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IITA Strategic Plan 1989 - 2000

Prepared for Discussion at the 45th TAC Meeting
Rome, March 1988

International Institute of Tropical Agriculture

About IITA

The International Institute of Tropical Agriculture (IITA) is an autonomous, non-profit corporation with headquarters on a 1,000-hectare experimental farm at Ibadan, Nigeria. It was established in July 1967 as the first major African link in an integrated network of international research and training centers located in all the major developing regions of the world.

Funding for IITA came initially from the Ford and Rockefeller foundations. The land for the experimental farm was allocated by the Government of the Federal Republic of Nigeria. Principal financing has since 1971 been arranged through the Consultative Group on International Agricultural Research (CGIAR).

Financial support for the core program during 1987 was provided by Austria, Belgium, Canada, China, Denmark, the Federal Republic of Germany, the Ford Foundation, France, India, Italy, Japan, the Netherlands, Nigeria, Norway, Sweden, the Rockefeller Foundation, the United Kingdom, the United Nations Development Program, the United States Agency for International Development and the World Bank. In addition, many organizations and governments also provided funds for special projects and specific training activities.

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International Institute of Tropical Agriculture
Ibadan, Nigeria

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The numerous consultants who participated in the program review meetings (listed in annex 4) were asked to reflect intensively on a wide-ranging set of issues for a period of a week or more. They provided valuable expertise and insights on IITA's present program and potential future direction.

Extensive background studies were prepared on the economic and ecological aspects of the agricultural production systems of West and Central Africa. These were important to decisions on research priorities, and they are summarized in chapter II of this document. The authors of these studies include: Dr. J. A. Akinwumi (University of Ibadan); Dr. Malik Ashraf (IITA); Professor Randy Baker (Cornell University); Dr. Kirby Davidson (Rockefeller Foundation, retired); Dr. Paul Dorosh (IITA); the late Dr. Pascal Fotzo (University of Dschang); Dr. Abe Goldman (IITA); and Dr. Victor Nyanteng (WARDA).

Throughout the course of the strategic study, Professor Randy Barker served as special consultant, and Dr. William Steele (IITA) was responsible for managing and overseeing its progress. All of the IITA program leaders and most of the scientific staff members participated in and contributed to the review meetings. Many also read, commented on, and contributed material to sections of this report.

Dr. Ralph Cummings, Sr. was instrumental in arranging the production of three maps of West and Central Africa which will be included in the final published edition of this report, and IITA gratefully acknowledges the assistance and cooperation of the cartographic section of the World Bank for producing and making these maps available for our use. Janet Keyser edited and helped produce an earlier draft of this report which was presented to the IITA Board of Trustees. This final version of the report has been written and edited by Drs. William Steele and Abe Goldman.

The sad and untimely death of Dr. Pascal Fotzo occurred in a plane crash in December 1986. All of those at IITA who had known and worked with him feel deeply the loss of a colleague and friend, and wish to extend our sympathies to his family.

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I. THE IITA STRATEGIC PLAN:

BACKGROUND AND OPERATING PRINCIPLES

As IITA approached its 20th anniversary in 1987, it became evident that the nature and pace of its progress and the rapidly changing African scene made strategic planning an urgent and imperative task. IITA's present and projected resources would be insufficient to sustain the past research agenda and to move in urgent new directions. Sharper program focus, new and more effective modes of collaboration, and more effective strategies would be needed to deal with the related issues of malnutrition, poverty and sustainability in tropical Africa.

IITA therefore launched a strategic planning study in 1986. The study was a lengthy, multi-phasic process due to the scope of IITA's mandate and the complexity of the African environment. The phases of the planning process involved a strategic diagnosis of IITA's environment (the ecological, economic and institutional setting), a formulation of program objectives and a vision of IITA's future role, the setting of program strategies and priorities to realize the objectives, and the translation of these into strategic plans for the future. The implementation of the strategy is provided for in the IITA Medium-Term Plan, which is described in a companion volume to this strategy document.

The study was conducted by IITA scientists and management assisted by small numbers of carefully selected consultants (listed in annex 4) who visited IITA to join the staff in five study groups, one for each research program. There were two distinct phases in the study. In the first phase, the study groups reviewed past achievements and current research, and recommended future research strategies and priorities within each program. In the second, IITA's management met with the chairpersons of all of the study groups, and with representatives of the Board of Trustees and the Technical Advisory Committee (TAC) of the CGIAR to make judgments about the future allocation of resources among programs.

To assist the work of the study groups, IITA's scientists prepared economic analyses of the present and likely future economic significance of the Institute's mandated crops and studies on the broader issues of demography and agroecological variation, all of which have an important bearing upon setting of strategies and priorities for future research. Summaries of those ecological and economic studies are presented in chapter II.

A central objective of the study was to set strategies and goals within the individual commodity programs. For each commodity, this involved a systematic examination of "relevance indicators" (discussed in the introduction to chapter IV) derived from the 1985 TAC *Review of CGIAR Priorities and Future Strategies.* The purpose of this analysis was not to evaluate the efficiency of current commodity

improvement research, but to determine the relevance of future research, to set priorities among researchable issues, and to assess the resources needed to carry programs to a successful conclusion.

The study of the Resource and Crop Management Program followed a different pattern. It was chiefly concerned with establishing an appropriate conceptual and institutional framework for this kind of research, which has been far less well defined within the CGIAR system as a whole than has commodity research. There was also considerable discussion of the characteristics of diverse ecologies in the context of setting priorities for research. The study recognized both the conceptual link and the operational distinction between the two facets of resource and crop management research at IITA – increasing crop productivity on the one hand, and sustaining resource productivity on the other. Furthermore, the study recognized the critical role of the Resource and Crop Management Program as the channel through which the products of commodity research are incorporated into appropriate farming systems innovations. The outcome has been a new and well defined focus for resource and crop management research at IITA.

The strategic planning study did not produce easy solutions to the critical issues, but it did mobilize the best talents in the developed countries and in Africa to assist IITA in making informed judgments on the delicate balances that would make best use of limited resources:

(a) The balance in the IITA research program between the urgency of increasing food production today and the long-term research required to develop sustainable production systems.

(b) The balance between downstream, adaptive research in collaboration with national systems and the need for strategic upstream, more basic research on the technical problems that block the progress of IITA scientists.

(c) The balance within the commodity improvement programs between concentration on a few key staples and the large number of crops that play critical roles in the farming systems of the tropical regions.

(d) The balance between research at IITA and outreach activities that strengthen the capacity of national systems to do their own research.

PROGRAM OBJECTIVES

IITA conducts international agricultural research and outreach activities in partnership with African national agricultural reseach systems, so as to contribute to sustainable and increasing food production in the humid and subhumid tropics and thereby to improve the well being of low-income people. IITA has a long and complex formal mandate, from which the Board of Trustees has distilled four operational program objectives:

(a) To develop systems for the management and conservation of natural resources for sustainable agriculture in the humid and subhumid tropical zones. There is global concern that Africa's rapidly growing population is placing increasing pressure on basic natural resources and threatening the viability of traditional farming systems.

(b) To increase the performance of selected food crops that can be integrated into improved and sustainable production systems. This is the central thrust of the CGIAR system, the approach that initiated the "green revolution" in rice and wheat, and it remains valid for tropical Africa, although the problems are more complex and the rate of achievement not as spectacular. IITA is currently conducting varietal improvement research on three primary and three secondary food crops.

(c) To strengthen national agricultural research capacities in developing countries in order to accelerate the generation and utilization of improved technologies by means of training, information and other outreach activities. The objective is to enable IITA's partners in national systems increasingly to meet their own technology requirements.

(d) To improve quality characteristics and postharvest technologies in order to realize the more complete utilization of food crops within IITA's mandate. For a number of IITA commodities, particularly roots and tubers, the lack of efficient technology for storage, processing, and conversion to commercial products is a serious barrier to their increased use as both food and feed.

These objectives and the operating strategies described in the next section are the foundation for a new sense of scientific purpose and collaboration at IITA, a basic philosophy and vision of the future that can guide and enhance the policies and actions of the present. The objective is an IITA with a high degree of scientific creativity; with organizational cohesiveness based on a common philosophy and shared values; with a decentralized, lean operating structure; with an ecological and systems orientation to assure that IITA understands its ultimate clients; with effective working relations with national agricultural research organizations; and with resources clearly focused on the most critical problems.

PROGRAM STRATEGIES

Four program strategies were developed during the strategic planning study and have been adopted by IITA to assure greater focus in the use of its limited resources.

1. Primary Emphasis on West and Central Africa

To increase program focus, IITA will place primary emphasis on improving the farming systems of the lowland humid and subhumid tropics of West and Central Africa. West and Central Africa account for the greater part of these lowland ecologies in Africa. This geographic focus is consistent with the international objectives of IITA. Research findings in Africa will be shared through germplasm exchange, publications and training with tropical zones in other continents.

In the strategic planning study, a research agenda for this region was developed without regard to, at the first stage, who would implement it. The questions were asked: How can international agricultural research contribute to the development of West and Central Africa? What are the researchable issues? What will be the socio-economic value of improved technologies?

IITA clearly cannot do this job alone. It will continue to work closely with partners, both in sister centers and in national systems, to improve existing modes of collaboration and to develop new ones that will best serve the interests of Africa.

IITA is a link in a chain that stretches from the basic research laboratories of the first world through national agricultural research and extension agencies to the ultimate target, the African farmer. It depends on sister international centers with global mandates because they have a comparative advantage in some areas of strategic upstream research and because of the diversity and quality of their germplasm.

On the other hand, IITA's comparative advantage rests upon 20 years of experience with the farming systems of West and Central Africa, an enormous, complex region with over 40 percent of the population of sub-Saharan Africa. IITA has the infrastructure, program momentum, and long established, strong links with the national systems of the region. At present, IITA has 50 scientists outside Nigeria working in 12 African countries, and over the past decade has accumulated more than 300 scientist-years of experience working in and with African national programs. It is thus in an excellent position to facilitate intercenter cooperation and the evolution of a coherent CGIAR program to strengthen African national systems.

2. Focus on the African Smallholder or Family Farmer

The second program strategy is to focus on the African smallholder or family farmer, as contrasted with the large scale commercial enterprise. Small farms, usually under three hectares, remain the basic food production unit in West and Central Africa. They employ about 75 percent of the people of the region. The aim increasingly will be to raise the productivity of the farmer rather than to maximize yields from his land. This means that farmers – both men and women – must be the center of IITA concern. Industrial or urban growth cannot absorb ever-growing rural populations. Most farm families have no employment alternatives. Increasing their productivity and income is an efficient means of producing more food; it is also a moral imperative that cannot be ignored.

IITA distinguishes two groups of smallholders as beneficiaries of its research. First, there are resource-poor farmers largely ignored by conventional research. To break the subsistence pattern of their lives requires technologies independent of inaccessible purchased inputs – it requires varieties resistant to diseases and insect pests and tolerant of adverse environmental factors; it requires biological approaches that reduce dependence on chemicals and that work with nature to solve farmers' problems; and it requires management practices that save labor and raise productivity.

Second, there are small farm families who are able to produce some surplus for the market. IITA will generate technologies for these farmers who will be able, through the increasing commercialization of their operations, to adopt improved technologies that will become driving forces for change in Africa.

3. Ecological Orientation

The third program strategy is to establish small research substations or satellites in the key ecologies of the region. Decentralization of IITA's research is a logical stage in the evolution of the Institute. In the first stage of IITA's history, it was apparent that commodity research could make the greatest impact by developing germplasm resistant to major diseases for use by national systems. With access to genetically diverse germplasm and sophisticated research support, the commodity scientists could do this work most effectively at IITA headquarters.

Moreover, they were notably successful in breeding resistance to major pathogens – cassava bacterial blight and African mosaic disease, diseases of maize such as lowland rust and blight and the streak virus, rice blast, and numerous cowpea diseases. These successes now permit a significant decentralization of research from Ibadan headquarters to the ecologies where the commodities studied are important food crops.

The key ecologies in West and Central Africa are the humid forest, the narrow forest/savanna transition zone where IITA is situated, the moist savanna, and the inland valley ecosystem which is to be found in all three of these ecologies. (See the map of agroecological zones at the back of *IITA Medium-Term Plan 1989-1993).* Table I.1 shows the importance of IITA commodities in these ecologies.

The forest and transition ecologies together represent over 50 percent of the land area within the countries of West and Central Africa. The region is characterized by high rainfall, ranging from around 1,400 mm to over 4,000 mm annually, with from 6 to more than 9 humid months when rainfall exceeds evapotranspiration. Half or more of the forest areas is covered by acidic ultisols and oxisols with low inherent fertility and long fallow requirements. While the original forest cover helps to mitigate the effects of intense rainfall and to maintain a stable recycling of nutrients, widespread cultivation removes nutrients and exposes the soil to the effects of rain, heat, and sunlight. This can lead to rapid loss of soil productivity through leaching, acidification, erosion and structural deterioration. The forest zone of West Africa contains close to half its total population on less than 40 percent of the region's area, and thus has the highest rural population densities of the region.

The farming systems in most forest zones have remained productive because smallholders have a wide range of strategies to maintain and restore soil productivity – including various shifting cultivation and bush fallow rotations, complex cropping patterns and sequences, mixtures of tree crops and annuals, and intensive compound gardening techniques. These function to replicate the protective and fertility-restoring effects of the original forest cover. Nonetheless, serious degradation has already occurred in a number of areas, and in many others the ability of current practices to maintain productivity is threatened, either by population pressures in the high density areas or by labor shortages in the low density areas.

The moist or Guinea savanna zone of coastal West Africa includes almost 45 percent of the area, but only 30 percent of the population of the region. It is an area of considerable agricultural potential, particularly for arable crops. High solar radiation during the growing season, warm day temperatures, and low night

Table I.1 Importance of IITA commodities by ecological zone

	Humid forest	Transition	Savanna moist	Savanna dry	Inland valley
Cassava	XXX	XXX	XX	X	X
Maize	X	XX	XXX	X	X
Rice[a]					
Cowpea		X	X	XXX	X
Soybean[b]					
Plantain	XX	X			
Yam		XX	XX	XXX	
Working group system base[d]	cassava	cassava/ maize	maize	sorghum/ millet[c]	rice

Notes : The number of Xs indicates the relative importance of IITA's mandated commodities in each ecological zone.

a IITA works on rice only in the inland valley ecosystem which occurs in all ecologies.

b Soybeans are not a significant component of any West or Central African farming system at this time. Nonetheless, research into their potential will be undertaken in the transition and moist savanna ecologies, and the inland valleys.

c IITA cowpea breeders collaborate with ICRISAT in this ecology.

d The crop-based systems working groups are described in chapter III (B).

temperatures result in high biomass potential. However, the soils of most of the moist savanna zone require careful management to sustain production.

Rice ecosystems are not restricted to a major ecology. The most important classification criterion is the water regime, since technology requirements and production constraints differ markedly in a moisture continuum from flooded inland valleys to dry uplands. Within the inland valleys there are hydromorphic areas characterized by the presence of a fluctuating underground water table, from 60 cm below the surface to above ground at some stage. These soils can often be continuously cropped with rice in the rainy season, followed by other crops whose root systems exploit the underground water in the dry season. Although they are rainfed uplands, they are treated as a separate category because the availability of soil moisture associates them more closely with lowland areas in terms of their rice production potential and technology needs.

These inland valleys are for the most part underutilized though they collectively comprise a very large total area in Africa (FAO has estimated 200 million hectares). Many reasons are given for this lack of development – including health hazards, scarcity of labor and of investment resources needed for improvement, and an absence of population pressure on the land. It is also believed that cropping systems well adapted to this ecology have not been available to farmers.

IITA plans to locate one research station in the humid forest ecology, primarily for work on cassava and resource management; two others in the savanna for work on maize and cowpeas; and a fourth in an inland valley for rice research. An exception to the regional and ecological focus will be the extension of cassava research to a substation in the mid-altitudes of East and Southern Africa in collaboration with the Southern African Centre for Cooperation in Agricultural Research (SACCAR). These research stations will be staffed with small teams of scientists who will be able to set research objectives based upon close study of the farming systems in the ecology in which they are living. With strong support from Ibadan headquarters, they will increase IITA's ability to help national programs in the region.

4. Farming Systems Orientation

The fourth program strategy is to inculcate a farming systems orientation through IITA. This will assure that the technology generated will be productive in the real world of the African farmer. Interdisciplinary cooperation is needed to integrate research on improved varieties with work on management practices. Too often in the past, crop improvement scientists have worked independently of one another and of scientists involved in farming systems research.

After considering various organizational alternatives for promoting multidisciplinary collaboration, the simple innovation of interprogram, crop-based, systems working groups was adopted. The commodities that serve as the base for these working groups are shown in table I.1. This new mechanism, described in chapter III (B), was established in 1987 and is leading to a profound reorientation in the way that IITA scientists think about their research.

II. THE ECOLOGICAL AND ECONOMIC BACKGROUND

A. *Demographic And Policy Trends*

POPULATION GROWTH IN AFRICA

In recent years, the rate of population growth in most of Africa has been higher than anywhere else in the world, and unlike in other regions where the rate has slowed markedly, population growth in sub-Saharan Africa is continuing to accelerate. In most countries of this region, according to the Food and Agriculture Organization (FAO) and World Bank projections, the annual rate of population growth between 1980 and 2010 will be over 3 percent, making this the most intense period of population growth in recent African history (FAO, 1986; World Bank, 1986a & b).

This rate of increase is unprecedented in modern history for so large a region; the highest growth rates in Europe, Asia, or Latin America, even during their periods of most rapid population and economic expansion, were below 3 percent per year. By early in the 21st century, sub-Saharan Africa's 1985 population of about 460 million will have more than doubled, and it will reach over 1 billion by 2010 or earlier. This means that agricultural production, employment opportunities, and social services will all have to increase at a rate of over 3 percent per year just to remain at their 1980 levels. The rapidity of this required increase will place great pressure on agricultural and other resources and allow little time for adjustment of attitudes and institutional capabilities.

A recent World Bank analysis of population growth and its implications in sub-Saharan Africa (1986b) reached the following conclusions about demographic trends:

1. Substantial growth in population over the next few decades is inevitable given the age structure of the present population; even an unexpectedly rapid decline in fertility will not prevent total population from increasing by two and a half times or more by the middle of the next century.

2. For the next 15 to 20 years, the population growth rate will remain above 3 percent; it will begin to decline only after the turn of the century.

3. A rapid decline in fertility rates, resulting from appropriate policy measures and changes in behavior, can make a significant difference in growth rates after the year 2000. While the period of intense population growth will be over by the

middle of the next century, the total population by that time would be 40 percent higher if the rate of fertility decline were slow rather than rapid.

Given the inevitability of this period of very rapid population growth, lasting for at least the next two decades, it is of utmost importance that the consequences of this growth be managed successfully. Among the most important of the consequences will be an extremely rapidly expanding need for food production, and associated with that, the need for markedly greater productivity of the resources engaged in agriculture. Achievement of these productivity increases will require a broad range of new agricultural technology, and given the variability of agricultural environments and farming systems in Africa, different technologies will be needed in different areas. The humid and subhumid lowlands of West and Central Africa, because of the nature of the resource base as well as the demographic characteristics and recent history of policy in the area, are likely to have great need for improved agricultural technology both to increase productivity and output rapidly and to cope with the resulting pressure on agricultural resources.

WEST AND CENTRAL AFRICA

The countries of humid and subhumid West and Central Africa* contain over 40 percent of the total population and represent over 25 percent of the total land area of sub-Saharan Africa (FAO 1986, World Bank 1986a). West Africa itself is the most densely populated portion of sub-Saharan Africa, with about one third of its total population on a little over 10 percent of the area (table II.1). Moreover, one West African country, Nigeria, is the most populous country on the continent, containing over 20 percent of total sub-Saharan Africa population and over 50 percent of the total population of West and Central Africa. In contrast, Central Africa is relatively sparsely populated, as are a number of other regions of sub-Saharan Africa. These facts, of high total populations but widely varying population distribution, are important in an understanding of the demographic setting of the region and some of the characteristics of agricultural change and development there.

As in other parts of the continent, the population of West and Central Africa has been increasing steadily and has entered a period of extremely rapid growth. The area as a whole is projected to have an annual rate of population growth of 3.25 percent between 1980 and 2010, with the most rapid growth – over 3.5 percent – in the largest country, Nigeria (FAO, 1986). By 2010 the population of the area is projected to reach a level of about 415 million (of which Nigeria will comprise almost 55 percent), being more than two and a half times the 1980 level of 160 million people.

In addition, the region's population is becoming younger and more urbanized, which implies a reduction in the proportion of the population productively engaged in agriculture. Between 40 and 50 percent of the total population in virtually all the countries of West and Central Africa is under age 15, a proportion that will

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* Humid and subhumid West Africa includes the countries of the West African coast from Guinea Bissau to Cameroon. (Some semiarid regions are also included in these countries, chiefly in northern Nigeria; altogether, these comprise somewhat under 20 percent of the total land area.) Except where otherwise specified, the term West Africa refers just to the humid and subhumid countries of West Africa. "Central Africa" includes all the lowland Central African countries, but does not include Rwanda and Burundi because of their ecological and demographic distinctiveness.

Table II.1. Populations, areas, and population densities in West and Central Africa

Region	1980 population (1,000)	% SSA[a]	Area (1,000 km2)	% SSA[a]	Density (persons/ km2)
West Africa[b]	125,628	33	2,534	11	50
Forest zone[c]	60,300	16	973	4	62
Moist savanna[c]	38,945	10	1,106	5	35
Central Africa[b]	33,861	9	3,518	15	10
Total West & Central Africa	159,489	41	6,052	26	26
Total sub-Saharan Africa	386,368	100	23,659	100	16

Sources: FAO (1986), World Bank (1986b), Le Houérou & Popov (1981)

Notes: *a* Sub-Saharan Africa.

b "West Africa" includes the countries of the West African coast from Guinea-Bissau to Cameroon; "Central Africa" does not include Rwanda & Burundi.

c The "forest zone" includes areas normally considered humid forest and transition zone in West and Central Africa. The areal estimates are adapted from Le Houérou and Popov (1981). Population figures are IITA estimates. The residual from the forest and moist savanna represents the population in the dry savanna in these countries.

decline only slowly until well into the next century (World Bank, 1986b). Since another 2.5 to 5 percent of the population is over 65, this means that only slightly over half of the population is of working age. The proportion of working age population has declined steadily throughout the region since the 1960s or earlier.

With almost 28 percent of its 1980 population in urban areas, West and Central Africa is more urbanized than sub-Saharan Africa as a whole (in which the percentage of urban population is about 22 percent; FAO, 1986). The countries of Central Africa are particularly heavily urbanized, with close to 40 percent urban population by the early 1980s. The annual rate of growth of urban population in the region is estimated to be almost 6 percent, as a result of which the proportion of urban population is projected to increase to almost 50 percent by 2010. Moreover, as they do at present, young males are likely to comprise a disproportionate share of urban in-migrants, thereby removing an especially important source of agricultural labor from the rural areas. Together with the changes in the age structure of population, this means that the economically active population remaining in agriculture will need to be significantly more productive just in order to maintain the supply of domestically produced food at 1980 levels.

It should be remembered, however, that a large number of people will still be living in rural areas and dependent on agricultural production for their livelihoods. In fact, although the proportion of rural population is declining, the *total size* of the rural population will increase by over 80 percent between 1980 and 2010. This almost certainly implies a large increase in the number of small-scale farms and farmers (see section C below). It also means that there will be an inevitable and sizeable intensification in the pressure on land and other agricultural resources, virtually all of which will have to become more productive in order to meet the challenge of rapidly increasing demands and needs.

This raises the issue of the productive capability and special character of the natural resource base in West and Central Africa, particularly in relation to demographic trends. The current distribution of population over the rural landscape is highly variable, both between and within areas of ecological similarity. Some areas of considerable potential are only sparsely populated whereas others, which may have limited potential for increased productivity, are already very heavily populated (see section B below).

Moreover, the massive increase in rural population over the coming decades is not likely to be uniformly distributed. To some extent, the needed increases in output – and in agricultural employment – will come from the extension of cultivation to relatively underused and sparsely populated areas, such as found in much of Central Africa and parts of the moist savanna in West Africa. However, these areas will not be able to provide more than a share of the needed productive increases, because of inherent physical limitations and because they are often remote and have limited infrastructure, and because access to them is restricted by numerous political and cultural barriers. The largest portion of increased output is likely to have to come from increased productivity on land that is already in use, often in areas where population and land use pressure are already relatively high.

Increases in short-term productivity, however, will be only one aspect of the technology needs. One of the basic characterisitics of the humid and subhumid lowlands of Africa is the susceptibility of these soils to degradation and the tendency for soil productivity to decline rapidly with repeated cultivation, especially in the deeply weathered soils of the humid regions. As a result, techniques of soil and

resource management usually involving extended fallow periods are integral parts of the farming systems in the area. It is likely, thus, that new and significantly altered systems of resource management will be needed to sustain the rapid increases in output that will be needed in response to population growth. These issues are discussed in detail in the following sections, but before turning to them, some of the relevant aspects of agricultural and other policy are dealt with below.

FOOD DEMAND AND POLICY

In addition to increasing the size of market demand, the growth of urban areas has helped to alter the composition of national food demand in favor of foods such as bread, rice, and easily prepared derivatives of cassava. Population growth and the growth of urban markets can, of course, act as important stimuli to production, provided the capability exists to increase production and bring the supplies to market. In some cases, however, the economic and ecological capability to satisfy demand for these commodities does not exist in the countries themselves, and this has resulted in strong pressures for imports of these products. Food imports, especially of cereals, have increased dramatically: currently, it is estimated that over 50 percent of marketed cereals in West and Central Africa – which are sold mainly in urban areas – are imported (FAO, 1986).

Although domestic food production has increased in most countries in response to growing demands, the growth of production has generally not kept pace with the rate of population growth. In the period 1970-1984, per capita food production in West and Central Africa *declined* at an annual rate of almost 1.5 percent. In fact, only two countries in West and Central Africa – Côte d'Ivoire and Gabon – had a positive growth rate in per capita food production in the 1970-1984 period, and in one country, Ghana, per capita food production declined by almost 4 percent (FAO, 1986).

In many instances, unfavorable economic policies have discouraged increases in agricultural productivity. Underinvestment in rural infrastructure has perpetuated high transport costs that increase the difficulty of marketing agricultural products. Exchange rate and related policies have encouraged food imports at the expense of local production. Various kinds of subsidies to urban consumers have led to declines in the real prices for agricultural products and a general deterioration in the terms of trade between the agricultural and nonagricultural sectors.

All of these have discouraged investment of capital, labor, and other resources in agriculture so that modernization has been thwarted, and progress in the agricultural sector has lagged behind that in other areas. Declining earnings from exports of agricultural products have often further eroded the interest of governments as well as of growers. Finally, in a number of countries (Nigeria in particular), the oil boom of the 1970s played a major role in attracting people and capital investment away from agriculture and into oil enterprises and urban areas.

In many cases, this process has been self-fueling as the growth of urban population has generated further political pressures for an urban bias in national food and economic policies. As a result, policy preference has been given to maintaining low food prices and a high volume of food imports rather than encouraging increased domestic agricultural productivity.

Many of those factors have been responsible for inhibiting interest in the technologies developed by research institutions. Recently, however, government policies in most countries have begun a process of substantial change which may reverse the relative neglect of agriculture. As a result, the demand for improved technology is likely to grow markedly over the next two decades. Among the indications of this are the following:

(a) Restrictions on food imports have begun to be instituted in some countries, and these are likely to become more widespread and stringent because of the limited availability of foreign exchange. In addition, foreign exchange earnings from sales of the major export crops of the region – including palm oil, groundnuts, cocoa, and coffee – as well as from petroleum exports have generally declined and are not likely to be sufficient to finance increasing imports of foodstuffs for domestic consumption. As a result, the demand for domestically produced food will increase sharply.

(b) It appears that the production and marketing of crops and locally processed foodstuffs for urban markets has become an increasingly attractive economic activity. Both output and adoption of new technology seem to be growing substantially, at least in favorably situated areas.

(c) Currency devaluations, such as have recently occurred in Nigeria, Ghana, and Sierra Leone, as well as other economic policies are also likely to be more favorable to domestic agriculture. These should decrease the relative attractiveness of imports, including food, and increase the returns to domestic production.

These changes will represent an opportunity for significant progress in agricultural output and productivity in many parts of Africa. It will be important, however, for institutions such as IITA to understand and monitor the changing nature of demand for new agricultural technology and to have available both completed technologies and procedures for developing new innovations suited to the varying demands that are likely to appear. To this end, IITA will need to be able to monitor and analyze the implications of agroecological and socioeconomic conditions as they vary over the area of focus, as well as of trends and changes in government policies.

CONCLUSIONS

1. Sub-Saharan Africa as a whole and West and Central Africa in particular are in a period of extremely rapid and unprecedented population growth, which will have major impacts on the agricultural economy of the continent. The duration of the period and eventual size of the "equilibrium population" will vary by region and with the nature of policy and individual response. However, at least a doubling of current population levels within the next several decades is virtually inevitable.

2. Agricultural output, productivity, and employment will all have to increase substantially to keep pace with this population growth. In particular, there will need to be: (a) increases in labor productivity, since a larger proportion of the population will be living in urban areas or will be under or over working age; (b) increases in land productivity, since despite some extension of agriculture into new areas, the largest part of output increases is likely to have to come from greater

production on land already in use; and (c) significantly improved methods of sustaining and regenerating the productivity of the land resources. The latter is particularly important in much of West and Central Africa in order to prevent a possibly irreversible degradation of the resource base under the pressure of intense demand for increased output.

3. Government policies that have been unfavorable to domestic agricultural production are beginning to change and are likely to continue to become more favorable. The receptiveness to new technologies by farmers and agricultural institutions is also increasing. However, changes in needs and conditions are likely to come rapidly, and both policymakers and developers of new technologies will have to be flexible and be able to monitor and respond to changes as they occur.

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B. AGROECOLOGICAL ZONES IN WEST AND CENTRAL AFRICA

Most agroecological classifications of West and Central Africa are based either on vegetation or climatic variables, or a combination of the two. A similar and distinctive pattern of ecological variation emerges with virtually all variables. West Africa is characterized by a series of east-west isocontours resulting mainly from the decline in rainfall as one moves north from the coast. In Central Africa, the basic pattern is more circular, centered on the humid Congo Basin and becoming drier on the eastern and southern fringes. In both regions, the major ecological distinction is between the humid forest and the savanna. Within the savanna zone, conditions range from subhumid to semiarid.

The central area of focus for IITA is in the humid forest and moist (i.e., subhumid) savanna zones. There is also an important transitional zone between them, often known as the derived savanna or the savanna-forest mosaic area. The major agricultural conditions and constraints found in the forest and savanna zones are summarized in table II.2.

The total areas of the forest and moist savanna in West Africa are roughly comparable. Most of Sierra Leone and Liberia, approximately half of Côte d'Ivoire, 30 percent of Ghana, 25 percent of Nigeria and 60 percent of Cameroon fall in the forest and transition zones. Two thirds of the total forest zone in West Africa is accounted for by Nigeria, Cameroon, and Côte d'Ivoire.

The moist, or Guinea, savanna is the single largest zone in coastal West Africa, accounting for about 45 percent of the land area. It is the dominant zone in all of the countries except Sierra Leone, Liberia, Cameroon and Côte d'Ivoire (where it is only slightly smaller than the forest-transition area). The dry (Sudan) savanna accounts for an additional 17 percent of the land area. Over half of the total of this zone is in Nigeria. (The Sudan savanna and Sahel are predominant in the northern portion of West Africa.)

In Central Africa, the forest and transition zones are clearly dominant, accounting for almost 70 percent of the area. Two thirds of this is found in Zaire (roughly proportionate to its land area, which accounts for almost 65 percent of the total area of Central Africa). The moist savanna (including the drier mid-altitude parts of Zaire) totals about 30 percent of the area and is found mainly on the fringes of the large forest region in the Central African Republic and Zaire. The dry savanna is insignificant in Central Africa.

THE HUMID FOREST AND TRANSITIONAL ZONES

The forest and the forest/savanna transition zone together represent over 55 percent of the land area of IITA's main focus countries in West and Central Africa. The region is characterized by high rainfall, ranging from around 1,400 mm to over 4,000 mm per year, with from 6 to over 9 humid months. Half or more of the forest areas is covered by acidic ultisols and oxisols with low inherent fertility and

Table II.2 Comparison of main conditions

Environmental factor/constraint	Humid forest/transition zone
Rainfall / moisture regime	1300-4000+ mm/year 6-9+ humid months 3 or fewer dry months (>25mm rain) Growing period 240-365 days Mostly monomodal rainy season in south; bimodal pattern in much of transition zone. Continual high humidity makes drying & storage of grains & other crops difficult; often increases pest & disease pressures. Heavy rainfall causes leaching, waterlogging, erosion & structural deterioration of many soils.
Temperature	Average daily maximum all months <33.5°C; average daily minimum one or more months >20°C. Forest clearing allows increase in soil temperatures which can lower productivity.
Soils	Acidic ultisols and oxisols in at least 50% of region; less acidic soils (alfisols, etc.) in some areas (parts of Cote d'Ivoire, Ghana, Nigeria, others). Coconut sands, mangrove & freshwater swamp soils along many coastal areas. Most soils lose fertility after a few years of cultivation & require rest periods longer than cultivation period. Acidic soils require longer fallow periods. Fallow needed even with high input use. Limited water-holding capacity of many degraded soils can cause moisture stress in short dry periods. Fertilizer use may be inefficient because of heavy rain & leaching.
Sunshine	Insolation during growing period often limited by cloud cover.
Vegetation	Prevalence of woody species increases efficiency of fallow in restoring soil fertility. Numerous broad-leaved & other weed species.
Pests & diseases	Wide range of pests & diseases encouraged by humid conditions; can be especially severe on late-planted crops or in second season. Animal pests are important in some areas.

