) (Adamoli et al. 1985). However, the range between minimum and maximum temperature is higher in the dry season than in the rainy season.

There are four ecophysiographical zones that affect the cerrados, the Atlantic rainforest to the east, the Pantanal to the south-west, the Amazon rainforest to the west and north-west, and the semi-arid Caatinga to the north-east (figure 1). The core area of the cerrados is marked by the highlands, with an altitude of 1000 m above sea level. The mean monthly precipitation in the cerrados of Sete Lagoas, Mato Grosso, 1928-1986 (58 years) is shown in table 1. The number of rainy days and the standard deviation is an indication of the erratic occurrence of dry spells during the rainy season . These dry spells may affect the performance of annual crops when prolonged beyond 15 days. The shallow rooting of cultivated plants makes them more susceptible to dry spells; rice and maize appear more susceptible to moisture stress than soybean. The benefits of improving soil fertility will mitigate water stress, but only several years after the virgin areas are developed for farming (Ritchey et al. 1980). Aluminum tolerance is another approach to solve this problem and is discussed later in this paper.

Table 1. Rainfall distribution in the Cerrados of Sete Lagoas, MG, 1928-1986 (Assad et al. 1991)

Month	Mean (mm)	Standard deviation (mm)	C.V. (%)	Number of rainy days
January	266	150	56	17
February	174	111	63	12
March	147	90.8	62	12
April	59	44.6	75	7
May	22	23.3	107	3
June	7	13.9	196	2
July	10	16.7	172	2
August	8	12.9	160	1
September	33	30.5	92	4
October	109	59.3	55	10
November	209	95.5	46	13
December	300	126.7	42	20

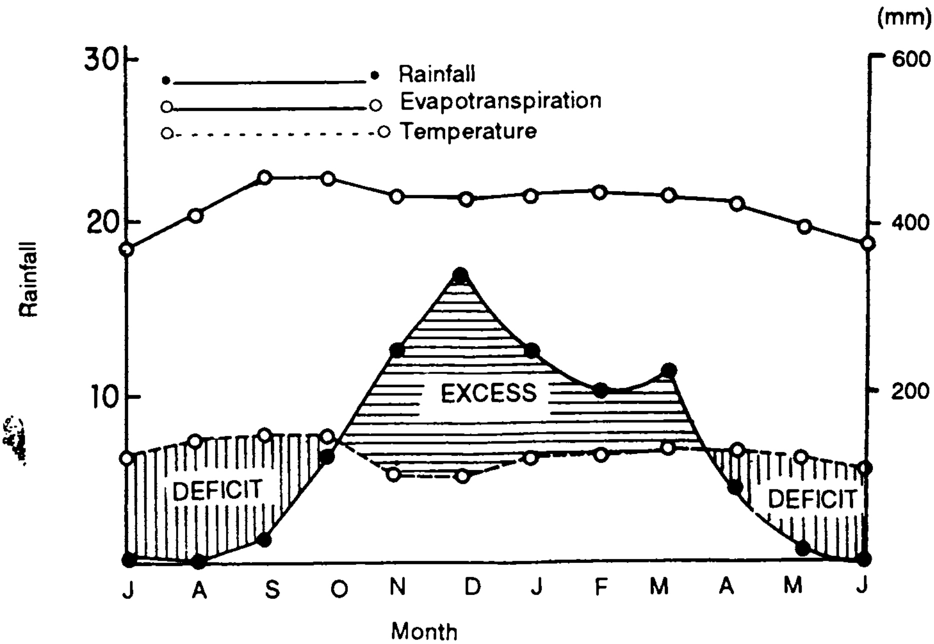

Figure 2. Annual evapotranspiration, rainfall and temperature in the core cerrado area

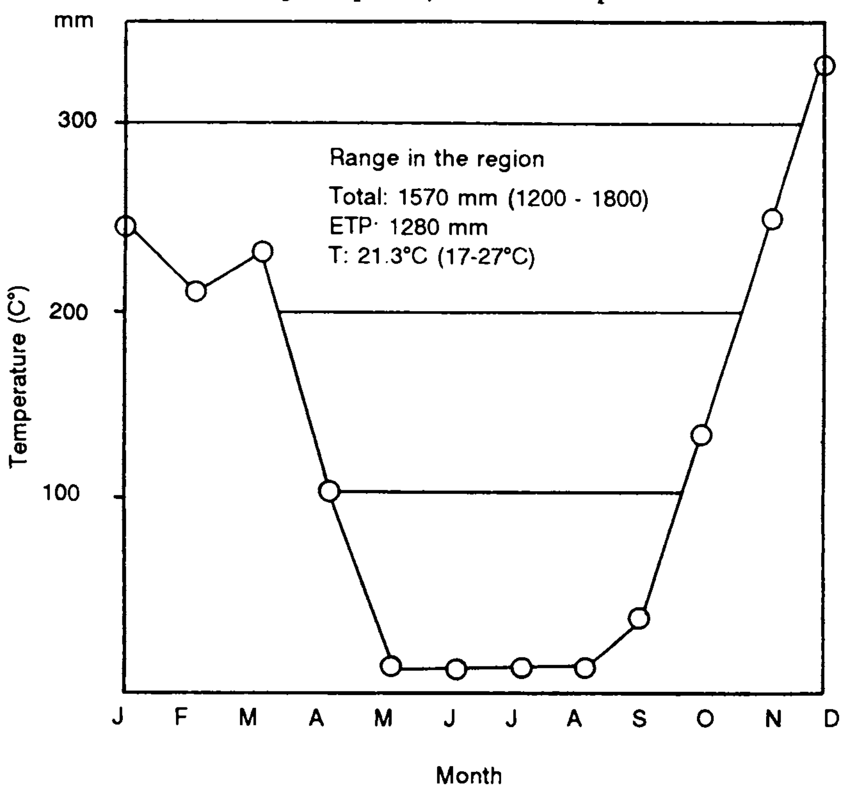

Figure 3. Rainfall distribution and evapotranspiration (ETP) in the core cerrado area

2.2 Soils

The cerrado soils are poor, with a pH of 4.0 to 5.5 and high aluminum saturation. Exchangeable aluminum may occupy up to 80% of the saturation base. More than 95% of the soils are dystrophic. The soil clay fraction consists mainly of kaolinite and iron and aluminum hydroxides, with a very low cation exchange capacity (<13 cmol/kg) (Madeira Neto et al. 1982). Available P, K, Ca, Mg and Zn are very low.

Oxisols (Latosols) are dominant accounting for over 90% of the total soil types (Grove et al. 1980, Ritchey et al. 1982) and are widely used for agriculture. More recently, land with Inceptisols (Arenosols) have also been cleared for farming.

Table 2. Major soils of the cerrado (Adamoli et al. 1986)

Brazilian	USDA	FAO	Area (km^2)	Rate (%)
Latossolos	Oxisols	Ferralsols	935.870	46.0
Areias Quartzosas	Inceptisols	Arenosols	309.715	15.2
Podzolicos	Ulti/Alfisols	Acri/Luvisols	307.677	15.1
Litolicos	Entisols	Lithosols	148.134	7.3
Plintossolos	Ox/Inceptisols	Luvi-Gleysols	122.664	6.0
Cambissolos	Inceptisols	Cambisols	61.943	3.0
Concrecionarios	Ultisols-Oxisols	Acrisols	57.460	2.8
Gleis	Inceptisols	Gleysols	40.752	2.0
Terras Roxas	Alfisols	Nitosols	34.231	1.7
Outros	Other	Other	19.154	0.9
Total			2,037.600	100

The physical characteristics of the main cerrado soils are presented in table 3. Base saturation is low (>50%). The main common physical characteristics of these soils are the high to moderate drainage and a profile depth of >2 m with very little difference between the horizons A and B.

High Al and low Ca levels limit the deep root growth of most cultivated plants to enable them exploit the deeper nutrients and water. In addition, soil texture ranges from clayey to very sandy. The latter predominates in large areas of Northern Mato Grosso, Western Bahia, Tocantins and Southern Piauí States. The moisture holding capacity of these sandy soils is even less than for the clay soils, and this can result in total crop failure if the dry spell is prolonged.

2.3 Relief

The main soil classes occur in certain geomorphic toposequences (fig. 4). The red-yellow Latosols predominate in the flat areas of the plateaux. The slopes are typically formed by dark red Latosols which are saturated with Al throughout the soil profile (table 3). Most of the soils are devoid of nutrients due to prolonged water saturation during the rainy season. Finally, the alluvial soils vary in iron reduction and organic matter levels.

Table 3. Selected data showing physical characteristics for main soils in the cerrados (Maderia Neto et al. 1982)

Horizon	Sand	Clay	pH H_2o	C (%)	S (mg/100g)	CTC of soil	V (%)	Al saturation %	P Extr. (mg)
				Dark red Latosol, dystrophic, acidic, clayey					
A	25±19	61±19	5.3±0.6	2.40±0.90	3.9±3.8	11.4±3.3	31±25	35±25	1±0
B	23±18	65±0	5.1±1.1	0.63±0.32	0.8±0.6	4.3±1.8	17±9	17±9	<1
				Dark red Latosol, dystrophic, acrid, loamy					
A	80±6	14±4	5.0±5.0	0.90±0.30	1.65±1.60	5.4±1.6	28±18	42±24	3±2
B	72±6	20±5	5.0±5.0	0.15±0.05	0.30±0.15	2.1±0.5	14±5	73±9	4±17
				Red-yellow Latosol, dystrophic, clayey					
A	43±15	41±11	4.0±0.5	1.40±0.50	0.6±0.6	8.5±2.6	7±6	78±17	2±1
B	34±13	52±9	5.0±0.5	0.35±0.10	0.3±0.3	3.6±1.4	11±8	68±32	<1
				Red-yellow Latosol, dystrophic, loamy					
A	68±10	21±5	4.9±0.4	0.75±0.38	0.6±0.6	4.4±1.9	13±9	60±23	1±1
B	60±11	26±5	5.0±0.4	0.25±0.15	0.4±0.4	2.4±0.8	15±8	52±27	<1
				Dusky red Latosol, dystrophic, clayey					
A	17±7	64±5	5.2±0.5	2.28±0.75	6.2±5.0	13.9±4.4	40±22	26±21	2±2
B	14±7	71±7	5.4±0.4	0.44±0.16	0.6±0.3	5.2±0.9	10±4	73±9	<1

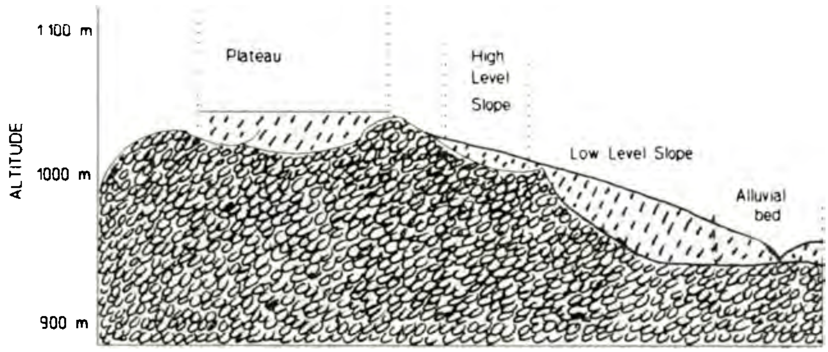

Figure 4. Typical cerrado geomorphic surfaces (Adamoli et al. 1968)

The flat areas are less exposed to run-off and soil erosion and are thus better for for agricultural purposes. This has facilitated the expansion of mechanized farming of such crops as soybean, and more recently, maize. However, excessive tilling has led to soil problems.

2.4 Vegetation

The vegetation of the Brazilian cerrados resembles that of the African savannas. However, the floral distribution is characterized by permanent deep rooted plants and shallow rooting ephemeral species and grasses which may belong to either of the two groups and vegetate only in the rainy season. The distribution of species varies from open grassland to dense woods and is closely associated with soil fertility (table 4).

