IITA: 50 Years After

IITA

Transforming African Agriculture

50

1967 - 2017

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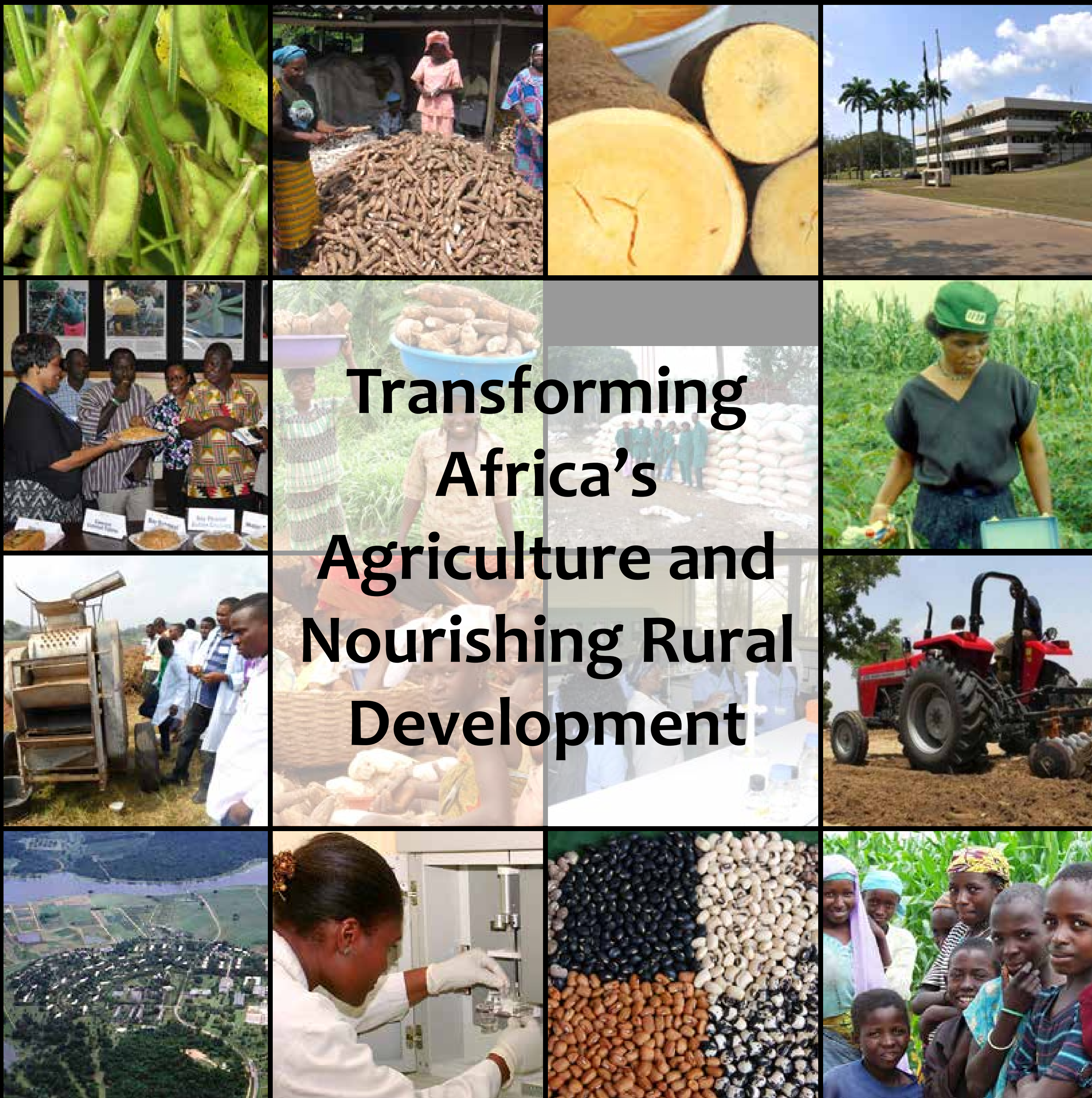

Transforming Africa's Agriculture and Nourishing Rural Development

IITA:

50 Years After

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Compiled by
Rodomiro Ortiz

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IITA: 50 Years After, Transforming Africa's
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We are 50!

This year IITA turns half a century old—one of only four CGIAR Centers (IRRI, 1960; CIMMYT, 1966; and CIAT together with IITA, 1967) that has so far reached this prestigious milestone, and the only Africa-based center to do so.

This publication chronicles IITA's 50-year journey from its inception and establishment in 1967—its transitions and transformations, its highs and lows, and the personalities that shaped it into the resilient and vibrant institution that it is today.

This "golden" milestone gives us an opportunity to pause and critically reflect on the lessons of the past, and see how we could leverage on these lessons to make us and our science more relevant and responsive to the ever-changing agricultural landscape of Africa and the rest of the world.

IITA was borne out of the need to have an African version of the "Green Revolution" that substantially increased agricultural production in Asia in the 1960s. Since then, there has been broad and strong interest in (and concern about) agriculture in this part of the world, as the continent is rocked by a myriad of challenges to food security and its twin problem of poverty. Today, these problems have been further compounded by climate change that is threatening the livelihoods of smallholder African farmers.

We ask ourselves, in five decades, has IITA really made headway against the challenges previously alluded to? I would confidently say, yes! As you go through the accounts in this book, you will see how our science, and our hardworking people, stayed the course to provide research- and evidence-based solutions to the problems of hunger and poverty in Africa, and in the process, achieve far-reaching impacts on the lives of the people that it serves.

Additionally, consider that in 1967 when we were first established the population alone of Africa was about 339 million. Today, it stands at roughly 1.2 billion, close to a 400% increase; that's a lot more mouths to feed given basically the same—and even dwindling—agricultural resources. Now, more than ever, the excellent science and development work that IITA is doing becomes even more relevant.

Despite some successes these past five decades, not everything has been all smooth sailing. Changes in the physical and donor environments, the reforms within the CGIAR, the state-of-the-art in agricultural science, and even transformations within our own structure through the years have, in one way or another, affected the way we did things, some positively, others not so much.

I strongly believe that these same “speedbumps” have also contributed to the strength and resilience of IITA as an institution. And to this end, I would like to especially thank our numerous partners and sponsors that have stayed with us through thick and thin—we will always be grateful and indebted to them for the support that they have provided, which enabled us to weather the storms.

More than anything else, this book is dedicated to IITA’s heart and soul: its people. For without their persistence, dedication, hard work, ideals, dreams, and aspirations, IITA would have never reached this golden milestone. Dedication, service, and excellence: these have always been at our core for the past 50 years, and will be for the next 50 or even more. For what is an institution but a collection of the individuals that comprise it, that makes it a breathing, living, and feeling entity?

Lastly, I would like to express my gratitude and honor to be helping guide the management and staff of this institution at the time that we celebrate our golden anniversary. It is, indeed, a once-in-a lifetime opportunity.

I hope you enjoy flipping through the pages of this book of IITA’s rich and colorful story and history.

We look forward to celebrating our centenary.

Bruce Coulman
Chair
IITA Board of Trustees
2011–present

ACKNOWLEDGEMENT

Information for this publication was taken from IITA's annual reports, institutional briefings and publications, external program and management appraisals, and the references included under "Further Reading" or in footnotes as well as from talks with IITA founders and colleagues. The author thanks especially the late Professor Dr Lowell Hardin (Purdue University, Rockefeller Foundation) and the late Mr David Sewell (IITA) for sharing their insights about IITA's first 40 years, Mrs Jenny Cramer (IITA) for sharing her knowledge and asking him to put together in 2004 "IITA: 40 years after. Historical account for the Handbook of IITA Board of Trustees", Dr Ylva Hillbur (IITA) for inviting him to update this early publication, Ms Katherine Lopez (IITA) for providing him with IITA publications from the last decade, Mr Shalewa Sholola for retrieving IITA's budget data, Ms Lilian Mendoza for an update on human resources, and Ms Evelyn Ohanwusi for information on IITA Youth Agripreneurs.

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Compiled by

Rodomiro Ortiz

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Researcher with a healthy bunch of cassava roots. Photo by IITA.

Pre -1967 The Beginning[1]

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"The challenge of increasing food security to keep pace with demand, while retaining the ecological integrity of production systems, is colossal both in its magnitude and complexity ... These realities require agricultural systems that focus as much on people as they do on technology, as much on resources on the long term as on the short term. Only those systems can meet the challenge of the future."[2]

As many references to IITA origins state: "The International Institute of Tropical Agriculture was established in July 1967 as the first major African link in an integrated network of international agricultural research centers located throughout the developing regions of the World. ... Funding for IITA came initially from the Ford and Rockefeller Foundations, and the land for the headquarters was allotted by the Government of the Federal Republic of Nigeria."

However , the idea of an institute to conduct research in the tropics of sub-Saharan Africa had been conceived some years before that by the founders of IITA. Indeed, it was in 1962, two years after the Ford and Rockefeller Foundations helped to launch the International Rice Research Institute (IRRI, Los Baños, the Philippines) that both Foundations began discussing the possibilities of centers concerned with improving the yield and quality of tropical food crops other than rice.

IITA Administration Building (Building 500) 50 years after.

[1] World Commission on Environment and Development (G.H. Brundtland, Chairman). 1987. Our Common Future. Oxford University Press. p. 144.

[2] Lawani, S. 1992. IITA. Sustainable Food Production in sub-Saharan Africa. I. IITA's contributions. IITA, Ibadan, Nigeria. Pages. 1–23.

As told by the late Lowell Hardin, former professor of economics at Purdue University and officer at the Ford Foundation in the early 1960s, many of the original centers of today's CGIAR were conceived in the daily exchanges of two neighbors traveling to work each day in New York City. They were George Harrar, the first leader of the Rockefeller-Mexico program and then president of the Rockefeller Foundation, and Forrest ("Frosty") Hill, then vice president of the Ford Foundation. As a result of their exchanges of ideas the Office for Special Studies in Mexico evolved into the Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT, Texcoco, Mexico), and later in the 1970s its potato program was included in the newly launched Centro Internacional de la Papa (CIP, Lima, Perú). In 1967, two multi-crop centers with similar names in English and Spanish but with clearly distinct agroecosystem geo-domains were added to what later was to be known as the Consultative Group on International Agricultural Research (CGIAR). These centers were Centro Internacional de Agricultura Tropical (CIAT) in Cali (Colombia) and the International Institute of Tropical Agriculture (IITA) in Ibadan (Nigeria). IRRI, CIMMYT, CIAT, IITA, and CIP were the first international centers of the CGIAR network that today includes another 10 institutes worldwide, addressing a broad range of issues in agriculture: fishery, forestry, livestock, water and other natural resources management, plant genetic resources, research capacity building, and food policy.