Sources: Papadakis, 1966; Harrison-Church, 1974; Kowal & Kassam, 1978; FAO, 1978; Lawson, et al.,

and constraints in forest and savanna zones

Moist savanna
880-1500 mm/year 4-6 humid months 4-5 dry months (<25mm rain) Growing period 140-240 days Partly bimodal in southern savanna; mostly monomodal in north. Going north, total amount & length of rainy season decreases, variability of beginning & end of season increases. Drought stress in dry spells. High intensity rain in wet season can cause erosion & waterlogging in some areas. In bimodal southern savanna, crop water requirements not easily matched to rainfall pattern. Uncertainty in start of first season & risk of early end of second season. Long dry season allows better drying & storage of grains.
Average daily maximum of 1 or more months >33.5°C. Wide daily variation in temperatures in certain months can delay growth of some crops. Low night temperatures decrease respiration losses & increase dry matter production.
Mainly alfisols & related soils (approx. 60% of area). Entisols & vertisols in some areas. Acidic soils in some areas. Some nutrient leaching & acidity problems, but less than in forest zone. Laterite formation on some soils. Erosion hazard during heavy rains. Phosphorus & nitrogen deficiencies common. Rest period need somewhat longer than cultivation period (R=30+). Good response to fertilization. Potential for continuous cultivation with input use.
Higher insolation during growing period, esp. in northern areas; high potential photosynthesis. Lower in southern savanna.
Mainly grass fallows; less efficient in restoring nutrients. Grass weeds (e.g. *Imperata*) often difficult to control.
Long dry season, esp. in north, limits many pests & diseases except on groundnuts, cowpeas & cotton. Bird problems for grains in many areas. *Striga* problem in many areas. Tsetse flies affect human and animal populations, esp. in south.

1979; Young & Wright, 1980; Norman, *et al.*, 1982

long fallow requirements. While the original forest cover has helped to mitigate the effects of the intense rainfall and maintain a stable recycling of nutrients, widespread cultivation not only removes many of the nutrients directly, but exposes the soil to the effects of rain, heat, and sunlight. This can lead to rapid loss of soil productivity through leaching, acidification, erosion, and structural deterioration.

Recent studies indicate that even with high material and management inputs, permanent cultivation of annual crops is probably not possible in many of these humid forest areas; fallows that are equal to or longer than the periods of cultivation are still necessary for sustainable production of most crops (FAO 1986). Most researchers see this limited productive capacity of the soils and their susceptibility to deterioration as the key bottleneck to increased production in the forest zone.

Despite the ecological difficulties, many parts of the forest zone are intensively cultivated and support large numbers of people. Indeed, the forest zone of West Africa contains close to half of its total population (on less than 40 percent of the region's area) and the highest population densities of the region. In parts of southeastern Nigeria, population densities reach over 500 persons per square kilometer – among the highest rural population densities anywhere in Africa – despite the fact that the agricultural ecology of the area is not especially favorable. In contrast, other parts of the forest zone (e.g., large areas of Zaire and other parts of Central Africa) have low population densities, often below 10 or even 5 persons per square kilometer. This wide range in the extent of land use pressure is reflected in the range and complexity of farming systems in the forest zone – and thereby of demands and needs for new agricultural technology.

The farming systems in most forest zone areas have been able to remain productive through use of a wide range of strategies to maintain and restore soil productivity – including various shifting cultivation and bush fallow rotations, complex cropping patterns and sequences, mixtures of tree crops and annuals, and intensive compound gardening techniques. Much of the function of these is to replicate the protective and fertility-restoring effects of the original forest cover. Nonetheless, serious degradation has already occurred in a number of areas, and in many others the ability of current practices to maintain productivity is threatened, either by population pressures in the high density areas or by labor shortages in the low density areas.

THE MOIST SAVANNA ZONE

The moist, or Guinea, savanna zone of coastal West Africa includes almost 45 percent of the area but only about 30 percent of the population of the region. It is an area of considerable agricultural potential, particularly for arable crops. High net solar radiation during the growing season,* warm day temperatures, and low night temperatures result in high photosynthetic potential. In addition, the soils of most of the savanna zone, although still requiring careful management, can be more productive than most forest soils and are generally more responsive to improved inputs and management. With correction for phosphorus, nitrogen, and other

* Because of extensive cloud cover during the long rainy season in the forest zone, net solar radiation during the growing season is lower in the forest than in most of the savanna zones.

deficiencies, not only yields, but the frequency and intensity of cultivation can be significantly increased.

Finally, adequate moisture is available in most parts of the Guinea savanna during the growing season, though there are problems in some areas and some periods (e.g., dry spells at the beginning of the season can affect the establishment and yield of crops, and heavy rains in the middle of the season can cause flooding, erosion, and nutrient leaching). Effective water management can be a key element in achieving yield potentials, though the problems and constraints are less severe in the Guinea savanna than in the drier Sudan savanna region to the north. As a result of these conditions, the potential for improved crop varieties is extremely high.

In addition, the moist savanna areas in West Africa have, for various historical reasons, been relatively underpopulated. Resource pressures are much less severe than in the forest zone or some of the more densely populated parts of the dry savanna. Improved infrastructure and market access, together with a favorable policy environment, can be the critical elements in many parts of the Guinea savanna to generate demand for new agricultural technology. The recent expansion of production of maize and other crops in the moist savannna of Nigeria may be an example of the beginning of this process.

These summaries suggest that there are significant distinctions between the forest and moist savanna regions in West and Central Africa with respect to ecological conditions, the opportunities for and constraints to increased production, and the nature of existing cropping systems. As a result, the two regions should generally be considered separately in designing and extending new agricultural technologies and innovations. The potentials and constraints of the regions may be summarized as follows.

(a) The ecological limitations of the forest region and the resultant complexity of the farming systems there imply that:

(i) attempts to improve cropping systems and increase output in the region must include soil and resource management considerations;

(ii) trees and perennials will generally be essential components of farming systems in the forest; and

(iii) priorities for new technologies are likely to differ significantly between the high and low density portions of the forest zone.

New crop varieties or other new technologies can make useful contributions to productivity in the forest zone, but they are likely to be most successful when the systems are understood as a whole and, in particular, when the resource management objectives of the system are also considered. Because of the relatively dense population, there is considerable need for improvements in both crop productivity and resource management, though these improvements may not be easy to achieve.

(b) The potential productivity of the moist savanna in West Africa is great, and the ecological limitations are generally less stringent than in the forest zone. Increases in output and in the demand for new technology, especially yield-enhancing technology, are likely to be closely related to the development of improved market access and infrastructure. The lower population densities in most of the area imply that pressure on resources is less severe, but in some cases the lower population

may constrain increased production because of labor shortages. As a result, labor-saving mechanization technologies may be attractive, especially in those areas where there are significant opportunities for market production.

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C. ROLE AND FUTURE FOR THE FAMILY FARMER AND SMALLHOLDER

The small-scale farm, or family farm, less than 5 hectares in size, remains the basic food crop production unit in West and Central Africa – currently producing 90 percent of the food and supporting from 50 to 80 percent of the people in most countries (Mellor *et al.*, 1987; World Bank, 1986). In view of the importance of the smallholder sector to the total economic health of the region as well as to its food supply, IITA will, as a matter of policy, focus its research on technology that will improve small-farm productivity and thereby increase total food production. The improved technology will be directed toward progressive family farmers who have the potential for good management and improved practices. To the extent that this technology is scale neutral, it will have positive benefits for large-scale farmers as well.

THE TARGET GROUP: THE AFRICAN SMALLHOLDER SECTOR

West and Central Africa are accurately described as regions of small holdings. Average farm size for the 3 million farm households in Zaire, for example, is about 1.5 cultivated hectares, with this average ranging from about 2 hectares in the savanna to less than 1 hectare in the forest zone (Roth *et al.*, 1979). Similarly, in Nigeria average farm size for the 9 million farm households is about 2.5 hectares. Almost 90 percent of those farms is under 5 hectares, normally consisting of small plots dispersed over a large area (World Bank, unpublished data).

Large commercial farms that produce mostly cash crops made up only 10 percent of total area cultivated in 1970. The countries of West and Central Africa differ from some other sub-Saharan African countries such as Kenya, Zambia and Zimbabwe, where substantial groups of larger commercial farmers play an important role. The number of comparable "large" farms in West and Central Africa – over 500 cultivated hectares – is very small.

In this setting, IITA strategy is to promote productivity increases by the small farmer, rather than simply maximizing the yields from the farmer's land. There are two target groups: subsistence farmers with meager resources, and smallholders with sufficient land, labor and the means to purchase farm inputs who can produce a surplus for the market.

For the larger subsistence group, IITA is developing technologies which do not depend on purchased inputs. Among these technologies are disease-resistant and insect-resistant varieties which can tolerate adverse environmental conditions; biological approaches which can reduce dependence on chemicals; new management practices which can save labor and raise productivity, as alternatives to shifting cultivation. For the smallholder group which can produce marketable surpluses, IITA is developing crop management and resource management practices, and improved crop varieties, that are suitable for the level of inputs which these farmers are capable of providing.

A distinguishing characteristic of these farms is that the household's own labor and management are major inputs into production, however limited they might be. This sector, as opposed to the large commercial farms, is expected to use improved technologies in increasing the commercialization of farming operations, thus accelerating the growth of food production in sub-Saharan Africa.

EMPLOYMENT AND INCOME GENERATION

The goal of IITA's work in Africa is not simply to increase food production, but to increase food production in a sustainable way and in a way that is most likely to lead to increased employment and incomes and improved nutrition for the majority of Africa's people. Substantial increases in aggregate food production will not reduce the malnourishment and food insecurity experienced by a large segment of the population in many countries unless individual households are able to produce enough food themselves or have adequate resources to purchase required food from the market. Attention must therefore be paid not only to aggregate food supply, but to the employment and income generation impacts of agricultural production.

As discussed above, the population of sub-Saharan Africa is likely to double in the next 20 to 30 years. Thus there is an urgent need to increase total food production. Equally important, however, is the need to ensure that the poor in these countries have access to food. The majority of the people (typically 50 to 80 percent) in most countries of sub-Saharan Africa live in rural areas and depend on agriculture for employment and income. In spite of rapid urbanization, the absolute size of the farm population is expected to continue to increase for several decades. Although the percentage of population in urban areas doubled (from 11 to 22 percent) between 1960 and 1984, the farm labor force has continued to grow at an annual rate of approximately 2 percent* (Johnston, 1986). Generating employment and adequate incomes for the rural majority will necessarily be a major element in any successful development strategy.

A food policy that tries to increase food production through large-scale farms alone could have serious negative consequences for the majority of the population – even if such a policy were successful in achieving an increase in total food production and maintaining a lower food price level for the urban poor. Unless the rural farm population is increasingly productive, lower food prices will result in lower farm incomes. The result is likely to be worsening malnutrition for the rural majority. Moreover, in the absence of increasing employment opportunities in the rural areas, migration to cities is likely to accelerate, exacerbating the problems of urban unemployment, and inadequate water, sewage facilities, and other social services.

Small-farm development strategies based on improved labor-using technology could generate increased rural employment and incomes and thus help ensure that the rural majority has access to food. Widespread increases in productivity among a country's small farm units can also have a multiplier effect in expanding opportunities for productive employment, increasing purchases of inputs

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* In humid and subhumid West and Central Africa, the rural population is projected to decline from 72 percent of the total to 50 percent by 2010. Even so, the rural population will have increased by 80 percent (FAO, 1986).

and consumer goods from other sectors of the economy, helping reduce income differentials and slowing the rate of rural-urban migration.

RELATIVE EFFICIENCY OF LARGE AND SMALL FARMS

Despite the above arguments about the benefits of a small farm research and development strategy, such a strategy would be futile if it were in fact impossible to increase the productivity of the small farm. The evidence, however, suggests that the small farmer can compete successfully with large-scale producers and that small farmers are responsive to technological opportunities, good support systems, and production incentives. This has been strikingly demonstrated in the cases of the Kenya Tea Development Authority, hybrid maize production in East Africa, cocoa development in Côte d'Ivore, and cotton in Mali.*

The small farmer has an important advantage over the large-scale commercial farmer because the costs of family labor are less than the costs of hired labor. Because crop production is spread over time and space and subject to the uncertainty of weather, many "on-the-spot" supervisory decisions must be made. Commercial farms with large agricultural work forces often have difficulty attracting the required levels of management and technical expertise. Large farms, therefore, have a strong incentive to adopt capital-intensive and labor-saving technologies in order to reduce the problems associated with managing a large work force of hired laborers.

Large-scale capital-intensive farming has not been very successful in sub-Saharan Africa. The consensus of agricultural economists is that it does not have the potential to overcome the growing food deficits in countries of the region; moreover, as argued above, it does not provide a sound basis for long-term agricultural growth (Mellor *et al.*, 1986). The reliance of large farms on capital draws on the resource that is invariably the most scarce, foreign exchange. And there are serious questions about the sustainability of large-scale farms in the humid and subhumid tropics: the soil degradation that has accompanied mechanization has been an important factor in the failure of many large farms (Bentley, 1986).

Government measures to promote agriculture often focus on the small but politically influential large-farm sector. Large farmers have preferential access to institutional credit, usually at artificially low interest rates, and they receive import licenses and underpriced foreign exchange to purchase large tractors. Government distribution of subsidized fertilizer usually reflects the same tendency toward preferential treatment of large and politically influential farmers. Excessive investment of resources in promoting large farms is often accompanied by inadequate support for agricultural research, extension, farm roads, and other rural infrastructure in support of small farms.

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* John Mellor *et al.* (1986) state that experience with maize production in Zimbabwe re-inforces the view that smallholders can compete with large-scale producers. Zimbabwe's smallholders supplied only 5 percent of marketed maize at independence in 1980. Yet smallholders were already beginning to profit from research, prices, and infrastructure that had been provided for large-scale farmers. After 1980, smallholders gained improved access to markets, services, and infrastructure. Marketed production of both food and export crops grew dramatically. In the 1983/84 season, despite three previous years of drought, marketed maize from the smallholder sector rose to over 30 percent of total deliveries. This sector is already the major purchaser of hybrid maize seed.

Many African economies have also followed a pattern of industrialization that squeezes the agricultural sector, with features that include: underpricing of foreign exchange and overpricing of labor; overprotection of manufactured goods, under-investment in public infrastructure, especially rural infrastructure, and excessive investment in private real estate construction. These national policies, which squeeze the agricultural sector (and especially small farmers who do not benefit from large-farmer-oriented agricultural policies outlined in the preceding paragraph), make the introduction of new technologies more difficult. The emphasis in many African countries has been on industrialization first, at the expense of agriculture. This is contrary to the experience of Japan, Taiwan, and other developed areas where productivity rose more rapidly in agriculture than in industry, and where the rise in agricultural productivity and income enjoyed by the *majority* of the farmers was a driving force for national economic development. This is now being more clearly recognized by an increasing number of African governments.*

TECHNOLOGY AND SMALL-SCALE AGRICULTURE

Given the small farmer's resource base, there are very good reasons for many of the traditional farming practices such as intercropping – including soil maintenance, pest control, and better use of available land (through intercropping of plants that vary in their growth periods and heights). Moreover, there are other benefits for the small farmer to growing more than one crop (not necessarily in the same field), such as reducing risks of weather and pest-related crop failure, lessening dependence on markets and spreading out the timing of labor inputs across the crop calendar. In developing new technologies appropriate for the small farmer, it is essential to take into account current farming systems and practices. Some crop varieties, for example, are more suitable for intercropping than others because of plant architecture, differences in growing period, or speed of establishment.

In addition, new technology must be appropriate for the small farmer's management capabilities and access to inputs, as illustrated in figure II.1, which shows the hypothetical response of different types of varieties to increased input levels. The traditional local cultivar (variety A) has a moderate yield under traditional levels of management and a low response to additional inputs such as fertilizer. Variety C performs much better under high inputs but no better or even worse under traditional management practices. The small farmer typically has insufficient resources and/or access to credit and inputs to realize this new varietal potential. Varieties are needed for the small farmer that perform as well or slightly better than traditional varieties under traditional levels of management, but yield substantially more under slightly improved management (e.g., variety B).

Variety C in figure II.1 illustrates a case of technology that is not "access-neutral." The constraints that prevent the small farmer from obtaining access to the

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* The merits of such a policy were recognized by Nigeria's President Babangida in his 1986 Budget speech. As reported in the *Daily Times* (Nigeria), January 1, 1986, he said, "We must pursue a food policy agenda such that the present urban bias and international dependency are reversed. We must achieve a sustained level of internal self-sufficiency in food in the shortest possible time. We must create job opportunities for...our unemployed citizens....Smallholders have clearly demonstrated that, given the right price and non-price incentives, they can produce the food and fiber required by the nation."

new technology and the required inputs are largely institutional constraints – absence of credit, weak input distribution systems, and uncertain markets for output – and it may be years or even decades before these institutions develop sufficiently. In the interim, the small farmer may find that the new technology is not a feasible alternative to his current practices. And if appropriate new technology is not forthcoming for the small farm sector in the medium run – 5 to 10 years – the development of the institutions needed to make the high input technology applicable to the small farm sector may never occur.

CONCLUSIONS

From the initial establishment of international agricultural research centers, it was assumed that agricultural development depended upon increasing the productivity of the small farmer in Asia, Africa and Latin America. In recent years, the CGIAR has increasingly emphasized the need to stimulate small farm production. In a review of priorities and research strategies, the CGIAR (1985) stated, "Much of the increase in production required to meet rising food needs in developing countries in the short to medium term will depend on generating surplus production from the small, often resource poor, farmers who predominate in rainfed and marginal agricultural areas. The immediate challenge for agricultural research is to design technologies which are appropriate for the management conditions of these units and will enhance their capacity to produce commercially."

With the rapid growth of African populations and the fragility of much of African soils, it is urgent to conduct research based on priorities that meet the needs in Africa. Measures to increase labor productivity in the smallholder sector are at the heart of improving African agriculture and food production. IITA will give preference to research objectives that have the potential to improve this productivity.

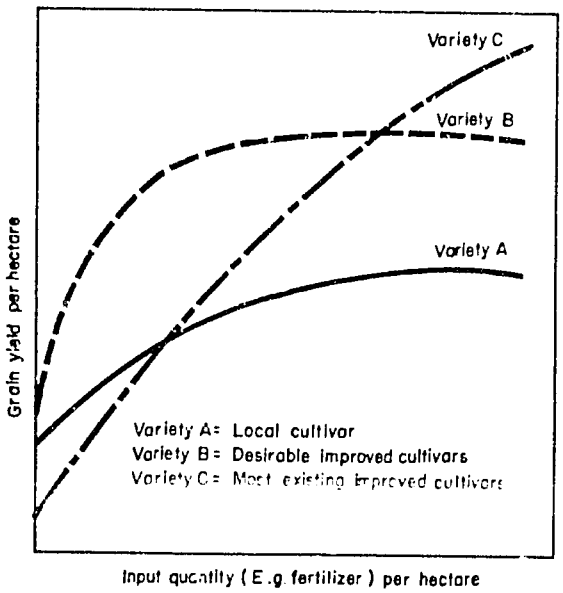

Figure II.1

Hypothetical response of different types of varieties to increased input levels

(Source: Spencer, 1985)

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D. RELATIVE IMPORTANCE AND FUTURE PROSPECTS FOR THE FOOD CROPS IN IITA'S MANDATE

An up-to-date analysis of the relative importance of the crops included in IITA's mandate and the factors determining trends in supply and demand is considered of prime importance to the establishment of research priorities for IITA. The following comparison considers various measures such as production of calories and protein, value of production, and number of consumers. It has been patterned after the CGIAR relevance indicators (described in chapters I and IV). It should be noted that data on agricultural production in Africa are weak, and estimates of production and consumption are often based on simple projections. The data presented here should therefore be regarded more as a generalized picture of the relative importance of the commodities than as exact measurements.

INDICATORS OF RELATIVE IMPORTANCE

Production of the major crops is unevenly distributed across Africa (table II.3). Two thirds of the production of cassava, yams, cowpeas, and plantains are found in IITA's area of special focus, humid and subhumid West and Central Africa. If Madagascar is excluded, the same can be said for rice. About 40 percent of sub-Saharan Africa's groundnuts (which are included here instead of soybeans because of their considerably greater importance at present) are grown in the humid and subhumid tropics, the area of special focus of IITA.

Maize and cassava are the staple foods of the largest number of people in sub-Saharan Africa.* (Staple foods are defined here as those which account for more than 200 calories per day in the diet of an individual.) About 200 million people, or 50 percent of the population, consume maize as a staple food, while 160 million people, or 40 percent of the population, consume cassava as a staple. Rice is a staple food for about 90 million people. Only for maize, cassava and rice are there sizeable numbers of people who derive more than 600 calories per day from that single energy source. For maize, the 50 million heavily dependent consumers live mostly in East and Southern Africa. For cassava and rice, the heavily dependent consumers live in Central and West Africa, respectively. Yams and plantains are also staples in the diets of relatively large numbers of people (60 and 40 million people, respectively), but sweet potatoes and cocoyams are minor staples from a continent-wide perspective.

Tables II.4 and II.5 show the relative importance of commodities by region in terms of calories and protein produced, respectively. The data shown include adjustments for seed, inedible portions, and other losses, but are not adjusted for trade or nutrient losses in processing. Cassava produces more than 2.5 times the calories produced by the second or third ranking crops, maize and yams, in West and

* The number of consumers was estimated using FAO 1984 *Food Balance Sheets* (1979-81 average) and other information about the distribution of consumption within countries.

Table II.3 Distribution of production of major food crops in tropical Africa, 1982-1984 average

(percentages of total production)

	Cassava	Maize	Rice	Cowpea	Yam	Sweet potato	Plantain	Groundnut
Nigeria	22.5	11.2	18.8	51.7	75.5	5.1	21.3	13.8
Other West Africa[a]	10.7	13.9	29.0	11.1	19.9	6.0	43.4	11.1
Central Africa	34.9	6.6	4.5	3.2	2.1	40.2	26.6	14.6
Total West & Central Africa	68.1	31.7	52.3	65.9	97.5	51.3	91.3	39.5
Sahel	1.1	1.9	6.0	19.8	1.0	3.3	nil	32.9
East Africa	15.7	36.9	7.3	9.9	1.6	32.4	8.4	17.3
Southern Africa	15.1	29.5	34.4	5.0	nil	13.0	0.3	10.3
Total sub-Saharan Africa	100	100	100	100	100	100	100	100

Sources: Barker and Dorosh, unpubl. working paper based on data from *1984 FAO Production Yearbook;* M. Ashraf, unpubl. working paper; and P. Dorosh, unpubl. working paper.

Note: a "West Africa" includes the countries of the West African coast from Guinea-Bissau to Cameroon. Central Africa includes Rwanda and Burundi.

Table II.4 Calories produced by major food crops in tropical Africa, 1982-1984

(1,000 million kilocalories)

	Cassava	Maize	Rice	Cowpea	Yam	Sweet potato	Plantain	Groundnut
Nigeria	12.3	5.2	2.0	1.8	13.6	0.3	1.2	2.2
Other West Africa	5.9	6.4	3.0	0.4	3.6	0.3	2.6	1.8
Central Africa	19.1	3.0	0.5	0.1	0.4	2.0	1.5	2.4
Total West & Central Africa	37.3	14.6	5.5	2.3	17.6	2.5	5.3	6.4
Sahel	0.6	0.9	0.6	0.7	0.2	0.2	nil	5.3
East Africa	8.6	17.0	0.8	0.3	0.3	1.6	0.5	2.8
Southern Africa	8.3	13.6	3.6	0.2	nil	0.7	0.0	1.7
Total sub-Saharan Africa	54.7	46.2	10.4	3.6	18.0	5.0	5.8	16.2

Sources: Based on data from *1984 FAO Production Yearbook.* (Nutrient values of the crops were obtained from FAO and US Department of Health, Education and Welfare [1968] food composition tables.)

Table II.5 Protein production of major food crops in tropical Africa, 1982-1984

(1,000 tons protein)

	Cassava	Maize	Rice	Cowpea	Yam	Sweet potato	Plantain	Groundnut
Nigeria	99.0	133.5	37.8	122.4	217.4	3.3	10.9	94.1
Other West Africa	47.2	165.3	58.4	26.2	57.2	3.9	22.2	75.7
Central Africa	154.0	78.6	9.0	7.5	6.0	26.3	13.6	100.1
Total West & Central Africa	300.2	337.4	105.2	156.1	280.6	33.5	46.7	269.9
Sahel	4.9	23.0	12.1	46.8	2.8	2.2	nil	225.0
East Africa	69.3	439.8	14.8	21.1	4.6	21.2	4.3	118.4
Southern Africa	66.4	352.3	69.3	11.9	nil	8.5	0.1	70.5
Total sub-Saharan Africa	440.9	1,192.5	201.4	236.8	288.0	65.4	51.1	683.7

Source: Based on data from *1984 FAO Production Yearbook*. (Nutrient values of the crops were obtained from FAO and US Department of Health, Education and Welfare [1968] food composition tables.)

Central Africa (table II.4). With a correction for imports, rice would approach maize and yams in terms of importance in the diet in this region. On an Africa-wide basis, cassava and maize are by far the dominant sources of calories among the crops considered.

Table II.6 compares the four main staples on a number of important measures of productivity: value of output per hectare, calories per hectare, value per man-day, and calories per man-day. Although all of these crops are often intercropped, the calculations shown here are an attempt to measure productivity of a sole-crop system. Largely because of their high market price, yams rank first in terms of value per hectare, with more than four times the value of cassava, and more than six times that of rice or maize. The price of yam per calorie is four times that of cassava (as gari) and three times that of maize.

Yams have the highest labor input per hectare, and maize the lowest. Despite the large labor input, the value of yam production per man-day is highest. Maize ranks a distant second by this measure. In terms of calories produced per man-day, maize is highest and rice is lowest. In the region of special focus, labor productivity is generally a more important measure than productivity per hectare in assessing the comparative advantage of crops, and in determining research priorities, because labor is more often the limiting factor. For example, rice has a distinct disadvantage over other crops in terms of labor productivity. Thus, it may be that a first priority in rice research should be to raise labor productivity rather than yield per hectare. Of course, higher yields achieved without a large increase in labor input can also contribute to higher labor productivity.

The same four staples (cassava, maize, rice, and yams) are also major sources of protein (table II.5). Cassava is shown as a leading source of protein even though these figures do not include the relatively protein-rich cassava leaves, which are widely consumed in Central Africa and parts of West Africa. However, this high protein figure reflects the large amount of cassava consumed rather than the protein content per serving, which is very low. Groundnuts and cowpeas, though relatively limited sources of domestic food calories, are important sources of protein. Moreover, these commodities have an amino acid balance which complements that of cereal grains.

ECONOMIC ANALYSES OF INDIVIDUAL CROPS

Rice. Rice production in Africa accounts for only about 2 percent of the world total. Apart from Madagascar and Egypt, which together account for about half of Africa's production, the largest concentration of rice production (about 35 percent of the total) is in West Africa (figure II.2).

Average rice yields in West Africa are only about 40 percent of the world average. Moreover, the gap between yields in West Africa and the rest of the world has been widening. Average yields in West Africa have increased by only 12 percent in the last two decades, a period in which average yields worldwide increased by 48 percent. A major factor behind these trends is that only 6 percent of area planted to rice in West Africa is irrigated; upland rice represents nearly 60 percent of rice area, and the remainder is lowland non-irrigated rice (grown in inland swamp, riverine, and mangrove swamp areas).

Table II.6 Measures of gross returns to production of major food crops in Nigeria

	Cassava	Maize	Rice	Yam
Yield (tons/ha)[a]	9.0	1.5	1.5	12.0
Yield dry matter (tons/ha)	2.7	1.3	1.3	3.6
Price ($/ton)[b]	60	192	243	197
Kilocalories/ton[c]	1,103	3,132	1,634	762
Price (US$/kilocalorie)	—	.061	.149	.259
(gari)[d]	(.054)			
Value of output ($/ha)	540	288	365	2,364
1,000 kilocalories/ha	9.9	4.7	2.5	9.1
Man-days/ha[e]	168	75	215	310
(gari)[d]	(329)			
Value/man-day ($)	—	3.80	1.70	17.80
(gari)[d]	(1.60)			
Kilocalories/man-day	59	63	11	30
(gari)[d]	(30)			

Notes: *a* 1982-1984 average yield in Nigeria, *1984 FAO Production Yearbook*, for cassava and yam; maize and rice figures are estimates of monoculture crops.

b Prices shown are based on weighted averages of market prices in Nigeria, Cameroon and Côte d'Ivoire. The assumed exchange rate was 3 Naira = 1 US$.

c Includes adjustment for seed and losses.

d Gari is cassava meal.

e Knipscheer (1980). Figures shown assume no labor for fertilizer application.

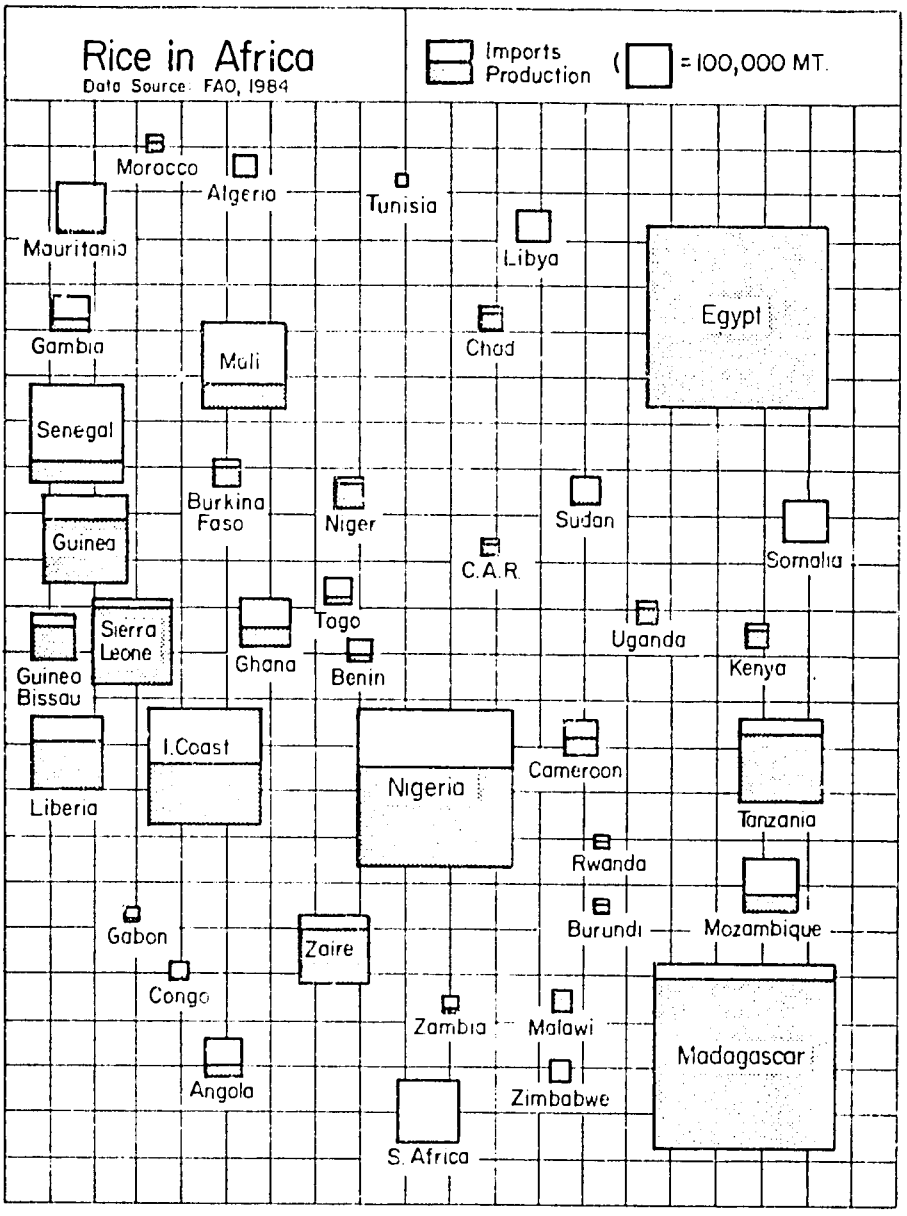

Figure II.2 Rice production and imports in Africa, 1984

Labor productivity for non-irrigated rice in West Africa is extremely low. Gross value per man-day is roughly half that of maize and about equal to cassava (as gari), but in terms of calories produced per man-day rice is only about one-sixth as productive as maize and one-third as productive as cassava (gari). Bird scaring and weeding require substantial labor inputs for rice, and water control in lowland areas and soil fertility maintenance in upland areas are important management problems limiting rice yields.

In the early 1960s, West Africa produced over 80 percent of the rice it consumed. However, rice consumption has grown at 5.6 percent per year in West Africa over the last two decades. More than half of the growth can be attributed to an increase in per capita consumption and the remainder to population growth. Since production grew at 3 percent, by the early 1980s, West Africa was relying on imported rice for approximately half of its consumption needs.

Assuming per capita consumption of rice remains at the current level over the next 20 years, production would have to increase at 5 percent per year to meet the increased demand due to population growth. The alternative to rapid increases in production – further growth in rice imports – may not be feasible because of shortages in foreign exchange. Thus there is likely to be continuing pressure to increase rice production in West Africa and growing demand for new rice technology.