Due to intermittent dry spells and soils which are highly acidic and Al-rich, the perennial plants have developed a sclerotic leaf structure for water economy, and as a consequence of Al levels. Woody stems, coriaceus leaves with conspicuous veins, greenish yellow dry leaves and light blue fruits are some of the characteristics associated with Al-tolerant plants, e.g., *Vochysiaceae, Melastomataceae* and *Robiaceae* (Ferry 1976). Frequent fires have also resulted in the evolution of fire-tolerant species.

Field surveys have been carried out to evaluate the economic potential of native species for medicine, as ornamentals, wood, forage and food. Species suitable for feed and grazing include *Aeschynomene brasiliana, Arachis glabrata, Galactia glaucescens, Solanum lypocarpum, Stylosanthes* spp. and the grasses *Echynolaena inflexa* and *Paspalum* spp. Other species are still to be identified.

Table 4. Native vegetation in central Brazil and mean top soil characteristics

Soil property	Grassland	Base grassland	Cerrado	Dense cerrado	Forest
pH (H_2O)	4.87a	4.94ab	5.0b	5.14b	5.28c
pH (KCl)	4.16a	4.25b	4.25b	4.32	4.35b
ΔpH	-0.71a	-0.69a	-0.76bc	-0.82cd	-0.93d
Organic matter	2.21a	2.33a	2.35a	2.32a	3.14b
Exch. Ca (meq/100 cc)	0.20a	0.33ab	0.45b	0.69c	1.50d
Exch. Mg (meq/100 cc)	0.06a	0.13a	0.21b	0.38c	0.55b
Extr. K[1] (meq/100 cc)	0.08a	0.10ab	0.11b	0.13b	0.17c
Exch. Al (meq/100 cc)	0.74a	0.63a	0.66a	0.61a	0.78a
Eff. CEC (meq/100 cc)	1.08a	1.19a	1.43b	1.81c	3.00d
Al saturation	66a	58b	54b	44c	40c
Extr. P[1] (ppm)	0.50a	0.5a	0.9b	2.1c	1.4bc
Extr. Zn[1] (ppm)	0.58a	0.61a	0.66b	0.67b	1.11c
Extr. Cu[1] (ppm)	0.60a	0.79ab	0.94b	1.32c	0.95bc
Extr. Mn[1] (ppm)	5.40a	10.30b	15.9c	22.9d	24.1d
Extr. Fe[1] (ppm)	35.70a	33.90a	33.0a	27.1b	37.2c
Clay (%)	33a	36a	34a	32a	37a
Silt (%)	20a	16b	15b	16b	16b
Sand (%)	46a	48a	51a	53a	47a

Notes: Means for each line not followed by the same letter are significantly different at the 0.05 probability level.

Locally recognized medicinal plants are *Andira humulis, Anemopagma arvense* and *Tabebuia caraiba*. Some of the fruit and woody species under investigation include *Astronium urundeuva, A. fraxinifolium* and *Copaifera langsdorfii*. More than 70 species which have economic potential have been identified from the families Anacardiaceae, Leguminoseae, Annonaceae, Moraceae, Malpighiaceae, Vochysiaceae, Myrtaceae, Caryocaraceae, Araliaceae, Icacinaceae, Apocynaceae, Guttiferae, Tiliaceae, Sapindaceae, Sapotaceae, Solanaceae, Loganiaceae, Symplocaceae, Melastomataceae, Rubiaceae, Bignoniaceae and Palmae (EMBRAPA-CPAC 1980).

3. Cerrados Land Occupation

Until the first half of this century, cultivation in Brazil was concentrated in the naturally fertile areas of the south and southeast, with maize, rice, beans, coffee, sugar cane and cotton. With industrial development, however, large numbers of migrants from the northeast came to settle in these areas and agriculture production expanded rapidly, depleting the naturally fertile lands.

The cerrados remained a largely uninhabited wilderness — exploited only for subsistence agriculture and beef cattle ranching — at the rate of one head/5 ha grassland (table 5). The local populations were limited to small villages. Farming in the cerrados was hindered by lack of storage facilities and the virtual absence of transportation. This situation began to change in the mid-1960s, when the relatively transportation. This situation began to change in the mid-1960s, when the relatively low price of land, subsidized credit for development and attractive prices for commodities, created a momentum for the conquest of the Brazilian cerrados. Unfortunately, the expansion was not accompanied by good agricultural practices and has led to land degradation.

Table 5. Population (x 10^3) of the main states of the cerrado region (IBGE 1991)

States	Year			
	1960	1970	1980	1990
Mato Grosso Do Sul	-	-	1,370	1,797
Mato Grosso	889	1,597	1,138	1,727
Goiás	1,913	2,940	3,860	4,943
Federal District	140	537	1,180	1,864
Minas Gerais	9,960	11,645	13,635	15,831
Brazil	70,070	93,139	119,000	150,368

4. Crop Adaptation to the New Frontier

4.1 Annual crops

Since the 1960s, the cultivation of upland rainfed rice and artificially established pasture has increased in the cerrados (Fageria et al. 1989). Soybean, a flourishing cash crop in the South, occupied only 10 thousand hectares in the cerrados, which is negligible when compared with the national acreage (Miyasaka and Medina 1981). Although the low cost of land attracted farmers from southern Brazil, the lack of Al-tolerant crops hampered agricultural expansion and permanent settlement (Spehar et al. 1992).

Soybean cultivation in the low latitudes of the Brazilian cerrados has been limited by the length of day, which results in reduced plant height. The selection that culminated with the release of the *Doko* variety has taken day length, climate and soil conditions into account. The Doko genotype is reputed to have enhanced soil fertility and give more stable yields. The present stage of hybridization of soybean is been a consequence of the dynamics of crop expansion in recent years. In the last 20 years, the cerrados have accounted for nearly 50% of the national production of soybean (table 6).

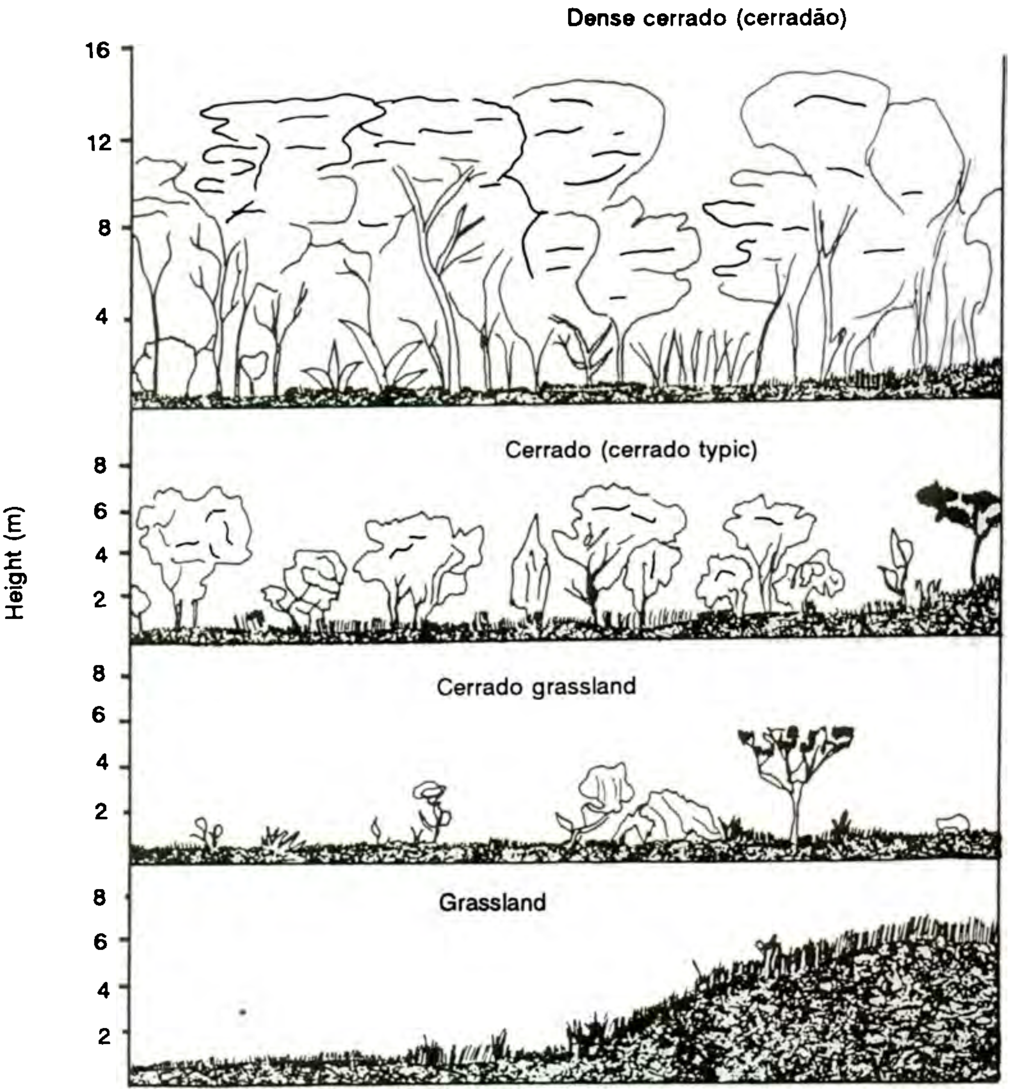

Figure 5. Main cerrado vegetation types

Table 6. Contribution of cerrados to national soybean production

Year	Production		Cerrado contribution		Yield	
	Brazil	Cerrado	Area	Production	Brazil	Cerrado
	------ ($x10^6$ t) ------		------ (%)t ------		------ (t/ha) -----	
1975	9.9	0.2	3	2	1.69	1.30
1980	15.1	1.6	11	10	1.73	1.72
1985	15.5	4.2	26	27	1.65	1.69
1989	23.0	10.3	42	45	1.89	2.03
1990	20.0	6.8	38	34	1.73	1.55

Source: IBGE (1991)

Area under cultivation, production and average yields for rice, beans, maize, soybeans and wheat are presented in table 7. Maize has only recently become a major crop in the cerrados. Grown in rotation with soybean, maize yields are as high as in areas where maize was traditionally grown. Its share of the national production has increased from 17 to 33%. There are limiting factors, however, as maize requires N fertilizer (30-120 Kg/N/ha) and additional labor/capital for storage (EMBRAPA 1992). In areas where the rains are prolonged, a second maize crop may be planted after the soybean harvest. The highest yields have been recorded under full mechanization, however, subsistence agriculture is still common and contributes to the low average yields (table 7).

Table 7. Cultivated area, production and average yield of the main cerrado annual crops (EMBRAPA/CPAC)

Crop	Area		Production		Average yield	
	Brazil	Cerrados	Brazil	Cerrados	Brazil	Cerrados
	---- ($x10^5$ ha) ----		---- ($x10^6$ t) ----		---- (t/ha) ----	
Rice	3.95	1.64	7.42	1.55	1.88	0.95
Beans	4.60	0.80	2.23	0.43	0.48	0.54
Maize	11.39	2.73	21.34	4.50	1.87	1.65
Soybeans	11.48	4.30	19.99	6.80	1.73	1.55
Wheat	2.68	0.16	2.09	0.18	1 15	1.18
Total	34.18	9.71	53.97	13.47	-	-

In modern farming systems, upland rice is often planted in rotation with other crops; though in the past upland rice was associated with pasture establishment. This was done by sowing both rice and grass seeds at the same time. After the rice was harvested, the area was left to be colonized by the grass. Reduced fertilization, poor crop husbandry, the incidence of *brusone* disease and the relative frequency of drought were the main contributing factors to the low yield of upland rice in the cerrados (table 8). However, new high yielding and disease resistant varieties have enabled farmers to obtain more stable yields. The Cerrados have contributed 25% of the national rice production in recent years, however, this has declined, due to the expansion of soybean and maize cultivation. With increasing irrigation, it is expected that the cultivation of rice will continue to develop in the region.