In October 1963, Harrar and Hill visited Nigeria to explore the feasibility of such an international undertaking. The visit was followed by an extensive tour around the country by Richard Bradfield, an agronomist of the Rockefeller Foundation, and Frank Moore, a program specialist in agriculture at the Ford Foundation in Nigeria, and together with Donald Kingsley, the Ford Foundation

IITA entrance under construction in 1968.

representative in Nigeria, they recommended the establishment of the Institute "*on or adjacent to the campus of the University of Ibadan*". In December 1963, the Ford Foundation Board authorized its staff to submit the proposal for such an international organization to be jointly funded by both Foundations.

Throughout 1964 and 1965, David Heaps, the new country representative of the Ford Foundation, had extensive exchanges on the proposal with the Government of Nigeria, which published a notice of its intention to acquire the land in the Official Gazette of 23 December 1965. In March 1966, agreement was reached on the objectives, organization, funding, tax status, land needs, and other matters, and IITA was thus established. That same year, the Ford Foundation appropriated US$5 million for the building of IITA's headquarters on land at Ibadan, donated by the Government of Nigeria and named Will Martin Myers as the first director-designate. His tenure was short-lived when in early 1967 Myers left IITA to take up the post of vice president of the Rockefeller Foundation. Although civil war broke in Nigeria, the construction of IITA began in 1967 under the leadership of the first Director General of IITA, Herbert R. Albrecht—a leading agronomist from the University of Wisconsin–Madison and former president of North Dakota State University—with the backstopping of Haldore Hanson from the Ford Foundation in Nigeria.

The strong commitment by the Government of Nigeria since 1963 had been the key to IITA headquarters being kept in Nigeria despite the political turmoil and civil war. Another exhibition of commitment was the legal status given by the Government of Nigeria to IITA, both as its inception with Decree No. 32 and later with the signing of the headquarters agreement included in the 1991 Diplomatic Immunities and Privileges Order. In 1992, the Government of Nigeria issued a million copies each of four commemorative stamps to mark the Silver Jubilee of the Institute.

IITA staff celebrates 50th year in 2017!. Photo by IITA.

Banana is one of IITA's mandate crops. Photo by IITA

1967–1975 The Early Mandate: What Founders Had in Mind for IITA

2

As a Ford Foundation working document dated 1963 states, the overall rationale for establishing IITA as an international, high-quality research organization was to achieve the following:

- Find ways to enhance the yields and quality of tropical food crops other than rice. The research domain included all aspects that allow the quality of food to be increased and improved.
- Provide in collaboration with the strongest university in the region, high-level professional training for carefully selected citizens of tropical countries who should serve later in the home institutes dealing with food security and quality.
- Be a pacesetter that improves the effectiveness of research, training, and extension of other organizations in the region.

The original objectives were further fine-tuned by Myers who wrote the scope of IITA's first research program. Ahead of its time, (20 years before the Bruntland Report), the document written by Myers brings some of the issues that today are associated with the term "sustainability". The program he envisioned also stressed the need for trees and animals in agricultural systems and suggested projects on biological control and pest ecology. Myers was clear about the dual character of the challenge to IITA and provided the initial thoughts about its mandate when he wrote, "*The research of the Institute is to focus primarily on problems of improving food crop production in the humid tropics and on the soil and crop management requirements for developing a stable, permanent agriculture in which food crops occupy a central position.*"

The objectives of the Institute were clearly spelt out therefore in the Government of Nigeria Decree No. 32 which added the following to those included in the original Ford Foundation thinking:

- Publish and disseminate research findings in recommendations of the Institute
- Distribute improved planting materials to other research centers where they may be of significant value in breeding or improvement programs
- Establish, maintain, and operate an information center and library to provide interested scientists and scholars everywhere with a collection of the world's literature in tropical agriculture
- Organize or hold periodic conferences, fora, and seminars, whether international, regional, local, or otherwise, for the purpose of discussing current problems in the field of tropical agriculture.

Dr Herbert R. Albrecht

Gen. Yakubu Gowon

On 20 April 1970, the dedication of the headquarters was witnessed by the Head of State Major General Yakubu Gowon, the President of the Ford Foundation McGeorge Bundy, and the President of the Rockefeller Foundation George Harrar. In his speech Bundy insisted on the need for a *"new kind of institution charged to attack the knowledge gap."*

Early thoughts for bringing food security to African homes

Albrecht and Hanson agreed that the first priority for the newly launched international research organization was to assemble the existing knowledge of African food crop production which was, of course, an immense task for its time. The information was incomplete and scattered among the then 45 African governments, and in the archives of research organizations and universities of the former colonial powers: Belgium, France, and the United Kingdom. They organized 12 conferences at Ibadan in 1970 and 1971 that brought together about 600 scientists of tropical Africa together with the best-known experts from Asia, Europe, Latin America, and the USA. Some of the seminars were devoted to individual crops, others to crop husbandry, agricultural engineering, or natural resource management. In the opening lecture on 26 January 1970, Hanson challenged the scientists. "I suggest that the agricultural scientists in this room and their colleagues can be a key factor in launching a green revolution in tropical Africa in the 1970s. Unless this green revolution begins soon, there will develop gradually during the next 30 years, political unrest accompanied by more military governments, more civil wars, more conflicts between African nations, and disruption of economic growth. In short, agricultural scientists hold a special responsibility to decide whether black Africa can remain at peace." In his view, which later he acknowledged

President of the Ford Foundation McGeorge Bundy speaking at the dedication ceremony of IITA, 20 April 1970. Photo by IITA as incomplete, the main obstacles were shifting cultivation, irrigation, lack of mechanization, land tenure, input prices, particularly for agro-chemicals, and inadequate marketing arrangements.

As a result of the series of seminars a book—among IITA's first international public goods—was released by Oxford University Press in 1977. This book, Food Crops of the Lowland Tropics, (C.L.A. Leakey and J.B. Wills, eds.), was for many years a classic for agricultural researchers on the continent and significantly influenced IITA efforts to transform Myers' early thoughts on the scope of the scientific program into a set of research undertakings for the Institute. The arguments of the first chapter on research strategy by Albrecht and Guy Vallaeys—who later was Board Chairman—remain compelling today. "The word 'strategy' conjures up ideas of the art of war, and in this case we can say we are planning the war on hunger. Such strategic planning inevitably involves deciding the geographical and chronological order of priorities for guiding combined efforts. It has to be admitted that the deliberations of the Ford Foundation/IITA/IRAT seminar did not in fact succeed in defining a limited number of specific objectives for concentrated priority effort. One of the difficulties which faced participants was the very wide range of food crops that form a characteristic feature of the region as a whole. Such variation in food crops is not found to the same extent in any other tropical region." About 45 years ago, the participants in the seminar series highlighted the absence of management options for improving or maintaining soil fertility to allow settled rather than shifting agriculture. They also recommended the need to integrate the social sciences to ensure a farming systems approach in the Institute as well as the need to collect, conserve, use, and exchange crop genetic resources, and noted that there was little attention given to improving the nutritional quality of tropical crops. Some of their

IITA Board of Trustees in a meeting, 1967. Photo: IITA suggestions were new undertakings by IITA researchers that brought impacts both on science and African livelihoods in the decades thereafter.

Under the tenure of Albrecht (1967–1975) the human resource policy encouraged the hiring of highly motivated and professionally skillful researchers and support staff. This asset was always in the heart of IITA founder "Frosty" Hill who at a Board meeting underscored the quality of the staff with his famous words, "Dollars aren't going to solve anything, and buildings won't solve anything, but the scientists themselves, by staff cooperation, are the ones who will bring the desired results." W.K. Whitney, an entomologist, was the first IITA scientist to join the Institute in late 1968. Fields Caveness, a nematologist, followed him and by April 1969 both researchers had established experiments in Ibadan according to their professional domains. A research committee was created soon afterwards and agronomist Rodney A. Briggs was appointed as the first Director of Research. He resigned two years later and John I. Nickel replaced him until 1974 when he left to take a new job in Colombia as Director-General of CIAT. During Nickel's tenure as Director of Research the IITA agenda was organized into four programs: Farming Systems under the leadership of James C. Moomaw (who later became the Director General of AVRDC, today's World Vegetable Center with headquarters in Taiwan), Cereal, Grain Legume, and Root and Tuber Improvement with Michael N. Harrison, Kenneth O. Rachie, and Sang Ki Hahn, as heads of each crop-led program, respectively. In 1974, Dennis J. Greenland started his 3-year tenure as Director of Research and Bede N. Okigbo took over as Assistant Director in the research leadership of the Farming Systems Program.

Understanding soil fertility management as an alternative to "slash-and-burn"

Myers brought to the IITA research agenda the need for natural resource management because of his strong views that research on food crops in the humid tropics would hinge on sustaining or increasing soil fertility while moving into intensive settled agricultural systems rather than continuing with shifting cultivation. As a result, IITA gave special attention in its early years to tropical soil research, crop rotations, and management using soils more intensively. Hence, it was not surprising that in the first decade of research the team of scientists of the IITA Farming Systems Program investigated why the small farmer in the humid tropics practiced shifting cultivation using the bush fallow system, and why soils became unproductive and useless after only a few years. A 10-year, 60-hectare watershed management research effort in Ibadan demonstrated that the extensive land clearing and leveling so often thought to be the only road to "farming" were nearly always a mistake but there were some land clearing and post-clearing practices that could conserve the soil's viability. Building upon the foundations laid by agricultural scientists in Africa in preceding decades, the IITA research team (which over the years included Anthony S.R. Juo, soil chemist; B.T. Kang, soil fertility specialist; Frank R. Moorman, pedologist; Aba Ayanaba, soil microbiologist; and Rattan Lal, soil physicist) quantified the interrelations of these practices with soil physical and chemical priorities, water and nutrient availability, soil fauna, organic matter levels, water runoff and erosion, rainfall, temperature, various cropping methods and crop yields to establish a scientific basis for predicting the effectiveness of cropping practices. Through this research and those of others before them, it was established that a large part of humid and subhumid tropical Africa is dominated by highly weathered, structurally fragile, coarse-textured soils that are characterized by a shallow rooting depth, low available water and plant nutrient reserves, and soil acidity. Though extremely susceptible to erosion and compaction, these soils remain ecologically stable as long as the natural vegetation is not disturbed. But once the cover is removed and high input technology is applied, these soils often suffer rapid physical, chemical, and biological degradation. These results represented a major correction in what was once the commonly held perception of agricultural potential in the African tropics: bush growth on rich soils, waiting only for modern agricultural methods to be brought to full food production. Soil research during IITA's early years was to provide a basis for the systematic targeting of technology, while technology development was to generate different prototypes broadly adapted to specific classes of soils and environments. Soil and water management research, therefore, subsequently concentrated on cropping technology that prevents soil erosion, maintains a continuous ground cover and provides a source of organic matter, offers an effective nutrient recycling mechanism (i.e., like the forest tree), and generates favorable conditions for active soil fauna. In addition, having learned a great deal about the actual farming conditions in Africa and the generally resource-poor Africa farmer, IITA researchers sought to develop technology that requires a minimum of purchased inputs. Although their research did address real technical challenges for intensified production, it was largely supply-driven rather than a direct response to demands from farmers. Nonetheless, by 1980, IITA showed progress in farming systems using minimum tillage, no plowing, and with pesticides for weed control.