Maize. Maize production is spread throughout both the tropical and sub-tropical regions of Africa. The two largest producers of maize in Africa, the Republic of South Africa and Egypt, which accounted respectively for 31 percent and 13 percent of total maize production in Africa in 1980/84, are outside of tropical Africa. West and Central Africa account for only about 30 percent of the maize in tropical Africa and about 15 percent of total African production (figure II.3).

There is no statistical evidence that average maize yields in West and Central Africa have increased significantly in the last 20 years. Instead, increased production has come from an expansion of about 2.5 percent per year in the area harvested. In East Africa, yields have increased by 30 percent over the last two decades due in large measure to the adoption of improved varieties, use of purchased inputs, and expanded sole cropping.

Maize has been expanding in the Guinea savanna of Nigeria, in part replacing sorghum. About 40 percent of Nigeria's maize is produced in this zone, 20 percent in the Sudan savanna, and the remainder in the forest and transition zone. Maize is commonly intercropped with cassava in the transition zone and southern Guinea savanna, and with sorghum in the northern Guinea savanna, but it is increasingly grown as a monoculture in many savanna areas. Labor productivity for maize cultivation here is high, both in terms of calories produced per man-day and gross value of output per man-day, even with relatively low yields. With new technology – improved seeds and fertilizer – higher yields requiring little additional labor input are possible. In the forest zone, much of the maize is planted in complex mixtures with other crops and harvested green; humid conditions and inadequate storage facilities limit expansion of maize production for dry grain, especially in the first season.

Although dry maize is not a preferred staple in much of West and Central Africa, continuing population growth and the adoption of new technology that reduces the cost of maize relative to other food crops are likely to boost demand for maize as

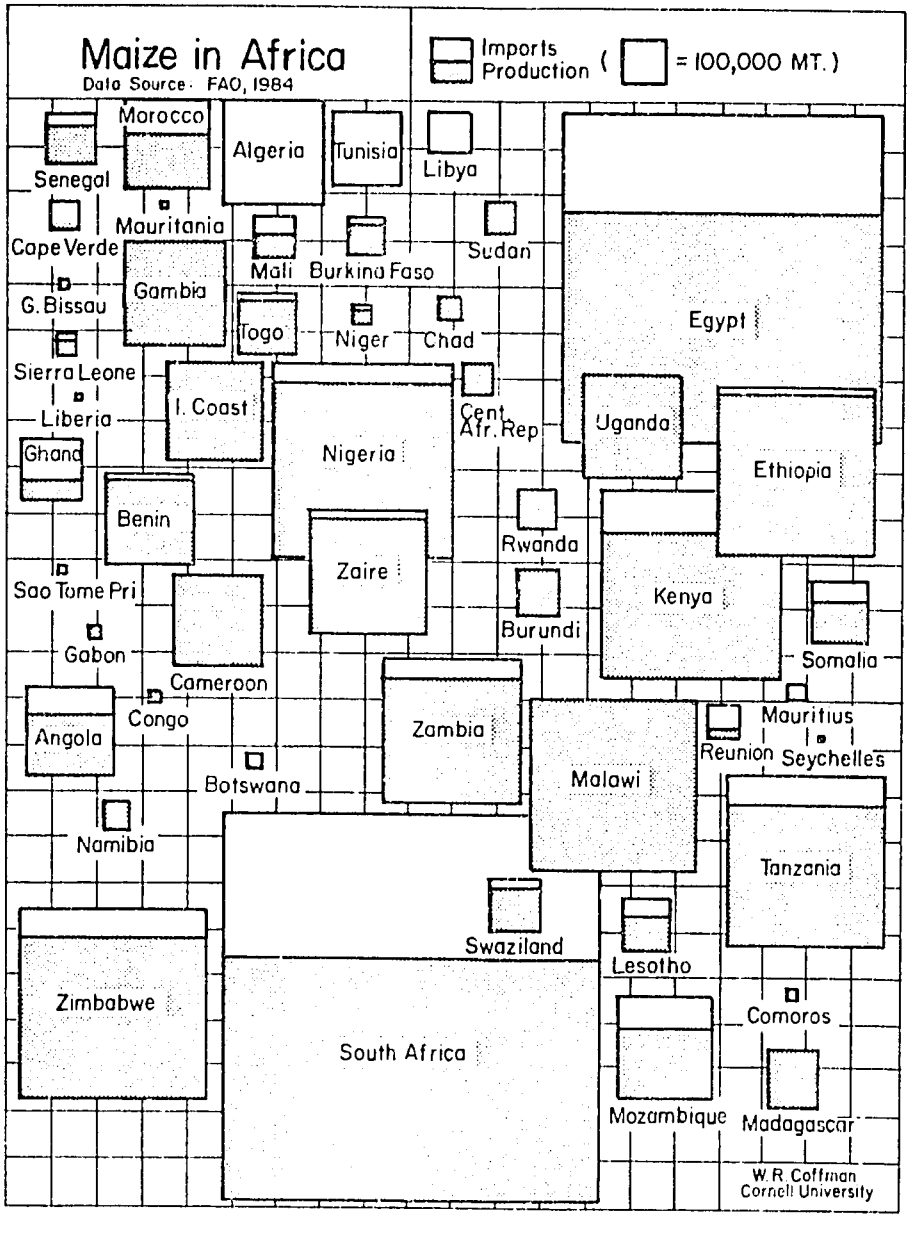

Figure II.3 Maize production and imports in Africa, 1984

food. Demand for domestically produced maize as animal feed is also likely to grow, especially as per capita incomes rise and trade and exchange rate policies help make it competitive with imported maize.

Cassava. Cassava is the single largest source of calories produced throughout tropical Africa. West and Central Africa each account for about one third of cassava production in Africa; Zaire and Nigeria are the continent's leading producers (figure II.4). About three fourths of the cassava in West Africa is grown in the forest and moist savanna zones. Data on production of root crops in Africa are especially suspect, but production of cassava has undoubtedly increased in West and Central Africa, although perhaps not as fast as population. Almost no export/import trade in cassava products is recorded, but some trade does take place across land borders.

Cassava is more productive under poor soil conditions than are most other crops, and for this reason it often is planted last in the cropping sequence, just before the land reverts to fallow. Production of cassava roots requires relatively little labor compared to rice or yams; moreover, the timing of these labor inputs is very flexible since the root can be left in the ground for periods of several months or even a few years in some cases before harvesting. Cassava's ability to withstand drought once the plant is established has also encouraged its use as a famine reserve crop in drier parts of Africa. Tolerance of poor soils and low and flexible labor requirements help explain why cassava production has historically increased in areas where the best land and most of the available labor are devoted to cash crops (cocoa, cotton) or labor-intensive food crops (yams). As population pressure leads to increased use of marginal lands, the area planted to cassava is likely to expand.

The labor required for processing the roots into gari, one of the most widely consumed cassava products in West Africa, is very high and equals the total labor input for production of the roots themselves. This processing is usually done at the household or village level, almost exclusively by women and children. The end product is suited for low income urban consumers because of its low cost per calorie (slightly lower than that of maize) and because it requires almost no further processing. The low protein content of gari is augmented by the soups and meat with which it is usually consumed.

Potential demand for cassava as animal feed depends on relative prices and availabilities of grains and protein supplements (e.g., soybean or groundnut cake). In Western Europe, large amounts of imported dried cassava are used as animal feed because price and trade policies make the cost of imported and domestic maize prohibitive. When protein supplements such as soybean or groundnut cake become available at low cost in Africa, cassava can be increasingly used for animal feed, especially where grains are relatively expensive.

Yam. Yam is an important staple food in the countries of the yam zone of West Africa, stretching from Côte d'Ivoire to Cameroon, but it is a minor crop throughout most of the rest of the continent and the rest of the world. Nigeria alone accounts for three quarters of Africa's yam production (figure II.5).

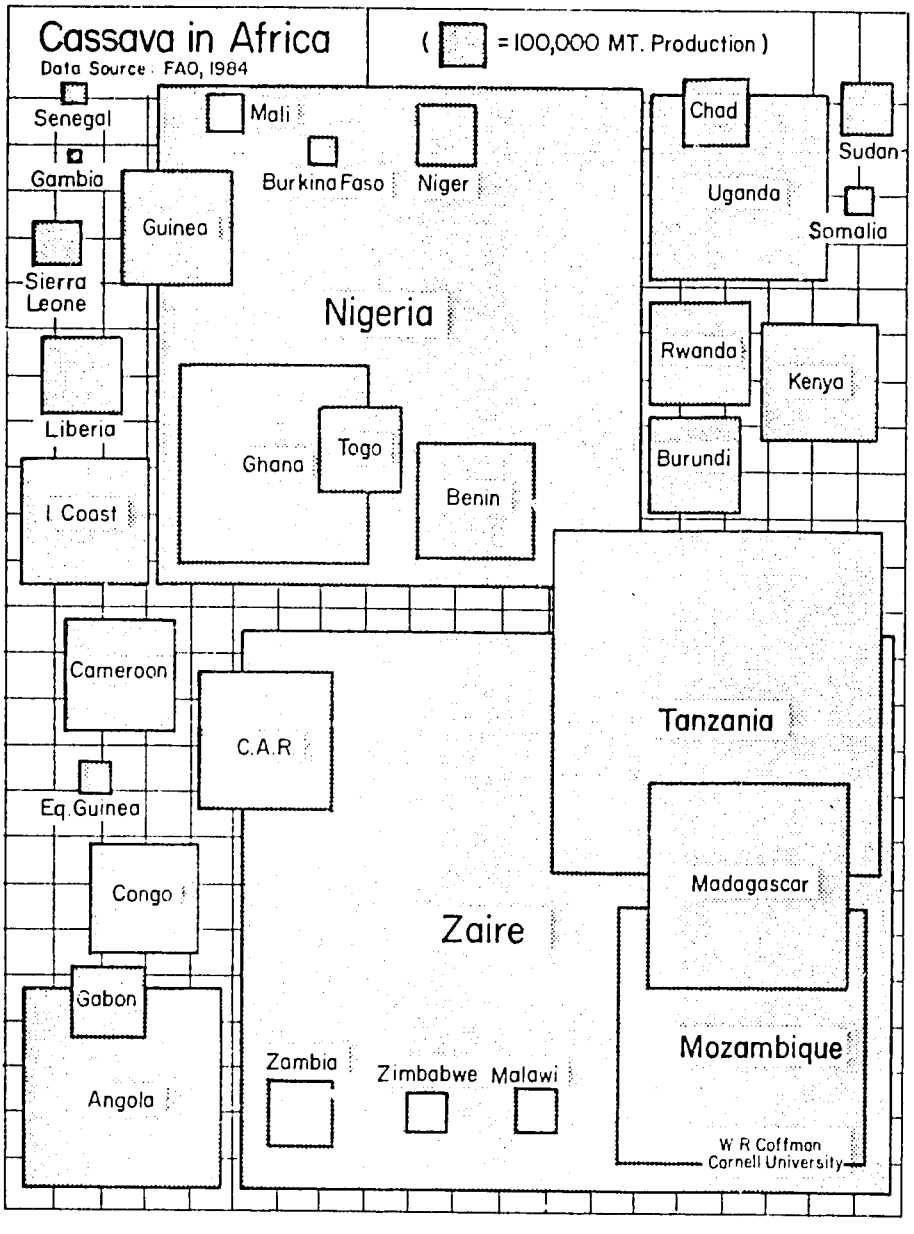

Figure II.4 Cassava production in Africa, 1984

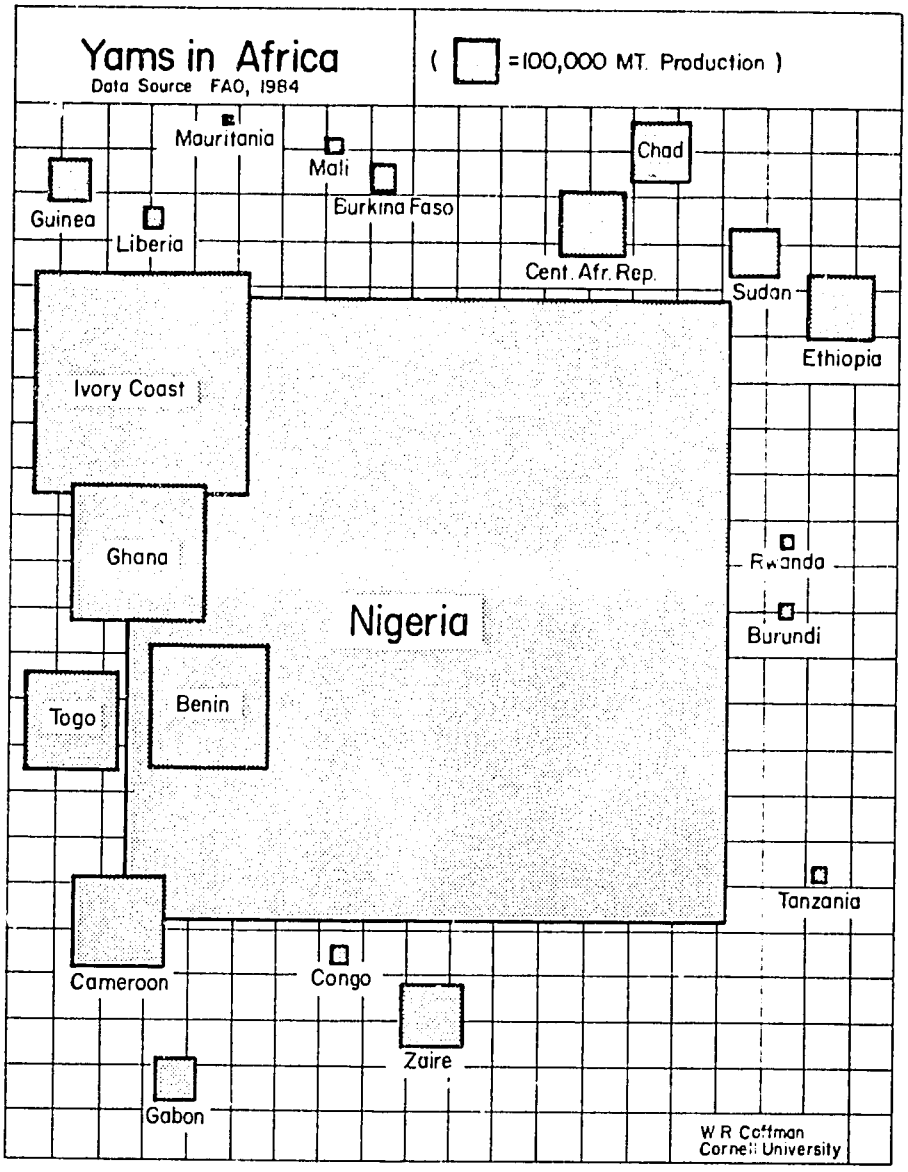

Figure II.5 Yam production in Africa, 1984

Production costs for yam are extremely high because of the large amounts of labor needed for mounding, staking (especially in the forest zone), weeding, and harvesting. As a result, labor input per hectare is roughly twice that for cassava and four times that for maize. The best land is often allocated to yams since the crop requires deep, fertile, well-drained soil. Costs of planting material are also very high since about one quarter of the total weight of each year's harvest of yams (in the form of pieces of large "ware" yams or small "seed" yams) is used to plant the next year's crop. The "minisett" technology, which uses small pieces of yams as planting material, allows potentially large savings in terms of the amount of the harvest of ware yams used for seed, but the actual savings in costs of production are considerably smaller since production of the seed yams from minisetts requires significant labor and capital inputs. Potential for increased production of yams seems highest in the savanna zone where higher intensity of solar radiation makes staking less important, and there appear to be fewer limitations on the availability of fertile land.

Yams are a preferred staple which are highly appreciated for their taste and their role in the culture of many of the people of the yam zone. High costs of production, however, make the per calorie cost of yam almost four times that of gari or maize, and processing yam tubers into pounded yam is a laborious task. Thus, yam is generally not a major food source for the urban poor. Large increases in production of yam in the future may depend on consumer acceptance of small yams, which could be produced at lower cost per kilogram.

Plantain. Plantains differ from various kinds of starchy bananas by their genomic formula (AAB for plantains, AAA for most bananas, including dessert bananas). Plantains account for about one third of total bananas and plantains produced in Africa, and are grown mainly in the forest zone of West Africa and lowland Central Africa (figure II.6). Starchy bananas (both those used as cooking bananas and as beer bananas) are mainly found in the highland areas of East and Central Africa.

The great majority of plantains are grown by smallholders, who invest little labor in their cultivation. The crop is a perennial with new suckers bearing fruit each year, but except for plantains near the household compound, which benefit from the addition of household organic waste, yield decline of subsequent harvests is often so severe that in practice only one or two crops are harvested. The most pressing problem for plantain production is black sigatoka disease, which was introduced into Africa several years ago and threatens to devastate the crop in the next decade if not checked (see chapter III).

Where plantains are consumed as a major staple, they are usually prepared together with cassava or another root crop, so that they do not account for more than 20 percent of the calories consumed for large numbers of people. Plantains harvested green can be stored for several weeks without refrigeration or other treatment and there are sizeable shipments of plantain to urban markets for sale.

Cowpea. Production of cowpeas is concentrated in West Africa, where about 80 percent of Africa's cowpeas are grown (figure II.7). Nigeria alone accounts for half of Africa's cowpea production. In West Africa cowpeas and groundnuts are the major grain legumes, but in most other parts of Africa *Phaseolus* beans and/or

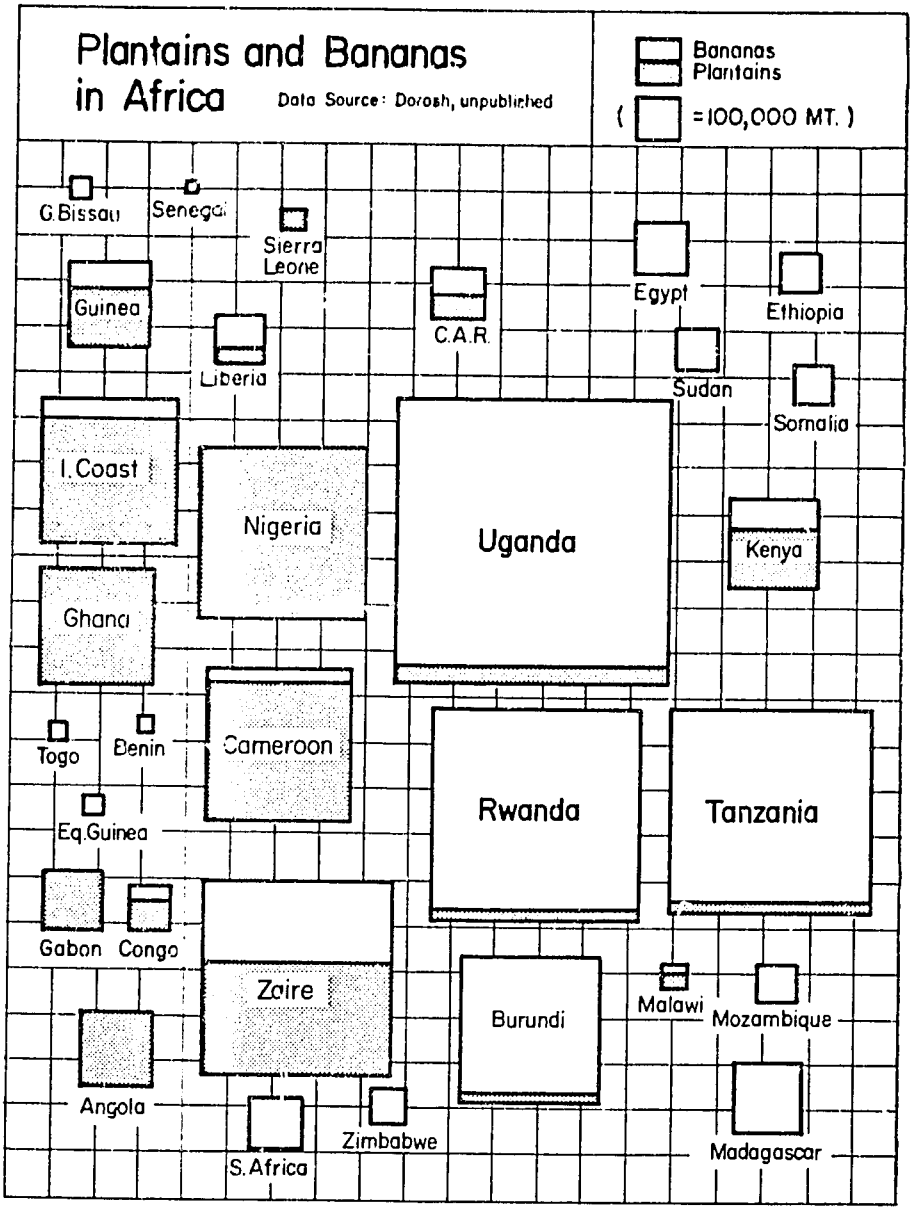

Figure II.6 Plantain and banana production in Africa, 1984

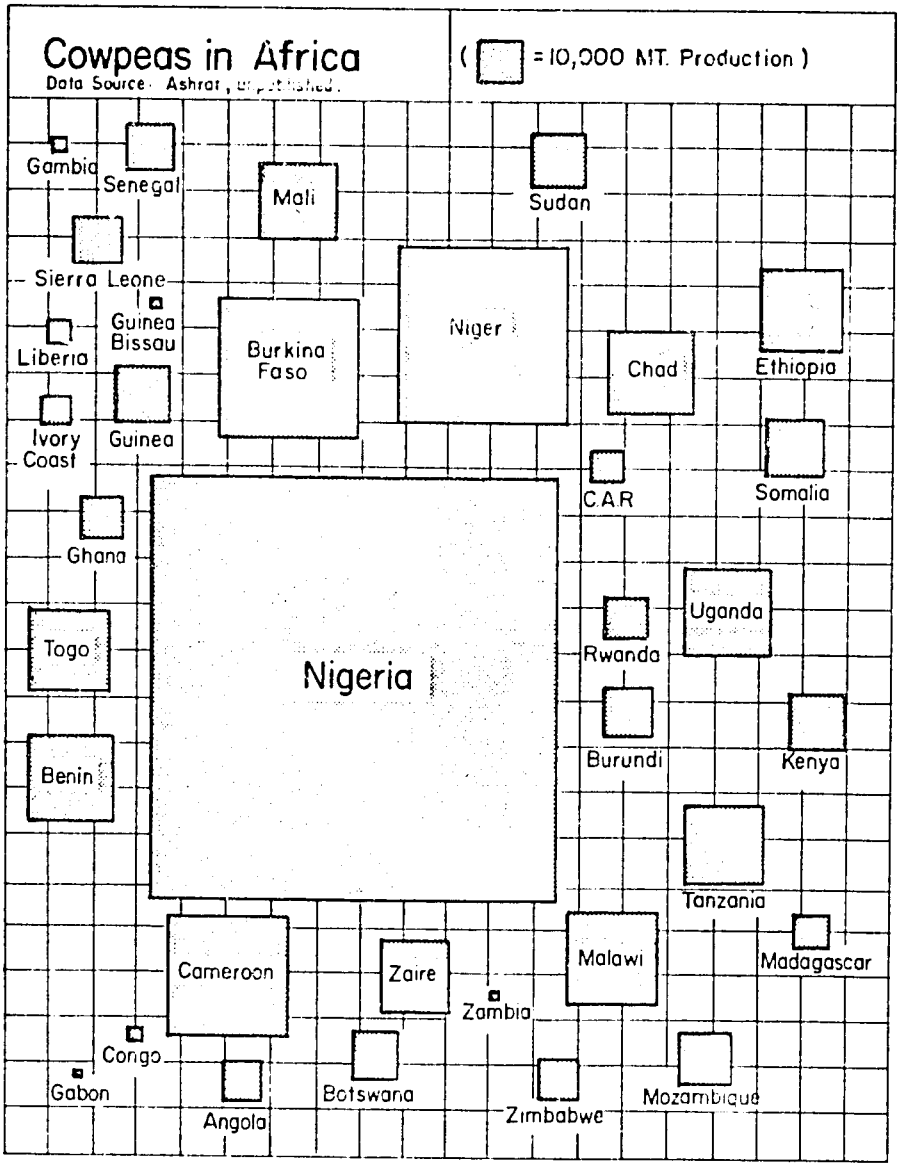

Figure II.7 Cowpea production in Africa, 1984

groundnuts dominate.

Cowpeas are grown for the most part in the semiarid and arid ecologies, where they are usually intercropped in sorghum- or millet-based systems. Less than 5 percent of cowpeas is grown as a sole crop. The development of improved cowpea varieties with a plant type suitable for intercropping with maize would facilitate the spread of cowpeas to the southern Guinea savanna. In the intercropped systems, cowpeas are rarely sprayed with pesticides, but for cowpeas grown as a sole crop, spraying is required to limit insect damage.

Most farmers who grow cowpeas both harvest the grain for human food and use the haulms as fodder for animals. The value of these haulms is about one third the total value of the crop. Cowpea leaves and pods are also eaten as fresh vegetables. Cowpeas are an important source of cash income for small farmers. The dry peas are widely traded, both in the drier areas in which they are grown as well as in many parts of the forest zone, where consumption is increasing (M. Ashraf, unpubl. working paper).

Soybean. Soybeans were first introduced to Africa in the late 19th century, primarily as an export crop to European countries. Until the early 1970s over 80 percent of soybeans in Africa were grown in Nigeria (about 60,000 tons/year), and most of these were exported to Europe. Production of soybeans in Africa has remained very small: about 200,000 tons were produced in 1985, which is about one eighth the production of cowpeas. In recent years soybean production in Zambia and Zimbabwe has increased dramatically, and these countries currently account for about half of sub-Saharan Africa's production. Nearly all of the soybeans in these two countries are grown on medium- to large-scale mechanized commercial farms. In Nigeria (where 35 percent of sub-Saharan Africa's soybeans are produced), soybeans are mostly grown on small family farms in intercropping systems.

Despite the high nutritional quality of soybeans and considerable effort to promote consumption of the crop, only about 10 percent of soybeans in Africa are processed and consumed as human food (M. Ashraf, unpubl. working paper). As food, soybeans compete with other legumes (cowpeas, groundnuts, and *Phaseolus* beans), which are generally preferred in terms of taste and are already established in African diets. Nearly 90 percent of Africa's soybean crop is crushed to make soybean oil, which competes with other domestically produced vegetable oils (especially groundnut oil and palm oil) in African markets, and soybean cake for animal feed.

Sweet Potato. Production of sweet potatoes in Africa is small relative to other food crops – only about one tenth that of cassava. Moreover, Africa accounts for less than 5 percent of world sweet potato production. Sweet potatoes are grown mainly in the highlands of Central and East Africa – Rwanda, Uganda, Tanzania, and Burundi together produce more than half of Africa's crop. Production has increased especially fast in Rwanda, a country of high population density, where the sweet potato's low labor requirements (ground cover is established quickly, greatly reducing the need for weeding), tolerance of poor soils, and short growing season have encouraged increased production. A major source of expansion of area planted to sweet potatoes has been in valley bottoms – areas which are flooded in the rainy season but which are suitable for a short-maturing crop in the dry season.

Sweet potatoes appear to have potential for increased production in lower elevation areas of Africa also, but the taste is a major constraint on consumer

demand in West Africa, where sweetness is not a desired characteris-tic for staple foods. Where population pressure has not yet made the availability of well-drained land a constraint, other longer-maturing root crops such as yam or cassava are preferred.

Cocoyam. The crop commonly known as cocoyam consists of species from two separate genera: *Colocasia* and *Xanthosoma*, which are grown in approximately equal quantities in Africa. Cocoyams are a minor crop in Africa: cassava and yam production are 13 and 6 times greater, respectively, than cocoyam production. The plants require a large amount of moisture and are tolerant of shade, making them a valuable part of farming systems in the humid forest zone of West Africa where nearly 90 percent of the cocoyams in Africa are grown. Cocoyams are not a preferred staple, however, in part because of the presence of oxalate crystals, which give cocoyams a "scratchy" taste. FAO data indicate that production (and consumption) of cocoyams has increased at less than half the rate of population since the early 1970s.

MAJOR SOURCES OF FUTURE INCREASES IN FOOD SUPPLY

At present, three commodities – maize, cassava and rice – are the dominant staples in the humid and subhumid regions of tropical Africa. Production and consumption of other crops such as yam, plantain, or sweet potato are concentrated in smaller regions, and these crops rarely account for as much as 20 percent of calorie consumption even in these regions.

Although increases in domestic food production in most countries have not kept pace with population growth, the trends in production of individual crops have varied considerably. In the 20 years from 1961 to 1980, increased rice production accounted for 27 percent of the increase in production of major food crops in West Africa (including Sahelian countries). The shares of maize and cassava in food production of major crops also increased during this period, while the share of sorghum and millet fell. In Central Africa, nearly half of the increase in food production from major crops came from cassava – not surprisingly since cassava accounts for more than 40 percent of food production (Delgado, 1986).

In the 1970s and early 1980s, African countries relied to a large extent on imports of food, mainly rice and wheat, to meet the rising consumer demand, especially for urban populations and often at subsidized prices. Imports of rice into West Africa increased by an average of more than 10 percent per year from 1960/64 to 1980/84, so that the share of imports in total supply rose from about one sixth to one half. Imports and per capita consumption of wheat, of which there is no significant production in the region, grew even more rapidly. By the early 1980s wheat imports were six times the level of rice imports in Central Africa, twice the level of rice imports in Nigeria, and about equal in size in the rest of humid and subhumid West Africa.

In the future, as population increases, Africa's food requirements will rise accordingly. Shortages of foreign exchange are likely to restrict continued increases in imports. Governments that have in the past used food imports subsidized with an over-valued exchange rate to satisfy urban consumers and to compensate for

discriminatory policies against agriculture may be forced to turn to domestic production for increased food supplies.

If, as seems likely, rice and wheat imports are curtailed, or at least rise at a slower rate than population growth, increases in food supply will have to come from domestic production. Obviously, one source of higher production is likely to be rice, a crop which has grown rapidly in the last 20 years and for which there are likely to be higher producer prices and incentives. However, it is unlikely that domestic rice production can expand rapidly enough to maintain per capita consumption at current levels in West Africa. Thus, per capita consumption of both rice and wheat are likely to fall.

As rice and wheat prices rise to reduce demand to the level of available supply, consumer demand for other staples will increase. Maize and cassava, less preferred staples in West Africa, are likely to be the main substitutes for rice and wheat. Both these commodities increased their share of food production in West Africa in the 1960s and 1970s. Moreover, existing technologies that are not yet widely adopted can make possible substantial increases in domestic production. In Central Africa, where it is already the dominant staple, accounting for over 30 percent of calories consumed by 30 million people, cassava has retained its share of total food crop production since the early 1960s.

Thus in the next two decades, as population nearly doubles, rice, maize, and cassava are likely to be the major sources of the increases in food calories that will be required to feed the people of West and Central Africa.

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III. RESOURCE AND CROP MANAGEMENT

The renaming of the former Farming Systems Program as the Resource and Crop Management Program is a recognition of both the close link and the important distinction between the two facets of farming systems research at IITA – increasing crop productivity and sustaining resource potential. Resource management research at IITA has made substantial progress toward an understanding of tropical humid and subhumid environments. Important resource management technologies developed at IITA, such as alley farming, are now ready to be tested on farms in the moist savanna and transition zone environments, and, if proved to be valid, to be disseminated to national programs. Comparable technologies will result from research applied to the humid forest environment and to the important inland valley ecosystem. The critical interdependence of short-term crop productivity and longer-term resource conservation research is being addressed through recently established, multidisciplinary, crop-based systems working groups concentrating on the farming systems that incorporate two of IITA's major commodities, cassava and maize, and on the rice-based systems of the inland valleys.

A. Resource Management Research

THE IMPORTANCE OF SUSTAINABLE PRODUCTION

Among the most important research questions in the humid and subhumid tropics is how to generate the rapid increases in output needed to keep pace with population growth while avoiding degradation of the underlying resource base. This essentially requires finding sustainable production systems to replace the systems of shifting cultivation that have characterized African agriculture in most regions in the past. Traditionally, African farmers have allowed farm land to revert to natural vegetation after only a few years of cultivation because of the rapid decline in soil productivity that occurs in much of the humid and subhumid tropics. Fallow periods would range from 5 to 20 or more years, depending on demand for land and the rate of fertility restoration. As long as population and usage pressures on the land were not excessive, there was little problem of degradation in the system.

However, the rapid growth of population and of demand for food and other products in recent years have upset this balance. Population in sub-Saharan Africa has doubled since 1960, and will double again in the next quarter century or sooner. In order to meet the growing demand for food and other agricultural commodities, the area of cultivated land has increased significantly, but often at the expense of

restorative fallows. In addition, many new areas have been opened to cultivation using techniques that can seriously degrade the productive capacity of the land. As a result, the sustainability of the system is being threatened. There is an urgent need for new or improved techniques and systems of land development and management that will permit increased production, prevent degradation, and be compatible with prevailing farming systems so that they are readily adopted by farmers.

Following the strategic planning study, IITA has organized its research to address these issues as three major activities which are integrated through their focus on the major ecologies of the region, and through IITA's work in partnership with the scientists of African national research systems. These activities are:

1. Resource management research to study the natural resource base and to refine existing resource management technologies, or devise new ones in the context of smallholder farming systems.

2. Commodity improvement research to breed improved crop varieties that, through their resistance to biological and physical stresses, and their adaptation to ecological and agricultural requirements, stabilize and increase the smallholders' productivity.