Table 8. Effect of cultivation of soil loss and composition of sediment collected after two rains on the same area, 1977 & 1984 (Dedeceek 1986)

Treatments	Soil loss	pH	Al^{+3}	Ca+Mg	K	P	Org C
	(t/ha)	H_2O (1:1)	------ (meq/100g) -----		----- (mg/g) -----		(%)
	Date: 16-5-77		Rain 45.8 mm				
Uncovered soil	1.4	5.3	0.1	2.9	50	4	2.0
Maize convent.	0.3	5.3	0	3.6	37	3	1.7
Rice conventional	0.2	5.7	0	3.8	49	5	1.9
Soybean convent.	0.5	5.5	0	3.4	58	5	1.8
Soybean without residue	0.3	5.8	0	3.3	42	4	1.5
Soybean no tillage	0.5	5.4	0	3.7	44	5	2.0
	Date: 27-12-84		Rain 30.5 mm				
Uncovered soil	3.8	5.7	0.5	2.1	7	2	2.0
Maize convent.	1.1	5.7	0.5	2.6	27	5	2.4
Rice conventional	0.6	5.7	0.4	2.5	29	6	2.2
Soybean convent.	0.6	5.7	0.4	2.4	27	6	2.1
Soybean without residue	0.5	5.7	0.4	2.4	24	4	2.1
Soybean no tillage	0.1	6.0	0	4.0	71	11	3.1

The local beans traditionally cultivated by smallholder subsistence farmers was a low input crop with low yields compared to modern bean cultivation under irrigation. The introduction of new high yielding and disease resistant varieties, better disease and pest management, fertilization and improved cultural practices have contributed to an increase in bean production in the region. In 1992, the cerrados recorded a yield of 4,000 kg/ha of dry beans. This figure is much higher than the national average of 700 kg/ha (Azevedo, EMBRAPA-CPAC personal communication). Presently, the cerrados accounts for 25% of the national production.

Wheat and brewery barley are cultivated in southern Mato Grosso State as a second crop after soybean. The region contributes approximately 10% of the national production under a rainfed farming system. Recently, attempts have been made tc grow these cereals in the dry season, under irrigation. This system has a high energy cost, but if successful, Brazil may become self-sufficient in wheat production.

Research efforts have been concentrated on developing high yielding new lines suitable for the rainfed cultivation that are Al-tolerant and resistant to stem and leaf rust. Improved, high yielding Mexican varieties have been selected for irrigated cultivation, and are at present being released to farmers (Andrade et al. 1991).

Cassava cultivation covers an area of two million hectares in Brazil. However, only 8% of this area is in the cerrados, and this accounts for 8.3% of the national production. It is an attractive crop because it provides the highest rate of calorie/area/time. Cassava is traditionally a low input crop; it is drought resistant and relatively tolerant of pests and disease; it also has a flexible planting/harvest time. However, large-scale cassava production in the cerrados is limited by the lack of a local market and the need to process the crop soon after harvest.

4.2 Perennial crops

The cultivation of coffee occupies an area of about one million hectares in the cerrados and is concentrated mainly in Minas Gerais State (MG in fig. 1). This represents 32% of land under cultivation and 40% of the total Brazilian production. The demand for manual labor for coffee production brought 200,000 families to this region. Favorable climatic conditions together with the low price of land, was an incentive to coffee farmers who moved in from the states of Paraná, Sao Paulo and other parts of Minas Gerais.

The development of high yielding disease resistant varieties has been the main contribution of current research. The new genotypes have recorded yields between 2,700 and 3,300 kg/ha. This represents a 50% increase over the highest yielding old varieties (Sampaio and Guimarães 1991).

The climate in the cerrados is well suited to tropical fruit crops, although only 12% of the cultivated area is under fruit production. Banana ranks first followed by cashew and citrus. Pineapple, mango, avocado, sour-sop (*Annona muricata* L.), passion fruit, acerola (Barbado cherry) and other temperate fruits are cultivated on a smaller scale. Indigenous fruits of the cerrados with potential for cultivation include cagaita (*Eugenia dysenteria*) and mangaba (*Hancornia speciosa*) and also species from the Myrtaceae, Apocynaceae, Bromeliaceae. Annonaceae, Leguminoseae, Sapotaceae, Passifloraceae, Caryocaraceae, Malpighiaceae, Palmae and Caricaceae families (Silva et al. 1992).

Before the mid-1960s, timber exploitation in the cerrados led to the devastation of much of the natural vegetation. Yields varied between 30 and 130 m^3/ha. Increasing demand for charcoal, cellulose and wood has forced government to expand its reforestation programs in this region.

Eucalyptus spp. were introduced to the region, after being cultivated in other parts of the country. Results from trials have shown that species and provenances from Australia, Indonesia, Papua New Guinea and the Philippines are superior to the cerrado native vegetation for wood production. *Pinus* spp. have shown similar adaptability, although this species reaches its full economic potential later than *Eucalyptus*. Both species have already been grown in large areas of the cerrados, with yields in the range of 15 to 75 m^3/ha/year. In general the best provenances in the cerrados were the *Eucalyptus* spp from Australia and the *Pinus* spp from the Caribbean and Central America, where the soils and climate are similar. The successful adaptation of these species to the poor soils of the cerrados is attributed to their association with ecto-mycorrhizae fungus. Experiments with native and exotic legume species have also been conducted for the purposes of wood production and improving soil fertility through nitrogen fixation.

4.3 Forage crops and beef cattle

Forty-five per cent of the cattle in Brazil are found in the cerrados. *Brachiaria* spp grass has been the basic browse species. However, its low forage quality in the dry season sometimes causes a nutritional imbalance and weight loss in the cattle. When malnutrition is severe, it may result in miscarriage and the loss of calves and adults. In the 1970s, to overcome the scarcity of good quality forage, some new species of exotic grasses have been introduced to the cerrados. The three most promising alternatives are *Andropogon gayanus*, *Panicum maximum* (from Africa) and *Papsalum* spp. (which is found in the fringe areas between the cerrados and other regions).

Two legume species, which have shown great potential for improving pasture quality, are *Stylosanthes guayanensis*, and *Arachis* spp. Studies on nutrient requirements of selected forage species have been conducted in order to assess those with suitable biomass production (Sanzonowicz et al. 1991, Vilela et al. 1991).

Studies have also been done to assess the optimum grass-legume association in artificially established pastures and sole-cropped legumes on protein banks. Strategic herd management indicates how long grasses can be utilized in the rainy season and when to move the cows in order to maintain high forage quality throughout the dry season. In addition, techniques for supplementing animal diet with salt mixtures have been developed to help maintain live weight and reduce animal loss in the dry season (Lopes and Pereira 1992).

4.4 Potential crops

In order to reduce the risks associated with monocropping, investigations are underway to diversify the production systems. Research efforts have been concentrated on rubber trees, cotton, castor beans, sesame, annatto, quinoa (*Chenopodium quinoa*), chick peas and guar.

The cultivation of rubber trees has expanded considerably in the cerrados of Mato Grosso State, where it is free of the leaf fungus (*M. ullei*) which is very common in the Amazon. Cotton production has also expanded in rotation with soybeans. Another crop of economic potential is *quinoa*, a high quality protein grain which grows in the Andes, and could become a major source of food and an important feed component for poultry and pigs (Spehar and Souza 1993).

5. Soil Management and Conservation in the Cerrados

5.1 Maintenance of crop yield

Soil structure maintenance is a direct function of management practices such as tillage, organic matter maintenance and drainage. The repeated use of the disk harrow during the dry season to clear weeds exposes the soil to severe wind erosion and is one of the main causes of soil degradation in the cerrados.

Destruction of the soil structure results in soil compaction and run-off, even in the plateaux. Slopes with a gradient of 2% (or more) require conservation measures such as terracing and contour cultivation.

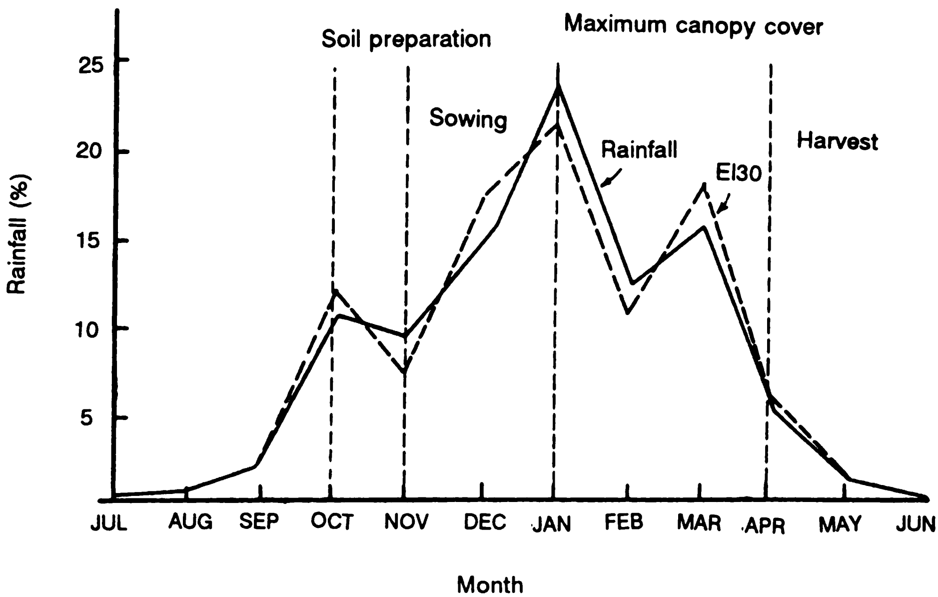

Figure 6. Rainfall distribution (%) and erosivity factor (E±30) during the crop season in the cerrado region (Dedececk et al. 1986)

Rainfall distribution is another factor which affects soil erosion. Seventy per cent of the total rainfall (1500 mm) occurs between November and March, peaking in January (fig.6) (Dedececk et al. 1986). This coincides with the early stages of annual crop growth. The soil and nutrient loss following heavy rain under different cropping systems is presented in table 8. Erosion problems could be reduced if farmers would clear only those areas which they want to cultivate, and avoid leaving the soil uncovered.

Soil compaction can be ameliorated by ploughing with an escarifier or a subsoiler. The success of the operation depends on the appropriate calibration of the implements. The soil moisture level should suit the implement for the disk plough; the soil should be friable; and for the subsoiler, it should be dry. Improving the subsoil through better aeration and distribution of nutrients and water has been shown to increase the rooting depth of the soybean plant.

5.2 Tillage regimes

Minimum and no-tillage seedbed preparation are becoming popular in the cerrado region due to the fragile soil structure, low organic matter content and low moisture holding capacity. These practices have improved the efficiency of farming operations. In addition, minimum and no tillage improve the water economy and increase tolerance to dry spells. They also preserve and improve soil physical and chemical characteristics for annual cropping systems. This is important in areas with sandy soils (Inceptisols) and where soil conservation practices are a matter of survival.

5.2.1 *Minimum tillage*

Minimum tillage, locally known as *sowing on the weed*, is commonly used in areas with weed problems and on uneven land. The practice includes light disk harrowing at the end of the dry season to destroy persistent weeds. New weed infestation on the field is then easily controlled by herbicides

An alternative method uses double cropping, in which the second cultivation is sown, using the no-tillage method. The second crop provides ground cover, and utilizes residual soil moisture from the last rains. The second crop could be a grass (maize, sorghum, millet and oats) or a legume (pigeon pea). At the beginning of the next rainy season, the plant residue is cut by a shallow disk, prior to sowing. This method is only suitable in areas with a long rainy season.

5.2.2 *No-tillage*

No-tillage farming consists of sowing on untilled ground. The seeds are placed in furrows or hills of sufficient density and depth to assure suitable seed cover and soil contact. No-tillage agriculture tends to reduce soil micro-organism activity in the low profile, measured by the rate of cellulose decomposition in the Latosol, which helps to preserve soil organic matter content.

No-tillage requires less labor, is suitable for double cropping and crop rotation and it saves time and money since it does not require heavy machinery. If no-tillage is properly utilized, it improves soil fertility, reduces water loss, controls weeds, provides mulch and reduces the number of farm operations. Where the soil is compacted, it is necessary to ameliorate the compacted layer before using the no-tillage system.