Arid land in East Africa. Photo by IITA.

Woman selling maize grains. Photo by IITA

1975–1980 Shifting from the Initial Mandate and First Impacts

3

Evolving mandates and changes in management are usual for dynamic organizations that aspire to influence others. IITA was not an exception and some ideas for changes came throughout its history from the Board of Trustees or were initiated by the new Directors General or research leaders who often sought staff inputs. The first change in the IITA mandate was brought by the launching of the CGIAR in 1971 and the first external review (hereafter EPMR) of IITA. The Board of Trustees accepted the EPMR recommendation to broaden the geo-domain and therefore added the African tropical savannas since the headquarters at Ibadan lie in the transition zone between these savannas, and the lowland humid forest, being mindful also of the complementary economic relationships between both agroecosystems. Such a change brought to the IITA mandate an ambitious "wish list" of commodities (e.g., many grain legumes and root and tuber crops) as well as their problems for scientists to tackle. Likewise, this EPMR encouraged IITA to accept responsibility for improving important crops grown by African farmers for which other CGIAR centers had the worldwide mandate (e.g., cassava by CIAT, maize by CIMMYT, and rice by IRRI). At the Board meeting in June 1972, it was agreed to add plantain and banana to the IITA mandate because of their importance as food crops and their role in the farming systems of the humid tropics. The "champion" for both crops was Trustee Abdoulaye Sawadogo, then Minister of Agriculture of Côte d'Ivoire.

In 1974, when the Institute was just seven years old, IITA researchers were carrying out research on cassava, yam, sweetpotato, cocoyam, maize, rice, cowpea, soybean, lima bean, pigeonpea, winged bean, African yam bean, and velvet bean. Myers' idea of including livestock was not taken because of the launching in the 1970s of the International Livestock Center for Africa (ILCA, Addis Ababa, Ethiopia) although IITA continued forage research to investigate the nutritional value of some species. In May 1975, through an agreement with the International Board for Plant Genetic Resources (IBPGR, the predecessor of today's Bioversity International, Rome, Italy), IITA added a Genetic Resources Unit (now IITA's Genetic Resources Center) to collect and preserve the genetic resources of African grain legumes, rice, and root and tuber crops.

On 1 September 1975, William K. Gamble, an expert on rural education, started his 5-year tenure as the second IITA Director General. He submitted to the Board in early 1976 a new vision for the Institute entitled *The Purpose of IITA*. During

Dr William K. Gamble

his tenure the geo-domain mandate was enlarged to include humid and subhumid tropical zones, which were defined as "*all areas between the Tropics of Cancer and Capricorn in which average precipitation exceeds evapotranspiration for five months of the year*"; i.e., the humid forest and the Guinea savannas. After Greenland's departure, IITA economist J.C. Flinn acted as Director of Research until 1977 when S.V.S. Shastry started his 5-year tenure as the senior Research Manager of the Institute.

Unveiling the new African cassava: from a poor man's food security crop to a pacesetter

It was during Gamble's tenure that the first impacts from the results of crop improvement started to be seen on the continent. When S.K. Hahn arrived in Ibadan in 1971 to establish a Root and Tuber Improvement Program at IITA, he rightly saw that no amount of research effort would increase yields until the problem of *cassava mosaic virus* disease was solved. He recognized the enormous implications of an endemic disease aggravated by humans through the use of diseased cuttings, and focused cassava research tightly on this disease problem. With Eugene Terry as pathologist (who later became the Director General of the African Rice Center–known by its acronym then as WARDA, Bouaké, Côte d'Ivoire), Hahn began the arduous task of searching the germplasm for resistance characters and then combining those characters with clones having desirable yield and quality factors. Fortunately, Hahn had access to the mosaic resistant breeding populations developed by A.J. Storey in East Africa nearly 30 years before and those of Brian Beck at Moor Plantation (Ibadan) in the 1950s. These populations had, however, very poor root yields. He also brought cassava germplasm from Asia and South America. The latter incorporated wild *Manihot* genes that had been initially bred by Prof. Nagib Nassar (University of Brasilia) and other researchers in

Farmer displays harvest of big cassava roots. Photo by IITA

Brazil. The task of the IITA team—ably assisted by Audrey Howland, an outstanding breeding research associate—remained to cross, select, clone, challenge, rogue, and select, beginning each season with up to 10,000 seedlings, until the desired level of resistance was incorporated into "elite" IITA cassava breeding materials.

This work, plus an equally successful effort by the same IITA team against cassava bacterial blight, brought Hahn and the IITA Root and Tuber Improvement Program to the point he had foreseen in the early 1970s. Research could be launched to increase yields in a broad range of agroecological zones and cultivation systems to suit a wide variety of consumer preferences. As pointed out by the World Bank in its 2001 meta-evaluation of the CGIAR: "*Despite an over-ambitious research agenda, the frustrations of the 1967–70 Nigerian civil war and subsequent coups d'état, IITA researchers carried out several important research programs on cassava in the 1970s and 1980s. The first thrust was genetic research to boost cassava yields. Under the direction of S.K. Hahn, a cassava research team drew on mosaic-resistant cultivars that were developed at the Amani Research Station in Tanzania in the 1930s and crossed them with West African landraces. After only six years of research (1970–1976), IITA released high-yielding TMS cultivars that increased farm yields by 40% without fertilizer). The new TMS cultivars were widely adopted in Nigeria and in Ghana and Uganda after a time lag. Hahn devoted his 23-year career at IITA (1970–1993) to cassava improvement. Without question, the development of the TMS cultivars in the 1970s represents an important contribution to Africa's food security, especially among the poor. … The IITA partnership with cassava researchers in national programs has helped transform cassava from a famine-reserve crop into a high yielding and cheap source of calories for both urban and rural consumers. Nweke, Spencer, and Lynam conclude in '*The Cassava Transformation*' that cassava is a powerful 'poverty-fighter'.*"

High-yielding cassava varieties developed by IITA. Photo by IITA


Cowpea seeds on their way to the market. Photo by IITA

1980–1985 Refocusing the Mandate and Building Successes

4

Gamble left IITA in the third quarter of 1980 to be the Director General of the International Service for National Agricultural Research (ISNAR, The Hague, the Netherlands). In October 1980, agronomist Edmond H. Hartmans took office in Ibadan as the new Director General of the Institute. S.V.S. Shastry ended in 1981 his 5-year tenure as Director of Research, and Deputy Director General L.H. Shebeski was the interim senior Research Manager for the next two years. Hartmans was going to build upon the work of his predecessors and his tenure at IITA was going to be influenced by the CGIAR Technical Advisory Committee (TAC). The EPMR of 1978 by TAC headed by Guy Camus urged IITA to consolidate its activities and leave a number of commodities to be addressed by the National Agricultural Research Systems (NARS). In 1983, another TAC team led by Michael Arnold cautioned IITA against getting involved in too many downstream agricultural development projects. Likewise, funding shortcomings, affected by the oil boom in Nigeria in the late 1970s and early 1980s and its ensuing inflation, brought a period of staff retrenchment and a loss of purchasing power. In Hartmans' words, "*At a time when the situation in African agriculture is deteriorating rapidly, and when a build-up of research would be one of the most cost-effective responses by the international community, the Institute's program has had to be reduced in real terms by more than 26 percent.*"

Hartmans took the challenge of converting the funding threat into a new mandate opportunity for IITA and undertook an appraisal of "*... what has been accomplished, to take a hard analytical look at the complex problems facing agriculture in the humid and subhumid tropics and select the most important tasks which the Institute should tackle in the years ahead.*" The outcome of this undertaking was the first 10-year plan (1981–1990) of the Institute, *Tasks for the Eighties: A Long-range Plan,* that was spearheaded by Declan Walton, a consultant who later was Deputy Director General of the Food and Agriculture Organization of the United Nations (FAO, Rome, Italy). Walton and Hartmans sought views from staff and Trustees before submitting the draft to the Board meeting of 8 May 1983 which endorsed the new plan and its priority areas for investment from a troubled perspective owing to the funding shortcomings during the period. It was in that 10-year plan that the concepts of benchmark areas and on-farm research were clearly spelt out as elements of an eco-regional network that was shaped further in the 1990s: "*By 1985, IITA should have (a) series of basic technological packages aimed at enabling traditional mixed cropping systems to achieve*

Dr Ermond H. Hartmans

increasing production levels; such packages may include new cultivars and improved agronomic practices, and they should be tested on farmers' fields at representative or benchmark localities through a Cropping Systems Network." This plan also included monitoring tools to measure progress for each activity to be undertaken according to the objectives for each priority area. The 10-year plan did not add new geo-domains or crops but started capitalizing on some of the early research of the Institute, e.g., maize improvement and hybrids, that was encouraged by the Government of Nigeria and so brought new funding.

The maize revolution in Africa starts

Early emphasis in IITA in maize improvement research was on resistance to two diseases, lowland rust and lowland blight. These had been recognized for decades before the Institute was established as the most important constraints to maize production in lowland West Africa. Harrison and his Cereal Improvement team built upon the early work in Nigeria, especially that of the West African Maize Rust Research Unit. Harrison was a maize breeder who came to IITA after many years of maize work at Kitale (Kenya). He selected two Nigerian composites, A and B bred at Moor Plantation (Ibadan) from diverse source germplasm under a West African project supported by the Scientific and Technical Research Committee of the Organization for African Unity, as well as broad-based populations from Central America as the base materials for the IITA breeding program. His strategy, however, emphasized selection for a vigorous plant type that would respond well to enhanced crop husbandry, especially high plant density and fertilizer use. Using the IITA irrigation facility to grow three generations in one year and selecting for narrow and erect leaves above the ear, a short strong stalk, multiple ears per plant, and disease resistance, Harrison and his team produced two

Woman maize farmer with her healthy maize crop. Photo by IITA

Bird's eye view of IITA, circa 1980s.

outstanding open-pollinated varieties, TZB and TZPB, in a remarkably short time. Picked up by several agricultural development projects, these cultivars spread quickly throughout Nigeria and neighboring countries and were used extensively as breeding materials for maize improvement in Africa. In the late 1980s, TZB and TZPB were grown on over one million hectares in Central and West Africa.