3. Crop management research to synthesize the products of these two research efforts into sustainable and productive cropping systems compatible with the resources and objectives of the smallholder.

This section of chapter III deals with the first of these activities.

THE AGROECOLOGICAL BACKGROUND

Ecological zones. As described in chapter II, there are three major zones in IITA's primary area of focus of West and Central Africa: (a) the forest (corresponding to the humid and perhumid tropics); (b) the forest/savanna mosaic, or transition zone (in which Ibadan is located); and (c) the moist, or Guinea, savanna (corresponding to the subhumid tropics). Scattered throughout these broad major zones is an important ecosystem, the so-called wetlands, consisting of several million hectares of inland valley swamps, riverine floodplains, and other lowland areas that are normally flooded during the rainy season. These have special production potentials and problems as well as important implications for the sustainability of the farming systems of which they are a part.

In addition to these broad climatic/vegetational zones, it is important in resource management research to distinguish regions on the basis of at least two other variables: soil type and population density. For the humid and subhumid tropics in Africa, it is useful to distinguish among areas with acid and nonacid soils, and among areas of high, medium, and low population densities.

Soils. A simple categorization of tropical African soils would include four general groupings: (a) highly weathered acid soils; (b) highly weathered nonacid soils; (c) soils derived mainly from basic and volcanic materials (nonacid); and (d) hydromorphic and alluvial soils (nonacid). The humid forest zone of West and Central Africa (which includes over 55 percent of the land area of the primary focus

countries) contains mostly highly weathered soils that are strongly leached and acidic. They degrade rapidly when cleared of their natural vegetation. The central agricultural problem of this region is the maintenance of soil fertility.

Although highly weathered soils are also found in subhumid regions, they are generally less leached and less commonly acidic. However, they are susceptible to compaction and soil erosion, and in some areas there has been acidification of soils that were originally nonacid (often resulting from use of acid-forming fertilizers). Less weathered soils derived from volcanic ash and ferromagnesian rocks are important and productive in the tropical highlands of East Africa and in western Cameroon. In addition, hydromorphic and alluvial soils are scattered throughout the humid and subhumid tropics in association with swamps, lakes, and rivers. As discussed below, these different soils have varying management requirements and varying tolerances for intensified or continual use.

Farming systems and population pressure. The traditional farming systems of most of tropical Africa involve multiple or mixed cropping and a resource management strategy based on shifting cultivation and related bush fallow systems with a minimal reliance on purchased inputs. At present, however, there is evidence of serious resource degradation in many traditional systems, in areas having either high or low population densities. In densely populated areas, fallow periods have often become significantly shorter, resulting in accelerated leaching of nutrients, rapid oxidation of organic matter, increased weed populations, erosion, and decreased moisture retention. The farmers' options for coping with these problems may be overwhelmed by the rapidity and extent of the changes, and, in extreme cases, irreversible degradation of the land and soil may result.

Paradoxically, there are other rural areas in which it is too few rather than too many people that makes it difficult to maintain productivity. Throughout humid tropical farming systems, substantial labor is required to clear land, keep weeds under control, and, in sloping areas, to construct ridges or terraces to prevent soil erosion. In many cases, the migration of large numbers of young males to urban areas, together with increased primary education for children, has removed a significant proportion of the agricultural labor force. As a result, it is increasingly difficult to mobilize sufficient labor to clear trees from land that has been under fallow for long periods, to carry out essential tasks such as weeding and planting at the optimal times, and to maintain ridges or other soil conservation measures. Thus, productivity may decline as lack of labor compels the repeated use of the same land, elimination of restorative fallows, and the neglect of tasks needed to maintain the resource base. New techniques to help assure sustainable production are, thus, needed for areas where labor is scarce, as well as for the densely populated areas where shortage of land is the central problem.

Productive potentials and limitations. Each of the main agroecological zones has different crop production potentials and constraints. In the humid forest, production potential is greatest for root crops, tree crops, and plantains, and in general multistory cropping systems are most appropriate. The acidic soils in these regions contain few nutrients, and toxic elements that can inhibit crop growth are found in much of the subsoil. Many of the important nutrients of the system are present more in the biomass than in the soil, and thus manipulation of the biomass is important in preserving productivity and making the best use of the productive potential. Use of fertilizers alone is usually not sufficient to overcome these

limitations because they can increase acidity and aluminum and manganese toxicity. Although annual crops can be grown on these soils, the decline in fertility is extremely rapid, and they often have to be left fallow after only one or two years of cultivation. It is estimated that with traditional techniques and low inputs, these soils can at best sustain cultivation no more than one year in five. Even with a high level of input use and intensive management practices, there is a sharp limit to continual cultivation.

In the moist savanna zone, the productive potential for cereal and grain legume crops is greater than in the forest, and soil constraints are generally not as serious. Most soils in the region are amenable to the intensified management required to increase production. However, poor soil structure and other physical soil problems remain important. There is also significant risk of erosion in many areas. Some of the main soil types in the savanna and transition zones (e.g., the kaolinitic alfisols) may have favorable pH values under natural vegetation but be subject to acidification when intensively cultivated. Erratic and unpredictable rainfall, and resulting periods of drought stress, are significant problems for crop production, and integrated soil and water management is often needed to achieve increased yields. Yield decline with continued cultivation is common, though usually not as severe as in the forest zone, but grass fallows are also not as efficient in restoring fertility as are forest fallows. In addition, weeds such as *Imperata cylindrica* frequently become major problems as land use is intensified, and they can be the main symptoms of land resource degradation. For large scale agricultural projects mechanized cultivation is often more appropriate for the moist savanna than forest areas, but research by IITA has shown that improper mechanized land clearing and cultivation can cause serious degradation of soil productivity.

The wetlands include coastal plains, inland basins of many of the river systems, river floodplains, and inland valleys and swamps. They form a significant proportion of the total land area of tropical Africa, particularly of the humid and subhumid lowlands of West and Central Africa, the region of primary focus for IITA. In many instances, their production potential has not been developed. The inland valleys are often especially suitable for smallholder development and for production of rice and associated crops. According to a recent estimate, they may comprise between 10 and 20 percent of the total land area of humid and subhumid West Africa (Andriesse, 1985). In general, sustainability of production is much less a problem in these wetland areas than in most upland regions. However, soil toxicity and pest and disease threats, both for crops and people, can be serious obstacles to development, as can socioeconomic factors that make it difficult to marshal the resources needed to develop and manage them.

In addition, the physical characteristics of the inland valleys are extremely variable, so that techniques that are appropriate for some areas may be unsuitable to others. In general, too, the Asian models for development of these kinds of wetlands are not suitable in most of Africa, and locally appropriate techniques and approaches have to be devised. Many recent studies have also shown that the wetlands are used by farmers as special niches within larger farming systems that include upland areas (e.g. Richards, 1986). The development of the wetlands should therefore be undertaken in the context of the farmer's system as a whole.

A FRAMEWORK FOR RESOURCE MANAGEMENT RESEARCH

Natural resource management involves the search for sustainable production systems. This task, fundamental to African agricultural development, is an enormously complex and long-term undertaking, a problem of the 21st century. Growing population densities and increased intensity of land use have caused the bush fallows of traditional shifting cultivation systems to be significantly shortened in many areas, resulting in sharply declining soil productivity. The process has especially acute consequences in the humid forest zones of Africa, where the deeply weathered, acidic soils lose fertility rapidly under repeated cultivation. Here there is an irreducible need for fallow periods to restore productivity. Some of the most densely populated areas in Africa are in this humid forest zone.

Resource management research involves three conceptual stages which are based on the Institute's experience in the forest/savanna transition ecology at Ibadan:

(a) Measurement and analysis of the physical, chemical, biological and socio-economic elements of the natural resource base.

(b) Analysis of the determinants of stability and degradation of the resource base by studying the dynamic interactions of these elements. This includes, for example, studies of transport and storage of water and nutrients; of soil erosion; and of fertility as measured by the physical, chemical and biological properties of the soil and their effects on biomass production.

(c) Designing resource management systems. The principles identified by the analysis of the determinants of stability and degradation are used to modify existing resource management practices, or to design new ones which are capable of stabilizing or increasing output while avoiding degradation of the resource base.

The traditional smallholder system for resource management has involved alternating crops with fallow under natural vegetation. The vegetative cover stops wind erosion and virtually eliminates water erosion. The multilayered network of roots and the buildup of organic matter reduces erosion and leaching by slowing downward movement and intercepting and recycling the major portion of the potentially leachable components. The deeper roots of the trees absorb minerals that are not available to the shallow roots of annual crops and deposit them in and on the surface soil through leaf litter. This not only establishes a greater reservoir of available nutrients upon which the crops can draw, but enlarges the volume of soil in which weathering steadily makes more of the total minerals available for biological processes. Finally, shade, surface mulch, and root competition combine to eliminate the light demanding weeds that normally occur in cultivated fields. However, local population pressures continue to increase, land has been left fallow for shorter periods and, as subsequent soil rejuvenation has become inadequate in many cases, crop productivity has declined.

This situation can be improved by resource management systems that maintain or increase the organic matter content of the soil and replace the nutrient elements removed by crops, or by erosion or leaching. One such cropping system is alley farming developed through research at IITA's Ibadan headquarters mainly for the forest/savanna transition ecology. The basic principles, the research method, and some of the specific components of this new resource management technology are applicable to the moist savanna and humid forest ecologies.

Resource management by farmers is inextricably linked with their productivity objectives and the ways in which they use the resources available to them to achieve these objectives. Consequently, it is important that there be an operational link between research to increase crop productivity and research directed toward long term maintenance of the resource base. This linkage is provided through the crop-based systems working groups, which are interdisciplinary teams responsible for developing and implementing the research agenda for particular types of farming systems. A major objective of the groups is to develop improved cropping systems that integrate the technologies developed by the commodity programs with resource management innovations that help to insure the longer term viability of the systems. The organization and research strategies of these groups are discussed in greater detail in section B of this chapter.

MAJOR ACHIEVEMENTS AND TECHNOLOGY OPTIONS

IITA's resource management research has focused on three major areas: (a) analysis of the processes of soil degradation in tropical ecosystems; (b) the development of methods for managing and reclaiming degraded systems; and (c) the development and testing of alternative techniques for maintaining soil fertility under intensified cultivation.

A significant amount of basic research has helped to identify and quantify the physical, chemical, and biological aspects of soil degradation, not only during the normal cultivation cycle but also as a result of varying techniques of land clearing, and in the course of longer term erosion processes. The effects of transferring temperate zone practices to tropical ecosystems have been analyzed, including the use of synthetic fertilizers, mechanized land clearing and cultivation, and monocropping. These have generally been shown to hasten the decline of soil productivity and/or to generate long-term problems of nutrient status, toxicity, structural condition, and biological activity in the fragile soils of these ecosystems. An understanding has been gained of the complexity of soil processes in the tropical environment and the extent to which these soils require management systems different from those used in the temperate zones.

1. General Guidelines

As a result of this work, a series of basic guidelines for preventing degradation and retarding the decline of fertility has been developed, and several promising technologies are available for further testing and agro-economic evaluation on farms. The essential principle for preventing or retarding degradation during cultivation is to maintain a continuous layer of organic residues on the soil surface. This mimics and replaces the effects of the forest ecosystem in protecting and regenerating the productive conditions of the soil. Its purpose is to protect the soil from structural damage by rain and from excessive temperatures, to provide a continuous supply of organic matter to replace that lost by microbiological processes, to encourage the beneficial effects of earthworms and other soil fauna, and to minimize nutrient leaching and acidification. This mulch layer can take different forms and derive from various sources, and it may comprise only one element in a set of multipurpose management practices. It is, however, an essential component

for intensifying production and maintaining soil fertility. Other important principles include the following.

(a) Use of heavy equipment on the land should be minimized, and any equipment used should be designed or selected to exert low pressure on the soil.

(b) When soil compaction occurs, through use of machinery or natural processes that cause breakdown of soil structure, measures should be taken to loosen the soil and restore the structure.

(c) Cropping patterns should avoid continuous monocropping in favor of mixtures of crops that maximize active plant cover of the soil; mixtures of shallow and deep rooting crops are most efficient in making use of nutrients at different levels in the soil.

(d) Fertilizers and other soil additives may be needed to balance soil nutrients and replace nutrient losses, but these should be used judiciously to avoid generating problems of acidification and toxification.

These principles have been put into practice in devising and testing a number of alternative management systems which are capable of increasing or stabilizing output while avoiding soil degradation. The detailed aspects of many of these systems have thus far been designed mainly for the transition zone ecology. However, the basic principles, research methodologies, and some of the specific components are equally applicable to the moist savanna and humid forest zones. Various adaptations are, of course, needed to develop fully feasible systems for different areas, and further on-farm validation and testing is needed in all cases, particularly in the exploration of socioeconomic and cultural aspects of these technologies. These are further discussed below in the detailed descriptions of the major technologies and the priorities of the research agenda.

2. Main Technology Options

A number of technologies and systems embodying these general principles have been developed and tested under diverse conditions. In many cases, further work is needed to adapt them to other ecological conditions or to examine their socioeconomic suitability. The major current options include the following:

(a) Alley farming. Agroforestry – the inclusion of woody species in food crop production systems – appears to be an important and suitable approach to maintaining productivity in the degradable soils of the humid and subhumid tropics. In bush fallow production systems, the crop and tree phases are separated in time. The main problems with this are the extensive reserves of land needed for the system to function, and the high labor requirements to clear land that has been in fallow for any extended time. In many cases, adequate land and/or labor are no longer available to sustain this system. An alternative approach which merges the crop and wooded phases is "alley farming," an agroforestry system in which food crops are grown between rows of nitrogen-fixing, leguminous trees. Under many conditions, alley farming can make possible continuous cultivation of food crops while at the same time providing numerous other benefits. The trees are pruned before and during the cropping period to prevent shading and to reduce competition with food crops. The prunings are used as a mulch to increase soil fertility, conserve water, and suppress

weeds. Prunings from leguminous species can provide as much as 60 kilograms of nitrogen per hectare per year for the crops. The system also provides other beneficial outputs, including animal fodder for cattle and small ruminants, staking material for other crops, firewood, and partial weed control. When the hedgerows are planted on the contour lines of sloping land, they can also help prevent erosion.

Compared with traditional practices, alley farming, with hedgerows of *Leucaena leucocephala* or *Gliricidia sepium* has been shown capable of producing higher yields of maize and other crops, without fertilizer and on a sustainable basis, on nonacid soils in the transition and moist savanna zones. On acid soils in the humid zone, other species are generally necessary, and some other elements of the system will probably have to be adapted. Species currently being tested for use on acid soils include *Acioa barterii, Cassia siamea, Flemingia congesta,* and *Cajanus cajan.* The suitability of various intercropping combinations in this system and their interactions with the tree species are now the subject of on-farm research, and work is beginning on economic evaluation of the system under different conditions. Modified forms of alley farming which involve alteration of existing systems to varying extent – but which incorporate the basic principles of alley farming – may also be developed, especially for the humid zone, where perennials are already important components of farming systems.

(b) Mulches and cover crops. Various forms of mulch farming have also been investigated for use under diverse conditions. These include a number of species of live mulches, which are generally quick-growing leguminous cover crops. These can provide a constant soil cover before, during, and after the cropping phase to prevent or retard soil degradation, and, in many cases, to suppress weeds. A number of useful species have been identified and selected, and experiments have been carried out to test their compatibility with different cropping systems and performance under various conditions. Simple hand drawn equipment for planting crop seeds through the mulch cover has also been developed. Work is continuing to identify appropriate species for the humid acid zone. There are also still some drawbacks to *Mucuna pruriens*, the main species currently being used for nonacid areas, and there is need for additional work to identify other suitable species.

(c) Land clearing and development. In the humid and subhumid tropics, land clearing for cultivation requires the removal of trees and shrubs. On small and medium-sized farms, land clearing is done manually. This has a distinct advantage over machine clearing since the area cleared is normally quite small, and the problems of soil compaction and erosion are reduced. The drudgery involved, however, makes some degree of mechanized clearing seem an attractive alternative. In the subhumid tropics, where there are fewer trees, mechanized land clearing is becoming more common on large commercial farms. These techniques can have drastic effects on soil structure and erosion. IITA research has shown that when heavy equipment is used, soil disturbance and subsequent erosion can be kept to a minimum with implements such as the shear blade, which cuts the vegetation at ground level. Minimum or zero-tillage with use of cover crops, mulches, and herbicides are necessary when the land is cleared in this way.

(d) Tillage methods. Various studies at IITA and elsewhere have shown the advantages of minimum or no-tillage farming. To be successful, this must be combined with appropriate land clearing and subsequent management practices,

including the use of mulches. Weeds are generally controlled with herbicides. This system has decided advantages in conserving soil and water and maintaining lower soil temperatures and higher levels of soil organic matter. However, further agronomic and economic analysis is needed to determine the conditions under which it would be most practical for small-scale farmers.

(e) Fertilizers and soil additives. There is clearly growing interest by small-scale farmers in much of Africa in the use of fertilizers and other chemical additives. In addition to increasing short term output, these can delay or modify some aspects of soil degradation. However, IITA and other research has shown that because of the greatly reduced buffering capacity of the weathered soils in the humid and subhumid tropical regions, excessive and inappropriate use of nitrogen fertilizers can cause severe acidification and soil toxicity problems. Careful use is critical.

(f) Improved fallows. A limited amount of research has been done on developing improved fallow management practices that will be more efficient in restoring soil fertility than unmanaged bush fallows. Some of the species used in alley farming experiments, such as *Leucaena*, can be beneficial in a managed fallow system. Moreover, there are areas in which farmers already plant or select certain fallow species, especially in the humid forest zone. This can provide the basis for further work, although the particular mix of species used may be quite site-specific.

OPERATIONAL STRATEGIES

Building on the principles and accomplishments of past work, resource management research at IITA will continue to emphasize the improvement of existing practices and the development of new techniques to prevent soil degradation in the humid and subhumid tropics while making more intensive use of land and other resources for increased production. There will be primary emphasis on validation and adaptation of systems that have shown significant promise in the forest/savanna transition ecology. In addition, there will be an integrated effort to develop technology suitable for the acid soil, humid forest zone, a large and important environment in Africa in which problems of resource degradation are especially severe.

Recommendations arising from resource management research generally call for changes in the cultural practices currently in use by African smallholders. The socio-economic viability of new technologies or of changes to existing practices must be validated on small farms. In addition, the results of past resource management research as well as the agenda for future work will be more closely integrated with the work of the commodity improvement programs through the crop-based systems working groups (as described in section B of this chapter).

The sequence of research priorities will be:

1. The synthesis and on-farm validation of existing resource management technologies that are appropriate for the transition zone and parts of the moist savanna;

2. The development of a research substation in the humid forest zone and the initiation of an integrated research effort for base data analysis, technology development, testing, and validation for this ecozone;

3. Base data and technology research on resource management for the inland valley ecosystem, which will be done in conjunction with the work of the rice-based systems working group and the inland valley research substation.

In addition, there will be continuing on-station research on fundamental issues relating to resource degradation, restoration, and management.

Synthesis and on-farm validation. As a first priority, IITA will concentrate on the synthesis and on-farm validation of the accumulated results of over 15 years of resource management research. Most of this has been conducted in the Ibadan area, located in the subhumid transition zone with predominantly nonacid soils. This synthesis of component technologies into viable systems, and their testing and validation on-farm will be carried out through collaboration with crop-based systems working groups. It is anticipated that some of these technologies, particularly alley farming, will be ready to hand over to the national programs for local adaptation and extension in a relatively short time.

The humid forest ecology. At a new substation in the humid forest ecology there will be a combination of commodity improvement and resource management research to develop sustainable farming systems, emphasizing tree and root crop interactions. Initial emphasis will be on the measurement of the resource base, on research aimed at a better understanding of resource and fallow management systems, and on the related physical and biological parameters, particularly those which influence nutrient leaching, acidification and low fertility. Appropriate adaptations of alley farming may provide the key technological innovation that allows increased labor and crop productivity, shorter and more productive fallows, and increased availability of the forest resources that are needed for the maintenance of farming and livelihood systems.

In the medium-term resource management research in the humid forest ecology is expected to have the following outputs:

(a) Increased knowledge of the resource base of traditional fallow systems.

(b) Knowledge of the processes influencing the rapid decline of soil fertility in cultivated land, including those which influence organic matter, nutrient recycling and soil acidification.

(c) A prototype alley farming system will have been developed with (i) alley tree species adapted to acid soils, and which have high biomass production and prunings which degrade slowly on the soil surface, and (ii) approriate cultural modifications of the system to accommodate root crops.

The moist savanna ecology. Some of the baseline research and the resource management technologies developed for the transition zone are applicable to many areas of the moist savanna. There are, however, differences in relative

priorities of some of the resource issues because of differences in environmental factors and in farming systems. In particular, soil fertility, soil compaction, and the need for biomass for feed and fuel are likely to be of relatively greater importance as resource issues. The loss in productivity, through invasion of grassy and other weeds, is also a high priority issue in many savanna areas. In the short to medium term this research is expected to produce:

(a) A prototype alley farming system with emphasis on: (i) nitrogen fixation to reduce the dependence on external inputs of nitrogen that may reduce soil pH; (ii) allocation of biomass for feed and fuel; (iii) ability to cycle fossil phosphorus to the surface layers; and (iv) the control of grassy weeds through manipulation of the canopy.

(b) An improved maize cropping system based on rotation and mixtures of cereals, legumes, and cover crops to enhance internal nitrogen supply.

The Inland valley ecosystem. Since this ecosystem is found scattered over the three major ecologies (forest, transition, savanna), and within these, any one farmer will allocate resources among rice and other upland crops, the research to quantify the resource base is included in that already discussed for the ecologies. As a priority, work will continue on resource management technologies involving minimum water control, ridging, fertility management, weed control and planting methods of rice, and the adaptation of other crops (including cassava, yam, cowpea, soybean and maize) for the system.

It is recognized that the most sustainable and productive rice growing systems include some form of water management. As a long-range goal, the benefits that derive from optimal water management should be possible for African rice growers in the inland valleys. Although the essential research program addresses the development of technologies for the lower, suboptimal levels of water management that now prevail, a desirable activity will be the determination of the most efficient paths for water control development and to identify the rice-based system technology that will be most appropriate for different developmental stages. Some of the expected short and medium-term outputs from resource management research in the inland valley ecosystem are:

(a) A resource management technology based on minimum water control and on soil management practices for: (a) effective weed control, (b) alleviation of the effects of toxic chemicals on rice (e.g. iron), and (c) optimal stand establishment, nitrogen fixation and root exploration by non-rice crops.

(b) An understanding of the effects of fluxes in the water table on soil properties (physical and nutrient), and on efficient use of applied nutrients. Researchable resource management problems include water supply, conservation and drainage, soil fertility and toxicity, weed management, and disease vectors (insofar as they interact with resource issues). Basic information is needed on the parameters of resource degradation in this ecology under the conditions of suboptimal water management that are likely to prevail during at least the immediate future.

On-station research. At Ibadan, the research program will focus on basic issues related to nutrient/water cycling and availability, modelling of crop/resource processes, basic studies on the control of important noxious weeds, and studies to

determine soil, water, and radiation parameters in farming systems. It is anticipated that the principles established will be relevant for the transition zone as well as the humid forest and moist savanna regions of sub-Saharan Africa. Among the expected outputs from this work will be:

(a) Improvements to alley farming systems in response to feedback from on-farm tests and the alley farming network: (i) improved stand establishment of the alley through choice of species and appropriate cultural methods, (ii) enhanced weed control through canopy management and through allelopathic effects of the alley species, and (iii) changes in the husbandry of the alley, in the configuration of the food crops, and in the judicious use of external inputs of fertilizers.

(b) Annual mulch cover crop systems with: (i) species that regenerate effectively to produce adequate biomass and nitrogen (symbiotic fixation), (ii) cultural methods which allow for planting through the mulch, and (iii) adequate control of the cover species to minimize competition with the basic food crops for light, water and nutrients.

(c) Improved knowledge of the relationships between properties of the resource base and their quantification, leading to indices of sustainability for use in cropping system research.

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B. CROP MANAGEMENT RESEARCH AND SYSTEMS-BASED WORKING GROUPS

Crop management research is concerned with adaptive development and testing, both on-station and on-farm, of modifications to existing agricultural practices and of new technologies that are intended to improve the productivity of the target farming systems. Research of this kind requires the cooperation and interaction of numerous scientists, who work together from the stages of initially defining the objectives and problems, to developing new technologies, testing them under field conditions, combining individual technologies into viable systems, and validating their suitability under varying conditions. Contact and cooperation with scientists and extension workers from national programs is an essential part of this effort. In addition, there is a need to understand the agroecologies, farming systems and economies, and crop ecologies and constraints, and how these vary across the regions of IITA's concern as well as what changes are occurring over time. This is critical to setting research priorities, selecting suitable research sites, and targeting technological innovations to the appropriate areas.

On-farm research of this kind by agronomists, economists and other scientists in collaboration with the scientists of national programs has always been a part of IITA's program. While this has included testing improved varieties, as well as other innovations, it has proved difficult to integrate these on-farm studies with the work of the commodity improvement scientists. There has been insufficient feedback from on-farm research to the commodity improvement programs; and it had also at times been difficult to integrate the shorter-term research on crop improvement with longer-term resource management research done by soil and other physical scientists. To conduct multidisciplinary farming systems research there was need for an organizational mechanism to achieve the essential linkages and feedbacks among resource management, systems and crop management research, and commodity improvement work in each ecology. The mechanism established by IITA for this purpose is the crop-based systems working group.

There are three working groups for cassava-based, maize-based, and rice-based farming systems, named after the predominant IITA mandated crop in the forest and moist savanna ecologies, and the inland valley ecosystem. Each group includes a full-time agronomist and agricultural economist as well as breeders for the system's major and secondary crops (e.g. grain legumes). A soil scientist, weed scientist, entomologist and/or pathologist, and a post-harvest technologist are also regular group members, depending on the particular issues being explored. Different group members participate to varying degrees in each of the main projects and activities defined by the group. Because commodity improvement scientists participate actively in each group, their farming systems orientation is strengthened, and their enhanced knowledge of the ultimate client improves their ability to define appropriate breeding objectives. Furthermore, the working groups offer excellent opportunities for cooperation with the scientists of national programs.

The central goal of the working groups is to bring component technologies together into viable systems for the major agroecologies of West and Central Africa. Such systems should be capable of meeting the dual objectives of increasing short-term productivity and assuring long-term sustainability of output and of the

resource base. The general goals of each group are to examine the constraints and potentials of farming systems in which cassava, maize or rice are the major component, and to devise appropriate research agendas for systems improvement.

They have three functions (ISNAR, 1987):

(a) A validation function involving on-farm screening, testing, and evaluation of technologies generated by experimental station research.

(b) An adaptive research function involving the adjustment or adaptation of existing technology to a particular set of environmental conditions, both agro-ecological and socio-economic, through on-farm research.

(c) A feedback function providing relevant information from farm-level characterization, diagnosis, and/or adaptive research to scientists developing resource management technologies or breeding improved varieties at research stations.

Each of the working groups identifies research issues that will help it to understand prevailing conditions and trends that are relevant to its current and future research agenda. Details of the 1988 activities of the groups are given in annex 2.

The selection of appropriate sites for on-farm research is vital to successful development and testing of agricultural technology. To this end, the working groups maintain an ongoing commitment to investigate the nature of the agroecologies and farming systems in their regions of focus, and how these vary both over time and space. Data gathered from surveys, site investigations, and secondary sources will be compiled and maintained in a computerized database so that continued updating, mapping, and analysis will be possible. Each of the working groups has identified one or more pilot on-farm research (OFR) sites, the characteristics of which reflect the agroecological and subject focus of the group's research priorities. Among the major criteria for site selection have been location in the agroecological zone(s) of primary focus (the humid forest and/or the moist savanna); predominance of the respective type of target farming system in the region; significant potential for technological change; the presence of extension and research support from the national agricultural system; and policy-level support for increased production in the area.

Although IITA cannot focus on all the variations of ecological conditions and farming systems even in its primary area of focus, it can work with national programs to develop methodologies for cropping systems research and can produce prototype systems. National program scientists can then refine and adapt them for use in their own countries. Moreover, the contributions of national scientists are extremely important in assuring that the methodologies and prototype systems coincide effectively with the resources and capacities of existing institutions. The working groups have initiated contacts with national programs already well known to IITA, and such collaboration is expected to comprise a significant part of their research agenda.

In summary, IITA has established a research framework that will promote the integration of three major activities: resource management research, commodity improvement, and crop management research, in order to achieve a common objective. Central to this framework is the integrative function of the crop-based

systems working group which ensures linkages and feedback between resource management and commodity scientists as they work together with economists in the study and improvement of smallholder production systems. Furthermore, several initiatives have been taken to strengthen existing linkages with the scientists of Africa's national research systems, for it is through them that IITA reacts to the needs of its ultimate clients in a continent so diverse as Africa. Chief among those initiatives are the IITA research liaison scientists and country teams, the visiting scientists from African national programs, and the increased emphasis on postgraduate research training for the future leaders of national systems.

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IV. COMMODITY IMPROVEMENT

A. INTRODUCTION

When the strategic planning study was initiated, IITA had breeding programs for nine commodities as well as a broader farming systems and resource management responsibility; together, these spanned four major agroecological zones in West and Central Africa alone. In addition, the Institute had research activities in South America, the Caribbean, and Southeast Asia. It was a basic premise of the study that so large and widely spread an involvement could not be met effectively with the resources at hand and that it tended to dilute the impact of the Institute's research efforts. Moreover, it was not considered feasible for the Institute to undertake full scale breeding programs on all nine of the commodities for which it had been given the mandate; namely, maize, rice, cassava, yams, sweet potatoes, cocoyams, cowpeas, soybeans, and plantains.

Given this background there were two broad issues that had to be decided in relation to IITA's commodity improvement programs. One concerned the relative priorities to be allocated among commodities, and indeed whether work on some should be stopped altogether, or transferred to another competent international center. The other was to determine the most important breeding objectives for those commodities to be retained.

These questions and issues were dealt with through the multi-stage process of the strategic planning study. Each of IITA's commodity improvement program–on roots and tubers (including plantains for the purposes of the study), maize, rice, and grain legumes – was the subject of a series of meetings which examined the economic significance of the commodities; the main constraints to increased yields; the previous directions and accomplishments of research by IITA, by Africa's national research systems, and other IARCs; and how major current research needs and opportunities vary by agroecological regions. Drawing on these analyses, management developed an operational strategy for commodity improvement; an assessment was made of the resources needed to implement it; and the mode of collaboration with national systems in Africa and with international institutions was considered. At the end of the study a meeting of the chairpersons of each of the commodity study groups and the heads of IITA's commodity improvement programs examined and reviewed priorities across the programs (for example, the relative priority to be accorded maize compared with cassava).

GOALS AND CRITERIA

To make judgments about commodity priorities and research agendas, criteria from a number of different sources were used, including the objectives and strategies that had been adopted by the Institute; the relevance indicators outlined by TAC to assess the significance of commodities; the likely productivity of research on any issue; and the achievements of past research, whether by IITA or others. The role of each of these is reviewed briefly below, and as an example of the study process used to address these questions, the record of the final meeting of the Rice Study Group is given in annex 3.

Program strategies. The four program strategies established by IITA to achieve its major goals (see chapter I) were influential in determining priorities among commodities and research agendas. These strategies include: (a) a primary focus on the lowland humid and subhumid tropics of Africa; (b) an emphasis on technology for small family farms; (c) a strengthened farming systems orientation; and (d) decentralization of research activities. These themes were expressed in various forms during the meetings of the commodity study groups, and they repeatedly played a role in decisions on future research orientations and goals.

Relevance indicators. The concept of "relevance indicators," taken from the 1985 TAC *Review of CGIAR priorities and strategies*, was used to assess the relevance of the various commodities to IITA's goals and the probable productivity of research on a given topic. This was very helpful in setting priorities among different commodities and deciding which research issues should receive priority attention. These indicators are listed in table IV.1.

The economic analyses of IITA's commodities, summarized in chapter II dealt mainly with the relevance of the commodity to IITA's research goals (see first column of table IV.1). The implications of these for policy, as well as the more technical issues relating to research productivity, were among the main subjects of the commodity program review meetings.

SETTING PRIORITIES

In the strategic planning study, IITA's management systematically sought to answer the following questions with regard to each of the commodities on which the Institute was conducting research:

1. How great are the present and projected contributions of the commodity to IITA's goals for African agriculture ?

2. How productive is further IITA research on the commodity likely to be over the next decade ?

3. To what extent does IITA have a comparative advantage in research on the commodity ?

This method of analysis, patterned after the 1985 TAC review of the CGIAR, was useful for setting strategies and priorities within each of the research programs.

Table IV.1 Relevance indicators for commodity research

Relevance of commodity to IITA goals	Research productivity
Importance of the commodity in the diet - calorie contribution - protein contribution - additional nutritional aspects (fats, vitamins, minerals etc.) - utilization aspects (storage, transportability, conversion, etc.)	*Researchability* - evidence that progress in production or productivity is constrained by lack of knowledge and/or technology *Research history* - current knowledge base - past gains/failures
Importance of the commodity in the production system - value of production (share in global/regional production) - contribution to sustainability - multiple purposes (livestock feed, energy, by-products) - area harvested - agroecological suitability	*Research opportunities* - extent of genetic diversity - yield levels, yield trends and potential gain - yield stability and defense of achieved gains - potential agroecological amplitude - unexploited areas for research - scope of application of results - estimated returns to proposed research
Relevance to target groups - income/employment generation - nutritional factors	*Potential for breakthrough* - technologies in the pipeline - emerging knowledge from basic research
Future gaps in demand and availability - self-sufficiency (macro-level) - food security (micro-level)	*Time frame* *Comparative advantage for IITA in research on the commodity*

In order to answer the question of priorities between commodities, IITA turned to a comparative analysis of the commodities, still within the context of the three questions. These comparative judgments were qualitative but they were informed by the extensive studies reported in chapter II. They were the basis for deciding on which commodities IITA should focus its research.