The data in tables 9 and 10 compare the effect of conventional tillage to no-tillage. The best root growth/depth was achieved with no tillage followed by mouldboard treatment.

Table 9. Root weight and micro-organism activity with different tillage methods (Cardoso 1993)

Tillage		Root		Cellulolitic activity
1979-1983	1984-1986	Depth (cm)	Dry weight (g/g soil)	---------- (%) --------- -
Conventional	Mouldboard	0-10	4.6	55
		10-20	2.9	35
		20-30	0.8	10
Conventional	Diskplough	0-10	6.3	71
		10-20	1.7	19
		20-30	0.9	10
Conventional	No tillage	0-10	7.7	78
		10-20	1.2	15
		20-30	0.5	7
No tillage	Mouldboard	0-10	10.8	62
		10-20	5.0	29
		20-30	1.7	9
No tillage	Diskplough	0-10	7.6	75
		10-20	1.7	19
		20-30	0.8	8
No tillage	No tillage	0-10	8.3	82
		10-20	1.6	13
		20-30	0.81	5

Table 10. Effect of tillage methods on the subsequent soybean and maize crops (Cardoso 1993)

Tillage method		Yield (t/ha)	
1979-1983	1985-1986	Soybean (1985)	Maize (1986)
No tillage	Diskplough	3.59	5.20
No tillage	Mouldboard	3.58	5.17
No tillage	No tillage	3.39	4.65
Conventional	Diskplough	3.31	4.52
Conventional	Mouldboard	3.06	4.42
Conventional	No tillage	3.03	4.40

No-tillage followed by disk ploughing gave the best soybean and maize yield, however, the effect of tillage on the mean yields of soybeans and maize was not significant, except in two treatments (table 11).

Table 11. Effect of tillage on mean yields of soybean (1985 & 1986) and maize (1986) (Dedececk 1986)

Tillage method		Mean yield (kg/ha)	
1979-1983	1984-1985	Soybean	Maize
Conventional	-	3130b	4702a
No tillage	-	3500a	4749a
No tillage	Mouldboard	3318a	4459a
No tillage	Diskplough	3446a	5184a
No tillage	No tillage	3206a	4532b

Note: Means for each column not followed by the same letter are significantly different at the 0.05 probability level.

No-tillage could have a significant impact under irrigated intensive cultivation schemes. Irrigation enables farmers to obtain three croppings in the same year, e.g., maize, soybeans or field beans and wheat; or soybeans, maize and peas. Crop sequences are determined by commodity prices and farm needs. The use of a mulch cover by farmers will reduce the cost of weed control, reduce soil and water losses and improve the physical and chemical properties of the soil. Table 12 summarizes the various tillage methods utilized in the cerrados.

Table 12. Tillage methods utilized in the cerrados (Cardoso 1993)

Implement	Depth (cm)	Crop residue	Weed management	Utilization	Conditions
Disk harrow + levelling disk (0 ~ two)	10-15	Shallow incorporated	Reduced control	-	Compacted layer + pulverization of soil particles
Disk harrow + levelling disk (1 ~ three)	20-30	Incorporated	Partial control	When stumps, roots and pebbles are present	Compacted layer
Mouldboard + levelling disk (0 ~ two)	20-25	Incorporated	Ploughed under	On soils without obstacles	Whole chisel - light soils Clipped chisel - clayey soils
Chisel plough	10-15	Left on the surface	No control	On compact soil	Fixed and mobile rods
Levelling disk (0 ~ two)	-	Shallow incorporated	Reduced control	To destroy stocking	
No tillage		Left on the surface	No control	When ground cover is > 70%	Feasible only with integrated management

6. Maintenance of crop yield

6.1 Improvement of soil fertility

Lime availability is no longer a problem for most of the cerrado region. However, excessive liming can lead to micronutrient deficiency, Zn, and Mn in Latosols and Cu in sandy soils. The low CEC of these soils is responsible for a low buffering and this has an immediate impact on the pH level. For clayey soils, 4 t/ha of lime (100% $CaCo_3$ equivalent) is necessary to obtain 50% base saturation. Subsoil liming is desirable to improve Ph, increase Ca and Mg levels, and to reduce toxic Al levels, although it is not always feasible for the farmers. Fineness of liming material is important but even larger particles react in the soil in the long run, leading to increased pH and micronutrient deficiency (Ritchey et al. 1982). For the pH level to reach desirable levels, lime should be applied three months in advance of cultivation. Its reaction in the soil as measured by pH changes is presented in figure 7. The same figure illustrates the occurrence of high pH values on excessive liming (11.2 t/ha).

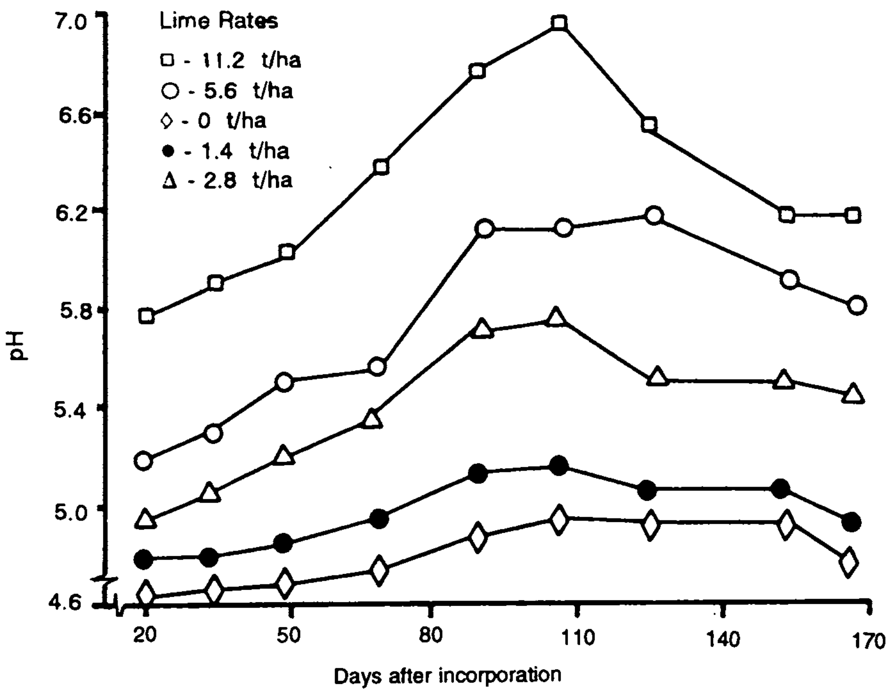

Figure 7. Changes in soil pH after lime application in a cerrado acid soil

Crops grown on cerrado soils reacted favorably to P application (fig. 8). For optimum soybean yield, a rate of 105 kg/ha P (1.2 ton/ha single superphosphate equivalent) is needed. Phosphate ore is available in the region, but farmers have to pay a high price for the long distances it had to be shipped over before it reached the

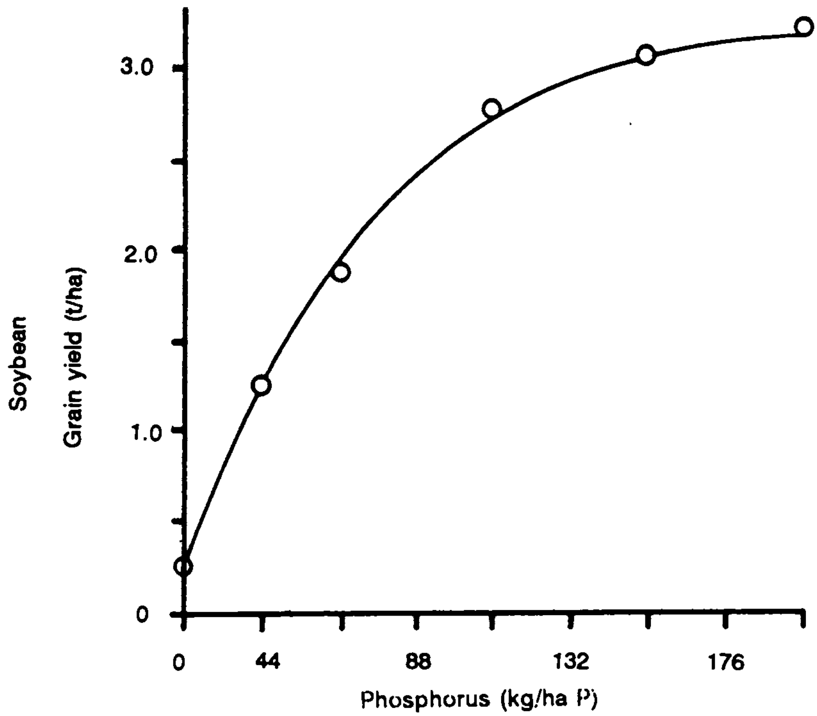

Figure 8. Soybean seed yield (cv. Cristalina) response to P application (triple superphosphate) on a cerrado dark red Latosol (Sousa 1987)

farm. In the past, farmers relied on government subsidies to keep suitable P levels in the soil, but this is no longer possible.

Availability of K is related to soil CEC; liming causes an increase in negative charges that retain K. However, poor soil management causes a reduction in organic matter, resulting in decreased available K. A split application of K is recommended in sandy areas, half in the furrow at sowing and half before bloom. This has been shown to improve soybean and maize grain yields (Vilela et al. 1985).

The use of gypsum (calcium sulphate) has been recommended to supply S ($CaSO_4$) and to increase Ca movement in the soil profile. A rate of 200 kg/ha $CaSO_4$/cultivation is needed for soils with a high Al saturation rate (>30%) at depths of >35 cm and with a Ca level <0.2 cmol/kg. Gypsum is recommended at rates of 0.5, 1.0 and 1.5 t/ha for sandy, mid-textured and clayey soils respectively.

There is a striking difference between the potential yield and the actual yield of crops in the cerrados (table 13). Most of the difference is due to reduced or inappropriate fertilization. Reduction in P application is related to increased fertilizer prices and reduced commodity prices. This is further aggravated by cutbacks in public expenditure on farmer subsidies. Insufficient potassium application results in reduced yields. Inappropriate crop husbandry (sowing pattern and date, plant population and variety) and disease, pest and weed controls are also important factors in yield.

Table 13. Actual and potential productivity (t/ha) in the cerrados (Souza and Goedert 1990)

Crop	Brazil (average)	Cerrados		
		Average	Good farmers	Research (potential)
Upland rice	1.9	0.9	3.1	4.8
Beans	0.5	0.5	2.0	4.5
Maize	1.9	1.6	7.6	14.0
Soybeans	1.7	1.5	4.0	6.0
Irrigated wheat	1.7	3.8	5.5	8.0
Rainfed wheat	1.2	1.2	2.7	3.5

6.2 Improving soil organic matter

The organic matter (OM) status of cerrado soils may reach 5%, although in 58% of samples, Resck (1991) reported values in the range of 1.8 to 2.6% for sole cropped soybean (fig. 9).