The widespread outbreak in the late 1970s of the *maize streak virus* (MSV) disease, which can wipe out the crop entirely, prompted IITA to establish a multidisciplinary team to develop resistant maize cultivars. Often associated with drought or erratic early rains, MSV appears sporadically. Spurred by the efforts of Ivan Buddenhagen, a plant pathologist, and Pablo Soto, an entomologist, a suitable and reliable protocol was then established to screen maize germplasm for resistance to a disease that occurs sporadically in the field. This included rearing the vector in sufficient numbers for mass testing, and collecting samples of the vector and the virus itself from many sources, including wild grasses, to ensure that all screened plants would be infected with all possible strains. With the development of this protocol and the identification of two sources of resistance, an intensive breeding program was initiated at IITA by crossing these sources to high-yielding and broad-based germplasm from CIMMYT, eastern and southern Africa, the temperate zone, Central and South America, Thailand, DEKALB, and other sources to breed MSV resistant populations and cultivars. These cultivars plus CIMMYT populations and pools converted to MSV-resistant versions through a partnership project were extensively tested for stability of resistance to MSV across 36 national programs in Africa. The sharp focus and concentrated efforts led to the development and availability of high-yielding MSV-resistant cultivars and hybrids with different maturity classes, grain colors, and grain textures for all the relevant agroecosystems in Africa by 1985. The principal work remaining was to incorporate this resistance in germplasm bred for use in Africa and

to maintain continued vigilance over the effectiveness of their resistance. The pioneering multidisciplinary research accomplishments of IITA to combat MSV won the CGIAR King Baudouin award in 1986, the first of the many internationally known awards that the Institute has received throughout its history.

To offer national programs a wide array of maize germplasm appropriate to various levels of institutional capacity, available research manpower and facilities as well as farmers' circumstances, IITA initiated a maize inbred line–hybrid development project in 1979. At the request of and with funding from the Government of Nigeria, this project was expanded in 1982 to include hybrid development. Using tropical and temperate germplasm from multiple sources, IITA maize scientists led by S.K. Kim bred vigorous tropically adapted inbred lines with good combining ability that are resistant to the major diseases. The use of temperate-derived lines was a major factor contributing to the success of developing hybrids with high level of heterosis. The inbred lines generated in this program were available to the NARS for use as uniform and homozygous sources of disease resistance, as parents for developing improved open-pollinated synthetics and breeding stocks as well as for the rapid generation of conventional or unconventional hybrids. The hybrids emanating from the hybrid breeding program with yields exceeding the best available open-pollinated cultivars by 25% were released for the first time in Nigeria in 1983. The spillover effect of this release was the formation of a small seed industry to market hybrid maize in Nigeria. A decade later, each of the three seed companies operating in Nigeria (Premier, UTC, and UAC) officially announced IITA open-pollinated and hybrid maize cultivars in their seed catalogues. Furthermore, IITA promoted community based seed production schemes in West and Central Africa with many regional partners to make improved seeds available to farmers.

Soybean: A "new" legume for Africa

During Hartmans' tenure soybean improvement also moved forward in the research agenda of the Institute. Prior to the establishment of IITA, high-yielding soybean cultivars bred in the USA and elsewhere could not be grown in Africa without rhizobia inoculation, an expensive and technically complex treatment for many farmers in this continent. The indigenous rhizobia are effectively symbiotic with other legumes such as cowpea and groundnut but could not be utilized by the imported soybean material. An IITA breeding program was therefore designed, principally by Edward Pulver, a physiologist/agronomist, and Eric Kueneman, a soybean breeder, to breed a new soybean for Africa with the plant type and production characteristics of advanced US lines that would nodulate freely with the rhizobia found in African soils. Their source of "promiscuous nodulation" was a traditional soybean cultivar from Southeast Asia, a poor-yielding, sprawling, viney plant that nodulated well with the indigenous African rhizobia. Using a carefully thought out but statistically complex methodology that included maize as a soil nitrogen check, the IITA soybean breeding team was able, over time, to combine the strengths of these two divergent populations into a desirable plant type that grew and yielded well without artificial inoculation. A second constraint to soybean cultivation in Africa has to do with seed longevity; i.e., under tropical conditions soybean seeds tend to lose viability long before the next planting season. To speed up the screening of families for seed longevity, the IITA soybean team developed a high-humidity, high temperature, ageing technique that mimicked ageing in ambient conditions but at an accelerated rate. In this way they were able to identify lines with good seed longevity in a relatively short time. Seed longevity has been successfully bred into IITA elite soybean lines, thus making available to African farmers the means to produce a high-protein food crop with a minimum of initial investment.

The genetic enhancement of soybean alone was, however, not having a good impact on African livelihoods. Government policy and farm-level technology were needed for the success of soybean in Nigeria during the 1990s. High-yielding soybean cultivars from IITA, resistant to pod shattering, increased farmers' average yields in Nigeria from 310 kilograms per hectare in 1991 to 730 kilograms per hectare in 2001, which led to an increase in production of nearly 300 percent—from 145,000 tonnes to 429,000 tons within the same period—though the area planted to soybean increased by only 26 percent. Children who consumed soybean showed a significantly better nutritional status than those who did not. Not surprisingly, several health centers and hospitals in Nigeria started using soybean products to treat malnourished children. This crop also contributed to the economic independence of women and the generation of more income, allowing the acquisition of new household items and the payment of medical bills and school fees. In the second half of 2000, IITA expanded soybean breeding to southern Africa, where cultivation by small-scale farmers was rising because the crop had less susceptibility to pathogens and pests, better grain storage than other legumes, large leaf biomass, and a secure commercial market, particularly in South Africa, Zambia, and Zimbabwe, where commercial soybean farms are found.

IITA's improved soybean varieties helped provide better nutrition for malnourished children. Photo by IITA

Soybean farmers admiring IITA improved varieties. Photo by IITA

1985–1990 Taking Stock to Sharpen IITA Focus

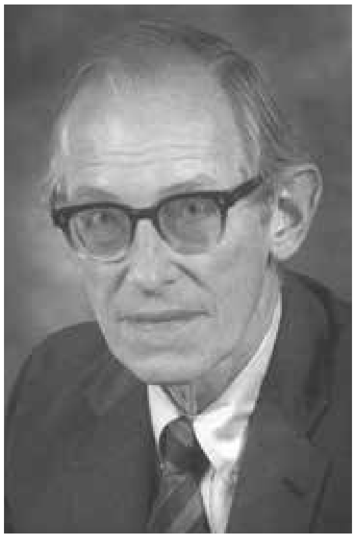
5

In the last quarter of 1985, the economist and former member of staff at Cornell University Laurence "Larry" D. Stifel replaced Hartmans as IITA Director General and took drastic actions that were regarded as a reinvention of the Institute. His main argument was that after 20 years IITA was ready for reengineering because many of the early assumptions by the IITA founders might no longer be valid. With the endorsement from the Board, he embarked the Institute on a comprehensive and lengthy strategic study with the able support of Kenneth S. Fischer, his newly appointed Deputy Director General of Research.

The main results of this exercise were brought to the attention of the IITA Board that adopted the following policy statements that shaped IITA in the second half of the 1980s and the early 1990s:

- Emphasizing primarily the farming systems of the African lowland and subhumid tropics, which are mostly in West and Central Africa
- Focusing on enhancing yields in the fields of African smallholders (< 3 ha of land) as they employ 75 percent of the labor.
- Decentralizing research through stations or satellite sites in the key agroecosystems of the subregion. Each station should include a small team of scientists to set clear objectives for research undertakings ensuing from a better understanding of the farming systems in their respective geo-domains. These were Kano in northern Nigeria for the Sudan savanna, Abuja in north-central Nigeria for the Guinea savanna, Onne in southeastern Nigeria for the degraded forest, Yaoundé/Mbalmayo (Cameroon) for the humid forest margins, and Cotonou (Benin Republic) for the coastal savanna, along with the headquarters in Ibadan (southwestern Nigeria) for the transition zone in the derived savanna.
- Ensuring a farming system culture throughout the Institute; as a result, the interdisciplinary commodity based working groups were established around cassava (humid forest), maize (moist savanna), and rice (inland valleys)

This *Strategic Plan 1989–2000* was meant to confine IITA to West and Central Africa and to keep, through networking, the Pan-African cassava mandate in Eastern and Southern Africa. One of the driving forces behind this reorganization of IITA was again the insufficient funding that could not bring the needed resources for an ambitious research agenda. Comparative advantages ensuing from the Institute's competitive edge defined the priority crops to be maintained in the agenda. IITA Board



Dr Laurence D. Stifel

decided to strengthen cassava, cowpea, and maize improvement, undertake innovative approaches for the genetic enhancement of plantain and banana, and keep a modest investment in both soybean and yam breeding. However, the Board agreed to terminate research on cocoyam, transfer the global mandate on sweetpotato to CIP, and the regional mandate on rice to WARDA. It was also accepted that the African mandate on maize improvement should be shared with CIMMYT that agreed to take the leadership in Eastern and Southern Africa. The main idea in simplifying its mandate on crop breeding was that the Institute could enhance in a short time frame its probability of success in the genetic enhancement of the six remaining crops. The Institute kept in its cropping systems research the investigations on crop and resource management for both rice and sweetpotato, including cultivar testing for the latter in Southern Africa through the Root Crop Network.

In the mid-1980s, IITA got capability to undertake On-farm Research (OFR) following changes elsewhere regarding the farming systems research approach. By the late 1980s, IITA began moving its researcher-controlled trials to carrying out demand-driven research in farmers' fields, especially in the savanna.

Towards the end of the 1980s, Prof B.N. Okigbo, the longest serving Deputy Director General of the Institute and one of the most prestigious scientists in the continent, known as the "Encyclopedia of African Agriculture," stepped down. Prof Okigbo moved to the United Nations University to share with researchers worldwide his superb

Intercropping of cereals and legumes. Photo by IITA knowledge of the crops and cropping systems of sub-Saharan Africa.