These comparative judgments are summarized in a highly aggregative fashion in table IV.2.

The reasoning behind IITA ratings in the table are summarized below for each of the three columns.

1. Projected importance of the commodity. The present relative importance of the commodities to total production of calories and protein in West and Central Africa is shown in the following table. Cassava is used as a convenient base for comparative purposes.

	CALORIES	PROTEIN
Cassava	100.0	100.0
Maize	39.1	112.4
Rice	14.7	35.0
Cowpea	6.2	50.0
Yam	38.1	93.5
Sweet potato	6.7	11.2
Plantain	14.2	15.6

Of the two remaining IITA commodities, soybeans makes an insignificant contribution to total production at the present time, and data are not available for cocoyams. Cassava, maize and yams are the major sources of food for the region.

IITA seeks to increase the productivity of family farmers and, particularly in areas where population density is high, the yields from their fields. IITA scientists made the following estimates for major food crops in Nigeria, again using cassava as the base for comparison:

	LABOR PRODUCTIVITY Calories/man-day	YIELD Tons/ha
Cassava	100.0	100.0
Maize	106.8	16.7
Rice	18.6	16.7
Yam	50.8	133..3

Table IV.2 Analysis of IITA's comparative advantage in commodity research

	Projected importance of commodity	Productivity of research	IITA comparative advantage in research
Maize	O	O	H
Rice	O	O	L
Cassava	O	O	H
Cowpea	M	H	M
Yam	H	M	M
Soybean	L	L	M
Plantain	M	M	O
Sweet potato	H	H	L
Cocoyam	L	L	L

Notes:
O = outstanding
H = high
M = medium
L = low

The labor productivity of cassava and maize is high, while high yam yields are offset by its intensive labor requirements. Rice is the least promising crop, in the static sense, but we know that production is driven by strong demand forces, especially in the urban centers.

For the purposes of setting research priorities, the relative importance of the crops was projected into the future, starting with an examination of trends in production over the recent past. IFPRI data on the five food crops that account for about 70 percent of food production in West and Central Africa are presented in table IV.3. The IITA commodities are expanding more rapidly than millet and sorghum, and IFPRI predicts that they, especially maize and rice, are likely to have the breakthroughs to accelerated growth.

Maize. There are now improved technologies for increasing maize production in ecologically suitable areas of West and Central Africa. Support services, stronger national maize systems, and improved varieties can catalyze substantial increases in production.

Rice. Rice's contribution to the increase of food production is substantially larger than its share of output. Although starting from a low base, rice production has increased more rapidly than any other cereal in West Africa over the last 20 years (although imports grew even three times faster). By the year 2000, IFPRI projects that rice may account for nearly one quarter of West African cereals consumption.

Cassava. Cassava cultivation area has expanded rapidly in the forest area and it will remain as the major source of calories for decades to come, especially for the poor.

Sweet potato and yam are projected to make "high" contributions to IITA goals of increasing food production by the year 2000. The sweet potato's short maturity, high yields and wide ecological amplitude make them likely to expand rapidly under the inevitable population pressures of the next decades, a phenomenon already demonstrated in high density countries like Rwanda. Yams are a preferred food and their recent expansion into the Nigerian moist savanna is the basis for the high projection, but cultural associations make it difficult to predict their spread beyond the present yam belt of West Africa.

Cowpea and plantain are projected to sustain their present relative positions in the expanding agricultural economy of West and Central Africa. Each commodity makes important contributions to IITA goals. Cowpeas have a valuable role in production systems because they grow on poor soils, withstand heat and drought well, and nodulate freely with rhizobia. Because there are photosensitive and day-neutral genotypes and a very wide range of growing cycles and plant growth habits, the crop fits well into diverse cropping systems. Barring a major spread of black sigatoka disease, plantains are expected to remain an important source of food, and a stabilizing component of farming systems in the humid forest zone, thus contributing to the research thrust on resource management in that ecology.

Table IV.3 Production trends in major food crops of West and Central Africa, 1961-1980

(percentages)

	Share of all major food crop production		Share of total increase of all major food crops 1961-1980	Annual growth rate 1961-1980	
	1961-1965	1976-1980		yield	harvested area
West Africa					
Maize	8	9	14	0.4	0.9
Cassava	13	15	16	0.1	1.5
Millet/Sorghum	40	37	16	-0.7	1.1
Rice (husked)	4	7	27	1.2	2.7
Total	65	68	73	0.2	1.4
Central Africa					
Maize	14	13	11	-0.9	3.4
Cassava	43	44	46	-0.4	2.2
Millet/Sorghum	11	8	2	0.1	0.9
Rice (husked)	1	2	4	0.0	7.2
Total	69	67	63	-0.4	1.8

Soybean and cocoyam are projected to have low significance to the end of this century. There is much discussion of soybeans' desirable characteristics and growth potential. It could and should become an important commodity in the region, but there is little evidence that it is growing beyond certain isolated special cases. Starting at such a low base, soybeans would remain of minor significance at the year 2000 even if moderate growth were already underway.

2. Productivity of IITA research on the commodity. Differences between commodities in comparative judgements about the future productivity of research arise from two basic considerations:

(a) *The extent to which successful research will influence future production or quality of the commodity.* Here there are two extremes, one hypothetical for IITA's commodities in which biological constraints are relatively insignificant factors, the other exemplified by soybeans in which successful research has already removed the chief biological constraints to production.

(b) *An assessment of the extent to which important biological constraints are "researchable".* This will depend upon the existence and utility of proven research methods, and the time needed to reach research objectives using them. Here judgments will vary primarily between researchable issues, not between commodities, such that a subjective synthesis is necessary to make comparative judgments between crops. For example, we know that methods are available to breed disease resistant cowpeas adapted to cereal farming systems relatively quickly, whereas research methods have yet to be perfected, and it will be a relatively long time before we breed cowpeas resistant to *Maruca* and pod sucking bugs. The overall judgment for these and other researchable issues in cowpeas is that future research has a "high" probability of being productive.

Based upon these considerations, IITA's nine commodities fall into four groups.

(a) Maize, rice and cassava. Future research on maize, rice and cassava will be outstandingly productive. In all three commodities there remains much to be done in the short term using proven methods to breed for resistance to diseases, for product quality, and for adaptation to specific ecologies and farming systems. There is already evidence to suggest that breakthroughs in breeding for resistance to mealybugs and green mites in cassava, and to the parasitic weed *Striga* in maize can be achieved in the medium term. Resistance to stem borers in maize and rice is likely to take longer, but the past history of breeding these crops suggests that these objectives can be achieved with very important consequences for production.

(b) Cowpea and sweet potato. The prospects for productive research on cowpeas and sweet potatoes are high. For cowpeas productive achievements can be expected in a relatively short time from breeding for disease resistance in genotypes adapted to cereal farming systems. But much remains to be done in research on host-plant resistance to insect pests, including collaborative basic research on the biology of the pests and mechanisms of resistance to them. Here is an area of research where both the risks and the rewards are high, but it is one for which IITA

has a obvious comparative advantage. For sweet potatoes there are proven breeding methods applicable to the researchable issues identified in the strategic study. Their impact will be high provided that the expected increase in the significance of the crop in Africa is fulfilled. In the medium term it will not be researchable biological constraints which limit the expansion of the crop, but its more widespread acceptance in the farming systems and diets of communities not presently familiar with it.

(c) Yam and plantain. The productivity of future research on yams and plantains is judged to be "medium" because breeding these crops is technically difficult. Among the yams hybridization is possible, and the frequency of flowering clones has been reported to increase in populations grown from true seed. None the less, choice of parents is constrained by many non-flowering clones in the germplasm collection, and there is much to learn about the cytogenetics of the crop. Breeding *Musa* is difficult and slow. The application of recent developments in biotechnology to the improvement of both these crops holds much promise, and should be pursued.

(d) Soybean and cocoyam. Research on soybeans and cocoyams is judged to have "low" prospects for productivity for opposite reasons. The outstanding feature of IITA's past work on soybean has been the production of high yielding, well adapted genotypes which nodulate freely with the rhizobial bacteria of African soils, and whose seeds remain viable for several months in warm, humid storage. Previously, elite, high yielding soybeans could be grown in Africa only after seeds were innoculated with cultures of Rhizobium, and where seed could be stored from harvest to sowing in controlled environments. Large scale production of soybeans was therefore limited to commercial farms in East and Southern Africa. The achievements of IITA's soybean breeders have overcome these problems and unlocked the potential of the crop for African smallholders, so that, while researchable issues remain to be addressed, there are no important biological constraints to greatly increased production. For cocoyams, though IITA produced seed for the first time from the crop in Africa, its improvement by breeding remains an intractable problem with little prospect of success.

3. IITA's comparative advantage in research on the commodity. By its location in West Africa, its international nature and security of funding, and the excellence of its research programs and their supporting services, IITA could be said to have an undoubted comparative advantage for research on all its nine commodities, and indeed on many more that are not in its mandate.

To develop the Strategic Plan, the institute's comparative advantage was assessed against the background of limited resources, and the need to apply them to greatest effect. It has been noted elsewhere that the TAC suggests a minimum of $3 million each year is necessary for effective research on a single commodity. To apply IITA's resources to greatest effect it was therefore assumed that the Institute would have comprehensive improvement programs on fewer commodities in future than it had in the past.

There are essentially only two other kinds of agricultural research organizations against which to compare the advantage of IITA; the national agricultural research systems (NARS), and the other IARCs. It is an important

objective of the CGIAR to improve the capability of NARS to the point where they will be able to do much of the work now done by the IARCs, whose reseach would then move gradually "upstream". For the present few African NARS have this capability, and IITA has a comparative advantage over them. There are, of course, exceptions to this where IITA's research has produced technologies suitable for extension by NARS and adoption on African farms. Proven crop varieties and the minisett and microsett methods for rapid multiplication of yams are examples.

The following summary shows the basis upon which IITA's comparative advantage has been judged to be "medium" or "low" in table IV.2.

Rice	Expected increase in future size and scope of WARDA's program.
Cowpeas	The capability of ICRISAT in the West African center of cowpea production.
Soybean	Given the resources, the capability of both AVRDC and INTSOY.
Sweet potato	Given the resources, the capability of both CIP and AVRDC.
Cocoyam	The low relative importance of the crop, and the intractability of researchable issues which will require considerable basic research.

On the basis of these analyses, the IITA Board of Trustees selected a small number of key commodities as the primary focus for its commodity research, while deciding to continue research on other commodities only if they have some special relevance to IITA capabilities and goals.

The rationale for this recommendation can be summarized in the following IFPRI statement:

> In the past, rapid growth in smallholder food production - be it in Kenya, Punjab or the Ile de France - has largely been an increased response to already favorable conditions for one or two crops. Increasing productivity is difficult, but research that focuses first on areas where the technical constraints are lowest have the potential for greatest success. Such areas exist within Africa, even in the most arid countries: however, most African countries have diffused their resources over all areas, primarily in response to political constraints. Research efforts on commodities are similarly diffused. The Consultative Group on International Agricultural Research (CGIAR) involving between 15 and 17 percent of all agricultural research in sub-Saharan Africa, is working on 12 commodities in the continent. Breakthroughs in Asia two decades ago came from intensive work on two commodities. This success was the result of interdisciplinary work organized along commodity lines.

Management further recommended that the primary commodities in the IITA research program be cassava, maize, and cowpea. Core resources would also be allocated for continuing research on yams (because of the need for upstream research), on soybeans (because of their future potential), and on plantains (because of their importance and a critical researchable problem).

In summary, the following are the major strategic decisions which will be implemented following the study of commodity improvement.

(a) Three primary commodities. IITA will give primary emphasis to the improvement of cassava, maize and cowpeas.

(b) Three secondary commodities. There will be smaller programs for the improvement of yams, plantains and soybeans.

(c) Rice improvement to be transferred to WARDA. IITA will transfer its mandate for rice improvement to WARDA.

(d) Sweet potato improvement transferred to CIP. IITA's world mandate for sweet potato improvement has been transferred to CIP.

(e) Cocoyam improvement stopped. Cocoyam breeding has stopped. The small germplasm collection and breeding material will be transferred to a competent West African national program.

(f) Integrated pest management. The biological control of insect pests, host-plant resistance and appropriate crop husbandry will be components of a strategy for integrated pest management.

(g) Decentralization. As well as continuing at the Ibadan headquarters, commodity improvement will be decentralized to research substations in key ecologies.

(h) Linkage with farming systems research. A new organizational mechanism to promote the linkage of commodity improvement with resource and crop management research has been established.

(i) Collaboration with African national programs. IITA will consolidate and strengthen its existing linkages with national commodity improvement programs in Africa through the continuing participation of its scientists in training at all levels, in the provision of improved germplasm and technical support, and through the new initiatives described in chapter V.

(j) Collaboration with other CGIAR centers. The Institute will strengthen its links with those IARCs whose global concerns are relevant to its commodity improvement objectives. There will be joint activities with CIMMYT for the improvement of maize in West and Central Africa, with CIAT for cassava in all of Africa, and with AVRDC and INTSOY for research on soybeans. IITA will make available its research support services to CIP for their work on sweet potato in Africa, and to WARDA for the improvement of rice.

(k) Strategic basic research. New arrangements will be made for collaboration with advanced institutes in developed countries for strategic basic research.

(l) Biotechnology. IITA will establish a capability in cell and tissue science and cytogenetics (or, if appropriate, molecular genetics) in support of commodity improvement.

PAST ACHIEVEMENTS

The studies of the commodity programs were greatly influenced by past achievements in Africa, especially breeding crops resistant to some of the most important and widespread diseases in the continent. At the time IITA was established, it was apparent that its commodity research could have the greatest and most rapid impact by developing germplasm resistant to the major diseases and providing this improved material to the national agricultural systems. Much remains to be done to breed for further disease resistance and to maintain the resistance already achieved against new mutant strains of pathogens. However, previous successes at IITA, other international centers and African national programs permit a change of IITA's emphasis in the commodity programs.

Throughout the strategic study, it was clear that two major future challenges for commodity research are: (a) breeding for adaptation to specific agroecologies and cropping systems, and (b) breeding for resistance to insect pests. New kinds of interdisciplinary collaboration are likely to be necessary for both of these objectives. In the former case, a better understanding of the variability of environmental conditions, cropping patterns, and farmers' needs and objectives is important to setting appropriate breeding goals and assessing accomplishments. The research substations and multidisciplinary crop-based systems working groups are designed to meet these needs, as discussed in this and the preceding chapters. In breeding for resistance to insect pests, the long-term strategy will include research on integrated pest management comprising not only host-plant resistance but also biological control and crop management practices designed to minimize the losses to insect pests. In addition to the research at IITA and its substations in these areas, this work will also often involve collaboration with advanced research institutes.

RESEARCH SUPPORT

IITA's six research support units provide essential services to the commodity improvement programs, and are collectively a feature of the Institute that contributes significantly to its comparative advantage in tropical agricultural research. The strategy for research support is to maintain existing units, and to add a capability in biotechnology (described in section G of this chapter) through the disciplines of cytogenetics and cell/tissue research.

Virology. The virology unit conducts research on the distribution, ecology, and pathogenic variation of the viruses causing diseases in IITA's mandate crops, and

on the etiology of the diseases. Through annual surveys, the virologists give commodity scientists current information about the incidence and importance of particular viruses to help develop appropriate resistance breeding strategies. Pure virus isolates are provided to enable breeders to screen germplasm for resistance. New viruses are identified and characterized, antisera are produced, and type virus samples are characterized for reference and comparison. Scientists visiting the unit from African national programs learn the latest techniques in virology. The two virologists supervise postgraduate students, and they participate in all crop production training courses.

Genetic resources. The genetic resources unit collects, evaluates, documents, and preserves the germplasm of food legumes, rice, and root crops in Africa. In collaboration with the International Board for Plant Genetic Resources (IBPGR) the unit has organized more than 40 plant collecting missions in Africa. From those explorations, and with seed samples received from collaborators worldwide, the unit now holds a total of more than 27,000 accessions of germplasm of its mandate crops. It has the responsibility to preserve and document the world collections of cowpea and yam germplasm, and the African land races of *Oryza glaberrima* and *O. sativa.* The modern laboratory and seed storage facilities recently installed with generous support from the government of Italy include two new seed stores for working collections, and a second -20oC store for long-term preservation of germplasm. Seed and information are freely available from the unit to scientists everywhere. The unit gives an annual training course in genetic resources conservation for participants from African national programs.

Biological control. Most of the current activities of IITA's biological control unit were funded until 1988 from extra-core sources, and the unit is therefore known as a "special project." Its past achievements for the control of cassava mealybugs and green spider mites in Africa are summarized with those cassava improvement. While the present project for the control of cassava pests will continue, IITA's future strategy is to incorporate biological control into its core research on the pests of its other mandated crops as a component of integrated pest management, and to investigate the biological control of important weeds.

Biometrics. IITA's scientists are advised by the biometrics unit in the design of experiments and surveys, the interpretation of results, the statistical content of publications, and more generally in mathematical applications appropriate to their work. The unit is also responsible for the statistical content of the Institute's many training courses, and it provides specialist training in statistics and statistical computing.

Analytical services. Each year the analytical services laboratory performs some 20,000 analyses involving more than 100,000 individual assays of soil, plant and water samples for the research programs, and for national research institutes and universities. Soil samples are analyzed for various physical and chemical properties including pH, N, P, K, exchangeable bases and acidity, organic carbon, cation-exchange capacity, and clay, silt and sand content. Plant samples are analyzed for primary and secondary nutrients, and for micronutrients, and water samples (or extracts) for nitrate, phosphate, ammonium, cations, pH, and electrical conductivity.

Farm management. The farm management unit is responsible for the general management and maintenance of three experimental farms in southern Nigeria as a service to the research programs. One is in the forest/savanna transition zone at the Ibadan headquarters, another at Ikenne in the same ecology some 65 kilometers south of Ibadan, and the third at Onne in southeast Nigeria on the acid soils of the humid forest ecology. In total these farms provide 412 hectares for field experiments, with 132 hectares at Ibadan and Ikenne irrigated and able to grow three crops each year.

The farm at Ibadan has 300 hectares carrying two rainfed crops each year. Of these, 100 hectare are irrigated by overhead sprinklers and carry a third crop for the breeders in the dry season. Farm management is also responsible for a seed unit at Ibadan. It processes around 150 tons of seed of improved varieties each year derived from field experiments, which are made available to national programs as foundation seed. The unit also manages a demonstration area at Ibadan where IITA's technologies are shown to more than 2,000 visitors each year; and it supervises the Institute's fisheries, which yield around 20 tons of fish annually.

At Ikenne, there are 32 hectares of irrigated land available for cropping three times each year. The uniformity of the soil there is excellent for field experiments.

The high-rainfall substation at Onne has 80 hectare and provides the Institute's only present facility for field experiments in this important ecology. However, it is intended to expand IITA's capacity for research in this ecology by establishing a second substation, or satellite, at another location in the humid forest zone. This will be specifically for research on resource management and cassava.

In order to help conserve the soil, no-till farming is practiced wherever possible on all three farms, and the farm management unit collaborates with the research staff to investigate methods of mechanized farming that minimize soil degradation.

THE REST OF THIS CHAPTER

The following sections of this chapter summarize the background to these decisions. In view of the decision to transfer responsibility for rice improvement to WARDA, the section on rice is abbreviated, but the full report of the Rice Study Group is included as annex 3 to serve both as a record of the decisions reached concerning future priorities for research on the crop, and as a detailed example of the study process. Each of the other sections begins with a brief discussion of some of the agroecological and other aspects of the commodity's production system that were relevant to decisions on research priorities. The main directions and accomplishments of previous research are then summarized, followed by the discussion of the operational strategies for future research. These discussions relate only to the breeding and related research of the commodity programs. Agronomic and cropping systems research as well as socioeconomic studies are carried out through the crop-based systems working groups, whose research strategies are discussed in chapter III.

B. CASSAVA IMPROVEMENT

IITA has a continental mandate for cassava in Africa, and it has been successful in developing improved varieties and breeding populations that are high yielding, resistant to two devastating diseases, low in cyanide, and popular with consumers. Cassava cultivation has expanded rapidly in the humid forest ecology of West and Central Africa, and it will remain as the major source of food calories for decades to come, especially for the poor. As population increases and marginal lands are brought into cultivation, its importance is projected to increase. There is also great potential for its use as a convenience food for the increasing numbers of people living in West and Central African cities.

In the strategy for cassava priority is given to breeding for local adaptation to diverse ecologies and cropping systems, with increased emphasis on the humid forest zone, where a research substation will be established. IITA will further extend its cassava breeding objectives by establishing a second substation to serve the mid-altitudes of East and Southern Africa, and in response to demand from national programs in West Africa, will breed cassava for the dry savanna ecology. Collaborative links with CIAT for cassava improvement will be strengthened, with emphasis on the more effective use of CIAT germplasm in Africa. There will be continued support to African national root crop research programs. Collaboration with advanced research centers for basic research will receive high priority.

CASSAVA IN AFRICA

IITA has the continental mandate for cassava in Africa, and the crop has primary importance among the commodities in that mandate. It is already the chief source of dietary food energy for the majority of people living in the lowland humid tropics and much of the subhumid tropics of West and Central Africa, providing more than two and a half times as many calories as either maize or yams, the next two most important staple foods in the region (see chapter II). The importance of cassava is likely to grow further, both because of advancing urbanization, and consequent demand growth for foods prepared from cassava, and because of population pressure to cultivate marginal lands. Cassava's ability to be more productive on poor soils than most other crops has been a major factor in its spread and increase, especially in the low nutrient and often acidic soils of the humid forest zone. Its husbandry also requires relatively little labor and allows flexibility in the timing of labor use, which is of great importance whenever labor constraints are significant. Cassava also tolerates drought and recovers well from the damage caused to aerial parts by pests and pathogens. Because the tubers of many varieties keep well in the ground for a year or more, it is a primary food reserve crop in Africa.

The postharvest processing of cassava tubers is labor-intensive, and offers scope for productive research. Indeed, processing labor requirements may equal or exceed those for all other preharvest production activities. With appropriate processing, cassava tubers have great potential as a source of cheap food for urban populations, or, if demand develops, as livestock feed. The prospects for alleviation

of many of the constraints to production by research are excellent, and it is also likely that the uses of the crop can be diversified in such a way that it could significantly improve the welfare of both rural and urban communities in much of Africa.

PAST ACHIEVEMENTS, CURRENT RESEARCH

Cassava mosaic virus disease is an extremely serious constraint to cassava production in Africa. Using the mosaic resistant but poor yielding cassava families developed in East Africa nearly 30 years before, and related work in Nigeria in the 1950s, IITA cassava breeders were able to develop lines that yielded well and were resistant to the mosaic disease. Subsequent research showed them also to be resistant to bacterial blight.

Although these clones were not specifically adapted to particular ecologies or farming systems, and they represented a narrow range of agronomic types and root qualities, the combined resistance to the two most destructive pathogens of cassava in Africa had dramatic impact. The rapid initial spread of the disease resistant material was hindered only by the slow rate of multiplication of cassava planting material and by the restrictions on its movement imposed by national plant quarantine regulations. These barriers have been partially overcome, and disease free clonal material is now transferred in vitro as shoot tip cultures.

Following this major success, the emphasis in the present program is on (a) the quality of cassava tubers; (b) host-plant resistance to mealybugs, green mites and grasshoppers (*Zonocerus* spp.); and (c) quantifying the yield losses caused by major insect pests and pathogens. Tuber quality is assessed in terms of starch quality for incorporation in bread flours, cyanide content, consumer preferences, and skin color. White skinned tubers will be preferred if they can be processed without peeling.

After the introduction from South America of cassava mealybugs and cassava green mites in the early 1970s, and widespread concern about the devastation they were causing, IITA appointed an entomologist to investigate the possibility of controlling them biologically with parasites and predators introduced from their place of origin. After extensive exploration in Central and South America, beneficial insects suitable for this purpose were found. Since then, the biological control of mealybugs and green mites has received extensive donor support. Beginning as a part of the Roots and Tubers Program, the IITA Africa-wide Biological Control Project for Cassava Pests is now a separately funded project. The project conducts intensive biological control research, and it has been very successful in controlling cassava mealybug.* Several predatory mites for the control of the cassava green mite have been reared and tested at IITA, but none has yet been established in the field. The project also runs a training program for technicians and scientists from the African national biological control programs it has helped to establish. This is a pioneering research activity and the first of its kind in the world to attempt biological control on a continental scale.

* A recent evaluation of the project by Winrock concluded that control of the cassava mealybug across the cassava belt of Africa would produce benefits estimated to exceed $3 billion.

OPERATIONAL STRATEGIES

Given the achievements of previous resistance breeding and the development of methods for multiplication of improved planting material, the major current needs are to diversify cassava genotypes to meet the needs of different ecological zones, farming systems, and farmer and consumer requirements. In particular, there will be greater emphasis on cassava in farming systems in the humid forest zone, and on the development of a cassava breeding capability at a research substation in the humid forest. In addition, a substation will be established in East or Southern Africa (linked to the successful East and Southern African Root Crops Research Network) to breed cassava for the mid-altitudes, and resources will be allocated to improve cassava for the dry savanna ecology.

The research agenda for cassava breeding will have the following broad objectives, in order of priority:

1. The selection of plant types suitable for the major intercropping systems in all the major cassava producing ecologies of Africa, with a range of plant architectures and maturities to fit diverse cropping systems and the varying requirements of farmers;

2. The selection and enhancement of tuber qualities suitable for the major types of utilization;

3. The incorporation of resistance to mosaic virus, bacterial blight, and anthracnose, and the enhancement of resistance to mealybugs and green mites, in all improved varieties; and

4. The enhancement of drought tolerance, especially in varieties intended for the dry savanna.

Special attention will be given to international testing, including the transfer of elite, virus-free clones in vitro. In addition, the use of recurrent selection methods for cassava improvement will be emphasized; populations grown from true seed will be screened and recurrently selected in a range of well-defined ecosystems.

Another important component of the program will be a number of more specialized areas of basic research that will be appropriate for IITA's biotechnology unit, described in chapter IV (G), and for collaboration with advanced institutes. Major topics of interest include: studies of the induction of flowering; somatic embryogenesis; production of haploid embryos; screening methods to assess tuber quality; the cytogenetics of related wild species; the biology of cassava symbiotic organisms; and cassava starch quality in relation to weaning diets for infants.

COLLABORATION

Links with CIAT will be strengthened, primarily through the location of a CIAT cassava breeder within the IITA cassava improvement program. Greater use will be made of the CIAT cassava germplasm, and collaboration will include inputs from CIAT on the physiology of cassava (especially with regard to drought tolerance), and on cassava utilization.

A major objective at the inception of root and tuber improvement at IITA in 1971 was to encourage the establishment of national root crops research programs in Africa, and then to strengthen their research capacities. There has since been substantial progress toward achieving this objective, especially in West and Central Africa (notable examples are the vigorous programs now in place in Zaire and Cameroon). IITA's root crops program has supported these developments through training at all levels; through the distribution of improved, disease-free clones as in vitro tissue cultures; through workshops and conferences; by participating in bilaterally funded root crops improvement projects in several countries; and by stimulating the formation of root crops research networks.

IITA will continue to support the development of national root crops research programs in Africa, and will be an active participant in the East and Southern, and the West and Central African, root crops research networks which it helped to establish.

C. MAIZE IMPROVEMENT

IITA will continue a full-scale improvement program for maize because of its importance as a source of food and feed, because of its high labor productivity, and because of its potential for rapid impact. Recent years have seen a significant expansion of maize production in West and Central Africa, and it is expected to become increasingly important as population growth and urbanization intensify demand for easily transported and storable food grains, and as demand for livestock products increases.

IITA's research strategy for maize involves a primary focus on the lowland moist savanna and humid forest ecologies of West and Central Africa. IITA will collaborate with CIMMYT in a joint germplasm development program for these ecologies, which will include work on both open-pollinated and hybrid varieties and efforts to maintain stable resistance to streak virus and lowland rust and blight. A maize research substation will be established in the West African moist savanna for the development of germplasm with emphasis on resistance to the parasitic weed *Striga*. At the Ibadan headquarters methods to screen germplasm for resistance to pests and pathogens and tolerance of other stresses will be refined. In addition, maize scientists will be actively involved in the maize-based systems working group. Collaboration with and support to West and Central African national maize improvement programs will continue, as will active participation in regional maize research networks.

MAIZE ECOLOGIES

Maize in Africa is grown in a number of markedly different ecological regions, in which there are different production constraints and research priorities. The major agroecologies for African maize production include the lowland moist savanna, the lowland humid forest, the mid-altitudes from 800 to 1,500 meters, the lowland dry savanna, and the highlands above 1500 meters.

The lowland moist savanna, or the Guinea savanna zone of West and Central Africa, with a growing period ranging from 150 to 240 days, is thought to have the greatest potential for future maize production in West Africa, and it has the highest priority for IITA's maize program. Over the past decade, maize has increasingly replaced sorghum in the moist savanna. In Nigeria, this followed the release of IITA varieties TZB and TZPB and their promotion by the Agricultural Development Projects, which made seed and fertilizer available to farmers. IITA's emphasis will be on improving maize as a component of low-input smallholder production systems within which farmers are able to improve upon current yield levels through the use of improved varieties, good husbandry and limited use of purchased inputs. However, the full productive potential of maize in the moist savanna (presently 8 to 10 tons per hectare on research plots) cannot be achieved without adequate applications of nitrogen and phosphorous, and sometimes of zinc, manganese, and sulphur.

The lowland humid forest is characterized by high rainfall and humidity and elevations below 800 m. It includes the coastal tropical rain forests of West Africa, the equatorial rain forests of the Congo River basin, and the coastal areas of Kenya, Tanzania and Mozambique. Because of the extended rainy season, two crops of maize can be grown each year in most places,* most commonly in interplanted mixtures with other crops (especially cassava). The smallholders' objective in these cassava-based systems is to optimize the productivity of all their resources – not simply to maximize the yield of maize. The rapid pace of urbanization in much of this ecozone has stimulated demand for fresh (green) maize as well as grain. However, this is a difficult environment for most maize cultivars because of very high disease and insect pressure (especially in the second season), low light intensity during most of the growing season, acid soils and low soil fertility in many areas, and the difficulty of drying and storage because of the high rainfall and humidity.

The lowland dry savanna, or the Sudan savanna, with 400 to 800 mm rainfall, is a marginal ecology for maize production where the major cereals are sorghum and pearl millet. Maximum potential maize grain yields, using available technologies, are 3 to 4 tons per hectare.

The mid- and high altitudes of eastern and southern Africa and parts of Cameroon produce approximately 65 percent of maize in sub-Saharan Africa (excluding the Republic of South Africa). The mid-altitudes extend from 800 to 1,500 m and, where rainfall is adequate, the combination of intense insolation, cool temperatures, and rich volcanic soils enhance maize productivity such that the yield potential may be greater than 10 tons per hectare. Similar yields can be obtained at the high altitudes above 1,500 m, which are characterized by long, cool growing seasons of 6 to 7 months duration.

PAST ACHIEVEMENTS, PRESENT RESEARCH

Research philosophy and approach. Most African farmers who grow maize cultivate their land with minimal resources and low input management practices. Maize yields are generally poor in relation to potential levels (commonly around 1 ton per hectare), because of various environmental and biological stresses and constraints. The main objectives of IITA's maize research program have been to provide these farmers with maize varieties that are (a) better adapted than their present cultivars to the environmental and agronomic conditions under which they grow maize, and (b) resistant to the major pathogens and pests affecting the crop; resistant varieties with the potential for high yields in various ecologies are also expected to diminish farmers' perceptions of risk, and so make an over-all improvement of management practices more economically rewarding.

The development of effective, uniform screening methods is essential for rapid breeding progress. Sources of resistance need to be identified and incorporated into environmentally adapted, high-yielding germplasm. The process of incorporating resistance must continue as new varieties are developed with characteristics that make them better adapted or capable of giving higher yields

* The second is commonly known as late, or second season, maize.

under specific conditions. Finally, the acquired knowledge must be communicated to national maize research programs, and assistance with their dissemination offered.

Population Improvement. Early emphasis in IITA maize improvement was on resistance to two diseases, lowland rust (*Puccinia polysora*) and lowland blight (*Helminthosporium maydis*), which had been recognized for decades as the most important constraints to maize production in lowland West Africa. Working with two composite varieties that had previously been developed in Nigeria and composites from Central America, two open-pollinated lines were developed, TZB and TZPB. These are not only resistant to foliar diseases, but have vigorous growth and respond well to intensified management (such as higher plant populations and fertilizer use). They have spread quickly throughout Nigeria as well as in several other Central and West African countries.

Hybrids. In order to offer national maize programs a wider range of germplasm, the Institute initiated a project for inbred line development in 1979. This was expanded in 1982 to include hybrid development at the request of the Nigerian government. Using germplasm from various parts of the world, IITA scientists have developed vigorous, tropically adapted inbred lines that are resistant to the major diseases and that express good combining ability. The inbred lines are now available to national programs for any of a variety of purposes, including utilization as uniform, homozygous sources of disease resistance, formation of improved open-pollinated synthetics and breeding stocks, and rapid production of conventional or unconventional hybrids. The program has developed hybrid varieties with yields that are more than 25 percent greater than the best available open-pollinated varieties. The hybrids produced by IITA helped lead to the formation of two Nigerian private seed companies in 1984 and subsequently to their successful operation.