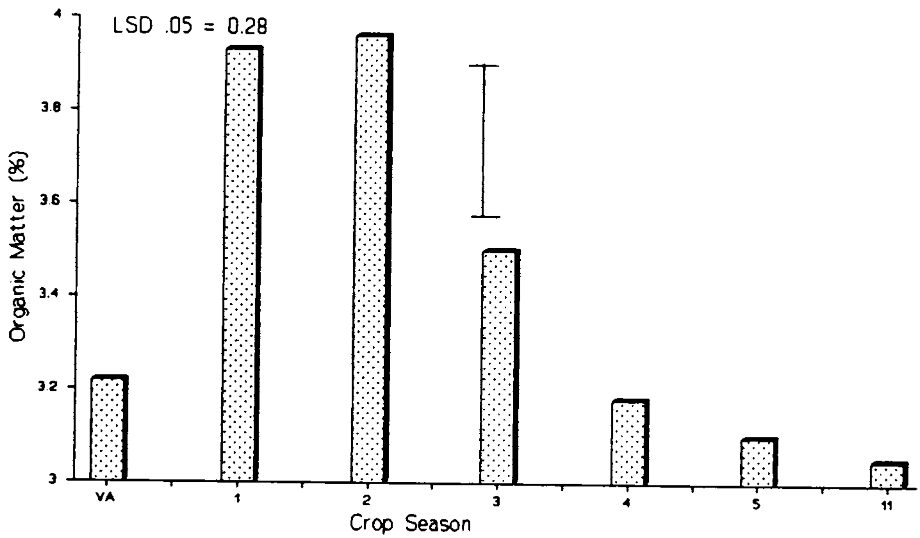

Figure 9. Organic matter content in a clayey Oxisol soybean monocrop as compared to virgin area (Resck et al. 1991)

After land clearing for farming, and subsequent liming and fertilization, the OM content will drop, probably due to higher microbiological activity. Burning of crop residue, which is sometimes practiced by the farmers for weed control, increases soil susceptibility to erosion, reduces organic matter, water movement and nutrient absorption.

Crop rotation can contribute to maintaining the OM level in the soil, depending on the C/N ratios. The sole cultivation of soybeans, however, has been shown to reduce OM, due to the low C/N ratio in its residue, which has a high rate of decomposition (Resck 1991). Additional advantages of rotation are higher yields of crops, reduced marketing risks, increased supply of food and feed for livestock, and environmental preservation due to control of pests and diseases.

7. The Past and Present Status of Cerrado Cropping Systems

The first stage of agricultural expansion in the cerrados was marked by the establishment of large farmholds. Investment on infrastructure, was, however negligible. Local differences in topography, soil texture and the location of springs were not considered in the initial stages of farm settlement. Balanced farming systems were not developed until the late 1980s.

There were virtually no adapted species, varieties of plants or information about suitable crop husbandry accessible to the pioneer farmers (Urben Filho et al. 1992). This resulted in poor farming practices, which led to reduced yield and soil erosion, particularly in areas with intense rainfall. The scarcity of labor compounded farming problems in the cerrados. It was not unusual, therefore, to observe fields being abandoned without sowing , due to heavy rainfall, or being sown at an unsuitable date.

Soybeans, a high yielding, low-risk legume was introduced as a monocrop in the 1970s, under partial or full mechanization. However, a decline in world agricultural prices affected this commodity, and farmers came to realize that it was necessary to maintain soil fertility and diversify their production. More recently, maize has been introduced in rotation with soybean. High-yielding Al-tolerant varieties (Lopes et al. 1987) were selected for cultivation in the cerrados (e.g., cv BR-201). In the 1980s, a national irrigation program was introduced to boost wheat production. Wheat yields in the dry season are high, in contrast to the erratic yields obtained from rain-fed double-cropping systems in the south of Brazil. Although newly developed Al-tolerant wheat varieties have contributed to the expansion of rain-fed wheat production systems (Camargo 1981). The major constraint in wheat production has been the high cost of production and low prices in the international market. The irrigation system, originally set up to promote wheat production, is also being used for soybean, common beans, peas and other food crops, including potatoes, tomatoes, carrots and other vegetables. It is expected that cropping systems in the cerrados will continue to diversify, with soybean as the major crop.

In newly cleared areas, highly productive and demanding grasses such as *Andropogon gayanus*, *Panicum maximum* and *Paspalum* spp have been successfully planted after soybeans in mixed farming systems. In addition to cattle, poultry and pigs have also played a role in diversifying farm production and establishing sustainable agricultural systems.

Coffee has become a major crop in the region, especially in Minas Gerais state, with yields comparable to those obtained in the traditional coffee-growing areas in the south and southeast. Although research has shown the potential of citrus and other fruits like avocado, acerola and mango, their cultivation has not expanded. Forestry has also played an important role in the cerrados, and has consisted mainly of the growing of exotic species for domestic and commercial wood production.

7.1 Impact of crop rotation

7.1.1 *Annual crops*

Table 14 illustrates the advantages of maize/soybean rotation using the same rate of N. Araujo et al. (1984) have shown that maize and soybean gave better yields when grown in rotation than as monocrops (table 15). Similar results were obtained by Mascarenhas et al. (1983). Crop rotation also disrupts the pest and diseases cycles and facilitates weed control and organic matter maintenance.

Table 14. Influence of N application on monocropped maize and maize in rotation in soybeans (Vasconcelos et al. 1984)

Nitrogen rate	Maize monocrop	Maize after soybean	Yield increase
		(t/ha)	%
0	2.88 (62)[2]	3.12 (67)[2]	5
40	3.23 (69)	4.28 (92)	23
60	3.67 (79)	4.26 (92)	13
80	3.92 (84)	4.44 (95)	11
100	3.51 (75)	4.66 (100)	25

Table 15. Yield of maize and soybean with monocropping and rotation (Araujo et al. 1989)

Crop season	Monocrop	Maize rotation	Gain	Monocrop	Soybean rotation	Gain/loss
	t/ha					
1983/84	5.07	5.51	+ 0.44	1.45	1.87	+ 0.42
1984/85	4.86	5.83	+ 0.97	2.23	2.12	- 0.11
1985/86	6.64	7.77	+ 1.14	2.31	2.41	+ 0.11
1986/87	3.67	4.25	+ 0.58	1.10	1.39	+ 0.29
1987/88	2.92	3.29	+ 0.37	0.84	1.00	+ 0.17
Mean	5.63	5.53	+ 0.70	1.59	1.76	+ 0.17

In a crop rotation experiment, Vasconcelos et al. (1984) evaluated the dry matter production of different cropping systems (table 16). The inclusion of green legume manure, either sole or intercropped with maize provides a large amount of nutrients for recycling. Higher yields for maize were obtained in rotation with soybeans, in addition to the positive effects of nutrient recycling and nematode control provided by the maize/legume intercrop (table 17).

7.1.2 *Annual crops and green manure*

Pereira et al. (1992) found that the grain crops following green manure application gave yields up to 46.6% higher than sole crops. Similar results have been obtained by Resck and Pereira (1979) in an experiment comparing soybeans as a sole crop with soybeans following green manure. Besides contributing to the improvement of organic matter in the soil, the use of green manure has been effective in reducing soil-borne diseases, such as root knot nematodes (EMBRAPA 1981). Different species of plants have been utilized as green manure and incorporated into the soil at blooming (fig. 10). The most promising species are *S. atterrimum, C. spectabilis, I. tinctoria, S. deeringianum, S. niveum, C. psoraloides, C. juncea* and *C. paulinea.*

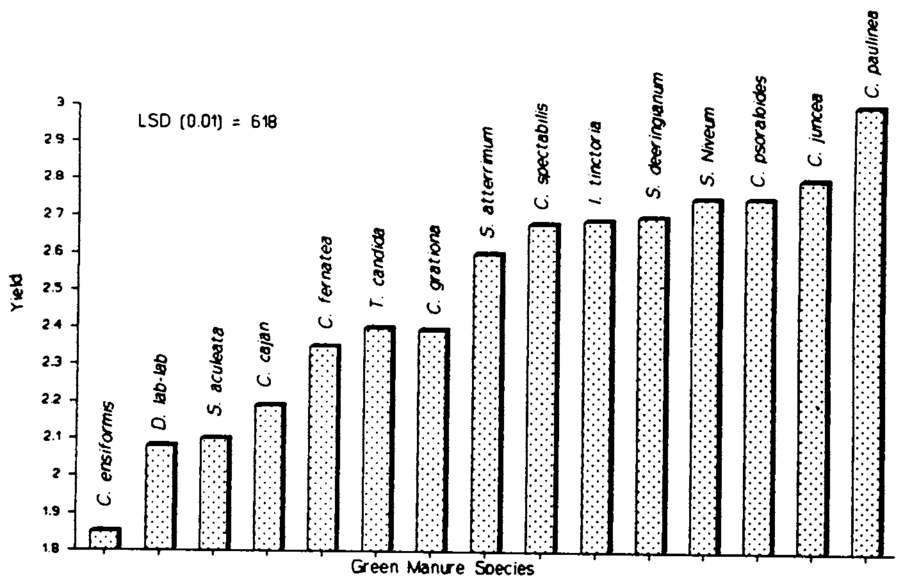

Figure 10. Soybean seed yield (cv.) in rotation with different species of green manure (Resck and Pereira 1979)

Table 16. Dry matter production and nutrient returned to the soil in different cropping systems (EMBRAPA-CNPMS 1992)

Cropping system	Crop season	Dry matter	N	P	K	Ca	Mg	Zn
		(t/ha)			kg/ha			g/ha
Legume	1983/84	4.40	101	7	57	38	8	95
S. aterrimum	1984/85	11.08	320	25	205	77	19	193
Soybean,	1983/84	3.29	29	2	17	19	9	-
cv Doko	1984/85	3.45	42	2	27	26	10	71
Maize	1983/84	3.60	20	2	14	12	6	-
	1984/85	3.06	27	1	22	6	5	104
Maize +								
Legume	1983/84	4.88	53	3	16	25	9	-
intercropped	1984/85	7.55	124	8	50	38	11	350

Table 17. Effect of cropping systems on maize yields (t/ha) in Sete Lagoas, Minas Gerais (EMBRAPA-CNPMS 1992)

Rotation	Crop Season 1984/85	Crop Season 1985/86	Crop Season 1986/87
		Yield	
Maize after			
Legume (*S. aterrimum*)	4.00 (114) a	6.35 (1.38) a	3.27 (107) b
Soybean	4.32 (123) a	6.03 (131) a	4.77 (156) a
Maize	3.50 (100) a	4.59 (100) b	3.06 (100) b
Maize + Legume (intercrop) after			
Maize	3.28 (94) a	6.03 (131) a	2.56 (84) b
Soybean	4.00 (114)a	6.42 (140) a	4.20 (137) a

Note: Means for each column not followed by the same letter are significantly different at the 0.05 probability level

There are a number of ways in which green manure has been utilized in the cerrado cropping system. The most common is sowing after the main crop has been harvested. Pereira et al. (1992) suggested the following green manure cultivation schemes:

a. Sow *C. juncea* at the beginning of the rainy season, plough under in January and sow field beans, wheat or sugar cane (in the cerrados of St. Paulo and Mato Grosso do Sul).
b. Intercrop maize with *S. atterrimum,* which is sown 30 days after maize. The legume seeds will be harvested in June by hand while maize will be combine harvested and the crop residue incorporated into the soil.
c. Sow maize and green manure at the beginning of the rainy season, harvest maize and incorporate the biological mass.
d. Sow *S. atterrimum* after early cycle varieties of rice, maize, beans, soybeans and peanuts and biomass at blooming.
e. Sow fallow fields with long cycle green manure in November to incorporate maize before cropping in the following year.
f. Sow maize in association with cotton.
g. Sow maize with associated perennial pasture legumes such as *Zornia* spp. and *Stylosanthes* spp.

7.1.3 *Annual crops and pasture*

An annual crop/pasture rotation, which alternates from an annual to a perennial crop is a very efficient nutrient recycling system that contributes positively to enhancing soil structure. This system is replacing the low-input traditional rice/pasture intercrop, which has created an estimated area of 30 million hectares of low standard pasture.

According to Spain (JM Spain, EMBRAPA-CPAC, personal communication), the grass/legume (pasture) association in rotation with annual crops offers the following advantages: soil fertility improvement by incorporating N, P, S and other nutrients through crop residues; increased biological activity in the subsoil due to the deep root growth of perennial acid tolerant plants and efficient nutrient recycling by plants and animals; improvement of soil physical conditions by better organic matter management and, consequently, reduced erosion; improvement of the soil microbiological activity (biological tillage); reduction of weed, pest and disease problems; elimination of some noxious weeds on pasture fields by ploughing them before sowing the annual crop.

To maintain soil productivity, it is necessary to establish production systems that sustain or improve the soil structure. It has been observed in farmers' fields, that annual crop/pasture rotation enhanced the soil physical characteristics. This has resulted in a more than two-fold increase in the animal/stocking of the pasture (Ayarza et al. 1993).