Sowing the seeds of success for the genetic enhancement of rice in Africa

The IITA Rice Program was a big component of the research agenda of the Institute until WARDA took it over. The IITA genebank had assembled a large rice collection and still keeps in trust about 12,000 accessions (> 20% of the West African species *Oryza glaberrima*), which are now under the WARDA mandate following arrangements by CGIAR with FAO in the 1990s. IITA-bred lines were widely distributed to African NARS that released many of these materials, particularly in irrigated areas where rice was intensively cultivated. This still does not seem to be the most common approach for producing this crop in the continent. IITA-bred germplasm for more extensive upland environments was making far less headway in replacing traditional genotypes, mainly because the former needed more weed control. Many of WARDA cultivars, over a decade later, were still using the letters "ITA" to acknowledge the source from IITA-bred materials. As a result of this transfer of the rice breeding mandate to WARDA, Monty Jones, then IITA rice breeder in Cameroon, left the Institute in the 1990s to breed the new rice for Africa (NERICA) at the Africa Rice Center. In 2004, Jones—from Sierra Leone—was the co-winner of the World Food Prize for this success in the genetic enhancement of rice that involved cross-breeding between African and

Women farmers in Africa harvesting rice. Photo by AfricaRICE

Asian rice with the aid of embryo rescue to produce hybrids between the two species as well as farmer-participatory plant breeding.

Cowpea: The African legume for the dry African savannas

Cowpea is widely grown in West Africa because it feeds people and livestock and, as a nitrogen-fixing legume, it improves soil fertility. This pulse is thought to be indigenous to the subregion. This circumstance put IITA in an ideal place to collect and conserve cowpea germplasm. The first leader of the Grain Legume Improvement Program at IITA, K.O. Rachie, was quick to recognize this opportunity and his early persistence resulted in a collection of over 4,000 accessions. The high humidity of the transition zone at IITA headquarters makes it a "hotspot" for cowpea pathogens and, therefore, an ideal location for the breeding of cultivars resistant to the bacterial, viral, and fungal diseases that limit yield in the humid tropics. Capitalizing on the obvious advantage of the extensive germplasm collection, Robert Williams, the first grain legume pathologist at IITA, had organized since the 1970s extensive screenings of all accessions for resistance to any of the prevalent diseases. Selected accessions and advanced breeding lines were then intensively screened, with particular emphasis on multiple resistance, i.e., to several pathogens within one plant. Promising material was shared worldwide through the International Cowpea Disease Nursery Program initiated to identify broad-spectrum, stable resistance to many different populations of pathogens over a wide range of environments. More than 100 sources of multiple disease resistance were identified from nearly 8,000 accessions. Working closely with the Cowpea Breeding team, Williams and his successor David Allen were successful in breeding lines with broad-based, multiple resistance to most of the

Diversity in cowpea seeds in the IITA genebank collection. Photo by IITA

Researcher looking at cowpea plants and pods. Photo by IITA

major diseases of cowpea grown in humid areas. The same techniques were used to combat the diseases—principally bacterial blight and brown blotch—threatening production in the savanna zones.

In the late 1980s, IITA Management moved the center of cowpea research from headquarters to Kano and asked Bir Bahadur ("B.B.") Singh, the cowpea breeder at headquarters, to relocate and reshape the breeding program with a cropping system approach that should guide the objectives and plant type for the new cultivars that later thrived in the African savannas. Owing both to increases in area and yield of cowpea—the largest among legumes in the continent and assuming about US$ 500 per ton—the increased production represents today an annual value of some US$650 million in Nigeria alone. In the early 1990s, IITA, in collaboration with the newly established International Livestock Research Institute (ILRI)—a merger between ILCA and ILRAD (the International Laboratory for Research on Animal Diseases, Nairobi, Kenya)—initiated a program to breed cultivars that provide both grain for human consumption and fodder for livestock in the dry season. Impact assessment showed that farmers could obtain substantial benefits by adopting dry season dual-purpose cowpea; their profits went up on average by 55 percent. These benefits include food security during a critical period of the year, cash income, fodder, and *in situ* grazing after harvesting, in periods when the prices of cowpea grain peak and good quality fodder is scarce. Dry season dual-purpose cowpea is therefore a profitable crop technology that will find economic and ecological niches in the mixed crop/livestock farming systems of the semi-arid zones of Africa. The CGIAR gave its 2006 Outstanding Senior Scientist Award to Singh for breeding fast-maturing "60-day" cowpea cultivars for the tropics, as well as cultivars with resistance to more than 10 pathogens, and other cultivars of this pulse that have tolerance for drought, plus heat. These IITA cultivars ensure that this early maturing "hungry season" crop provides income and sustenance to people in the period before cereal crops are harvested. In the first 1.5 decades of IITA, resistance breeding was the most frequently used method for combating diseases and insect pests. Since the late 1970s, against the cassava mealybug and the cassava green mite, biological control research was conducted in parallel with resistance breeding. Led by Hans R. Herren, entomologist, and Peter Neuenschwander, insect ecologist, the biological control team went well beyond the scope of most such projects in formulating the scientific explanation for the behavior of the host plant (cassava), the enemy (mealybug or mite), and the control agent (beneficial parasite or predator). Several significant contributions to the body of scientific knowledge were made by this IITA team and include the identification of the cassava mealybug as a pest newly introduced into Africa; the location of the same mealybug species in its area of origin in South America (in collaboration with CIAT entomologist Anthony Bellotti); the successful rearing of cassava mealybugs and mites as well as their imported natural enemies in the laboratory at IITA; the migration and dispersal data assembled after the release of the beneficial parasite—a predator wasp—*Apoanagyrus* [syn. *Epidinocarsis*] *lopezi,* the impact studies (rarely attempted exclusion experiments and population dynamics and biological data on both pest and parasite or

A healthy crop of cassava. Inset: Cassava mealybugs. Photos by IITA predator), and the development of a simulation model showing plant/pest/predator-parasite interactions. The introduced parasitoid *A. lopezi* dispersed and controlled the cassava mealybug wherever it was released. For control stability, a complex of natural enemies is more desirable than a single species. The IITA team gathered considerable data on several mealybug predators but none has shown the survival and dispersal qualities of *A. lopezi*. The spectacular control of the cassava mealybug was the first of many successes in the history of the Biological Control Center for Africa, set up by IITA at Cotonou in the 1980s. It yielded economic returns of 200:1, with minimum benefits of US$2.2 billion from a total expenditure of US$14.8 million. The 1990 CGIAR King Baudouin Award was given to the IITA and CIAT teams for Africa-wide cassava mealybug control. This was followed by the 1995 World Food Prize and other international awards to Herren. One could easily conclude that, without biological control, the mealybug would have destroyed most of the cassava grown across Africa. This project was unique in its geographic scale, organization, and level of documentation, and became a classic textbook example. As noted by Herren, biocontrol does not, however, replace mismanaged plant production and to have its full power, the production system must be fully integrated into the larger agroecosystem following the principles of agroecology.

The potential of agroforestry and cover crops in West African agroecosystems

In the late 1970s, B.T. Kang and co-workers started research on alley cropping as an improved fallow technology to replace slash-and-burn systems in African agriculture. The lack of widespread adoption by farmers led, however, to skepticism about its relevance and adoptability although research on such alternative resource management approaches led, later on, to the establishment of ICRAF—a center that was incorporated in the early 1990s to the CGIAR system and known today as World AgroForestry Center (Nairobi, Kenya). It appears that the decision to adopt alley cropping technology depends on the socioeconomic characteristics of farmers, the land tenure rights held by the farmers where alley cropping systems are used, and village-specific characteristics. Nonetheless, impact assessments show that maize production under agroforestry-based systems such as alley cropping may be socially profitable and financially competitive when compared with maize production relying only on chemical fertilizer, especially after policy shifts, e.g., Cameroon in the 1990s. At unsubsidized fertilizer prices, an agroforestry based technology that depends on internal nutrient cycling would be viewed differently and the interest from both farmers and policymakers in such a natural resource management technology could be expected to increase. For example, some farmers may adopt alley cropping in villages characterized by high land-use pressure, soil fertility decline, erosion problems, and fuelwood and fodder scarcity.

Population pressure forces farmers to shorten or abandon bush fallow systems. *Mucuna* fallows may be an option for soil fertility management in intensive agriculture as shown by IITA research. The most important factors influencing farmers' adoption of this cover crop technology were weed infestation, land tenure rights, and contact with extension services. Impact assessment showed that farming systems with *Mucuna* provided a higher benefit:cost ratio than those without this cover crop which provided yield gains, reduced labor, and restored soil fertility.

Researcher extracting DNA in Bioscience Center, IITA, Ibadan, Nigeria. Photo by IITA

1990–1995 Change of Guard: "Research is for Development"

6

One of the briefings for the CGIAR meta-evaluation by the World Bank indicated that it took about 5 to 10 years before most of the new centers were well established and became productive. Nonetheless, as shown above and in spite of inheriting "… *an overly ambitious research agenda, sometimes from consultants who completed their reports before the managers and scientists were hired*" as the briefing for the World Bank meta-evaluation of the CGIAR stated, IITA was standing as a mature international research organization at the beginning of the 1990s. However, as this briefing to the World Bank stressed, "… *TAC had great difficulty in becoming a credible and effective partner in guiding the evolution of the CGIAR System in Africa. For example, in the mid-eighties, TAC had an opportunity to prepare a CGIAR strategy for Africa when it carried out a 30 month global study of priorities under the leadership of Guy Camus. The TAC report, CGIAR Priorities and Future Strategies, acknowledged that 'a clear strategy will be required to guide the CGIAR System's approach towards Africa's technology requirements … Due to the limited time available, no attempt was made in this paper to develop such a strategy'*". It was in the 1990s that subregional organizations such as the West and Central African Council for Agricultural Research and Development (CORAF/WECARD), the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), and the Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA—formerly known by its acronym as SACCAR) started influencing the research agenda and the priority setting of CGIAR centers working in the continent. As concluded in the briefing for the World Bank meta-evaluation of the CGIAR "… *the 1970–1989 period was a 'breaking-in period' for the CGIAR in Africa.*"

Dr Lukas Brader

Entomologist Lukas Brader started his 11-year tenure as Director-General in December 1990. He came to the Institute after serving as Director of the Crop Protection and Production Division of FAO's Agriculture Department and with a rich and distinguished career in the management of scientific research and agricultural development programs. During Brader's tenure a new culture evolved in the organization that was slowly able to understand that the main role of science in agriculture has been topropel the evolutionary process by generating innovations that allow more production with less land and less effort. In this new mindset it was clear that, owing to the complex nature of the agricultural problems in sub-Saharan Africa, solutions cannot be based around a "one-fix" approach. Research was still required to develop decision-making processes that took into account natural resource fragility, community

Researcher in the lab. Photo by IITA

vulnerability, risk profiles, asset resilience, market options, service provision capacity, and competitive advantage as the guiding principles to develop solutions that could be applied to the needs of specific clients, given their own peculiar circumstances.