The development of open-pollinated varieties and of inbred lines are viewed at IITA as mutually supportive activities. Genetically uniform inbred lines and hybrids gave unexpected benefits when, for instance, differential reactions to *Striga* (1982), zinc/magnesium deficiency (1985), and moisture stress and *Sesamia* (1986) were found in field experiments.

Streak virus resistance. As maize production has spread north into the savanna, fostered by these improved varieties, it has encountered *Cicadulina* leafhoppers, vectors of maize streak virus disease. Often associated with drought or irregular early rains, maize streak virus appears sporadically, but epidemics can entirely destroy a crop. Beginning in 1975, the maize program adopted the goal to find and incorporate stable, multigenic resistance to it in all IITA improved lines. In order to accomplish this, new reliable screening methods had to be developed, and large numbers of the vector had to be reared. Two sources of resistance (one an IITA line, TZ-Y, and the other from a variety developed in Reunion Island) were identified, and an intensive breeding program was initiated. This included testing for the stability of the resistance in as many as 36 African national programs. By 1985, and in collaboration with CIMMYT, high-yielding streak resistant varieties and hybrids with different maturity ranges, grain colors, and grain textures were available for all the relevant ecologies in Africa. The success of this research was recognized by the 1986 King Baudouin Award for International Agricultural Research.

INTERNATIONAL VARIETY TESTING

The purpose of multilocation international variety testing is to distribute improved germplasm to national programs for testing and identification of suitable germplasm/varieties for local use. A secondary purpose is to provide feedback to breeders on the performance of the germplasm and the relevance of the selection goals. Systematic international variety trials were first organized by IITA in 1982 to distribute newly developed streak resistant, open-pollinated varieties to 18 national programs in Africa. In 1987, the Institute distributed 450 maize variety trials of seven kinds to 34 collaborating national programs.

OPERATIONAL STRATEGIES

As a result of the Strategic Planning Study, IITA concluded that a strategy for maize improvement in the region needs to take account of and be based on the following major trends and conditions.

(a) The vast area and large population imply a great potential for increased production and use of maize not only as direct human food, but as livestock feed and for industrial use, provided some of the main production and utilization constraints are alleviated.

(b) Over the next several decades, population growth and urbanization, especially in the humid forest zone, will intensify demand for food grains that can be stored and easily transported (i.e., compared to most root crops), among which maize is likely to become increasingly important. In addition, throughout the region, there will be increased demand for poultry and other livestock products, and consequently for maize as a feed source.

(c) It is expected that the areas in which maize production will increase most rapidly are in the subhumid Guinea savanna and transition (derived savanna) zones. There will, however, also be substantial increases in the humid forest zone, mainly for supply of fresh maize and dried grain to urban centers, particularly if various production constraints inherent to this agroecology can be overcome.

In order to deal adequately with the research priorities of these two ecologies, and to produce technological advances that are appropriate to the farming systems of the region, IITA will continue research at Ibadan for the humid forest ecology, and establish a research substation in the moist savanna. Germplasm development for the region will be a collaborative program of IITA and CIMMYT. This joint germplasm development unit will ensure that full use of global germplasm is made in the development of materials specifically adapted to the constraints and cropping systems of the region. The following are the priority research issues for the main ecologies.

The lowland moist savanna. (a) Development of screening methods and breeding for resistance to the parasitic weed *Striga;* (b) maintenance breeding to sustain resistance to streak virus and to lowland rust and blight; and (c) enhancement of drought tolerance and adaptation to drought stress. Termites are also serious pests of maize, but there is no present prospect of breeding varieties resistant to them.

The maturities and grain types of varieties and hybrids required for the lowland moist savanna, in order of priority, are (a) late white dent and flint, (b) late yellow for poultry feed (grain texture is not important), (c) intermediate white dent and flint, (d) intermediate yellow, and (e) very late white and yellow for regions with rainfall duration of five months.

Striga can be a major parasite of maize in the moist savanna regions of West Africa, and in ecologically similar areas of Central and East Africa, and is likely to become among the most important constraints to increasing maize production in this zone. The plant has always been a serious parasite of several of the traditional crops of the African savanna, attacking sorghum, pearl millet, groundnuts, and cowpeas. Maize is probably more seriously affected than other cereals largely because the crop is relatively new to the region and has not coevolved with the parasite. Awareness of the importance of *Striga* as a maize parasite is also recent because it is only within the last decade that maize has been widely cultivated in the moist savanna of West Africa. *Striga* deserves priority attention as a research issue not only because of the high yield losses it can cause in any one year (ranging up to total crop loss), but also because it can lead farmers to abandon maize cultivation in some fields altogether. Basic research is needed on the relations between the parasite and its host, on possible resistance mechanisms, and on means of developing effective resistance screening methods. Studies of its economic impact are also needed and will be important in the assessment of the viability of various farm-level control measures.

The lowland humid forest. IITA's maize improvement for the lowland humid forest will be conducted from the Ibadan headquarters. Resistance to streak virus and lowland rust and blight diseases have already been combined and incorporated into all IITA varieties for this ecology. In addition to breeding required to maintain this resistance, the research priorities in the humid forest include: (a) development of screening methods and breeding for resistance to the main stem borers, *Eldana* and *Sesamia* , which cause major losses in late-planted or "second season" maize; (b) breeding for resistance to downy mildew, a disease of growing importance which has great destructive potential; (c) breeding for resistance to ear and stalk rots caused by *Botryodiplodia, Fusarium,* and *Macrophomina;* (d) improvement of husk cover; and, (e) research on post-harvest insects, chiefly weevils (*Sitophilus* spp.) but also the greater grain borer (*Prostephanus truncatus*) which has recently been introduced from America and poses a major potential threat to maize in Africa. Lower priority is accorded to research on mottle virus and tolerance of acid soils.

The maturities and grain types required for the lowland humid forest zone, in order of priority, are (a) late white dent and flint, (b) late yellow, for poultry feed, (c) early white dent and flint for the second season and for first season green maize, (d) intermediate white dent and flint, and (e) early and intermediate yellow.

Lepidopterous stem borers are the most important insect pests of maize in Africa. Four species cause significant yield loss: *Sesamia calamistis, Eldana saccharina, Busseola fusca,* and *Chilo partellus.* The first three are African in origin and are present in most countries of sub-Saharan Africa, while the latter is Asian and only recently introduced to eastern Africa. Host-plant resistance, combined with good agronomic practice, is seen as the most economical, effective, and environmentally sound means of controlling borers and limiting their economic impact. Resistant varieties could help overcome the high losses commonly suffered in second season maize in the humid forest, and thus increase maize production in

these regions. Special research emphasis will be on perfecting methods to screen germplasm for resistance, particularly to the species of African origin, and on devising reliable methods to assess the damage they cause. IITA will also investigate the potential of the biological control of these pests of maize as a component of integrated pest management.

Downy mildew in Africa, caused by the fungus *Peronosclerospora sorghi*, is already present in ten countries, and it appears to be spreading. It is usually the most important production constraint in the areas in which it occurs, and it is acknowledged as the most important maize disease in Southeast Asia. Little is known about its epidemiology in Africa, nor about its alternate hosts. However, sources of resistance to the disease developed by national programs in Asia and from CIMMYT have been incorporated into adapted and productive maize varieties for the humid ecologies of West and Central Africa.

Other ecologies. In the strategic planning study IITA also considered the priorities among research issues in three other ecologies, and recognized that maize improvement in them all will benefit from common access to germplasm, and from a range of common "pre-breeding" activities. Among examples of the latter are the maintenance of wild populations of *Cicadulina* and of genetic diversity in the streak virus, and research to mass rear stem borers, and then to develop effective methods to screen for resistance to them.

The lowland dry savanna includes a progression from the moist savanna to the semi-arid tropics. Maize varieties for it need to be of short duration, and in addition to drought, will encounter similar factors to those which limit production in the moist savanna. IITA and CIMMYT will provide support to maize research in this ecology through links with the SAFGRAD Maize Research Network.

The highest research priority in the **mid-altitudes** is to breed combined resistance to mid-altitude rust and blight and to streak virus diseases. Ear and stalk rots, drought, soil acidity, the stem borers *Busseola fusca* and *Chilo partellus*, and maize mottle virus are other potential researchable constraints to production. Highest priority is given to late white flint and dent varieties, then to intermediate and early maturities. IITA has conducted maize research on some of these issues at mid-altitude sites in Cameroon, at Jos in Nigeria, and in Zimbabwe (in collaboration with CIMMYT). Maize production in the **high altitudes** is chiefly limited by cool temperatures, cool-climate foliar diseases, ear and stalk rots, the stem borer *Busseola fusca*, low soil fertility, and soil erosion. Late white flints and dents are required for this ecology. IITA does not plan to work on maize for the high altitudes.

COLLABORATION

As well as the full integration of maize improvement by IITA and CIMMYT in West and Central Africa, support to national maize programs in the region will continue to have high priority. It will be provided through the exchange of germplasm, through training and technical support, by visiting scientists from national programs working with the IITA/CIMMYT team, and through active participation in maize research networks.

D. COWPEA IMPROVEMENT

IITA will continue its cowpea breeding program because the crop is second only to groundnuts as a food legume in West and Central Africa, and because of its importance as a nitrogen-fixing legume in the widespread cereal farming systems of the Sudan savanna and Sahelian zones of Africa. Resistance to most of the major pathogens of cowpeas in Africa has been found and incorporated into improved varieties. With access through collaborative basic research to recent advances in plant improvement, there are prospects for success in breeding for host-plant resistance to insect pests that would have a dramatic impact on cowpea production by African smallholders.

The geographical focus in the future strategy for cowpea improvement will be on tropical Africa with emphasis on West and Central Africa. Priority among objectives will shift from breeding determinate, erect types suitable for sole crop cultivation to photosensitive varieties adapted to the cereal intercropping systems of the West African savanna. Enhanced host-plant resistance to insect pests will be a major objective of all cowpea breeding at IITA.

Support to national grain legume improvement programs in Africa, and collaboration with ICIPE for research on the insect pests of cowpea, and with ICRISAT for research on cowpeas in sorghum/millet systems will continue. New links will be established with advanced laboratories for basic research on host-plant resistance to post-flowering pests.

IN CEREALS-BASED FARMING SYSTEMS

Grain legumes of various kinds (including *Phaseolus* beans and groundnuts as well as cowpeas and numerous other native and introduced species) are important elements of most African farming systems as well as in African diets. In most of West Africa, particularly throughout the savanna zones, cowpeas are an important nitrogen-fixing component of sorghum and pearl millet cropping systems, and second only to groundnuts as a food legume. Their range as an important protein rich food source extends even farther, including much of the humid forest zone, to which large amounts of cowpeas are traded from the savannas. As a result, they are an important income source as well as food crop, and in addition, cowpea haulms are widely used for livestock feed.

There are two broad agroecologies and cereal farming systems in which cowpeas are chiefly grown in West Africa: (a) the pearl millet system of the Sahelian zone, and the sorghum and pearl millet systems of the dry or Sudan savanna; and, (b) the sorghum, pearl millet, and, more recently, maize systems of the moist (Guinea) savanna and forest/savanna transition zones. The main differences among these, and in the role and problems of cowpeas in particular, relate to latitudinal variation in the lengths of the growing season (that is, the duration of rainfall), ranging from two to three months in the north to five months

or more in the southern savanna. A range of improved cowpea varieties adapted through their response to photoperiod to these varying lengths of season is needed. In general, as a crop very tolerant of drought and heat, cowpeas are a major component of the dry northern farming systems, whereas in the southern moist savannas, farming systems are more complex, and cowpeas are relatively less prominent. It has been estimated that as much as 80 percent of West African cowpeas are grown in mixtures with sorghum and pearl millet, in most cases interplanted in an apparently random fashion. Because they have coevolved with the cereals over many years, they are well adapted, both physiologically and morphologically, to this kind of husbandry.

Present cereal cropping systems are expected to change as improved germplasm of cereals and legumes as well as other new technologies become available and as increasing population pressure demands more intensive land use and greater productivity from farm labor. Examples of such change include the trend from sorghum to maize in much of the moist savanna, the increased utilization of wetland areas, and the gradual change from the traditional, somewhat random mixtures of cereals and legumes towards more structured and potentially more productive cropping systems. These may involve monocropping in some cases, or strip cropping, which preserves the multiple outputs of the traditional system but in a more structured fashion, or various forms of relay cropping. Any of these may be more suited to realizing the yield potentials of improved germplasm and other new technologies (including some mechanization and the use of agricultural chemicals), which can both be more profitable and can alleviate the land use pressures on the traditional systems.

The principal biological constraint to cowpea grain production in most African farming systems is the damage caused by post-flowering insect pests. If this constraint can be alleviated, cowpea production may increase not only in those areas in which it is already grown, but it may also spread to new areas, where it can contribute to improved nutrition as well as increased incomes. However, progress in pest resistance research faces many obstacles and will require methodological as well as scientific breakthroughs and significant supportive work.

PAST ACHIEVEMENTS, CURRENT RESEARCH

Since the Grain Legumes Improvement Program was established in 1970, it has made significant progress to improve cowpeas. Advances in breeding have been based upon a large collection of germplasm maintained by IITA's Genetic Resources Unit, which is mandated by the CGIAR to hold the world collection. It now contains around 12,000 accessions.

Using this pool of genetic diversity, the grain legume program has been active in searching for sources of resistance to the many diseases of cowpeas, with special emphasis on breeding varieties with multiple resistance. The transition zone environment of Ibadan has been a productive location for this research because of the intense disease pressures which occur there. A second major objective has been to identify resistance to the main insect pests of cowpeas, including especially the storage weevil, aphids, flower thrips, and pod borers and bugs. In some cases, notably the storage weevil and aphids, significant levels of resistance have been found and incorporated into elite varieties. In others, none or only partial resistance has been identified, and the search for good sources continues. Altogether,

sources of resistance or partial resistance to the following pathogens and pests have been identified.

Fungi:	- Cercospora leaf spot (*Pseudocercospora cruenta* and *Cercospora canescens*) - Septoria leaf spot (*Septoria vignae*) - Web blight (*Rhizoctonia solani*) - Brown blotch (*Colletotrichum capsici*) - Scab (*Sphaceloma* spp.) - Anthracnose (*Colletotrichum lindemuthianum*)
Bacteria:	- Bacterial blight (*Xanthosoma campestris* pv *vignicola)* and bacterial pustule (*Xanthomonas* spp.)
Viruses:	- Yellow mosaic - Aphid borne mosaic - Golden mosaic
Insects:	- Leafhoppers (*Empoasca dolichi*) - Aphids (*Aphis craccivora*) - Thrips (*Megalurothrips sjostedti*) - Bruchids (*Callosobruchus maculatus*)

Elite varieties combining many of these resistances have been distributed to national programs throughout sub-Saharan Africa and to countries in Latin America and Southeast Asia.

The breeding focus in recent years has been on erect and semi-erect, early maturing, photo-insensitive cowpeas suitable for sole crop production using insecticide. Breeding lines such as the semi-erect TVx 3236 have been adopted by farmers in northern Nigeria using ultra-low-volume electrostatic crop sprayers. Because this variety flowers over a short period of two weeks and is resistant to low populations of thrips, two or three applications of insecticide suffice to control post-flowering pests, and grain yields of 1.5 tons per hectare or more are attained by smallholders.

Other erect varieties such as IT82E-60 and IT82D-889 mature in as few as 60 days after sowing, and they have been adopted for cultivation in rice fallows in the Philippines, parts of Southeast Asia, and a few restricted areas (such as Bida) in Nigeria. They are sown on paddies immediately after the rice harvest and reach maturity using only the residual water in the soil, often producing a crop where none had been grown before. Their usefulness is being further explored by IITA's rice-based systems working group (see Chapter III), which is concentrating on improvement of farming systems in the inland valley ecosystem.

Further improvement of sole crop cowpeas for Africa currently involves attention to seed quality, which is largely a matter of seed size, testa texture and testa color (large white or brown seeds with rough testas are preferred in the West

African savanna zones); and continued breeding for multiple resistance to pests and pathogens, including the incorporation of storage weevil resistance in all elite varieties.

Cowpea improvement has recently included the development of dual purpose seed/forage varieties suitable for relay or strip cropping with cereals. This work will become more important in the future. There is also potential for vegetable cowpeas, grown for their fresh, immature pods, which are widespread in Southeast Asia and Oceania. Although they are not currently widely grown in Africa, they have potential in the humid forest zone. Non-climbing varieties have been bred at IITA that produce good yields without the trellises needed to grow existing varieties. There is scope for improved disease resistance in vegetable cowpeas, especially if they are to be adopted in the humid forest zone.

Collaboration with national programs in Africa. Since 1970 support to African national programs has taken many forms. Early efforts involved a gradual expansion of variety testing in partnership with national programs; the location of IITA scientists with national programs to serve a country or a region; and both headquarters-based and in-country training programs, including postgraduate research training. More recently (1986-87), 20 African countries received cowpea and soybean germplasm from IITA as international trials or as segregating lines, and 18 African countries have recommended IITA materials for release to farmers. Regional coordinators were located in national programs in Zimbabwe for southern Africa, in Tanzania for eastern Africa, and in Kenya (at ICIPE) for northeastern Africa. An IITA cowpea breeder is located at the ICRISAT Sahelian Center at Niamey, Niger to serve those West African countries where cowpeas are important in millet-based farming systems. Until resident research ended in 1988, IITA provided a team of scientists to SAFGRAD to develop cowpeas adapted to the semi-arid ecology where sorghum is the predominant cereal, and will continue to provide the coordinator of the SAFGRAD Cowpea Research Network (with headquarters at Ouagadougou, Burkina Faso). IITA also supports a cowpea breeder who assists the Ghana national program to develop cowpeas for maize-based cropping systems in collaboration with CIMMYT. Finally, the Institute is negotiating with SACCAR to locate a team of four scientists in Maputo, Mozambique in 1988 to give regional support to the SADCC countries for cowpea (and soybean) improvement.

OPERATIONAL STRATEGIES

The strategy for cowpea improvement will continue to give high priority to pest and disease resistance. However, there will be a significant change from the policy of breeding varieties for grain production as sole crop with use of insecticides. Although the latter has been successful, it is highly dependent on the cost and availability of insecticides and sprayers, and it is likely that the majority of cowpeas in Africa will continue to be grown in mixtures with cereals without the use of insecticides to control post-flowering insect pests. In addition, breeding objectives will take into account the importance of cowpea haulms, which are a source of animal feed in most of the cowpea growing regions of West Africa. Thus, the major thrust of future research will be to breed varieties that are well adapted to the cereal farming systems of the African savannas and that meet the dual needs for grain and fodder.

Given this general objective, the main researchable issues for cowpeas in cereal mixtures include: (a) their morphological and physiological adaptation to interplanting with cereals in a range of environments with varying lengths of growing period; (b) the identification and incorporation of multiple pest and disease resistance into adapted varieties; (c) the nitrogen economy of the cereal/legume systems in terms of biological nitrogen fixation; and (d) the basis and improvement of drought tolerance in cowpeas, especially for the millet farming system of the semi-arid zone. IITA's strategy to improve cowpea production in these cereal-based systems involves situating the principal cowpea breeder and supporting scientists (including a physiologist and a pathologist) at a research substation in the savanna zone, where they will also collaborate with ICRISAT for farming systems research on cowpeas in cereal systems.

The research program of this substation will have supportive basic research and other technical services from the Ibadan headquarters and possibly from other collaborating institutions. This support will be mainly in the areas of genetic resources, hybridization, rapid advancement of breeding generations, virology, entomology, and other general research services. Some of the specific needs include the following.

(a) The search for host-plant resistance to cowpea pests will involve three essential strategic components: (i) the refinement of existing methods and the development of new ones to identify better sources of resistance, which will require substantial research on the biology and rearing of the pests; (ii) the extensive collection by the genetic resources unit of new germplasm, especially of wild relatives in Africa, and the intensive evaluation of both existing and new collections and of breeding materials; and (iii) collaborative basic research for the study of pest biology, wide crosses, resistance mechanisms, and innovative screening methods. These activities will be carried out at Ibadan or at collaborating advanced laboratories. If resistant material is identified, it will be used for adaptive breeding at the savanna substation.

(b) As a relatively less significant activity at the Ibadan headquarters, there will be continued effort to improve seed quality and resistance to the major field and storage pests in elite materials already bred for grain production as sole crops.

(c) As a lower scale activity at the Ibadan headquarters as well as at a forest zone substation (to be established primarily for resource management research and cassava breeding), the resistance of vegetable cowpeas to the diseases of the humid zone will be improved.

(d) Basic and applied research will be conducted on the biological control of the post-flowering pests of cowpeas as part of the Institute's strategy for integrated pest management.

E. YAM, PLANTAIN AND SOYBEAN

IITA will continue small, well focused improvement programs on yams, plantains and soybeans because it has been strongly urged to do so by the leaders of West and Central African national programs, and because there is a potential for strategic basic research to overcome some of the technical barriers to breeding yams and plantains which have previously blocked progress.

The on-going yam breeding program and the collection and conservation of yam germplasm will continue, as well as basic research in collaboratrion with advanced laboratories and in IITA's biotechnology unit.

A program to breed plantains resistant to black sigatoka will be initiated, while at the same time resistant East African cooking bananas will be identified for introduction to West and Central Africa. Other breeding objectives will also become important later. Collaboration with the International Network for the Improvement of Banana and Plantain (INIBAP) will continue, and links will be established with plantain breeders in Central America and the Caribbean.

The strategy for soybean improvement is to maintain a capability to respond quickly should the desired adoption of improved varieties take place on a large scale. There will be continuing improvement of elite germplasm, and the genetic resources of soybeans, which have been gathered at IITA because of their value to African breeding programs, will be maintained.

YAM

Yams are important throughout much of coastal West Africa, where some 60 million people obtain more than 200 dietary calories per day from them. West and Central Africa produce 93 percent of the world's yams, and of this amount, 77 percent is grown in Nigeria. In view of their importance in West Africa, and because there are good prospects that basic research will lead to breakthroughs which will enhance the productivity of yam breeding, the Institute will continue its breeding program and its collection and maintenance of yam germplasm.

Links with advanced research institutes in other parts of the world for collaborative basic research will be an essential aspect of the stategy for yams. The purpose of this collaboration will be to develop effective breeding methods through research on reproductive biology (especially the induction of flowering), the cytogenetics of *Dioscorea*, somatic embryogenesis, and the production of haploid embryos to overcome the restrictions on breeding imposed by the high and complex levels of polyploidy in the genus. Breeding objectives will be limited until there are sufficient scientific breakthroughs from this basic research.

Yam breeding began at IITA in the late 1970s, first with the refinement of techniques, originally developed at the University of Accra, Ghana, to germinate yam seeds and grow seedlings, and then with the development of methods to hybridize flowering clones. These were major research achievements. Simply by growing

populations from seed derived from uncontrolled pollinations, vast amounts of genetic diversity were exposed for selection. Unfortunately, many clones of yam never flower, especially those of the water yam, *Dioscorea alata*, and among those that do there are dioecious, monoecious, and hermaphrodite forms.

Despite the complex reproductive biology of yams, the present program makes crosses, and grows up to 10,000 seedlings annually for clonal (F_1) selection. Selection criteria are chiefly disease expression, storability, utilization potential, consumer acceptability, and tuber shape. In collaboration with IITA's genetic resources unit, the program collects, maintains, and evaluates yam germplasm. It is studying the storage pests of yams; nematode populations and the effects of nematode destroying fungi as biocontrol agents; the cultural control of yam viruses; meristem culture, virus indexing, and in vitro distribution of clones; the chemical and physical properties of yam flour and starch in relation to consumer preference; the effects of day length, light intensity and growth regulators (GA3) on flowering; and the effects of intercropping on the growth and yield of yams.

The main breeding objectives for yams include minimizing staking needs through improved disease resistance and changes in plant habit; finding resistance to nematodes, yam beetles, mosaic virus, and storage rots; and breeding tubers whose shape makes them easier to harvest.

PLANTAIN

IITA will conduct research on plantains because they are an important component of farming systems in the West and Central African humid forest ecology, and because there are good prospects that critical constraints to production (notably black sigatoka disease) can be alleviated by research. It has been estimated that about 40 million Africans obtain more than 200 dietary calories per capita per day from plantain fruits.* There are various types of bananas and plantain cultivated in Africa and other parts of the world. These vary in their genomic constitutions as follows.

Dessert bananas	AAA
East African cooking bananas	AAA
Plantains	AAB
Bluggoes and Sabas	ABB

"True" plantains, with the genome AAB, are predominant in West and Central Africa (although the FAO definition of plantains in Africa includes the East African

* The word "plantains" is here used to include the Bluggoes of lowland East Africa and the "cooking bananas" of Uganda as well as the classical "plantains" of West Africa. In this broad sense, the crop is important in Uganda, Rwanda, Burundi, Kenya, Tanzania, Gabon, Congo, Zaire, Cameroon, Nigeria, Ghana, Côte d'Ivoire, and Guinea.

cooking bananas). The crop came to Africa from Asia. It is not clear why cooking bananas (AAA) have become predominant in East Africa, while plantains (AAB) predominate in Central and West Africa. IITA confines its research to the AAB genome plantains.

Plantains grow well in the equatorial forests, and they extend into the transition zone between forest and savanna. They are often cultivated in association with other crops, such as oil palms, and provide shade for young tree crops, including cocoa and coffee. Plantains are thought to be among the most conservative of crops in terms of natural resource degradation in areas of very high rainfall. Labor productivity in growing them is high. In the first year of cultivation yields as large as 20 tons per hectare can be obtained with a labor input of 100 person-days. Subsequent yields in West Africa decline except when the crop is grown with the continuous addition of organic mulch, a practice which characterizes plantain culture in compound, or home, gardens.

Research on plantains at IITA began in 1973. Early work was located at Ibadan, with associated activity in Côte d'Ivoire, Nigeria, Ghana, Gabon, Zaire, Guinea, and Cameroon. Later, the center for IITA research was transferred from Ibadan to Onne where there are now two scientists working on a collection of cultivars, in-vitro preservation, international transfer of material, "yield decline" syndrome (which occurs when the crop is not grown with continual mulching in compound gardens), rapid multiplication, plantains in the alley farming system, and nematodes.

Research by IITA is linked to work in Honduras and elsewhere through INIBAP. With its headquarters at Montpellier, France, INIBAP coordinates plantain and banana research worldwide and plays a major role in the transfer of germplasm and information. For example, INIBAP coordinates the West African Regional Cooperative for Research on Bananas and Plantains (WARCORP). The Institute participates in this regional research network.

The main constraints to increased plantain production are:

(a) Black sigatoka disease;

(b) Yield decline: nematodes and other pathogens affecting the roots are implicated, but basic nutrient problems may be involved in some situations;

(c) Banana weevil/borer;

(d) Slow suckering, which increases costs and restricts the availability of planting material;

(e) Lodging, or "tip over", caused by "high mat" (elevation of the corm above the soil surface);

(f) Seasonality in marketing and prices;

(g) Fruit perishability, and the concomitant need for improved storage and preservation (processing).

At present, black sigatoka (caused by the fungus, *Mycosphaerella fijiensis*), is the overriding constraint to future plantain production in Africa. The fungal

spores are dispersed by wind and water and are thus beyond the control of plant quarantine measures. Losses can be so high that the crop is no longer economical to grow. The disease was recently introduced to Gabon from Asia, and it has since spread rapidly to the north, first to Cameroon, and within the last year to Nigeria, Ghana, and Côte d'Ivoire. When black sigatoka reached Latin America some years ago, it had a devastating effect on plantain production. The impact in Africa will be very serious if the disease remains unchecked.

Breeding for resistance to black sigatoka is a costly but potentially highly rewarding endeavor, and there are reasons to be optimistic about the prospects for success. The only currently active breeding program on plantains is under the auspices of the Honduras Foundation, which was formerly operated by the United Fruit Company. This program emphasizes dessert bananas and devotes only a small proportion of its resources to plantains. However, they have had some success achieving resistance to black sigatoka in bananas, which suggests that resistance in plantains may be achievable. At present, there is no breeding capability for plantains within Africa. The development of such a capability would be important not only for work on sigatoka resistance, but would also enable plantain improvement in a more general sense, including improvement in yield, stature, and other needed attributes.

The major production constraint imposed by black sigatoka will be addressed through two short-term research activities as well as a longer term strategy. First, collaboration will be established with the Honduras Foundation with assistance from INIBAP. The products of the Foundation's breeding program in West Africa will be screened for resistance by importing cultures in vitro. Secondly, East African cooking bananas will be screened for resistance to the disease so that a potential alternative to plantains in West and Central Africa is available in the event that the impact of the disease is severe enough to reduce plantain production markedly. For the longer term, IITA will seek to establish a plantain breeding capability with a core-funded team including a breeder, pathologist, and physiologist. If this can be accomplished, it would be possible to undertake breeding for other objectives as well, including dwarfism, improved harvest index, resistance to nematodes, and avoidance of yield decline.

SOYBEAN

While there are at present no significant biological constraints to the production of soybeans on family farms in suitable African ecologies, it has not yet been widely adopted. However, because of the potential of the crop for production and processing by smallholders as a source of protein food and oil, IITA will continue a small breeding program, and will maintain its germplasm collection in order to be able to respond rapidly should the desired adoption occur.

Unlike cowpeas, soybeans were introduced to West and Central Africa, although there are some areas in Nigeria and elsewhere where they have been planted since the 1930s. Recently, there has been greater interest in soybean production in a number of areas, partly because of new uses and markets (especially for locally produced vegetable oil), and partly because research advances have overcome some of the main obstacles to their cultivation in Africa. The devastation of the West African groundnut crop by rosette virus and drought in the 1970s has created an increased demand for soybeans as a source of vegetable oil, and they have also begun to be more

widely used in production of local food flavorings (replacing to some extent the traditional use of the seeds of *Parkia* for this purpose in parts of Nigeria). In addition, soybeans have potential both as a source of animal feed and to enhance human nutrition, particularly as appropriate processing methods and new products are developed and extended to rural and urban areas. Moreover, they are at present subject to less disease and pest pressure in the moist savanna and transition zones than cowpeas and other food legumes. If the desired adoption of the crop does occur in West Africa, it is likely to become most important in these ecologies, where maize also has its greatest potential.

Prior to IITA's research achievements, high-yielding soybeans developed in the United States of America and elsewhere could not be grown in Africa without rhizobial inoculation, an expensive and technically complex treatment generally beyond the means of African smallholders. Although some indigenous rhizobia are symbiotic with legumes such as cowpeas and groundnuts, they could not be utilized by the imported soybean varieties. An established Nigerian variety ("Malayan") that nodulates well with indigenous African rhizobia, was used as the source of this trait. Promiscuous nodulation was transferred from it to high yielding varieties which have agronomic characteristics appropriate for African farming systems.

The second main constraint to soybean cultivation on African family farms has to do with seed longevity. In the warm, moist tropics, soybean seeds tend to lose viability soon after harvest, and long before the next planting season. After a number of years of work, seed longevity has been successfully bred into elite soybean lines which readily nodulate with indigenous rhizobia, thus making available to African smallholders the means to produce this high-protein food crop.

The principal objective of soybean research will be to incorporate these previous successes – promiscuous nodulation and seed longevity -- into otherwise agronomically superior lines. In addition to grain yield, desired characteristics include resistance to lodging, pod bugs, and shattering. Aside from pod bugs, pests and diseases are not currently constraints to soybean production in the West African moist savanna, although it remains to be seen whether this will change if the crop becomes widely grown.

F. RICE IMPROVEMENT

The strategy for rice improvement is to support the development of the rice research capability of WARDA, and eventually to transfer to it all of IITA's rice improvement activities. Subsequenly IITA will retain only its responsibility for the collection, preservation and study of the genetic resources of rice in Africa, including pre-breeding research on *Oryza glaberrima* and its wild relatives with a view to their use by rice improvement programs.

Until the transfer of responsibility to WARDA has been made, IITA will continue to breed rice for the inland valley and hydromorphic ecosystems .

Transfer to WARDA. By the end of 1991, IITA will have transferred to WARDA its rice improvement activities, and its responsibility for the International Rice Testing Program for Africa. Thereafter the facilities developed at IITA for rice improvement, especially research support services and the irrigated rice fields, will be available for use by WARDA. IITA will collaborate with WARDA to conduct resource and crop management research in the inland valley ecosystem, and will continue to collect and preserve the genetic resources of rice in Africa, to duplicate the collections at IRRI, and to conduct pre-breeding research on African rice.

IITA strategic study of rice. Following the same pattern as the strategic studies of maize, root crops and grain legumes, the rice study examined the present and projected economic importance of rice in Africa, rice ecologies, and constraints to production, all with a view to establishing priorities for future rice improvement.

The rice study group report was written without regard to future responsibilities for rice improvement among the international centers. It serves as an impartial assessment of research priorities and as an example of the detail of the study process, and is therefore reproduced in full in annex 3 to the IITA Strategic Plan.

G. BIOTECHNOLOGY

Several of the plant breeding objectives having high priority in the IITA Strategic Plan are not easily achieved by conventional breeding. Among these are host-plant resistance to insect pests, often requiring the transfer of resistance genes from wild to cultivated plants, and black sigatoka disease of plantains. New approaches to crop improvement are also likely to facilitate more rapid advances in the improvement of yams and cassava.