Additional studies on annual crop/pasture agriculture systems are planned to further refine information for the farmers. It is expected that with a diversification of the cropping systems, the extensive cerrado pastures, which have poor and acidic soils, will evolve into more intensive beef and dairy cattle production and this will result in more stability for the region.

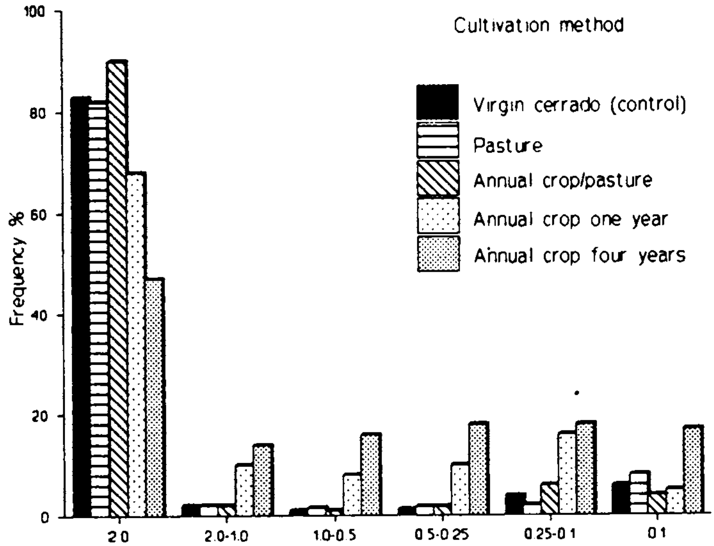

Figure 11. Effect of cultivation method on aggregate size and distribution of a yellow red sandy Oxisol in Minas Gerais (Ayarza et al. 1993)

8. Future Prospects

The problems that resulted from the erratic exploitation of the cerrados have been largely identified, although more research effort should be devoted to soil conservation and the preservation of the cerrado genetic resources. Several species of plants typical of this region are endangered.

Brazilian law provides that woods along river banks, lakes and natural or artificial water reservoirs, in catchment areas, on top of hills and mountains and on fringes of plateaux and slopes be preserved. In addition, 20% of the virgin land in the area is to be kept as reserves. However, unless the law is enforced, valuable forest and genetic resources will continue to be exploited.

The initial approach toward sustainable agriculture in the cerrados concentrated on soil fertility improvement and plant adaptation. Although liming and fertilization are now routinely applied, the effectiveness of these methods was proven through experiments which showed the positive cost/benefit of maintaining soil fertility. More attention must be devoted to the genotype/environment interaction, so that breeding programs develop genotypes which meet the needs of cerrado. This will enhance efforts in promoting sustainable production programs.

More complex problems such as moisture stress, Al-toxicity, nutrient deficiency and imbalances, plant pests and diseases require a holistic approach with an integrated research team. The results of such research should contribute not only to rational solutions, but should also prevent the occurrence of an unfavorable environmental impact.

It is necessary to learn from the troublesome beginning of massive agricultural expansion in the cerrado region. The massive global incentives from government to expand agricultural production during the three decades after the World War II, in order to increase food supply, is the probable origin of the present low commodity prices. However, the present economic trend toward market driven commodity prices, no longer accommodates artificial incentives for agricultural production.

Land tenure has changed structure in the cerrados over the last twenty years. Initially, the cerrados was occupied by large free-ranging cattle ranchers, with little or no input. Post-World War II incentives from government and the low cost of land, enabled entrepreneurs to purchase large tracts of land and move into the farming business. The high prices of commodities and government subsidies favored even the inexperienced farmers. However, the present market situation favors good managers with a real inclination for agricultural enterprises, and the traditional economic principal of optimum management of limited resources has overtaken subsidized agriculture. Government is, however, providing management training for farmers to compensate for lack of subsidies.

The large farmholds have benefited more from research achievements mainly because of the higher education level of their owners. However, the smallholder farmers, have also benefited from up-dated technology through cooperative associations in which information, input, machinery and marketing are shared by the members. Government should, as a matter of priority, assist these smallholder farmers to establish cooperatives and self-help associations.

The most recent approach to agricultural exploitation integrates farming with the microbasin or catchment area in an environmentally balanced system. In this system farmers share the common natural resources of the area. There are four great river basins in the cerrado region, namely, Tocantins-Araguaia, Paraná-Plata, Amazon and São Francisco. Even though they are complex, it has been suggested that they should be the basis for planning farm settlements (Resck 1991). From the main stream up to the catchment areas, the potential of each environment should be identified according to soil type, climate, relief, natural vegetation, hydrology and geology. These will determine the cropping systems that should successfully create permanent settlements.

Pilot studies have been undertaken from which further studies will be carried out to systematically determine the pattern of settlement that will preserve the environment and suit the needs of the already growing regional population. It is expected that these studies will be conducted by research organizations, state extension services, cooperatives and communities.. It is expected that appropriate government policies will make integrated planning a priority, in order to create an awareness at the community level of the need to utilize farm methods which will maintain the cerrados' environment. The main challenge of agricultural settlement in the Brazilian cerrados is to create a stable and environmentally balanced system that should be the basis for generations to come and, at the same time, offer solutions to similar environments in the world.

9. Conclusions

1. Investment in agricultural research and farming incentives are required to develop the Brazilian savanna (cerrado) into a major agricultural, beef, and forestry producer on a sustainable basis.
2. Early agricultural expansion in the cerrados was favored by environmental conditions such as sufficient rainfall, definite wet and dry seasons, temperature, and good soil drainage.
3. Pioneer farmers were innovative and this allowed new technologies to be quickly adopted for the success of agriculture in the region, notably the soybean crop.
4. The adaptation of soybean to savanna cultivation increased the possibilities of crop rotation.
5. Economic P fertilization of annual crops, (soybean, maize, field bean, cassava) and perennial crops (coffee, fruit, pasture and forestry) has permitted the viable expansion of agriculture in the cerrados.
6. Soil organic matter management is of paramount importance for yield stability and can be achieved through alternate cropping and tillage systems.
7. Minimum and no-tillage methods are beneficial to moisture conservation, reduce erosion, help maintain OM and soil aggregation and do not require machinery and save labor time/energy.
8. Lack of suitable planning and technology transfer, labor shortages, and an inadequate knowledge of the environment by the pioneers, explains most of the failure at the beginning of the cerrado settlement.
9. Developing an awareness of the benefits of a community-based utilization of natural resources such as hydrology, natural vegetation and geology can help farmers define cropping systems for permanent settlements.
10. More realistic government policies on transportation, education, welfare and infrastructure will assist the cerrados into developing into a major agriculture producer and help reduce global food shortages

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PART 6
Workshop Summary and Recommendations

RESEARCH AND DEVELOPMENT ISSUES IN THE MOIST SAVANNA ZONE OF SUB-SAHARAN AFRICA: A Synthesis of Workshop Papers

Robert Brinkman
Land and Water Development Division, Food and Agriculture Organization, Rome

Various papers were presented giving overviews of the savannas in sub-Saharan Africa (SSA); these included their biotic and abiotic environment; the farming systems practiced in them; and the policy issues and socio-economic constraints that affect those farming systems and the people who depend on them. Various examples of technology development, testing and transfer were discussed within this context. However, the identification of needs as perceived by the farmers, or methods to provide systematic responses to those needs were not covered in the same depth as the other topics.

Characterization

The moist savanna zone of sub-Saharan Africa (SSA) was described as a broad band of variable width stretching across West and Central Africa to the east and south, and sweeping back to the Angolan coast. This band is further subdivided into ecozones, which are largely determined by the amount of rainfall, temperature and altitude. The vegetative structure of the lowland savanna is dominated by tall grasses, trees and bushes; this vegetation gradually thins out as one moves further north or into higher altitudes and low rainfall regions. These ecozones were closely reflected in the agroclimatic definitions given on the basis of length of growing periods, mono or bimodal rainfall distribution and mean temperature and elevation. A further subdivision of the drier zone was given for practical agronomic reasons, the boundary being a six-month length of growing period.

The heterogeneity within the subzones was emphasized by many speakers, both in presentations and discussions, in terms of vegetation, hydrology (inland valleys vs uplands); and soils.

The varied vegetation in the moist savanna zone was recognized both as a resource, e.g., for increasing soil fertility, and as a problem. For example, weeds, broadleaves in the humid parts to grasses and *Striga* in the driest parts, with sedges and wild rice in the wet valley bottoms. Natural species were also shown to host crop pests which could be carried over to the next season's crops.

The varied opportunities and problems for agriculture of the different soil-climate combinations were illustrated in several papers, but crop distribution was described mainly in terms of an agroclimatic and hydrology matrix, with little explicit reference to soil differences. Examples were given of long-distance correlation of climate-soil homologues which can assist the efficient transfer of soil and crop management information, of innovations with application to specific soil-climate combinations, or of information on specific problems or research needs. This demonstrates to what extent soil and agroclimatic information in readily accessible Geographic Information Systems (GIS) form can be interpreted to respond to varied questions.

An overview was given of the structure and uses of GIS, with several examples, such as the delineation of target areas for successful introduction of *Gliricidia* or *Leucaena* into farming systems. The examples showed the use of agroecological, land-use and population information combined in a decision tree.

Farming systems

Farming systems were discussed in a multiple framework consisting of agro-climate, landscape and hydrology. It included the dynamic changes caused by increasing population or market access, or by the introduction of non-indigenous new crops from other continents — mainly in the distant to the recent past — and more recently, new varieties of existing crops.

Methods to capture and describe the great diversity of farming systems were discussed, including agroecologic and socio-economic zoning. In cases, where the diversity could not be presented in map form, typologies of farming systems, classified on the basis of a small number of simple key variables were prepared and these could assist extension personnel to identify the appropriate groups to be approached with management advice, or to be consulted on existing problems for which a research effort would be relevant. The discussions also covered the development of rice-based cropping systems in inland valleys and other swamp areas, their relationships and necessary integration with adjacent upland parts of total farming systems.

Resource-use conflicts and the various important synergies between livestock and crops were discussed. These two subsystems could be linked within a given farming system, or through the household. Different actors, each managing their own farming system, could also interact with each other. Such interactions could occur within a given area, or between subzones. The synergetic benefits obtainable would be maximized if research themes could include such interactions, both within and among farming systems.

Modelling of farming systems with a view to optimalization was discussed, including considerations of variability and risk. Attention was drawn to the need to include crop by-products or niche uses in the objective function of farming systems models, which presently are almost always restricted to the financial returns from the main crops in the system.

Policy and governance

Policy and governance in Africa and the influence of external policies on Africa were discussed, and the reasons why African agricultural productivity lags behind development in other regions were .analyzed. High-level policy and planning recommendations to improve the situation included:

- democratic governments and peace
- transparent accountability of governments
- increasing the share of rural development in government budgets
- regional market integration
- reductions in tariff and quota barriers

Other policy aspects discussed, at a lower and more attainable level in the context of this workshop, included:

- use of realistic controls in experiments, approximating actual farming systems
- enhancing farmer participation in development
- increasing the research focus on farmers' recognized needs
- strengthening NARs, increasing operational budgets where possible, and improving specialization and cooperation between them
- working towards farming system intensification while making maximum use of internal resources, including N_2 fixers, mycorrhiza, positive effects of crop/livestock interaction
- developing input-efficient varieties that fit farming systems, including the need for crop by-products
- developing and disseminating low-cost postharvest storage methods

Technology development, testing and transfer

It was clear from the discussions on technology development, testing and transfer that low external input solutions could not be the only ways of achieving development. In many cases, especially where there is adequate market access, gradual capital generation and moderate or high input systems have been proved feasible. However, less dependence on purchased inputs, where this is economically and environmentally sustainable, would increase the resistance of the farm household to shocks.