Brader also brought changes in both administration and research management. The position of Deputy Director General for Research was replaced by a 5-member Research Directors' Committee under his chairmanship, and four Divisions were created, three for Research and one for International Cooperation. The research divisions were headed by a Research Division Director and the Division of International Cooperation by a Deputy Director General. Mark D. Winslow, a cereal breeder, was the interim Director of Crop Improvement until the plant physiologist F. Margaret Quin took office. Herren remained in the leadership position for Plant Health Management and Dustan S.C. Spencer, an economist, for Resource and Crop Management. Jacques Eckebil retained his post as Deputy Director General for International Cooperation. Each research division included research programs and units that were organized according to what the research leaders regarded as the best groupings. For example, the four programs on Crop Improvement were organized according to clusters of plant species: maize, grain legumes, plantain and banana, and root and tuber crops plus two units: Biotechnology and Plant Genetic Resources at large. Plant Health consisted of research programs on biological control, host plant resistance, and habitat management. Resource and Crop Management was organized according to the main agroecosystems of Western Africa, savannas, inland valleys, and humid forest, which built upon the interdisciplinary, commodity-based working groups established in the late 1980s.

Pan-African impacts with root and tuber crops and early-maturing grain cultivars

During Dr Brader's tenure, IITA became a truly Pan-African undertaking. Under his leadership the Institute established in the 1990s the Eastern and Southern

Africa Regional Centre (ESARC) for the improvement of cassava, banana, and plantain in collaboration with the National Agricultural Research Organization (NARO) in Uganda. NARO provided offices, labs, and fields at its experimental stations at Kawanda and Namulonge and facilitated funding for the initial investments through country mission grants that needed the endorsement of the Government of Uganda. Work by IITA at ESARC was further strengthened by the Root Crop Networks in both eastern and southern Africa. As a result of IITA research-for-development in the subregions, the World Bank stated in its CGIAR meta-evaluation "*... in the 1990s, IITA and the Root Crops Network jointly tackled the African* cassava mosaic virus *in eastern Africa. This partnership has been identified as a good example of collaborative work by the donors involved—USAID, IDRC, Gatsby, and the Rockefeller Foundation ...*" Indeed, the total benefits from the cassava multiplication partnership project between NARO and IITA to combat the cassava mosaic disease pandemic in six districts of Uganda was approximately US$36 million over 4 years (1998–2001) for an initial investment of US$0.8 million. In 1999, the CGIAR recognized IITA virologist James Legg with the Promising Young Scientist Award for his contributions to this successful partnership with NARO and the East African Root Crops Research Network (EARRNET, Kampala, Uganda) to fight cassava mosaic disease in the subregion. Also research associate Paul E. Ilona got the 1999 CGIAR Outstanding Scientific Support Award for his work in cassava breeding.

Partnerships among NARS, non-governmental organizations, and IITA were the key to this and other successes in the genetic enhancement of crops in Africa. In this regard, the first-ever CGIAR Outstanding Scientific Partnership Award was given in 1996 to the Institute of Agricultural Research (Sierra Leone) and IITA in recognition of the outstanding

View of IITA campus. Photo by IITA.

achievement in collaborative research for cassava improvement in West Africa. Similarly, the impact of another important partnership between IITA and partners through the Southern African Root Crops Research Network (SARRNET, Lilongwe, Malawi) was acknowledged in the briefing for the World Bank meta-evaluation of the CGIAR that indicated "… *cassava is starting to replace maize in the diets of the poor in Malawi and* Zambia …" Another successful IITA-SARRNET project led by agronomist/breeder Maria Isabel Andrade in collaboration with the Government of Mozambique and 250 other partners, mostly from the civil society, was able, after multi-site and on-farm testing, to bring selected planting materials of orange-fleshed sweetpotato (OFSP) with high storage root yields (mostly from China, Kenya, Perú, Tanzania, and the USA) to 122,216 households across the country by the end of 2001 after a devastating flood which displaced 450,000 people. A preliminary impact assessment noticed a return rate of US$4 for each US$1 project grant just after two years of the scaling-up for technology exchange in this project. With this country network, IITA started distributing in 2004 new cultivars with tolerance to cassava brown streak disease throughout the coastal areas of Mozambique. In 2016, Andrade, who led IITA's sweetpotato breeding and germplasm testing in Southern Africa from 1996 to 2005, was awarded the World Food Prize for developing the single, most successful example of biofortification: OFSP. As a result of her tireless and convincing public health campaigns—using bright orange clothing and trucks painted with slogans promoting the high β-carotene sweetpotato cultivars—promoting these and other cultivars she bred thereafter, OFSP are found along the roads of this southern African country whose children (about 70%) suffer from vitamin A deficiency.

Orange-fleshed sweet potato.

As acknowledged by Maria, from Cape Verde, a turning point in her professional career had been her joining IITA, "*which exposed her to the international agricultural research environment, widened her perspective , and showed her the role she could play in food security*."

IITA and national or local partners generated several new cultivars of yam, such as the water yam (*Dioscorea alata*), with high and stable yield of tubers (50 to 100% superior to popular local cultivars), as well as good storability and food quality attributes through breeding and selection. High levels of host plant resistance bred into the cultivars against the two most important diseases of the crop, yam anthracnose disease and yam mosaic virus, contribute significantly to the high level and stability of field performance. With the aim of limiting production cost, the improved cultivars were selected for good performance in the absence of external input of fertilizer or staking (in the moist savanna zone) and emphasis was placed on tuber shapes that facilitate harvesting. Many of these new cultivars were assessed at multiple sites in the yam-producing locations of West Africa for suitability for local farming and food systems in comparison with popular indigenous cultivars and with the active participation of potential farmers. Three IITA-bred cultivars of *D. rotundata* (the indigenous white yam) were formally released by Nigeria in 2001. Several others were released thereafter in the other major producing countries in the West African subregion. IITA, together with the National Root Crops Research Institute of Nigeria, developed in its early years a propagation system for yam based on mini-setts. Small (20–25 g) tuber pieces are used to produce planting material for ware tuber production. During the 2000s, IITA further improved yam propagation by

Yam is an important cash crop in West Africa. Photo by IITA.

developing an innovative technique that uses vine cuttings. After forming roots and shoots, the vines are transplanted to nursery beds to produce mini tubers, which are then used as planting material for the next crop. Reducing the use of ware tubers as seeds allows farmers to have more yam available for food or for sale.

High adoption rates of early maturing cultivars do not always translate into large yield gains because they are targeting new land thought to be marginal for agriculture. Hence, the main aim of IITA for breeding early maturing cultivars in crops such as maize and cowpea was not to improve yield *per se* but to enable the crop to be grown in new areas — perhaps by replacing other crops. For example, maize displaced sorghum in drylands. Indeed, early maturing maize cultivars allowed the crop to be grown in the semi-arid tropics of Burkina Faso, Guinea, Mali, Niger, and Senegal in the 1990s. Likewise, crop breeding for pests or abiotic stresses was a cornerstone in stabilizing yields and reducing risks in pest-prone, low-input, rainfed environments—where drought may often occur—rather than resulting in potential yield gains by small landholders who do not have easy access to credits for inputs or to output markets.

Cooking banana and plantain hybrids for African farmers and markets

West African plantain in the lowlands and East African highland banana (for both cooking and beer) are examples of the African farmer's ingenuity, tenacity, and organizational and inventive capacity in adapting this imported *Musa* crop species from Asia to the respective African environments. Although asexual propagation may limit crop evolution, today both subregions are

A vibrant banana market in Nigeria. Photo by IITA acknowledged as secondary centers of variation for plantain and banana, because farmers selected sports (mutants) arising in their fields, and these today account for most of the caloric intake from fruit crops in the African diet. In 1987, African governments encouraged IITA to launch an urgent research program to combat black Sigatoka (also known as black leaf streak). This fungal leaf spot disease causes significant yield loss in plantain, an important food and cash crop for more than 70 million people in sub-Saharan Africa. As an interim measure, IITA introduced black Sigatoka-resistant cooking banana from Asia while the long-term strategy was to develop black Sigatoka-resistant plantain. After their introduction to Nigeria, cooking banana plantlets were produced in two tissue culture laboratories located at the IITA High Rainfall Station (Onne, near Port Harcourt) and the Agricultural Development Program at Owerri (in Imo State). With the collaboration of 24 institutions, vegetatively propagated planting materials (suckers) were distributed to 29,585 farmers in 710 villages. Impact assessments showed that cooking banana gained a high level of acceptance and spread among the people, and thus established itself within the farming system in southeastern Nigeria. The crop was adopted by 55 percent of farmers, occupying about 26 percent of total fields; its cultivation had increased by more than 930 percent since introduction, with a multiplication rate of 600 percent across farmers. The introduction of cooking banana and the subsequent adoption and diffusion made a positive impact in southeastern Nigeria: on farmers' farm enterprises, farm resource use and allocation, income, and the food base of the people, as well as employment generation. Hence, the potential contribution of cooking banana to bridging the hunger gap and uplifting the income level of farmers in southeastern Nigeria was relatively high. As such, it should not be appropriate any longer to regard cooking banana as a stopgap measure but rather as a suitable supplement to plantain for some Nigerian farmers and consumers.

Owing to its pioneering research-for-development on breeding hybrid plantains resistant to black Sigatoka and for advances made in the genetics of *Musa,* not an easy task for a triploid species, IITA received the CGIAR King Baudouin Award in 1994. The potential impact of using black Sigatoka-resistant plantain shows a benefit:cost ratio of 10:1 over using fungicides during periods of adequate production in rural southeastern Nigeria. This dramatically influences the prices of plantain fruit although this advantage may be reduced to 5.5:1 during periods of scarcity in plantain production. The successful professional career, solely in Africa, of the former leader of this IITA team, the late Dirk R. Vuylsteke, was acknowledged by dedicating to him the 2001 annual series *Plant Breeding Reviews*—the first ever given to a plant breeder of the CGIAR.

PITA 14 (or TMPx 7152-2) appears to be one of the most promising IITA plantain hybrids with resistance to black Sigatoka because of its early fruiting, high bunch weight, and big fruits. While detailed analysis of the acceptability of PITA 14 in southeastern Nigeria was still under way, it was noteworthy that several farmers established sucker multiplication plots and sold suckers to other farmers. In 2002, IITA started large-scale introduction (on-farm) of hybrids with black Sigatoka resistance to the farming community in 11 Nigerian states of the plantain belt. The target was 20,000 farmers as direct beneficiaries of this 3-year undertaking that built upon a series

Banana plantation. Photo by IITA

of ad-hoc distributions of improved hybrids via numerous public or non-governmental public extension services. Furthermore, six pilot propagation centers were established at nodal locations across the Nigerian plantain belt to ensure the continuous dissemination of healthy seedlings using high throughput propagation methods. In Ghana, another major hybrid dissemination process began its second phase. Phase 2 mass-propagated and disseminated improved hybrids to farmers from the secondary sites. Other West African countries targeted for mass distribution of improved hybrids were Cameroon and Côte d'Ivoire, where preparation started for the distribution of hybrids. Similarly, hybrid dissemination was undertaken in Uganda and thereafter in Malawi, Mozambique, Tanzania, and Zambia. Outside of Africa, IITA-bred hybrids have been reaching farmers in Latin America and Asia. For example, the banana hybrid BITA-3 (or TMBx 5295-1) was used for producing chips in Kerala State of India, where it compares favorably with the local cultivars. Thus, funding from development investors has permitted IITA, in collaboration with other research institutes, to generate fruits that are making a difference in the livelihoods of people in Africa and beyond, clearly a high return on investment that needs to be assessed in quantitative terms in the years ahead. Another key public good from this investment in *Musa* genetic enhancement at IITA was the abundant knowledge gathered and shared worldwide through many publications in reputed international journals. As noted in the 2001 TAC EPMR of IITA, "*the published output on breeding methodology and genetics of* Musa*, about 12 articles per year, deserves particular attention*".