The Institute will therefore develop a capability to assess the relevance of recent advances in cell and tissue science and molecular genetics, and apply those which are appropriate to its research, either directly or through collaboration with other organizations. To this end a cytogeneticist with knowledge of molecular genetics, and a scientist familiar with recent developments in cell and tissue research, will be appointed to form a biotechnology unit in association with IITA's existing virologists and microbiologist.

POSSIBLE APPLICATIONS

Although conventional plant breeding has had and continues to have great impact on genetic improvement, there are obstacles to rapid improvement, particularly in the case of interspecific hybridization wherein it is often difficult or impossible to transfer pest or disease resistance genes from wild species. In some cases these obstacles can be overcome by relatively simple techniques such as fertilization in flower buds, in vitro fertilization, and embryo rescue. For the vegatatively propagated crops, micropropagation techniques, already widely used at IITA, hold interesting possibilities as a means to increase genetic diversity through somaclonal variation, provided that regeneration of new plants is possible. New techniques involving molecular genetics may be applicable to some of the more intractable breeding problems faced at IITA.

Cowpeas. Among the most destructive insect pests of the cowpea are the pod borer *Maruca*, and three kinds of pod-sucking bugs. The wild species *Vigna vexillata* is apparently resistant to them all, but it has proved impossible to obtain progeny when it is hybridized with cultivars. Collaboration with advanced research institutes in Europe and the United States of America is already in progress to address this problem. Studies of the histology of embryo development following the cross are expected to provide information that will make in vitro fertilization and embryo rescue possible. Work is also under way to investigate recombinant DNA techniques to transfer desirable traits from wild to cultivated cowpeas. In Italy, protoplast isolation and multiplication techniques have been developed, somatic fusions have been made, and tolerance of cowpeas to abiotic stresses (e.g. aluminium toxicity and drought) is being studied on protoplasts and free cells.

Plantain. IITA is well advanced in the use of micropropagation techniques for plantains. Several somaclonal variations have been produced and regenerated, and there are prospects for collaborative work to increase this variability through the use of mutagenic agents. It has been suggested that an appropriate method for seeking resistance to black sigatoka will be through alien gene transfer by assymetrical somatic fusion. Further research is needed to produce and isolate protoplasts from wild and cultivated species in order to investigate this approach.

Cassava. In vitro multiplication methods, with or without mutagens, is a possible source of somaclonal variation in cassava. Somatic embryogenesis techniques have been developed recently. Protoplasts can be isolated and multiplied to form callus tissue, although regeneration has so far proved to be difficult, and is an area for collaborative basic research. Cytogentic studies of cassava and its wild relatives will be important for new initiatives in cassava breeding.

Yam. Cytogenetic research will have high priority as support to the yam breeding program. Indeed, progress will depend in part upon a much better understanding of the nature of polyploidy in the genus *Dioscorea*. Research on micropropagation, or the regeneration of plants from callus tissue, is a possible source of variation in those species where sexual seed is presently difficult or impossible to obtain.

Maize. A possible line of research in the search for resistance to *Striga* is the induction of mutants by irradiation of microspores, followed by the production of haploid plants to be screened for their inability to produce strigol, the maize exudant which stimulates the germination of *Striga* seeds.

Virology. Monoclonal antibodies are currently used for the specific detection of viruses at IITA, and for IITA by collaborators.

Microbiology. IITA has a well equipped microbiology laboratory where research on nitrogen fixation is in progress. This is an area where more active collaboration with advanced laboratories will be pursued.

V. INTERNATIONAL COOPERATION

The goal of international cooperation activities is to strengthen the capability of national agricultural research systems to screen and generate agricultural technology in order to satisfy their own needs. IITA has the largest portfolio of special projects to develop partnerships with national programs in the CGIAR system. This has enabled the Institute to engage in a wide range of collaborative activities that extend technologies to specific agroecologies and build national systems throughout Africa. Since 1972 IITA has trained about 5,000 Africans, mostly technicians, in group courses, but 7 percent have been scientists receiving research training for postgraduate degrees. IITA scientists work with IITA alumni who are rapidly moving into key positions of responsibility in African national systems. Large institution-building projects in Zaire, with 14 scientists, and in Cameroon, with 16 scientists, are strengthening the capacity of those countries to conduct adaptive research.

The research described earlier is conducted in close collaboration with scientists from national agricultural research systems. IITA has additional specific mechanisms to promote partnerships and national systems – research liaison scientists, training, resident scientist teams, networking, and information services. Plans for each of these activities will be presented after a discussion of African national agricultural research systems.

NATIONAL AGRICULTURAL RESEARCH SYSTEMS IN AFRICA

There has recently been a significant expansion of agricultural research in the developing countries after an initial, premature emphasis upon agricultural extension. The simple transfer of existing technology developed for temperate conditions had priority in the 1950s because it implied rapid results and was less costly than building a research system to produce relevant technology. But as awareness grew that extension without relevant technology was empty, the global balance of expenditures has now shifted from agricultural extension to agricultural research. Research expenditures as percentage of agricultural GDP increased from 0.3 percent in 1975 to over 0.5 percent at present, the target for 1985 suggested at the World Food Conference a decade earlier. The number of agricultural scientists in the developing countries doubled in the 1970s. Third world expenditures on agricultural research and numbers of scientists are well ahead of internationally accepted planning targets.

Nevertheless, national research systems are at very different stages in the development of their capabilities. Agricultural research in Africa has had less impact than has had research in other developing regions. This is partly explained

by the diversity of African ecologies, poorly developed infrastructure, and government policies that have tended to depress agricultural development. In its West Africa agricultural research review (February 1987), the World Bank provides an overview of the special problems faced by many West African countries:

> Most countries are too small to finance their respective national research on a scale needed to meet their total requirements. Small countries cannot individually and independently support research on their agricultural activities at levels required for sustained progress. Of the 24 countries of the region, six have populations of less than 1.0 million each, eight lie between 1.0 and 5.0 million, seven are between 5.0 and 10 million. Further, ecological variations subdivide most countries into several zones of crop and agricultural enterprise adaptation. Thus the units of agro-ecological adaptation within each country are quite small, with resultant small units of affordable investment in agricultural research.

In a summary of the funding provided by the governments for agricultural research, the review notes that 15 of the 24 countries in the region spend less than $3 million each year. The review goes on to say:

> Each country, however small, needs to have a "critical mass" of investment for adaptive and maintenance research. The smallerthe country or production unit serviced, the greater is the cost of research per unit of area served. Ecological complexity within the countries divides the areas served into smaller and smaller units. This points up the need for drawing as heavily as feasible on international or regional research programs for back-up basic,strategic, and applied research information.

A further and more detailed extract of the West Africa review is given in annex 1.

Although research expenditures and research personnel increased rapidly in the 1970s, for many countries in West and Central Africa, the year 1980 appears to have been something of a watershed, according to IFPRI studies. Financial support for research has deteriorated in much of the region since 1980, while the number of scientists and technicians continued to grow. The result in many countries is an increasing shortage of operating funds for research operations and declining morale of scientists frustrated by inability to carry out their work.

IITA RESEARCH LIAISON SCIENTISTS

IITA places high priority on understanding the needs of national agricultural research systems of all sizes and stages of development. IITA scientists have consulted with national systems throughout the region and invited leaders to IITA for special meetings to discuss alternative modes of collaboration. There is agreement that it is essential to distinguish national system requirements at different stages of institutional development, from an early "embryonic" stage through medium strength to maturity. Table V.1 presents a model illustrating how IITA mechanisms for collaboration with national systems evolve over their growth paths. This conceptual framework does not imply linear progress from stage to stage nor any moral judgment. It merely emphasizes that IITA must be prepared for a dynamic

relationship with national systems that will be continuously evolving and changing over time.

During the period of the Strategic Plan, IITA will develop partnerships with national systems that are closely linked to the strategic needs at their respective stages of development. This will lead to a reduction in the total volume of such activities but an increased focus that will particularly benefit the least developed national systems.

The Strategic Plan provides for three research liaison scientists to study the requirements of individual national systems and to link them to IITA and other sources of technology. They will facilitate communication, identify training needs, determine effective locations for resident scientist teams, and generally assure that IITA is moving toward a constructive partnership with the national systems of the region.

In the conduct of their research, all IITA scientists will continue their direct involvement with national agricultural research scientists, but IITA needs a mechanism for understanding individual national systems and assuring that its input is consistent with and in response to genuine needs. At centers with few commodity programs, like CIMMYT, regional liaison officers for each program perform this function. Since IITA has an integrated program, it is necessary to have a holistic view of IITA's potential for collaboration with individual national systems and systematic knowledge of their requirements. Each of the three research liaison scientists, permanent members of IITA's scientific staff, will be assigned an area of seven or eight countries grouped on the basis of linguistic, ecological and geographic factors.

The research liaison scientists will assure that IITA understands the institutions, scientists, and requirements of the highly diverse national systems of the region and is, thereby, able to design suitable methods of collaboration. The research liaison scientist will coordinate IITA activities in each country, assisting other IITA scientists to focus their efforts on the most critical problems so that the total impact will be greater than the sum of the individual parts. The research liaison scientist will, for example, identify training opportunities, facilitate communication with appropriate scientists at IITA and elsewhere, encourage collaborative research projects, and arrange screening and testing of materials. One key role of the research liaison scientists will be to help rationalize and improve the effectiveness of research networks in the region.

Over the Plan period, IITA will have systematically acquired a deeper understanding of all the national systems in West and Central Africa. There will be a research liaison scientist who is the contact point for each national system and a dialogue will be under way on appropriate forms of collaboration. It is hoped that other CGIAR centers would wish to be associated with this initiative.

TRAINING

In the long run, training may be IITA's most enduring contribution to the solution of Africa's food problems, and it receives very high priority in the Strategic Plan. Like the other international centers, IITA has a unique comparative advantage in training because of its intimate involvement in applied agricultural research. In

wider terms, Prof. A.H. Bunting has said that "through its special advantages of continuity and cooperation, the international agricultural research system is building up living linkages in a world-wide invisible college, based on continuing personal relationships, which has no parallel anywhere else."

Various studies suggest that an enormous number of agricultural scientists trained in African agriculture will be required: 5,000 people by the year 2000 for West Africa alone. Clearly, IITA can meet no more than a small proportion of Africa's requirements for agricultural scientists. IITA's capacity is constrained both by financial resources and by the accommodations available on the Ibadan campus, which are already fully utilized. Therefore, it is necessary to establish clear priorities based on an understanding of IITA's strengths and the needs of national systems at different stages of development.

Five priorities have been established for the Strategic Plan that will increase the quality and relevance of training activities at IITA.

(a) IITA will devote more permanent resources to training in order to expand control over the basic decisions on training priorities. At present, training receives core resources sufficient only to cover its administrative overhead, to hold group courses, and to make a small number of graduate research grants. The high volume of training noted earlier has been supported by restricted funding. Many of the decisions concerning the courses to be offered, the selection of participants, and the award of graduate fellowships are, therefore, directly affected by donor concerns. While these activities are clearly desirable, they do not necessarily build on IITA's comparative advantage or reinforce its priorities for strengthening national systems of the region. An important objective of the training plan is a gradual increase of IITA's control over the basic decisions concerning training priorities and plans.

(b) IITA will increasingly decentralize group training to national institutions in response to their requests for the Institute to support more "in country" training.

IITA currently conducts a wide variety of group training courses on its campus – commodity research and field experimentation courses (so-called "production courses"), skill enhancement courses, and specialized courses such as seed technology or weed management.

Decentralization will permit an increase in the numbers trained, reduced costs, and more relevance to national problems.

IITA will develop criteria to guide the selection of countries for in-country training (or regions for in-region training), and reallocate staff time from activities in Nigeria to enhance human resource development in extension, technical support, and production techniques in national systems. Country interests and circumstances will affect the nature and length of specific courses.

By effective involvement of research, extension, and educational institution staff in such courses, it should be possible to generate a "multiplier" effect within the country. IITA will encourage in-country courses by providing training outlines and material, by training national trainers, and by providing IITA scientists and trainers

as resource persons. The goal is to strengthen the capacity of national organizations to satisfy their own requirements.

(c) IITA will shift emphasis at Ibadan from group training to individual research training, especially of Africans at the M.Sc. and the Ph.D. level. There is an important need to apply IITA's substantial research resources to training advanced researchers who will be able to address African problems in and through African national institutions.

IITA will introduce a competitive program of research fellowships for outstanding African students working on their degrees at universities anywhere in the world. Grantees will conduct research on topics relevant to their countries' needs and relating to IITA's mandate under the supervision of senior IITA scientists. The objective is to strengthen the leadership of African agricultural research institutions. IITA will also provide research fellowships for African scientists identified by IITA research liaison scientists as a means of strengthening the capabilities of national systems. The target number of fellowships considered necessary to accomplish these purposes is 70 per year. This scale will provide an intellectual environment in which the fellows profit from their own interaction and justify the costs of administering the program.

(d) IITA will strengthen its training materials. Effective implementation of the training plan requires the planning and design of new training materials.

IITA will develop improved training materials of four types:

1. **For presentation of information**, such as in support of lectures, in which audiovisual aids increase the attention of trainees, and make the subject matter easier to understand and accept; such materials include models, slides, films, flip charts, and related aids.

2. **For reference, refresher, and self-study**. These include publications, books, manuals, and charts and maps, all of which may help users to follow procedures, make diagnoses, or prepare their own materials.

3. **For self-instruction.** These consist of auto-tutorial modules made up of slides, sound tapes, and associated manuals.

4. **For encouraging trainee participation** and involvement in the learning process. These materials, including exercises, self-correcting examinations, and simulations, provide trainees and staff with information and insight on trainees' knowledge and skills.

These training materials will make instruction at IITA more efficient and relieve senior staff from repetitive teaching tasks, thus making them available for higher quality interaction with graduate fellows. In addition, the materials will support and supplement in-country training programs. Such aids must not replace interaction with scientists or with the crops in the field.

(e) IITA will seek effective means to increase the proportion of women participants at all levels. The record of the past four years shows that only 6.8

percent of African trainees at IITA were women. Given the important role women play in African agriculture, this record is obviously unacceptable. IITA will develop an affirmative action program to identify and encourage women to apply for training opportunities at IITA.

RESIDENT SCIENTIST TEAMS

IITA currently has 46 scientists providing technical assistance to national systems with the goal of strengthening their institutional capacity to conduct adaptive research. These scientists, hired on short-term assignments under special project funding, are concentrated primarily in two large institution-building projects. Although IITA's performance of these projects is considered successful and other institutions cannot provide these services at comparable quality, IITA will phase down these commitments and replace them with a limited and more cost-effective alternative.

The Strategic Plan provides for a small group of experienced scientists to continue this technical assistance as an essential service to national systems, on an exceptional basis, for the duration of the Plan. It is not normally appropriate for an international center to provide technical assistance to national institutions. It is justified as a transition mechanism in a region where 60 percent of the countries spend under $3 million each year on agricultural research. IITA technology is of little value for countries lacking the capacity for effective collaboration. IITA has a responsibility to assist in the process of building such capacity to the extent that it has a comparative advantage and that such activity does not weaken its vitality as a research institute.

IITA has a comparative advantage in strengthening national systems' capacity to conduct adaptive research. Over the last decade, IITA has invested over 300 scientist – years in working directly with national systems of the region. It has had marked successes, such as in helping to build the national cassava program of Zaire, and much has been learned in the process. The emphasis on building capacity for organizing and conducting adaptive research complements ISNAR's role in improving the management of research systems.

The Strategic Plan provides for a minimum of six resident scientists. They will be mature scientists, not a special cadre formed for this purpose, but permanent members of the IITA scientific staff. The number is deliberately set at this low level in order to avoid distortion of IITA's principal mission. These scientists will be assigned in teams of two or three, if feasible in association with scientists from other centers, to national systems at an early stage of development Table V.1 shows IITA's role at varying stages of development. High sensitivity will be required to locate such scientists strategically to countries where the maximum benefits are possible. IITA's liaison scientists will help in identifying countries where there is a demand for such assistance and the strong institutional commitment needed to make it successful. Resident scientists will be selected to suit the special characteristics of each assignment.

Building national research capacity is acknowledged to be a long-term process. Nevertheless, by the year 2000, it is expected that small national systems will have received technical assistance from IITA, and they will be clearly progressing from stage I to stage II on the growth path shown in the table.

NETWORKING

The Technical Working Group on Networking of the Special Program on African Agricultural Research (SPAAR) has developed a useful classification system that divides networks into three basic types:

1. **Information exchange networks** organize and facilitate exchange of ideas and methodologies, and may report on results of research underway.

2. **Scientific consultation networks** promote country-by-country or participant-by-participant focus on common priority areas of research which is initiated and implemented independently by the participating institutions. These networks hold regular meetings, and provide other means to exchange information on research as in 1 above.

3. **Collaborative research networks** involve joint inter-country planning, implementing, and monitoring of research on problems of mutual concern to countries within a region. These networks include information exchange, technical collaboration, and training.

Collaborative research networks (type 3) have a valuable role to play in the development and validation of new technologies for West and Central Africa, particularly because of the small size of many national systems. These networks will be successful if they have the following characteristics, identified by SPAAR:

(a) An important objective.

(b) A well-defined common theme or strategy.

(c) An existing or potential source(s) of improved technology (or ideas).

(d) A harmonizing (coordinating) institution.

(e) A steering committee.

(f) Regular meetings of participating scientists.

(g) An information exchange system.

(h) Free exchange of results and methodologies, including plant-animal materials, ideas, and people, among member states and scientists.

(i) Education and training opportunities.

(j) Financial support for in-country implementation of planned research provided by the respective national agricultural research systems.

IITA is presently participating in or seeking funding for the following collaborative research networks:

Table V.1 IITA - NARS collaboration

State of development	Commodity Improvement		Crop and resource
Stage I:	IITA	NARS	
Early	Adaptive breeding of finished varieties for NARS	Multi-locational testing of IITA varieties	Joint IITA-NARS participation in the description of
Stage II:	IITA	NARS	IITA
Medium	Applied breeding of parental lines for NARS	Line selection; national variety development and testing	Share component technologies and methodologies for combining them into improved systems
Stage III:	IITA	NARS	IITA
Mature	Maintenance breeding Pre-breeding research (biotechnology)	Major breeding program for national agro-ecological zones	Long-term, strategic, basic research on crop and resource management problems, including methodologies

by stage of NARS development

management research	Mechanisms for collaboration	
	IITA	NARS
existing systems and constraints analysis	Resident scientist team Training of technicians and MSc candidates	Counterparts to resident scientist team Training of selected technicians and graduates
NARS	IITA	NARS
Testing commodities and component technologies in national agroecological zones	Resident scientist team phases out IITA research liaison scientist provides linkage Training of PhDs and trainers starts up	MScs return from training and assume responsibility PhD candidates are selected In-country technical training is prepared
NARS	IITA	NARS
Adaptive on-station and on-farm research Testing new farming systems Participation in regional activities (networks, NARS-to-NARS exchanges)	IITA research liaison scientist continues linkage NARS visiting scientist IITA trains trainers and provides training materials	PhDs assume leadership Technical training conducted for national and regional requirements

1. Eastern and Southern African Root Crops Research Network
2. Central and Western African Root Crops Research Network
3. SAFGRAD Cowpea Research Network
4. SAFGRAD Maize Research Network
5. Alley Farming Research Network

IITA can play a valuable catalytic role in promoting and managing appropriate networks for the region. Because of its technologies, IITA will also be a valuable, often essential member of the networks. However, IITA will devolve the responsibility for managing networks to national institutions as soon as they have the capacity and willingness to assume it. There has been an increase in the number of networks in West and Central Africa that is sometimes confusing to national systems and may be leading to diminishing returns from new networks. The research liaison scientists will study the possibility of harmonizing or rationalizing present networks to be sure they are genuine expressions of the perceived needs of national leaders. They will also foster more simple forms of collaboration between individual or small numbers of national systems.

INFORMATION SERVICES

The Strategic Plan calls for information services to become a more active mechanism for collaboration with national agricultural systems.

Information involves the following functions:

(a) Publishing and disseminating research findings to scientists, policy makers, national research programs, development and extension personnel, and others concerned with the agriculture of the lowland subhumid and humid tropics.

(b) Maintaining a library with a comprehensive collection of pertinent literature on tropical agriculture to serve Institute scientists, trainees, and other scientists in the region.

(c) Providing support for conferences, symposia, and workshops and coordinating an active seminar program at IITA headquarters.

(d) Providing French interpretation and translation services to support the communication and training efforts of the Institute.

Major activities during the Strategic Plan period are outlined here:

1. **Library services.** The development of the integrated computerized library system will continue. A "core library scheme" will be initiated for the Institute's sub-stations as well as for resident scientist teams. The scheme involves acquisition of relatively small but carefully selected lists of journals, books, and abstracting services for deposit at sub-stations, national systems where country teams are based, and possibly elsewhere.

2. **Publications.** The IITA publications program will be pursued vigorously taking advantage of new technologies such as desk top publishing. After nearly 20 years of research, IITA has accumulated a large amount of research data, some of which have been published only in annual reports. Such information will be summarized in a series of technical monographs produced in close collaboration with the appropriate scientists. Extension-support publications based on the Institute's research findings and designed to upgrade the technical knowledge of national extension officers will be produced. Moreover, the production of training materials carefully written and planned for use in specific courses will receive high priority as a mechanism for facilitating the decentralization of training courses.

3. **Database development** IITA already has a well-developed library database and mailing list based on a sophisticated software package. These will be upgraded, and new databases will be developed on (a) IITA's research projects, (b) West and Central Africa national systems utilizing ISNAR's system, and (c) African women involved in agriculture.

4. **Public information activities.** In line with the decision of the center directors and the CG secretariat, IITA will engage in more activities designed to increase the public awareness of its work and the work of the system in the region as well as in donor countries. These activities will include, as appropriate, field days, media relations, open house, briefings and presentations to special groups, and participation in agricultural shows.

5. **Video technology.** Video technology will be used increasingly in IITA public awareness activities and, as appropriate, for training purposes.

6. **Translations.** To be effective in West and Central Africa, information services must be bilingual in English and French. During the period of the Strategic Plan, translation efforts will be increased to ensure that most of IITA's publications are available in both languages.

7. **Scientific literature service to national systems.** A major weakness in most national systems of West and Central Africa is the paucity of current agricultural and scientific information. Utilizing its considerable library resources, IITA will provide a regular literature service to national systems.

8. **Workshop and training courses on scientific editing and technical publishing.** Many national systems are incapable of documenting and disseminating the results of their work because they lack trained scientific editors and others knowledgeable in publishing. An annual training course on scientific editing and publishing will be a major help to national systems.

Annex 1

EXTRACT FROM *WEST AFRICA AGRICULTURAL RESEARCH REVIEW* by the World Bank (1987)

Chapter 3, "National agricultural research systems (NARS) in West Africa: an appraisal"

SIZE OF RESEARCH EXPENDITURES

3.4 Expenditures on national agricultural research in West and Central Africa have increased substantially since 1970. Expenditures in 18 countries in 1984 for which reports are available exceeded $300 million in current dollars, a four-fold increase in 15 years, measured in 1980 constant dollars. Table 1 shows that the four largest research programs, measured by funding in 1984 or latest available year, were:

	US$ (million)
Nigeria	181.0
Cote d'Ivoire	29.6
Cameroon	18.9
Senegal	17.9

3.5 Table 1 shows that external support for agricultural research in West Africa of some $80 million in 1980 constituted 26 percent of expenditures, but this calculation is distorted by the large national budget of Nigeria. If Nigeria is excluded, 18 countries for which data are available received 64 percent of their agricultural research funds from external donors. However, there was a significant drop in national research investment during the period 1980-84 due largely to a reduction of $86 million (in constant 1980 dollars) by Nigeria resulting from the slump in oil revenues.

INCREASES IN RESEARCH PERSONNEL

3.6 Since 1970, 21 of the 24 countries in the region for which data are available achieved a remarkable increase in number of personnel classified as researchers (holders of B.Sc., M.Sc., Ph.D. or equivalent degree), as reflected in the following regional staff inventory:

1970	1,006
1975	1,458
1980	2,687
1985, or latest data year	3,414

Table 1. *Agricultural Research Effort in 24 countries of Western Africa in 1984, or Latest Available Year*

Country	Column 1 Reported research expenditure (*total US$ 1000 in current US$*)	Column 2 Reported external support (*US$ 1000 in current US$*)	Column 3 Reported national & expatriate researchers	Column 4 Reported expatriate researchers included in column 3
Benin	1,583	332	58	3
Burkina Faso	9,255	8,098	126	60
Cameroon	18,937	9,696	225	65
Cape Verde	120	100**	16	8
C. A. R.	4,200*	3,600**	54	41
Chad	752	496	29	20
Congo	5,500*	3,400**	94	14
Gabon	2,642	1,300**	38	12
Gambia	NA	NA	28	7
Ghana	4,000*	2,800**	263	12
Guinea	NA	NA	35	NA
Côte d'Ivoire	39,600	24,235	254	180
Liberia	1,605	1,200**	45	7
Mali	7,555	4,911	268	38
Mauritania	NA	NA	11	10
Niger	3,144	1,528	68	35
Nigeria	181,000	1,000**	1,196	24
Senegal	17,851	12,139	283	119
Sierra Leone	1,390	1,000**	66	8
Togo	2,777	1,075	58	14
Zaire	5,874	3,000**	199	24
TOTAL	305,985	79,900	3,414	701

Source: All data in Columns 1 and 2 are from an unpublished IFPRI manuscript by Peter Oram, 1986, except items noted * and **

Notes: * IBRD/WAARR mission reports, data gathered in recipient country, 1985.

** IBRD/WAARR mission reports, estimated from partial data gathered in recipient country, 1985.

The 3,414 researchers in the latest year included 700 expatriates and about 2,700 nationals. The 80 percent nationals and 20 percent expatriates suggests how far Africanization has progressed since independence in the 1960s. As with expenditures, the numbers of researchers vary greatly between countries -- from about 1,000 in Nigeria to 11 in Mauritania, and no researchers at all reported in three countries.

3.7 Fortunately the level of educational attainment among researchers seems to be rising as fast as the numbers of staff, although no complete time chart is available on educational qualifications. Holders of the Ph.D. or equivalent degree comprised at least 10 percent of the researchers in Benin, Cameroon, Ghana, Nigeria, Sierra Leone, and Zaire.

STRENGTHS OF NATIONAL AGRICULTURAL RESEARCH CAPABILITY

3.8 West African agricultural research is characterized by a number of strong points.

(i) **Creation of National Agricultural Research Systems (NARS):** Eighteen countries have established national agricultural research systems. They vary in comprehensiveness, but each has become a tangible base on which to build. In 1984 the governments concerned spent $226 million of their own funds, not counting foreign aid, on agricultural research. Excluding Nigeria, the remaining 17 governments spent $46 million of their own funds for research, an impressive amount considering that some of the world's poorest nations are found in the region.

(ii) **Increasing the numbers of scientists:** A growing number of trained agricultural scientists now engage in research in West Africa. Approximately 2,700 national researchers had university degrees in 1984, compared to little more than 300 in 1970. The shortage of trained personnel, including upgrading the qualifications of existing resources, is still a problem in most NARS, but this should not obscure the fact that important progress has been made.

(iii) **Services from international and regional research agencies:** The international agricultural research centers supported by the CGIAR and others have assembled germplasm collections for many of the major crops in Africa, and are conducting research in cooperation with national programs. This gives national research systems better access to the world's body of scientific knowledge than existed hitherto. Participation in the world's research community is an essential strength of every national system.

(iv) **Networking:** Cooperative networks among the African governments and the IARCs have been organized to conduct trials, hold conferences, and provide personal contact among participants. This provides to NARS a reasonable substitute for the needed "critical mass" of national scientists and interdisciplinary teams that many African nations cannot afford.

(v) **Research underway:** Most NARS in West Africa are now engaged in crop breeding or crop selection for their major foodcrops; most now participate in regional crop trials; and most have released some new crop varieties. These activities have resulted in major increases of average yields for irrigated rice and cotton in some countries, and more localized yield gains for maize, sweet potatoes, yams, and cowpeas. Progress in other crops has been less significant. Research progress seems to have speeded up in the mid-1980s despite widespread drought.

(vi) **Access to supplemental funds from donors:** Research in West Africa has attracted donor support that reached about $80 million in 1984. This has added strength to the NARS. However, it also brought difficulties including burdensome visiting missions, frequent requests from assistance agencies for information, multiple evaluations, and conflicting advice.

Weaknesses of National Agricultural Research Systems

3.9 NARS' weaknesses are so evident that there is a tendency to overstate them. Those most commonly cited include:

(i) **National policies:** Few goverments in West Africa accord budget allocations commensurate to agriculture's place in the national economy. In most countries more than two-thirds of the population get their livelihood from agriculture. Lack of support for agricultural research and development is a major issue of national policy.

(ii) **Inadequate planning capacity:** Most national research systems lack a research plan based on national priorities and available resources, and the planning capacity required for its formulation and monitoring.

(iii) **Weaknesses in administration:** Some senior NARS personnel have cited stifling administration as one of their principal problems. Research agencies often lack meaningful financial controls, appropriate personnel policies, usable property records, and effective equipment maintenance.

(iv) **Personnel training and experience:** Very limited numbers of NARS researchers have the depth of academic background, maturity of research experience, and professional qualities that are required for dynamic leadership of a modern research program. There is need for mid-career re-training programs for research leaders, and opportunities for further university studies for NARS researchers at all levels.

(v) **Imbalance in assignment of research funds:** In some NARS an overwhelming proportion of the research budget -- frequently over 80 percent -- is devoted to salaries, wages, and benefits, leaving little for conducting the research itself. There is a strong tendency to expand administrative staff and relatively unskilled services at the expense of scientific activities. There is a frequent imbalance in allocation of resources between crops and livestock -- one large country reporting no researchers working on livestock. Moreover, research on soil and water management is generally neglected.

(vi) **Instability of funding:** Most NARS have suffered instability of funding caused by incomplete releases of approved budgets, or by fluctuating currency values, or by start-stop financing of external donors. In such circumstances, the most common response is to protect the salaries of the employees and to reduce the expenditures for research operations.

(vii) **Institutional structure and linkages:** NARS are commonly located outside the Ministry of Agriculture and separated from their principal clients, the extension service and farmers. Research on food crops and livestock is frequently undertaken by separate agencies. In many cases the Ministry of Agriculture has little influence over

the choice of research priorities. Given the diversity of African government structures, it is not practical to expect all NARS to adopt the same pattern. But the important considerations are that NARS maintain adequate linkages with agricultural support services and have an appropriate degree of autonomy sufficient, for example, to provide terms of employment that assure recruitment and retention of competent scientists.

(viii) **Inadequate agricultural extension services:** Existing extension services are generally unable to "market" the output of research or to provide guidance on required research focus, thus minimizing benefits from investment in research. The leaders of national research programs in western Africa are sharply critical of the impotence of extension work in their countries.

Annex 2

THE 1988 ACTIVITIES OF THE CROP-BASED SYSTEMS WORKING GROUPS

MAIZE-BASED SYSTEMS

The maize-based systems group examines the spread and impact of improved maize technology and major trends in production and consumption. It also studies farm level constraints which are widespread in the region. Specifically, it investigates on-farm storage losses of maize and cowpeas, crop disorders such as *Striga*, land and labor markets, the maize seed industry, farmers' seed practices, and the potential market for soybeans. The group also carries out studies intended to help the commodity programs set their research priorities. Examples include a study of the comparative advantage of maize production in the savanna and forest ecologies, and consumer preferences for quality characteristics of cowpeas and maize (both those produced for grain and for fresh consumption).

Current field research inludes on-farm trials to evaluate both hybrid and improved open pollinated maize varieties with various intercropping and planting patterns and fertilizer use; studies of the potential for increasing second-season maize production; the addition of cowpeas and/or soybeans into the maize system in suitable areas; and the effects of alley farming with various leguminous species combined with economic perennial and annual species in order to enhance the productivity and sustainability of maize-based systems. Operational scale trials are being carried out on alley farming as well as on the production, maintenance, and storage of improved maize seed. On-station research includes alley farming trials with maize varieties; the screening of varieties for green maize quality; and the screening and testing of cowpea varieties for intercropping with first season maize in humid and subhumid environments.

CASSAVA-BASED SYSTEMS

The cassava-based systems working group studies the role of cassava in farming systems in West and Central Africa and, in particular, the impact and roles of improved varieties. The varying significance of production constraints in different agroecological areas and farming systems is a major aspect of this research. In addition, postharvest processing and the influence of marketing factors receive attention as important factors that can govern the demand for cassava and preferences for various tuber qualities. Current activities include on-station studies to devise improved multiple cropping and crop rotation systems and to examine the response of improved varieties to extended in-ground storage. Questions to be examined in these trials include the use of alley farming in existing

systems to enhance and maintain soil fertility; the addition of a legume crop in the cassava/maize system to increase nutritional outputs and the screening of cowpea and soybean varieties for this purpose, fertilizer use in cassava/maize systems, and the evaluation of improved cassava and maize cultivars for the region. A further area of major concern for the cassava working group is to identify and establish collaborative research and training with national institutions in the major ecologies in which cassava is a significant crop. To this effect, research linkages will be established with West and Central African national systems.

Finally, until 1991, the cassava working group will have links with a large-scale economic study of cassava in sub-Saharan Africa that will be a joint research project between IITA and CIAT. Surveys and data collection will be carried out in all of the main cassava growing areas of Africa, with four main subject areas as the focus of the research: (a) the production, processing, and consumption of cassava at the village level; (b) the marketing of cassava products and price formation; (c) the effect of urban consumption patterns and food demand; and (d) the impact of national price and trade policies. The results of this study should provide an unprecedented data base for continuing research on the improvement of cassava-based farming systems throughout Africa.