Several contrasting examples of agricultural development were presented, each driven by market access. One, illustrated in two papers showed how a food crop (maize) with a local and national market formed a cash resource. In the second example, the good international market access of a fiber crop (cotton) provided the cash resource for agricultural transformation. Income and capital generation by successful innovation or intensification, when well connected with a market provide the driving force behind the widespread adoption, not only of the innovative complex itself, but also of other improvements in the farming systems: improvements that might not have been widely adopted in isolation. The third example was more diversified, with a range of market-connected options gradually made possible by systematic investment in the land resource to increase sustained productivity. In this case, there was a clear synergy between crop and livestock production. Again, adoption and adaptation by farmers was driven by the possibilities for capital accumulation. The fourth example was the successful gradual, but very significant, investment in an initially very difficult soil environment, supported by systematic research providing a range of economic options. Again, it should be highlighted that good international market access made all this possible, reinforced by the contributions of farmers with a certain capital base, and by subsidies on inputs. However, once the investments were made the system became economically and environmentally sustainable. This last presentation illustrated a successful combination of commercial and industrial demand; good cooperative research; farmers with some resources willing to innovate, given the demand; and innovative private and government entities working to introduce good, new processing and use options of the commodity (soybean), with great comparative cost advantage.

Through the various papers, the workshop was given an overview of the main research program of national governmental, intergovernmental, and national and international nongovernmental institutions as well as private enterprises. These activities focussed on the different priority opportunities and constraints depending, for example, on the different dominant land uses and agroecologies. The workshop took note of the major problems of researchers and research institutions. They include lack of funding, especially for non-staff for operations; difficulties in communication and access; and difficulties in reaching land users and interacting with them. The participants not only recognized the formidable array of constraints that bedevils the smallholder farmers and the other land users in the moist savanna zone of SSA, but also, the varied and important research being undertaken in many countries to help them tackle these constraints.

Clearly, this workshop is not the first response to the problems of the moist savanna zone of sub-Saharan Africa. Other existing and ongoing efforts include the recent regional intergovernmental initiative on the revitalization of agricultural research, by the Ministries of Agriculture, supported by SPAAR; many networks, of which CORAF is but one example; and many national systems which are presently engaged in a new round of priority setting.

Any initiative flowing from this Workshop will need to place itself in the context of such existing initiatives and ensure that synergetic relationships are built and maintained with all these efforts. Such initiatives will also need to recognize the limits of the collective mandate and responsibilities of the Workshop participants.

A selection of ongoing questions framed in general terms and not prioritized, selected from questions and challenges focussed on one crop, and presented in one of the papers is given below. These may need to be addressed in a cooperative research program and could provide a possible start for working group discussions.

- What are the major reasons for large yield gaps in major crops of the different subzones and how can farmers reduce this gap?
- How can farmers use mineral fertilizers efficiently in a cropping system, e.g. in a maize/soybean or sorghum/cowpea sequence?
- Which combination of cropping systems, including rotation or intercropping, could work best, in combination with crop tolerance, to minimize *Striga* damage on cereals?
- Which combinations of uses of different crop residues, by animals or as mulch, would give optimal benefits in farming systems with livestock?
- How can N_2 fixation by legumes and its utilization by the following crop in the cropping system be maximized?
- How can P use efficiency in different legume crops be increased to achieve higher productivity systems?
- IPM research, including work on predators and parasites of crop pests and host plant resistance, should be pro-active. Could the focus on providing containment before a given pest or disease appears become a major problem or disaster?
- How can limiting labor peaks during harvest be reduced, without concurrent reduction of losses during harvest and postharvest operations?
- How can conditions be created, or identified, where use and demand for a crop precede or run parallel with its introduction or with the introduction of a major productivity improvement; this may require work on creating links between producers and consumers?
- How can research be planned so that agronomic work will lead to optimized yields as well as synergistic benefits, prior to the large-scale promotion of a new crop in a farming system?

I thank all the participants who have assisted me in identifying some of the issues that I had not recognized.

IITA/FAO WORKSHOP RECOMMENDATIONS'

The general objective of the workshop was

> *To provide a forum for a review of research and technology development needs of farmers and to develop and prioritize action programs that will be appropriate for sustainable food production in the moist savannas of sub-Saharan Africa.*

RECOMMENDATIONS

1. Policy Development and Socio-economic Concerns

Policy issues and socio-economic factors play important roles in technology adoption, but are frequently omitted in development projects. This is especially true when development has a technological intervention bias. It is anticipated that agricultural production in the African savannas will shift more toward sedentary agriculture that will require investments from the land user in terms of inputs and long-term conservation practices. Policy and socio-economic issues include land tenure, credit availability for smallholder farmers, infrastructural development, the role of women in agriculture, population policies, and import and input policies.

1.1 Immediate objective

Establishment of a Task Force that will positively influence the decision of policy makers on the policy and socio-economic issues of countries in the consortium for sustainable research and development in the moist savanna zone (MSV).

1.2 Policy Issues

1.2.1 *Output 1*

A policy and socio-economic working group is to be established, which will be capable of organizing conferences and commissioning appropriate studies to provide feedback on policy and appropriate/sustainable technology development.

ACTIVITIES

a. Form working group for policy
b. Organize special workshops of concerned policy makers to review existing policies and consider policy options
c. Organize conferences for synthesizing finding as decided by policy makers, one per year for about 50 participants. Possible topics: SAP impact; land tenure

d. Commission studies to compare results and provide user-friendly information to policy makers

e. Establish a socio-economic working group

1.3 Conduct resource system management research
Resource evaluation and training to improve the capability of national agricultural research systems (NARS) in the moist savanna zone

1.3.1 *Output 1*
Socio-economic evaluation of the resource systems and technology needs

ACTIVITIES

a. Development and implementation of appropriate research tools for priority setting/resource allocation

b. Comparative analysis of the dynamics of resource-use systems

c. Benchmark site studies of farm-level inter and intra household resource allocation and welfare distribution

1.3.2 *Output 2*
Development of appropriate socio-economic and biophysical sustainability indices

ACTIVITIES

a. Workshop on sustainable indicators to review, select and harmonize appropriate and affordable indices of sustainability

b. Training session (sub regional) to develop and strengthen capacity for national implementation

1.4 Food systems improvement initiative
Production constraints will be reduced to increase food production

1.4.1 *Output 1*
Socio-economic evaluation of food system constraints and diversification opportunities

ACTIVITIES

a. Carry out economic analyses of storage losses under different technologies

b. Determine effective consumer demands for key savanna zone agricultural products (crops, forestry, livestock)

c. Undertake economic and technical analyses, i.e., profitability and efficiency of alternative processing technologies (currently used, or readily developed)

1.5 Technology testing and transfer

Researchers should understand the adoption pattern of farmers and the performance of the technologies in the moist savanna zone.

1.5.1 *Output 1*

Profile of socio-economic impact of new technologies

ACTIVITIES

a. Develop and strengthen NARS data collection and analysis capacity for impact assessment studies
b. Assess rate, level and patterns of adoption (aggregate and farm-level) and socio-economic factors affecting adoption
c. Determine distributional impact of introduced technologies
d. Determine the rates of return to research and investment

2. Resource Management Research

2.1 Immediate Objective 1

Technologies for sustainable farming systems using legumes as strategic components for soil fertility enhancement; erosion, weed and pest control; and livestock feed and manure production using the benchmark site approach.

2.1.1 *Output 1*

Increase soil fertility and reduce soil erosion

ACTIVITIES

a. Multilocational screening and testing of elite multipurpose legumes for their contribution to soil improvement and weed control
b. Test management options to optimize the contribution of legumes, including weed control

2.1.2 *Output 2*

Germplasm collection and building a database on multipurpose legumes in the MSZ

ACTIVITIES

a. To source information on legumes in existing national and international institutions
b. Identify germplasm collection and information gaps and working through constituent working groups

2.1.3 *Output 3*
Enhanced animal performance as a result of improved feed quality

ACTIVITIES

a. Evaluate the potential contribution of legumes as a feed supplement in crop/livestock production systems
b. Test animal performance using legumes as a strategic feed supplement

2.1.4 *Output 4*
Improvement of soil fertility by nutrient cycling through animal manure

2.1.5 *Output 5*
Successful rehabilitation of *Imperata*-infested grasslands and the integration of legumes into crop and livestock production systems

ACTIVITIES

a. Screen legumes for *Imperata* suppression
b. Mapping of *Imperata* infestation
c. Research on methods of managing fire incidence in *Imperata* grasslands
d. Establishment of improved fallow systems
e. Testing and transfer of technology for *Imperata* control

2.1.6 *Output 6*
Sustainable plant protection technologies particularly against *Striga* infestation

ACTIVITY

a. Screen and test legumes for *Striga* resistance and suppression

2.2 Immediate Objective 2
To create suitable knowledge systems inclusive of geo-referenced databases and interpretation. Synthesize production opportunities for adopting pathways that will protect the resource base while improving the wellbeing of people and animals

2.2.1 *Output 1*
Collate available biotic and abiotic data (climate, soil, vegetation, weeds, insect pests, etc.)

ACTIVITY

a. Identify available geo-referenced databases for SSA, such as climate, soil and terrain, cropping systems, etc., and distribute to partners

2.2.2 *Output 2*
Methods for ex-ante analysis of agronomic practices and management strategies for risk assessment (environmental and socio-economic)

ACTIVITIES
a. Identify and evaluate suitability of existing interpretation methods for solving critical problems including the identification of key research sites and homologous areas for technology transfer
b. Conduct research at benchmark sites to develop a minimum data set for testing and/or improving existing methods
c. Conduct training workshop for consortium members

2.2.3 *Output 3*
Adopt a framework for analysis of farming systems

ACTIVITIES
a. Convene a regional workshop of farming systems specialists to develop and implement an operational frame work for rapid evaluation for farming systems
b. Convene a regional meeting for numerators to explain analysis frame work and data collection practices
c. Organize the collection of baseline data by partners within a minimum of 10 (20 or 30) farming systems

2.2.4 *Output 4*
Distribution of digital database and interpretation methods

ACTIVITY
a. Organize workshop for validating data generated

2.2.5 *Output 5*
Description of farming systems for targeting technology

ACTIVITY
a. Report on status of farming systems in the region

3. Postharvest Activities and Human Nutrition

Postharvest covers everything from harvest to reaching the consumer, and includes storage, processing, transportation, marketing, economics and finance. Products covered are foods, feeds and non food item such as wood, fibers and skin. ***Human nutrition*** relates to the quality and quantity of food products.

3.1 Rationale
In the long run, in a free market economy and stable social environment, a farmer can only sell what a consumer is willing and able to buy. Postharvest activities are important means for enabling this to happen.

It is recognized that certain postharvest traits can be or are already addressed at the pre-harvest stage, e.g., in plant breeding. Postharvest can have a major impact on the quality of life because it enable the development of income opportunities for people outside of farming, e.g., young unemployed people who do not work on the land.

3.2 Possible Task Force recommendations

- Transfer and adaptation of local processing technologies

- Development of rural and peri-urban based agro-industries to improve the quality of life through the provision of:
  a. small-scale businesses
  b. women's enterprises
  c. employment in small rural towns
  d. peri-urban businesses
  e. job opportunities for young entrepreneurs

3.3 Issues
Investment efficiency is an important consideration because the private sector has a major involvement in postharvest activities; therefore, institutional involvement should becomes passive and entrepreneurs active.

Present evidence and experience indicate that a postharvest R & D initiative will have a catalytic (seed) role to which entrepreneurs will respond. We expect that, in due course, entrepreneurs will take over, and postharvest R & D as an institutional activity will decrease.

3.4 Assumptions
Many appropriate technologies are available, so development can be achieved using present technology, with research thrusts taking second place.

3.5 Immediate Objectives
An integrated postharvest approach which recognizes production potentials and

constraints and optimizes utilization of farm products should be implemented. This, implicitly requires the satisfaction of consumer requirements and demands.