Plant health management: Another successful Pan-African program after the spectacular control of the cassava mealybug by the introduced predator wasp

After the spectacular control of the cassava mealybug by the introduced predator wasp *A. lopezi* (Table 1), IITA researchers undertook the biological control of cassava green mite, larger grain borer, mango mealybug, spiraling whitefly, and water hyacinth, some of which made a significant impact on African agriculture. Water hyacinth made many lakes and waterways in sub-Saharan Africa impassable, thus adversely affecting the local economy and biodiversity. This weed was first controlled in Northern Australia, and IITA introduced weevils as biocontrol agents to Africa, where good control is clearly apparent in locations as far apart as Bénin and East Africa—the latter a cooperative effort with the National Biological Control Unit of Uganda.

The major achievements in the cassava green mite research until the early 1990s was the establishment of the mite's true identity, its behavior within the cassava ecosystem, and its damage to the cassava plant. It was in the second half of the 1990s that IITA researchers J. Steve Yaninek and Rachid Hanna succeeded with the classical biological control of cassava green mite by identifying, introducing, and establishing predatory mites (*Typhlodromalus aripo* and *T. manihoti*) and later an acaropathogenic fungus (*Neozygites tanajoae*) from climatically similar areas of Brazil. In areas where the predatory mites have been continuously present for at least two years, cassava green mite density declined by 30 to 60 percent and cassava yields increased by between 15 and 35 percent, with two cases of 62 and 85 percent increase in tuberous root yield. The addition of the fungus *N. tanajoae* led to a further 25 percent decline in cassava green mite populations. In West Africa alone, where the biocontrol of cassava green

Table 1. Major biological control of pests by IITA [#] and partners in Africa with an economic impact assessment[3] [[§]*In-country biological control of red waterfern in South Africa included as reference*[4]]

Pest species	Year of first occurrence	Loss (%)	Successful biological control agent	Start of campaign	Redress (% reduction in loss)	Savings (US$ million)	Discount rate (%)
Cassava mealybug[#]	1973	40	Encyrtid wasp *Anagyrus lopezi*	1981	90–95	7971–20226 [2]	6
Cassava green mite[#]	1971	35	Phytoseiid mite *Typhlodromalus aripo*	1983	80–95	2157 [3]	10
Mango mealybug[#]	1980s	90	Encyrtid wasp *Gyranusoidea tebygi*	1987	90	531	10
Water hyacinth[#]	1980	66[4]	Weevil *Neochetina eichhorniae*	1991	36 [5]	260	10
Red waterfern [§]	1978	6	Weevil *Stenopelmus rufinasus*	1997	[7]	206	8

[1] Initial losses of 80%, lower in highland areas
[2] Based on 27 countries in Africa, depending on scenario
[3] For Nigeria, Ghana, Bénin
[4] Damage of US$84 million to fishing and trade at peak of infestation
[5] Data from 1999; full impact yet to be achieved
[6] Average damage is US$533 per respondent (*N* = 30)
[7] Three years afterwards, weed was not regarded any longer as a problem.

[3] Neuenschwander (2004).

[4] McConnachie, A.J. et al. 2003. Economic evaluation of the successful biological control of *Azolla filiculoides* in South Africa. Biol. Control 28, 25-32

Classical biological control of cassava green mite by a predator mite. Photo by IITA

mite was first achieved, economic benefits reached a hundred-fold: US$100 in return for each US$1 invested in the program. This cassava green mite biocontrol campaign continued in central, eastern, and southern Africa with the addition of strains of predatory mites adapted to mid-altitude agroecologies, and the emphasis on the integration of cassava cultivars suited to predatory mites (which was a relatively nascent dimension of biological control in general), owing to the sensitivity of *T. aripo* to specific morphological characteristics of the cassava apex where the predators reside during much of the daylight hours.

Locusts are among the most important pests affecting farmers living around the world's deserts. Millions of liters of environmentally damaging pesticides are sprayed over vast areas of land to control them and the grasshoppers—another insect pest of crops. The Lutte Biologique contre les Locustes et Sauteriaux (LUBILOSA) project was set up in 1989 by IITA and research-for-development partners to develop a biological pesticide that kills. Locusts are among the most important pests affecting farmers living around the world's deserts. Millions of liters of environmentally damaging pesticides are sprayed over vast areas of land to control them and the grasshoppers—another insect pest of crops. The *Lutte Biologique contre les Locustes et Sauteriaux* (LUBILOSA) project was set up in 1989 by IITA and research-for-development partners to develop a biological pesticide that kills locusts and grasshoppers without harming the environment. Two crucial components for success of this biopesticide were the long-term commitment (10 years) from the development investors of this project to turn basic research into a useful product, and the broad range of stakeholders, which created a "constituency of support" around Green Muscle®, the by-product of this public–private partnership, licensed to a South African company for manufacturing. Both the eventual impact and return on investment in the LUBILOSA project depend on correcting a market failure that does not account for the human and environmental health costs of spraying chemical pesticides which are not charged to the purchaser. Policy changes are, therefore, required to overcome the market weakness for this and other bio-pesticides. Perhaps the "constituency's" power may be able to bring about this policy change. As a first step in this direction, FAO listed Green Muscle® at the top of two lists of insecticides that do not have a negative impact on the environment or on human health. Farmers, non-governmental organizations, and donor agencies involved in grasshopper control have used large amounts of Green Muscle, thus replacing synthetic insecticides.

It was in the 1990s that IITA management established the Germplasm Health Unit, which devotes attention to guaranteeing the absence of main diseases, particularly viruses, in planting materials. This appraisal is a prerequisite for the international transfer of vegetative materials of root and tuber crops as well as banana and plantain, and true seeds of crops such as cowpea and soybean. Early IITA research of the 1980s showed through extensive screen house and laboratory tests that there was no transmission of *cowpea yellow mosaic virus* through cowpea seeds. This discovery facilitated the shipping of cowpea seeds although these will be constantly indexed (tested) with reference to other viral strains. In 2003, IITA scientists—led by Jacqueline d'Arros Hughes, the head then of this Unit—and their research partners made a significant contribution to virology research in Africa with the publication of *Plant Virology in sub-Saharan Africa*, a book that provides updated information and shares knowledge about the most prevalent virus diseases of some of the continent's principal staple food crops. This book follows in the steps of another IITA publication of the mid-1980s, *Virus Diseases of Important Food Crops in Tropical Africa*, which presents in a concise form information gathered by IITA virologists of that time (Hennie W. Rossel and the late George Thottappilly) about the geographical distribution, symptoms, identification, and control of viruses affecting the main crops grown by the continent's farmers.

Seed testing. Photo by IITA

Food for thought: Capacity building for a new generation of African researchers

Parallel with its scientific achievements there has been, throughout the history of the Institute, a comprehensive training program to increase the capacity of African researchers to solve their food production problems. In the early days, emphasis was placed on group production courses for extension and technical personnel, a task that the Institute was increasingly able to pass on to strengthened national institutions. Degree-related training, group courses with a research emphasis, summer vacation projects for university-level students, and individualized programs to meet specific requests were all part of the training program in the mid-1980s and throughout the mid-1990s. Up to the beginning of the new millennium, the Institute had trained about 9000 professionals. About 10 percent of these were colleagues who obtained their MSc or PhD degrees through partnership research at IITA. Today the Institute's alumni are in virtually all African agricultural research institutes, quite often in leadership positions.

Grating fresh cassava using a medium-size machine. Photo by IITA

1996–2001 Renewing the Mission: Bringing Wealth to African Homes

7

During Brader's second term—in the second half of the 1990s—IITA updated its mission and mandate. The Board of Trustees approved this mission statement. "*IITA aims to enhance the food security, income and well-being of resource-poor people primarily in the humid and subhumid zones of sub-Saharan Africa by conducting research and related activities to increase agricultural production, improve food systems, and sustainably manage natural resources, in partnership with national and international stakeholders. To accomplish its mission, the Institute conducts research, delivers training, provides information, and participates in technology transfer activities with a wide range of partners. These activities are undertaken to develop and deliver technological options to improve food systems (production, transformation, storage, distribution, and consumption/end-use and natural resource use efficiency in a sustainable manner. They are conducted primarily for the benefit of farmers, other entrepreneurs, and consumers.*" This mission introduced a few changes in the Institute's undertakings, such as natural resource management for sustainable agriculture, preservation of the environment, enhanced commercialization to ensure improved food security, raised farmers' incomes, and a contribution to the development of an effective agro-industry. IITA research was meant to address the needs of both small and medium-scale farmers and entrepreneurs who were open to technology exchange. The goal was to make agriculture attractive and profitable to a new generation of rural populations, resulting in an enhanced standard of living with better health and longevity. This new IITA research agenda also sought to abate the potentially negative consequences of global climatic change and the increasing impact of human diseases such as HIV/AIDS and malaria on society.