RICE-BASED SYSTEMS

The rice-based systems working group focuses on improvement of rice-based cropping systems in the inland valleys, including hydromophic soils. It will in future collaborate with WARDA to do this in West Africa. A primary research need is to determine the location, importance, ecological variation, and production potential of these areas throughout West and Central Africa. Relevant trends in the use of inland valleys and their socioeconomic roles within the farming systems in which they occur are an important component of this basic data research. In addition, there are a number of research questions relating to general policy issues, including the impact of trade and exchange rate policies on smallholder rice production; general trends in rice production and consumption in West and Central Africa; and studies of the comparative advantage of rice production in the region.

On-farm studies of the rice-based systems working group focus on four major topics: testing and evaluation of new elite selections under farmers' conditions; screening rice selections for tolerance to such stresses as iron toxicity, low soil fertility, and pests and diseases; identifying improved cropping patterns for lowland planted rice that will be compatible with the remainder of the farming system (which often includes upland rice and other crops); and paddy improvement and water management. Improved cropping patterns using various additional crops (sweet potatoes, cassava, cowpeas, soybeans, maize, vegetables, etc.) planted on residual soil moisture and other component technologies are also studied both on-station and on-farm pilot research sites.

Annex 3

THE RICE STUDY GROUP REPORT (1986)

AN EXAMPLE TO ILLUSTRATE THE STUDY PROCESS

The Rice Study Group was asked by IITA to determine the rice research priorities and research requirements for an international program to be focused on West and Central Africa. Because of the uncertainty of future CGIAR support for WARDA and the recent recommendation by TAC that a new West African Rice Research Institute be created, we have made no assumption in this report as to which international organization or organizations would be responsible for conducting rice research in the future. In addressing the substantive research issues, however, we have given some attention to the possible location of the work.

The Rice Study Group met for one week in February and one week in July at IITA where it worked hand in hand with scientists in the Rice Program to develop the substance of this report. Between meetings, a number of study group members made trips to Sierra Leone, Liberia, Cote d'Ivoire, and Nigeria to review rice research in these countries.

The objective of this report is not to provide a set of recommendations. Rather, we have attempted to establish the research priorities and to suggest options for the future development of rice research. We have also tried to reflect as accurately as possible some of the differences of opinion among the group members on major issues. Thus, we hope that this report will be useful to whoever is responsible for charting the future course of rice research in Africa.

HISTORICAL PERSPECTIVE

Rice research in Africa has had a relatively long history. The Moor Plantation in Ibadan, Nigeria initiated a rice research program in the 1920s. The rice research station at Rokupr in Sierra Leone was established in 1934 and expanded in 1953 as the West African Rice Research Station to serve all anglophone West Africa. When the association of these countries was terminated at independence in 1962, it became the Sierra Leone Rice Research Station. A station for irrigated rice was established in 1953 at Badeggi, Nigeria. Rice research in Liberia began in the 1950s at the Firestone Plantation Company in Harabel, and shifted in 1960 to the Central Agricultural Experiment Station at Suakoko. Limited efforts in Ghana were centered at the Crops Research Institute in Kumasi and the Agricultural

Research Station at Kpong. Research was initiated in Malawi as early as 1935, and in Tanzania in 1965.

Rice research in francophone Africa began in 1933 at the National Institute for Agricultural Studies of the Congo (INEAC) in Zaire. Research on pluvial rice began in Senegal in the 1950s at Casamance. In 1960, IRAT assumed responsibility for rice research in Senegal. Rice research in Cote d'Ivoire was centered at Bouake under the Ministry of Agricultural Research until 1966 when IRAT assumed responsibility. More recently the Institut des Savannes (IDESSA) has assumed control, although IRAT is still a participant in the research program. In Madagascar research work began in 1927 at the Marovoay Agricultural Station.

Since independance, most national governments have given very little support to rice research, even in countries such as Liberia and Sierra Leone where rice is the most important food crop. In recognition of the need to strengthen the research effort, the West African Rice Development Association (WARDA) was created in 1971. In 1985 about 30 WARDA professional staff were deployed in special research projects in Sierra Leone (mangrove swamp rice), Senegal (irrigated rice), Cote d'Ivoire (upland rice), and Mali (floating rice). Recent budget constraints have forced a contraction of this number and a closing out of the work in Mali.

The research commitment of other international research centers has also grown significantly in the 1970s and 1980s. Rice research began at IITA as part of the cereal grains program in the early 1970s. In 1983, maize and rice were split into separate programs. There are currently 9 core staff members in the rice program at Ibadan and one at WARDA headquarters in Monrovia. One scientist is located at Onne in Nigeria, and two in the Cameroon on special project funding. IITA's program is focused on upland, hydromorphic, and swamp rice.

IRAT, as previously noted, has provided continuing support to research in Cote d'Ivoire under the auspices of IDESSA. Some IRAT scientists have responsibility for several crops, but a total of 5 person-years is devoted to rice. The WARDA team located at Bouake operates independantly of IDESSA. However, due to the presence of both WARDA and IRAT, plus the strong IDESSA program, Bouake has the largest concentration of rice scientists in Africa, and most of the research attention is devoted to upland rice.

IRRI's program in Africa is concentrated in Egypt and Madagascar where they have two scientists asssigned to each of the national programs. IRRI also has one liaison scientist at IITA and another scientist in Tanzania. IRRI's limited involvement in Africa has been focussed on irrigated rice

Historically, the bulk of the reseach in Africa has been devoted to varietal improvement. By contrast, there appears to have been relatively little research on various aspects of crop management. However, just as in the case of South and Southeast Asia before World War II, varietal improvement has not been the major constraint to increased production. New varieties have been released, but those adopted have been mostly selections of traditional types or crosses with traditional types. Modern varieties and other forms of modern technology, including large scale irrigation projects and mechanization schemes, have not yet had much impact on production in West and Central Africa.

Table 1. West African rice production and consumption trends 1960-1964 to 1980-1984 with projections to 2000-2004

Years	Production	Imports	Consumption	Consumption	Population
	----------1,000 tons milled ----------			kg/capita	
1960 - 1964	1,000	200	1,200	12	
1980 - 1984	1,800	1,800	3,600	22	
2000 - 2004	4,800	1,800	6,600	22	
	Percentage growth per annum				
1960 - 1964 to 1980 - 1984	3.0	11.6	5.6	3.0	2.6
1980 - 1984 to 2000 - 2004	5.0	0	3.1	0	3.1

THE PRESENT AND FUTURE SIGNIFICANCE OF RICE IN AFRICA

Egypt and Madacascar are the two largest rice producing countries in Africa, and the bulk of their production is from irrigated land. Figure 1 illustrates that, excluding these two countries, the bulk of production occurs in West Africa. There is a belt of high rice consumption extending along the coast from Senegal to Cote d'Ivoire. The most extensive area of rice production extends from Guinea Bissau to western Cote d'Ivoire and includes Guinea, Sierra Leone, and Liberia. The annual rainfall in most of this area exceeds 1,500 mm, and rice is produced in upland and swamp environments.

Nigeria is the largest rice producer in West Africa, but in contrast to the aforementioned countries, rice is the staple of only a small proportion of the population. Nevertheless, until the imposition of a recent ban on imports, Nigeria was the largest importer of rice in West Africa, followed by Cote d'Ivoire and Senegal.

Rice imports have been increasing rapidly in almost all countries of West Africa at a time when foreign exchange earnings from most of the major exports of the region have been declining. Thus, there is growing interest in seeking ways to increase agricultural production in general and rice production in particular.

Table 1 shows, for West Africa as a whole, past and projected trends in rice production, imports, and consumption. In the early 1960s the region produced over 80 percent of its needs. However, over the past two decades rice consumption has increased at 5.6 percent per annum. More than half of the growth can be attributed to increase in per capita consumption and the remainder to population growth. Since production grew at 3 percent, by the early 1980s the region was relying on imported rice for approximately half of its consumption.

From a purely economic perspective, the increase in imports should not be considered with alarm, particularly for those countries which have a comparative advantage in producing alternative crops for export. But given the growing uncertainty of export markets, there is a natural desire of governments to raise the level of self-sufficiency in major food staples even when these commodities can be purchased more cheaply on world markets than they can be produced domestically. Such is the case with rice, whose cost of production in West and Central Africa is extremely high due to low labor productivity and high transportation costs.

Let us assume that the West African regions as a whole held rice imports at current levels for the next 20 years (1.8 million metric tons, Table 1). Assume also that per capita consumption remained at the current level. In order to meet the growing demand from population alone, production would have to increase by 5 percent per annum for the next two decades. Over the past two decades production has increased at only 3 percent per annum, and this has come largely through growth in acreage not yield. These figures emphasize the urgent need for technology that can increase rice production and productivity.

PRODUCTION POTENTIALS OF RICE ECOLOGIES

The terms "rice ecology" or "rice ecosystem" are widely used in Africa to refer to the different physical environments under which rice is grown. As in Asia,

the most prevalent classification criterion, and this is the one used by both WARDA and IITA, is based on water regime. That is, classification according to variability in water regime is viewed as the most useful in establishing rice research priorities. This is because technology requirements tend to differ by water regime. However, there are other important environmental factors to consider in setting research priorities.

A common feature of rice classification schemes by water regime is the distinction between upland (dryland) and lowland (wetland) areas. The latter are flooded during some portion of the crop growing season. Lowland is further divided into irrigated and non-irrigated. Beyond this point, classification systems tend to vary considerably. The classification scheme used by the Rice Study Group represents a modification of both the IITA and the WARDA classification, with the upland and non-irrigated lowland divided into three sub-categories as follows:

Upland	unfavorable favorable hydromorphic
Lowland non-irrigated	inland valley swamps mangrove swamps riverine
Irrigated	

A major problem with this classification relates to the category of hydromorphic soils. Hydromorphic soils are characterized by the presence of a fluctuating underground water table (normally above 60 cm) which is able to provide moisture to the root zone of the rice plant. The root zone may become submerged at some stage in the growing season, and the soils can be continuously cropped. Thus, some scientists feel that hydromorphic is more closely associated with a lowland than an upland condition.

The hydromorphic and inland valley swamps can be seen as distinct from other ecologies in that they are evolving. Some, like Moorman and Veldkamp, suggest that a logical sequence of events would be the development from the simple, non-improved utilization of lands with sufficient additional water over and above the water provided by the rains, toward the improvement of such lands by paddy construction and water control. Thus, one would see the technology requirements of these ecologies differing considerably between the early and later stages of this evolution.

A distinguishing feature of our classification system, not followed by either WARDA or IITA, is the division between "unfavorable" and "favorable" upland. Unfavorable upland is characterized by low, unevenly distributed rainfall (less than 1,500 mm/yr) as an overriding constraint. Favorable upland has adequate and well distributed rainfall (at least 1,500 mm/yr), is freely drained with infrequent water stress, a water table below 60 cm, and leached acid soils with a loss of soluble nutrients. In short "favorable" refers strictly to the rainfall condition.

Farming systems can, and frequently do cut across rice ecologies. For example, inland valley swamps and uplands often comprise portions of the same farm. This association will affect the way in which farm resources are allocated between the uplands and the swamps. A focus on the farming system would require in many locations an integrated approach to research taking account the linkages between upland intercropping, farming on the hydromorphics, and low intensity swamp cultivation.

Our first step in establishing the priority or focus of a rice research program was to determine the relative importance of the various rice ecologies. In the estimates that have been made to date, there seems to be general agreement that close to 60 percent of the rice area in West Africa is upland. It is also clear that only a very small portion, about 5 percent, is irrigated. The largest area of non-irrigated rice is in the inland valley swamps. For the division between lowland and upland, and the percentage of area in each of the lowland ecologies, we have used the recent WARDA estimates (Table 2). The estimated percentages of area in each of the three upland ecologies represents the judgment of members of the Rice Study Group and IITA scientists. There was considerable disagreement among participants as to the percentages to assign to each ecology. The estimates should, therefore, be viewed with extreme caution.

The second step was to ask rice scientists familiar with the various ecologies to estimate present yield and a target yield that could be achieved in each of the ecologies over the next 20 years assuming advances in technology, but without a major breakthrough in basic scientific knowledge. The target estimates take into consideration the general physical and socio-economic constraints of the environment. Thus, they do not reflect the yield potential under ideal conditions.

The estimate of present yields and yield potential are shown in Table 2. Based on these estimates and the estimated share of the land in each ecology, the current average yield for the region is calculated at 1.4 t/ha which is somewhat higher than the WARDA estimate for 1980-1984 of 1.2 t/ha. The target yield for the region 20 years from now is 2 t/ha which assumes an average annual growth in yield of 1.8 percent.

The final step in this phase of the analysis was to determine the potential contribution of each ecology to the growth in rice production over the next two decades. This is simply a matter of weighting the yield gains by the rice area in each ecology. Some scientists felt that the inland valley swamp and hydromorphic areas would expand more rapidly than the other ecologies. The view was also expressed that a major expansion in the favorable uplands would tend to shorten the fallow period and make it even more difficult to achieve the proposed yield target. However, the calculations in Table 2 are based upon the assumption that the proportion of area in each ecology does not change. The inland valley swamps, hydromorphic, and favorable upland areas account for almost two thirds of the target yield increase over the next 20 years.

CONSTRAINTS TO PRODUCTION AND RESEARCH OPPORTUNITIES

The Study Group next considered the constraints to increased rice production, and the degree to which these constraints could be alleviated through an investment in research. A list was prepared of the major problems in the following categories:

Table 2. Potential gains in production by rice ecologies over the next 20 years

	Upland			Lowland				Average yield
	unfavorable	favorable	hydromorphic	inland valley	mangrove swamp	riverine	irrigated	
Proportion of total area (%)	10	24	24	19	8	9	6	
Current yield (t/ha)	0.5	1.0	1.5	1.5	2.0	1.5	3.0	1.4
Target yield (t/ha)	0.5	1.5	2.0	2.3	2.8	2.3	4.0	2.0
Yield gain (t/ha)	0	0.5	0.5	0.8	0.8	0.8	1.0	0.6
Contribution of ecology to increased rice production (%)	2	18	23	22	11	10	14	

Table 5. Development of rice research institute staffing pattern by priority stages

	Inland valley swamp/hydromorphic		Favorable upland		Mangrove	Irrigated	Over-all
	center	satellite	center	satellite	satellite	center	center
Varietal Improvement (13)[a]		BC[b]		FG[b]			
Breeding	A		E		I	I	
Pathology	A		E			I	
Physiology	D						
Eentomology							H
Crop Management (14)[a]		BC[c]		FG[c]			
Agronomy (Weeds)	A		E				
Agronomy (Fertility)	A		E				
Agronomy (Soils)					I		
Economics	A		E				
Engineering (Tillage)	D						
Engineering (Water)					I		
Engineering (Post harvest)							I

Notes: Priority ranked alphabetically from A (highest) to I (lowest).

a The numbers in parentheses refer to total staff for the group disciplines.
b The staff numbers in these satellites can belong to any of the disciplines within varietal improvement.
c The staff numbers in these satellites can belong to any of the disciplines within crop management.

diseases, insects, adverse soils, adverse environments, crop and resource management problems, and other (Table 3). Each of these problems was then discussed in order to arrive at a consensus on the relative severity of the problem within and across rice ecologies. Since the unfavorable upland was considered to have essentially no potential for yield improvement, it was dropped from consideration.

The ecologies were considered one at a time and the various constraints scored on a scale of 0 (unimportant) to 9 (very serious). Parenthetically, this is the same scale used by pathologists to score the severity of disease problems. The score assigned should take into consideration both the prevalence of the problem and the magnitude of the yield reduction.

What immediately stands out in Table 3 is the high scores in the crop and resource management area relative to all other categories. Weed control, tillage, and bird damage are the most pervasive problems across environments. Erosion control and maintenance of soil fertility are serious problems on the uplands, just as water management is a serious problem in the lowlands. Other management problems including rodent damage, stand establishment, and fertility are also serious constaints to production.

Three problems, insect damage to stored grain, grain quality, and processing losses, do not vary significantly by ecology. Losses in post-harvest activities including threshing, drying, storing, and milling of rice are extremely high.

The most serious disease problems are blast, grain discoloration and sheath blight in the uplands, sheath rot in the lowlands, and yellow mottle virus in irrigated areas. Insect problems are generally not as important as disease problems at present, although it is recognized that the increased use of modern inputs in the future could enhance insect damage.

The mangrove swamps face severe problems with acid sulphate soils and also crabs which destroy the young seedlings. Iron toxicity is prevalent throughout the inland valley swamps mainly on their margins. Drought and mineral availability are problems in the favorable uplands, and submergence tolerance in the riverine areas.

Table 4 summarizes the constraints across the major categories. If the target yields could be achieved by alleviating the listed constraints, yield would be increased by 600 kg/ha (see Table 2, 1.4 to 2.0 t/ha). Using the scores in Table 3 as weights, the contribution of each category to the yield gain is shown in kilograms per hectare and in percentages.

Despite the overriding importance of crop and resource management as a constraint to production, it was recognized that not all problems in this area could be solved through research. By contrast, research in varietal improvement can help to solve disease, insect, soil and environmental problems. Each of the constraints under crop and resource management were discussed to assess the research opportunities.

There is definitely scope for further research on weed control. Too much of the current research effort is devoted to screening of herbicides, virtually ignoring a wide range of other potentially more acceptable options. As with weed control, so also with tillage, much of what passes for research involves the testing of machines.

Table 3. Scoring of constraints by rice ecologies of West Africa from 0 (unimportant) to 9 (very serious)

Constraints	Upland		Lowland			
	favorable	hydromorphic	Inland valleys	mangrove swamps	riverine	Irrigated
DISEASES						
Blast	4	4	3	3	3	3
Neck blast	5	3	3	3	3	3
Yellow mottle virus	0	2	3	0	3	3
Bacterial leaf blight	0	0	0	0	0	3
Sheath rot	2	3	4	2	4	2
Sheath blight	4	4	2	2	2	2
Brown spot	2	3	3	3	3	3
Discoloration	4	4	3	3	3	3
Leaf scald	3	2	2	2	2	1
INSECTS						
Grain sucking bugs	0	2	0	0	0	0
Stem borer	4	3	3	3	3	4
Gall midge	0	0	1	0	1	4
Diopsis	1	4	4	2	4	4
Storage insects	4	4	4	4	4	4
Crabs	0	0	0	5	0	
ADVERSE SOILS						
Iron deficiency	0	2	0	0	0	0
Iron toxicity	0	2	5	6	0	1
Acidity	2	0	0	6	0	0
Salinity	0	0	0	6	2	2
ADVERSE ENVIRONMENTS						
Drought	4	2	0	0	0	0
Submergence	0	2	3	2	6	0
Mineral availability	5	3	3	0	2	0
Low temperature	0	0	0	0	2	7[a]
High temperature	0	0	0	0	0	7[a]
CROP AND RESOURCE MANAGEMENT						
Weed control	8	9	7	5	6	4
Tillage	8	9	8	8	8	5
Erosion	8	8	0	0	0	0
Water management	0	0	8	4	8	8
Birds	8	8	8	4	8	8
Rodents	5	5	5	0	2	2
Stand establishment	5	6	5	5	5	2
Fertility	8	6	5	2	2	5
OTHER						
Grain quality	2	2	2	2	2	2
Processing	8	8	8	8	8	8

Note: [a] Applicable to only a small proportion of the irrigated area at high elevations and latitudes.

Table 4. Contribution of removal of major constraints by category to the achievement of target yield increase of 600 kilograms

	kg/ha	percentage
Disease	136	23
Insects	82	14
Adverse soils	32	5
Adverse environments	38	6
Crop and resource management	254	42
Other	58	10
Total	600	100

More effort is required to see how machinery and equipment can be adapted to local conditions. Agronomic research is needed on erosion control measures, on maintenance of soil fertility, and on stand establishment.

There was considerable difference of opinion as to whether water management was an appropriate topic for research. Some expressed the view that both technical and socio-economic knowledge was needed to determine the most appropriate procedures for developing the inland valley swamps and hydromorphic areas. Others felt that the technical knowledge was already available, and the appropriate first step would be to synthesize the experience gained in a wide range of swamp development projects throughout the region rather than to "reinvent the wheel".

There was general agreement that research on bird and rodent control should not be a major undertaking at an international agricultural research institute. However, scientists should keep abreast of technology advances in this area.

The topics considered in Table 3 above do not encompass all of the researchable questions. In the area of physiology the following research topics deserve priority attention: (i) identification of the target traits for the hydromorphic plant type, (ii) stand establishment and the competitiveness of weeds with rice plant types, (iii) root studies focused on the uptake of nutrients. It was also suggested that priority be given to a survey throughout the region to identify and establish the prevalence of nutritional disorders in the rice plant.

Finally, research should be undertaken by economists along with other scientists to establish the relative costs of developing various rice ecologies, taking into consideration alternative ways of developing rice lands.

SCIENTIFIC MANPOWER REQUIREMENTS

The priorities for scientific manpower requirements were decided in the following manner. It was agreed that a viable international rice research program should have a minimum of 5 senior scientists. The disciplines and subject matter orientation of the scientists were identified, and the priority in terms of rice ecologies specified. Additonal senior scientists were added incrementally to the intial staff of 5 up to a total of 27. It was felt that 27 senior scientists with proper support would be adequate to cover all the rice growing ecologies in West and Central Africa and to provide minimal support to national research programs and development efforts.

There was general consenus in the priority order given to the staffing by discipline, but considerable difference of opinion among the Study Group members as to the order of priority to be given to ecologies. The basic disagreement on ecologies centered around the issue of potential for raising yield and creating a marketable surplus. Some felt that the greatest potential lay in the irrigated areas, and there would likely be no payoff for research on the favorable uplands. Others argued that if the rice consumption requirements of the future were to be met, priority must be given to the inland valley swamps, hydromorphic areas, and favorable uplands, which together account for nearly two thirds of the targetted potential (Table 2). However, everyone agreed that without a substantial development effort, no amount of research would enable the African countries to achieve their rice production targets.

A consensus was finally reached that first priority should be given to the inland valley swamps and hydromorphic areas, which are often found in close association, and second priority to the favorable uplands. However, as previously mentioned, some members felt strongly that there would be no payoff for research on the uplands, and certainly little if any potential for creating a marketable surplus.

The staffing patterns are shown in Table 5 (see page 123). For the minimum program, 5 scientists (identified by the letter A) would be located at the research center or headquarters. These would include a plant breeder, pathologist, agronomist with primary focus on weeds, agronomist with primary focus on fertility, and farm level economist capable of researching both the economic and social issues affecting both the development of the ecology and acceptance of new technology.

If the program could be expanded beyond 5, two satellite stations would be added (identified by the letters B and C in Table 5). Each of the satellites would be staffed with a scientist from one of the varietal improvement disciplines and a scientist from one of the crop management disciplines. They would conduct research in conjunction with the national programs, their research agenda being dictated by the problems of the local environment and the needs of the national program. They would also have responsibility for liaising with national program rice scientists in two or three neighboring countries.

The addition of a plant physiologist and an agricultural engineer to do research on tillage would round out the research team for the inland valley swamps and hydromorphic areas with a total of 11 scientists.

If the research program could be expanded to handle upland rice, the mix of scientific disciplines at the research center and in the satellites would be the same as that for the inland valley swamps and hydromorphic areas, except that the research of the physiologist and engineer would be expected to cover all three ecologies. Likewise, an entomologist would be added to the staff at headquarters to handle research for all three ecologies. The total number of scientists would now be 21.

The addition of 6 more scientists would complete the staffing for a comprehensive rice research program for West and Central Africa. Three would be assigned to work at a satellite station for the mangrove swamps, an additional breeder and pathologist would be located at headquarters for research on irrigated rice, and an engineer would do research on post-harvest technology.

In the composition of the staffing pattern, almost equal weight has been given to scientists concerned with varietal improvement, and those concerned with crop and resource management. About 60 percent of the staff would be located at headquarters, and 40 percent at the satellites. This reflects the fact that much of the research activities must be linked with development efforts and efforts to strengthen national programs. While international research centers have a comparative advantage in conducting research on varietal improvement, it is not at present the major constraint to increased rice production in Africa.

It was felt that, in addition to research assistants, each senior scientist should be supported with one postdoctoral fellow and one research scholar. The operating budget per senior scientist with full support was assumed to be $225,000 per year.

Under this assumption the total cost for the rice research program under varying budget constraints is shown below where the letters A to I are the levels of priority shown in Table 5 (p. 123).

		Persons	*US$1000*
A	Minimum staff for inland valley and hydromorphic	5	1,125
A - D	Complete staff for inland valley and hydromorphic	11	2,475
A - H	Complete staff for inland valley, hydromorphic and upland	21	4,725
A - I	Complete staff, all ecologies	27	6,075

In summary, a minimum program focused on two ecologies with no satellite stations would require an operating budget of $1,125,000. A complete program covering all ecologies would require an operating budget of $6,075,000. Under African conditions it would probably be necessary to double these figures to cover overhead costs.

In addition to the scientific research staff, support would be needed for training activities, for germplasm storage, for grain quality analysis, and for seed multiplication.

LOCATION ISSUES

During the discussion of scientific manpower needs, there was a simultaneous discussion of where the research should be located. With respect to the headquarters or research center, two options were considered: a single center vs. two centers, one for upland and one for lowland rice research.

If there were a single center, one would have to consider the possibility of locating it where there would be easy access to both the upland and lowland ecologies. Conakry, Guinea, which is the heart of the area of most intensive rice cultivation, was suggested as one possibility. As with the choice of any site, the key question is whether local facilities would be adequate to attract an international staff of high caliber. If there were two centers, one option would be to locate the lowland center at IITA and the upland center at Bouake, Cote d'Ivoire. The principal advantage is that each of these locations already has an on-going international rice research

program and has the facilities to attract a strong international staff. The additional capital investment needed would be minimal. The main disadvantage is that IITA is not located in a rice growing area even though all of the major rice growing ecologies are found in Nigeria. Likewise, Bouake is located in the unfavorable upland rice area, a considerable distance from the more favorable areas which would represent the primary research focus.

While no specific conclusion was reached on the location of the center or centers, the Study Group felt that the overriding factor in selection should be the ability to attract a high quality staff.

Selection of satellites poses less of a problem. Rokupr is the obvious location for work on the mangrove swamps. The inland valley and upland sites might be established in any one of a number of locations where national program research facilties were readily available. For example, it might be appropriate to continue research on iron toxicity being conducted jointly by WARDA and IITA at the Central Agricultural Research Station, Suakoko, Liberia. This would be a logical priority for the inland valley swamps.

LINKAGES WITH OTHER ORGANIZATIONS

The close working relationship between the international center and national programs would be fostered through the establishment of satellites, as has been described above. Another form of linkage with the national programs is provided by the International Rice Testing Program (IRTP) which is currently being conducted cooperatively by IRRI and IITA. The IRTP serves two functions: (i) it provides an avenue for the dissemination of germplasm, (ii) it provides feedback of information on varietal performance to breeders. However, the program needs to be carefully developed so that national programs do not become overburdened, screening an excessive amount of inappropriate plant material, and thus diverting attention from more important research issues. The program should be designed to meet the needs of Africa.

A workshop for rice research workers in Africa should be held annually. The main purpose would be to share research findings through formal presentations and informal discussion.

Because of the importance of strengthening the research and development effort at the national level, scientists at the international center should cooperate where practical in supplying technical knowledge and information to development projects. These projects often provide a testing ground for the feasibility of new technology.

There would presumably be opportunities for the international center to expand its activities through special project funding. However, the center should not seek or accept special project funding unless the activity fits in closely with the center's research objectives.

It is expected that IRRI will play an important support role for African rice research through degree-related training of African scientists, training of African support staff in research techniques, and sharing of research publications. Keeping abreast of scientific advances can be achieved not only through contact with IRRI

scientists, but also by encouraging graduate students doing PhD research in developed countries to conduct their research in the African rice research center.

TRAINING

Training has a vital role in any international agricultural research center. Three types of training activities were discussed by the Rice Study Group: (i) rice production and farming systems training, (ii) advanced research (degree related) training, and (iii) training for technicians in research skills.

The production training should not be the responsibility of the research scientists. Most of the training should be conducted by the training support staff, with scientists scheduled to give lectures on selected topics. Much of the training should be conducted in the priority ecological areas. It is recognized that at present the most suitable training facility is the WARDA Training Center at Fendall, on the campus of the University of Liberia about 30 km from Monrovia. While it is not located in an ideal rice growing area, there are living facilities to accommodate 64 trainees. With proper logistical support to allow trainees to spend adequate time in rice growing areas, this facility could be effectively utilized for production training. The course should run for 5 or 6 months to allow the trainees to work through one complete crop cycle.

There is a shortage of production training material to suit African conditions. Most of the materials are adapted versions of Asian manuals. Rather than taking the valuable time of scientists, it would be better to employ a consultant to re-write the rice production training manual.

As suggested in the previous section, a major effort should be made to encourage advanced degree students (research scholars), particularly PhD students, both from African and from developed country universities, to conduct their thesis research under the guidance of senor scientists at the rice research center. The advantage is twofold. In the short run, the presence of graduate students enhances the research capacity of the center, while in the long run the center helps to develop the much needed scientific manpower.

There is a general shortage of research assistants and technicians with the technical skills needed for rice research, e.g. making crosses, laying out experimental plots etc. Now most of these technicians learn these skills on the job. IRRI offers a training course for technicians. It might be desirable to set up such a course at the African rice research center. It would be useful to study the IRRI and CIMMYT training programs for technicians before making this decision. The appropriate length of time for such a course would need to be determined.

CONCLUDING REMARKS

The Rice Study Group has considered the priorities for international rice research in Africa (with emphasis on West and Central Africa) over the next two decades. The rapid growth in rice imports and declining foreign exchange earnings in many African countries emphasizes the urgent need to increase rice production.

Constraints to increased production and research opportunities to increase yield were identified for the separate rice growing ecologies.

The Study Group gave first priority for research on the inland valley swamp and hydromorphic ecologies. These ecologies seem to offer the greatest opportunity for both yield increase and area expansion. However, these ecologies will evolve over time as development efforts allow greater control of water. Thus, it will be necessary to conduct research to determine the most efficient path of development, and to identify the rice technologies that will be appropriate at different stages in the development of these ecologies. Furthermore, research will have to take into consideration the frequently close association among upland, hydromorphic, and swamp ecologies in the farming system.

In the selection of scientific staff to conduct the research, a balance must be struck between varietal improvement activities and crop and resource management activities. The major constraints are in the crop and resource management area, and research in this area seems to have been underemphasized in the past.

The staffing plans call for the location of approximately 40 percent of the scientists in satellite stations linked with national programs. This reflects the need to strengthen national rice research and development efforts.

The complexity of the African rice growing ecologies presents the researcher with a major challenge. Every effort should be made to assemble a high caliber scientific staff, and to provide scientists with adequate logistical and staff support. The ability to attract qualified staff should be a major consideration in the location of the research center.

Annex 4

CONSULTANTS TO THE STRATEGIC PLANNING STUDY

Small groups of consultants were invited to participate in the strategic studies of each of the five research programs in collaboration with the program scientists. The study groups met twice for each program to develop priorities and strategies for research over the coming decade and beyond. Finally, the chairmen of the groups met with the Institute's management to determine priorities for research among the five programs.

The consultants in each of the five groups are listed below.

1. Maize Research Program

Dr. L. E. N. Shebeski, Manitoba, Canada GROUP CHAIRMAN
Prof. I. W. Buddenhagen, University of California, Davis
Dr. Pascal Fotzo, The University Center, Dschang, Cameroon
Dr. Elmer Johnson, International Plant Research Institute, California
Dr. L. W. Kanenberg, University of Guelph, Canada
Dr. Guy Rouanet, CIRAD, France

2. Rice Research Program

Prof. R. Barker, Cornell University GROUP CHAIRMAN
Dr. Lekan Are, Nigerian farmer and retired from Government service
Dr. R. W. Coffman, Cornell University
Dr. M. Jacquot, CIRAD, France
Dr. V. Nyanteng, WARDA, Liberia
Prof. Akira Tanaka, Hokkaido University, Japan

3. Roots and Tubers Improvement Program

Dr. D. Plucknett, Scientific Advisor to the CGIAR GROUP CHAIRMAN
Prof. R. Barker, Cornell University
Prof. I. W. Buddenhagen, University of California, Davis
Dr. S. Lyonga, National Root Crops Research Project, Ikona, Cameroon
Dr. T. Phillips, University of Guelph, Canada

4. Grain Legumes Improvement Program

Dr. M. A. Arnold, Plant Breeding Insitute, Cambridge, England
GROUP CHAIRMAN
Prof. A. Emechebe, Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria, Nigeria
Prof. R. Murphy, Professor Emeritus, Cornell University
Dr. K. Rachie, Winrock International, USA

5. Resource and Crop Management Program

Dr. T. M. Wormer, Royal Tropical Institute, Amsterdam (retired)
GROUP CHAIRMAN
Dr. R. Adelhelm, GTZ, Federal Republic of Germany
Dr. P. Crosson, Resources for the Future, Washington, D.C.
Dr. K. Davidson, The Rockefeller Foundation (retired)
Dr. J. D'dungu, University of Makerere, Uganda
Dr. L. Frederick, USAID, Washington, D.C.
Dr. P. Hildebrand, University of Florida
Dr. D. Nygaard, Winrock International, USA
Dr. P. Porter, University of Minnesota
Dr. M. B. Russel, Professor Emeritus, University of Illinois
Dr. W. Stoop, ISNAR, The Hague, Netherlands
Prof. E. Tollens, University of Leuven, Belgium
Dr. F. Wangati, National Council for Science and Technology, Kenya