3.5.1 *Output 1*

To achieve efficient coordination, monitoring and evaluation of postharvest research and development on target commodities in the region

ACTIVITIES

a. Set up a postharvest working group to ensure effective coordination and information exchange through regular meetings and news bulletins
b. Make a directory of postharvest research and development capability in the region
c. Monitor and evaluate postharvest developments/changes in the region

3.5.2 *Output 2*

Collation and synthesization of information on postharvest systems for target commodities, covering the postharvest chain from farmer to consumer

ACTIVITY

a. Use a Task Force to analyze existing systems and report on findings and indicate/recommend priorities

3.5.3 *Output 3*

Formulate a master plan for regional and national level implementation, comprising a range of subprojects which cover technology transfer and adaptation, research and information exchange

ACTIVITY

a. Postharvest working group prepares subprojects based on task force report and in collaboration with NARS, regional bodies, and other interested parties, such as FAO, NGOs, women's groups, chambers of commerce, and farmers' organizations

3.5.4 *Output 4*

Transfer and adapt technologies to suit local conditions

ACTIVITY

a. Projects will be undertaken at appropriate sites for each target commodity based on the demand for and the availability of the technology

3.5.5 *Output 5*

Undertake research in priority areas; Task Force findings will assist in the identification of areas where intervention and innovation are required.

ACTIVITIES

a. Development of measures to reduce postharvest losses
b. Study market demand and opportunities
c. Develop quality control measures

3.5.6 *Output 6*

Improve information exchange and institutional capability for postharvest research and development.

ACTIVITIES

a. Maintenance and updating of the information generated by the Task Force
b. Investigate proper channels for information exchange between institutions, consumers and farmers. Utilize available/appropriate media for facilitating links between institutes; between farmers and institutes; and between consumers and farmers

4. Technology Testing and Transfer

4.1 Immediate Objective

Establishment of a technology testing and transfer (TTT) unit to coordinate exchange of technologies and reinforce capacity and methodologies for technology testing and transfer in the moist savanna of sub-Saharan Africa.

4.1.1 *Output 1*

ACTIVITIES

a. Appoint full time unit coordinator (head) within three months of start of project
b. Organize meetings of existing network coordinators, (farming systems research and commodity) and NARS, extension services and 10 representatives to determine and review TTT priorities. (years 1, 3 and 5)
c. TTT unit coordinator should facilitate the formation of sub-regional working groups and the identification of pilot zones, within first year
d. Steering committee of TTT sub-regional working group heads and ten selected representatives meets bi-annually to review and program TTT unit activities

e. TTT unit coordinator to organize site visits of network coordinators to pilot zones to reduce duplication of efforts and build consensus on greatest needs (two visits per year)

f. Prepare and distribute a quarterly bulletin (newsletter) of on-the-ground TTT activities

g. Organize thematic conferences to provide links between benchmark site research and TTT activities (one per year)

h. Synthesize and distribute participatory research and technology transfer methodology guidelines (within two years)

4.1.2 *Output 2*

Emerging technologies, such as improved fallows, fodder banks, agroforestry, etc., should be tested, adapted and validated by several institutions, using a farmer participatory research approach in pilot sites in the moist savannas of sub-Saharan Africa.

ACTIVITIES

a. Form working groups of farming systems scientists from institutions interested in farmer participatory approaches to technology testing

b. Identify a wide range of appropriate technologies/systems for testing

c. Program exchange of ideas concerning methodology in yearly meetings and prepare guidelines

d. Implement comparative studies of different mechanisms to ensure effective farmer participation

e. Implement testing, adaptation and validation activities using farmer participative approaches

f. Organize training courses and cross-site visits

4.1.3 *Output 3*

Technologies such as improved varieties, better management components will be tested by farmers for adoption in pilot zones of member countries

a. TTT unit to form a technology transfer working group (TTWG) lead by extension agents

b. Appropriate technologies will be identified by TTWG for extension services in pilot zones in member countries

c. Methodology protocol to be developed by TTWG for pilot extension campaigns including demonstrations, field days, farmers' visits, and cross-site field visits by extension agents

d. Extension workers to be train by national scientists assisted by TTWG

e. A pilot extension campaign to be implemented and monitored by extension agents assisted by TTWG

f. Impact assessment studies to be carried out by TTWG

g. Pre-requisites for large extension campaigns including seed multiplication (pilot/private), vaccines, etc. to be identified by TTWG

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List of Registered Participants

Dr A. Adesina
Principal Economist, WARDA
Bouaké, Côte d'Ivoire

Dr J.K. Adu
Animal Research Institute
P.O. Box 20
Achimota, Ghana

Mr C.W. Agyakwa
Res. Associate
IITA, PMB 5320
Ibadan, Nigeria

Dr M.R. Ahmed
Ministry of Food & Agric.
P.O. Box 14
Northern Region
Tamale, Ghana

Dr Kwaku Agyemang
Acting Team Leader
ILCA
Kaduna, Nigeria

Dr C. Akakpo
Agronome
INRAB
Cotonou, Bénin

Dr I.O. Akobundu
Weed Scientist
IITA, PMB 5320
Ibadan, Nigeria

Mr K. Atkinson
Head, Publications Unit
IITA, PMB 5320
Ibadan, Nigeria

Dr M. Ayarza
SQS 10 Bloco D. Apto 302
Brasilia, Brazil

Dr Doyle Baker
Director, RCMD
IITA, PMB 5320
Ibadan, Nigeria

Dr M. Bokanga
Biotechnologist
CID, IITA, PMB 5320
Ibadan, Nigeria

Dr B. Bolawole
Punch Nigeria Limited
Lagos

Dr Pierre-Marie Bosc
Agronomist, CIRAD-SAR
CIRAD BP 5035
Montpellier 34032
France

Dr M. Bossa
Report Radio Bénin
Cotonou, Bénin

Dr W. Boukary
Journaliste
ORTB-Radio BP 366
Cotonou, Bénin

Dr R. Brinkman
Land and Water Development Division
FAO
Rome, Italy

Dr R.J. Carsky
Systems Agronomist
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Dr J. Cecil
Ag. Ind. Officer
FAO, Rome, Italy

Dr A.C. Chilagane
Senior Agric. Res. Officer
ARTI, Ilonga - Kilosa
Tanzania

Dr C. Dia
Interpreter/Translator
IITA, PMB 5320
Ibadan, Nigeria

Dr I.J. Ekanayake
Physiologist
IITA, PMB 5320
Ibadan, Nigeria

Mr F. Ekeleme
Research Associate
RCMD-IITA, PMB 5320
Ibadan, Nigeria

Prof A.M. Emechebe
Deputy Director/Research
IAR, ABU, PMB 044
Zaria, Nigeria

Dr J. Fajemisin
IITA, Bouaké
01 BP 2551
Côte d'Ivoire

Dr M. Fobasso
Ingénieur d'Agric.
IRA
Foumbot, Cameroon

Mr S. A. Folayan
Computer Systems Manager
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Prof J.B. George
Res. Coordinator
IAR, PMB 540
Freetown
Sierra Leone

Dr Z. Haliu
ILCA, PMB 2248
Kaduna

Dr E. Hanak Freud
Economist
CIRAD, 42 rue Scheffer
75116 Paris
France

Dr S. Hounvide
Controleur Technique
ORTB Radio, BP 366
Cotonou, Bénin

Dr Oscar B. Hounvou
Interpreter
IITA, PMB 5320
Ibadan, Nigeria

Dr A. Isichei
Obafemi Awolowo Univ.
Ile-Ife, Nigeria

Dr L.E. Jackai
CID-IITA, PMB 5320
Ibadan, Nigeria

Dr S.S. Jagtap
Head, ASU
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Dr Y.W. Jeon
Postharvest Technologist
IITA, PMB 5320
Ibadan, Nigeria

Dr J. Kamau
Researcher
P.O. Box 340
Machakos, Kenya

Dr S.K. Kim
Maize Breeder
CID-IITA, PMB 5320
Ibadan, Nigeria

Dr E.A. Kueneman
Senior Officer, FAO
via delle Terme di Caracalla
Rome, Italy

Dr A. Larbi
Forage Agronomist
ILCA, Ibadan, Nigeria

Ms C. Lord
Translator
IITA, PMB 5230
Ibadan, Nigeria

Dr W. V. M. Manyong
Agricultural Economist
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Dr N. Masinmango
INERA
Zaire

Dr H.M. Mushala
University of Swaziland
Private Bag Kwaluseni
Swaziland

Dr P. Neuenschwander
Director, PHMD
IITA, Cotonou
B.P. 08-932
Bénin

Dr E.L. Ngantunga
Principal Agric. Res. Officer
Ministry of Agriculture
Dar-es-Salaam, Tanzania

Dr J,M. Ngeve
Director of Research
IAR-Nkolbisson
Cameroon

Mrs. E.T. Njiku
Agricultural Extensionist
Farmers' Education & Publicity Unit
P.O. Box 2308
Ministry of Agriculture
Dar-es-Salaam, Tanzania

Dr C. Nolte
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Dr F.I. Nweke
Project Director, COSCA
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Dr C. O. P'Obwoya
Research Officer
Box 7084
NAARI-Kampari
Uganda

Dr A. Ogungbule
IAR, Samaru
Kaduna, Nigeria

Prof B.N. Okigbo
Director, UNU/INRA
Accra, Ghana

Dr O. A. Osiname
AFNETA Coordinator
IITA, PMB 5320
Ibadan, Nigeria

Dr S. Paris
Environmental Specialist
Netherlands Embassy
Cotonou, Bénin

Dr E. Pulver
NARMAP
Belmopan, Belize

Dr F.M. Quin
Director, CID
IITA, PMB 5320
Ibadan, Nigeria

Dr P. Rebuffel
Agronomist
BP 5035 - Montpellier
France

Dr N. Sanginga
Soil Microbiologist
RCMD, IITA, PMB 5320
Ibadan, Nigeria

Dr S.V.R. Shetty
Principal Agronomist
ICRISAT
Niamey, Niger

Dr J.W. Smith
Animal Scientist
ILCA, PMB 5320
Ibadan, Nigeria

Dr H. Songre
Interpreter
IITA, PMB 5320
Ibadan, Nigeria

Dr M. Sonou
Regional Officer
FAO
P.O. Box 1628
Accra, Ghana

Dr C.R. Spehar
EMBRAPA-CPAC
73301 970 Planaltina DF
Brazil

Dr D.S.C. Spencer
Freetown
Sierra Leone

Dr J.B. Suh
Research Liaison Scientist
c/o Crop Research Institute
Kumasi, Ghana

Dr M. Tamo
Program Leader
IITA
Cotonou, Bénin

Dr D. V. Tran
Executive Secretary,
IRA, FAO-AGP
Rome, Italy

Dr M. Versteeg
IITA
Cotonou, Bénin

Dr K. Wydra
IITA
Cotonou, Bénin

Dr J.S. Yaninek
Entomologist
PHMD-IITA

INDEX OF BOTANICAL NAMES

About IITA

The goal of the International Institute of Tropical Agriculture (IITA) is to increase the productivity of key food crops and to develop sustainable agricultural systems that can replace bush fallow, or slash-and-burn cultivation in the humid and subhumid tropics. Crop improvement programs focus on cassava, maize, plantain, cowpea, soybean and yam. Research findings are shared through international cooperation programs, which include training, information and germplasm exchange activities.

IITA was founded in 1967. The Federal Government of Nigeria provided a land grant of 1000 ha at Ibadan, for a headquarters and experimental farm site, and the Rockefeller and Ford Foundations provided financial support. IITA is governed by an international Board of Trustees. The staff includes approximately 150 scientists and professionals from about 40 countries, who work at the Ibadan campus and at selected locations in many countries of sub-Saharan Africa.

IITA is part of the network of non profit, international agricultural research centers currently supported by the Consultative Group on International Agricultural Research (CIGAR). Established in 1971, CIGAR is an association of about 50 countries, international and regional organizations, and private foundations. The World Bank, the Food and Agriculture Organization (FAO) of the United Nations and the United Nations Development Programme (UNDP) are co-sponsors of this effort.

International Institute of Tropical Agriculture
PMB 5320, Ibadan, Nigeria
Food and Agriculture Organization (FAO) Rome, Italy

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