The IITA Strategic Plan 2001–2010 fittingly captures the new elements in which the benchmark approach in research-for-development was a prominent feature. In the last meeting of the former Research Program and Executive Committee held in October 2001 at IITA Humid Forest Eco-Regional Center in Yaoundé, it was agreed that the organizational structure and arrangements for implementing the research agenda of the new Strategic Plan needed interdisciplinary projects. As a result, six projects were included in the 2003–2005 Medium-Term Plan:

- Project A: Preserving and Enhancing Germplasm and Agrobiodiversity
- Project B: Developing Biologically Controlled Options
- Project C: Policy, Impact, and

- Systems Analysis
- Project D: Starchy and Grain Staples in Eastern and Southern Africa
- Project E: Diverse Agricultural Systems in the Humid Zone of West and Central Africa
- Project F: Improving and Intensifying Cereal–Legume–Livestock Systems in the Savannas of West and Central Africa

Researchers were programmatically assigned to one or more projects led by project coordinators, who were elected by their respective peers. The CGIAR interim Science Council (iSC) welcomed this new IITA Medium-Term Plan (MTP). In their words, *"The new MTP reflects IITA's plan for implementation of its 2001–2010 Strategic Plan, with consolidation of work into six projects. IITA plans to increasingly address the problems of poverty and food security through a food systems approach, both on the production technology side and through policy and institutional capacity building. Emphasis will be given to developing suitable environmental health and poverty indicators against which improvement in rural livelihoods and progress towards CGIAR goals can be measured. The new MTP responds to the need to strengthen the agroecological approach and to simplify project and management structures within the Centre. Its three agroecological zone projects are delineated both by climate and geography. The three "zonal" projects correspond to the mandate area of the three subregional organizations (SROs) that make up the Forum for Agricultural Research in Africa (FARA). The iSC supports this 'decentralized' and 'demand-driven' approach with its emphasis on predominant cropping systems and selected food systems within the agroecological zones. The three 'disciplinary' projects likewise represent logical clusters with germplasm enhancement and preservation, biocontrol, and impact and policy analysis. The elevation of biocontrol/IPM to a major disciplinary project, integrating biodiversity in sustainable systems, is appropriate. The combination of policy and impact assessment is also logical. Consistent with the CGIAR's new vision and strategy, the new MTP places stronger emphasis on poverty reduction. The iSC supports the stronger focus on market analysis, policy research, institutional reform, and business development as described in the Plan."*

Benchmark approach: A truly global public tool in research for development

Integrated natural resource management, which is derived from the key principles affecting

Adoption of mechanized farming helps reduce the drudgery in farming and produce more food in Africa. Photo by IITA planning and output delivery, may improve adaptive capacity by using new approaches and crucial tools for implementing a research-for-development agenda. This new integrated development approach brought changes in culture and organization of research-for-development; i.e., learning together for change, keeping in mind the underlying principle of going to scale but remaining practical to confront complexity in the field and to address productivity enhancement. The learning process at the early stages needed the blend of "hard" and "soft" science to allow local technology to lead to regional impact because there were multiple stakeholders with distinct views and approaches. Throughout the second half of the 1990s and early years of this millennium, colleagues in IITA from the former Resource and Crop Management Division elaborated on the concepts for putting into practice integrated natural resource management particularly in heterogeneous areas, where research-for-development undertakings needed a characterized benchmark area that considered farming system dynamics and diversity, representing a wider agroecozone to develop best-bet innovations and processes.

The benchmark area approach, to succeed in having an impact on farmers' lives, should pursue a characterization process that must understand and factor in those changes occurring in farming systems in response to the pressures felt by farmers. For example, it was noted that farmers cut down new forest because they believe that an important crop to them such as plantain grows well only in newly cleared forest. The basis for their thinking was related to the need of plantain to grow under good soil fertility, which should increase when nematodes attack and reduce the efficiency of the root system. IITA was able to show farmers that it was possible to grow plantain on land already cropped if the rooting material was treated with hot water to kill the nematodes and some fertilizer was added. Furthermore, this approach may be able to benefit farmers because it does not begin and end with characterization but it provides a guide for research and extension. It allows natural resource and plant scientists to see their work within a socioeconomic context and avoid spending many years developing a technology that may not be relevant or wanted. Last but not least, there was the potential of benchmark areas for scaling up because they are "incubators" having a critical mass of key research and extension stakeholders. IITA's experience on benchmark area in the CGIAR Eco-Regional Program for the Humid and Sub-Humid Tropics of sub-Saharan Africa (EPHTA) gives some guidelines (Table 2) for carrying out multi-site ecoregional research using this approach. Although IITA does not pursue it today, its research-for-development continues to be decentralized across sites in sub-Saharan Africa and involves various private and public partners with whom it interacts and collaborates through formal and informal platforms, jointly plans and implements programs, and analyzes the results and their implications.

The benchmark areas represent major features of the agroecosystem, and enable the creation of the knowledge networks among key stakeholders that are necessary to scale-up and -out. Characterization approaches take into account not only biophysical data from geo-information systems (GIS) but also known cultural and social factors influencing the likelihood of adoption and extrapolation of results. Hence, the benchmark area approach should be regarded as a truly global public research-for-development tool, which facilitates the exchange of best-best innovations from farmer to

Table 2. Lessons learned after using the benchmark approach in the the CGIAR Eco-Regional Program for the Humid and Sub-Humid Tropics of sub-Saharan Africa led by IITA in the 1990s[5]

1	Move quickly to doing collaborative research with partners and stakeholders to develop both technical solutions and the processes for their development and scaling-up
2	Start simple and small with a maximum of just two benchmark areas
3	Build the benchmark area approach up from the bottom "organically" rather than trying to impose an organizational blueprint from the top down
4	Choose benchmark sites in consideration of the key problems to be solved
5	Avoid large, unwieldy Steering Committees
6	Do not get bogged down in trying to develop a common set of concepts and seeking the perfect characterization paradigm
7	Ensure that culture and ethnicity are part of the characterization paradigm
8	Promulgate an understanding of the dynamic nature of the farming system
9	Make sure you have people with the necessary process skills to work in a collaborative and participatory manner with stakeholders
10	Make every effort to take others along, particularly people in your own Institute
11	Publish key concepts and approaches in peer-reviewed journals to show that the approach is sound
12	Be flexible and learn while going along

farmer or community to community within the same stakeholder group; i.e., scaling-out. At the same time, it ensures an institutional expansion of best practices from grassroots organizations to policymakers, development investors, and other stakeholders that keeps building an enabling environment for change; i.e., scaling-up. Integrating the benchmark approach with a sustainable livelihood framework will enhance our understanding of poverty and food insecurity by analyzing the relationships among relevant factors at the household, community, and regional levels; i.e., dissecting the complex in which people live. Likewise, by integrating the benchmark approach with the sustainable livelihood framework, researchers can identify recommendation domains that are similar, and therefore target appropriate technology in pilot sites that are outside the benchmark area but within the same agroecosystems. Pilot sites serve for testing and adapting technology ensuing from research-for-development in the benchmark areas.

Intellectual property policy in the era of globalization

Since the 1970s, IITA has been generating international public goods through the research carried out by scientists working in the Institute and in partnership with others, particularly the African NARS. Following the thoughts of IITA founders and stakeholders, the Institute still considers that every effort should be made to ensure that research knowledge and products developed by IITA are actively disseminated, adopted, and utilized by and for the benefit of people in the developing world, particularly in Africa, and for society in general. IITA believes that access to its outputs should be fair and equitable. In its May 2001 meeting the IITA Board of Trustees approved an intellectual property policy. The guiding principles clear stated, "IITA pursues publication and full disclosure and the open sharing of IITA data, information, and knowledge through the release of IITA research findings and products into the public domain. IITA respects the rights of others when using their materials, data, and other intellectual property, in research for development. IITA considers that excluding others from accessing IITA research products and results is contradictory to its mandate and mission. Therefore, IITA does not seek to secure patents or plant breeders' rights

[5] Douthwaite et al. (2005)

unless such protection is deemed necessary to keep IITA materials or technologies available and freely accessible to its beneficiaries. IITA does require recipients and users of data, knowledge, and any technology originating from the Institute to publicly acknowledge IITA as the source of the original information, material, or research product. In, addition, IITA respects the intellectual property rights of others, and will acknowledge and obtain appropriate permission for the use of others' data, knowledge, and technology."

The Institute, as part of the CGIAR, used at that time the CGIAR Center Statements on Genetic Resources, Intellectual Property Rights, and Biotechnology, jointly approved by the Center Directors and Center Board Chairs of the CGIAR. These statements included the CGIAR's Ethical Principles Relating to Genetic Resources and the Guiding Principles for the CGIAR Centers on Intellectual Property and Genetic Resources. IITA adheres to the principles contained in the Convention on Biological Diversity, the FAO–CGIAR Agreement on Genetic Resources, and the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). IITA uses therefore, material transfer agreements and germplasm acquisition agreements to facilitate access and ensure the continued free exchange of genetic materials and biocontrol agents. The main objective of these material transfer agreements is to maintain these materials in the public domain and to ensure their protection from ownership by others.

A set-back with the start of the new millennium

On Sunday, 30 January 2000, Vuylsteke—then ESARC team leader—together with his IITA colleagues Paul R. Speijer, nematologist, and John B. Hartman, banana postdoctoral breeder, were in the ill-fated Kenya Airways flight KQ433 that crashed shortly after taking off from Abidjan (Côte d'Ivoire) en route to Lagos (Nigeria). They were traveling to IITA headquarters at Ibadan to attend the annual Work Planning week. The loss of these three young international scientists, whose holistic banana research was, according to CGIAR Chairman Ismail Serageldin, among the most promising of all African projects carried out under the aegis of the CGIAR, was not only a great tragedy for their families, friends, and colleagues but also a significant blow to international agricultural research and to the African farmers to whom they had dedicated their lives. In the words of Brader, "It was a terrible loss and it took us considerable time to find our normal rhythm again." To maintain their work at ESARC, IITA received strong support from many people who, as a tribute to the late colleagues, wanted to ensure their research undertakings would lead to the goals so strongly pursued by all three: create better living conditions for African farmers. As pointed out in the annual report of a sister institute, "This was the worst tragedy of its kind to strike the CGIAR. Our staff travel extensively in some of the most difficult areas of the world, and we perhaps tend to take for granted the considerable risks and hardships they face on a daily basis, without complaint, in the pursuit of their passion—to help the poor and the hungry of the developing world. These bright, committed, idealistic young scientists represented the human face of our science in its best and truest sense. They were our friends, part of us, and will not be forgotten."[6]

[6] ICRISAT. 2000. *Science with a Human Face – Annual Report 2000*. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India. p. 3

Mass propagation of yam using aeroponics. Photo by IITA

2002–2011 IITA R4D: "The Course of True Love Never Did Run Smooth"[7]

8

After 11 years of service to African agriculture Brader stepped down as IITA Director General, and Peter Hartmann, an economist and former Director of International Programs in the University of Florida/IFAS in Gainesville, began his tenure as Director General in November 2001. Hartmann took the job at a time when budget constraints (Fig.1) were influencing the quality of science and peer-reviewed research output in IITA as indicated by TAC fifth EPMR of IITA held in the first half of 2001. Due to budget constraints, the number of internationally recruited staff fell from just above 100 in 1996 to about 80 in 2001—a loss of 22 percent in five years. The loss was partially offset by the employment of postdoctoral fellows, associate and junior professional officers, and visiting scientists. In short, IITA was under financial stress at the beginning of Hartmann's tenure as Director General. Hence his urgent task was to bring in more resources coupled with cost-saving measures across the Institute.

Dr Peter Hartmann

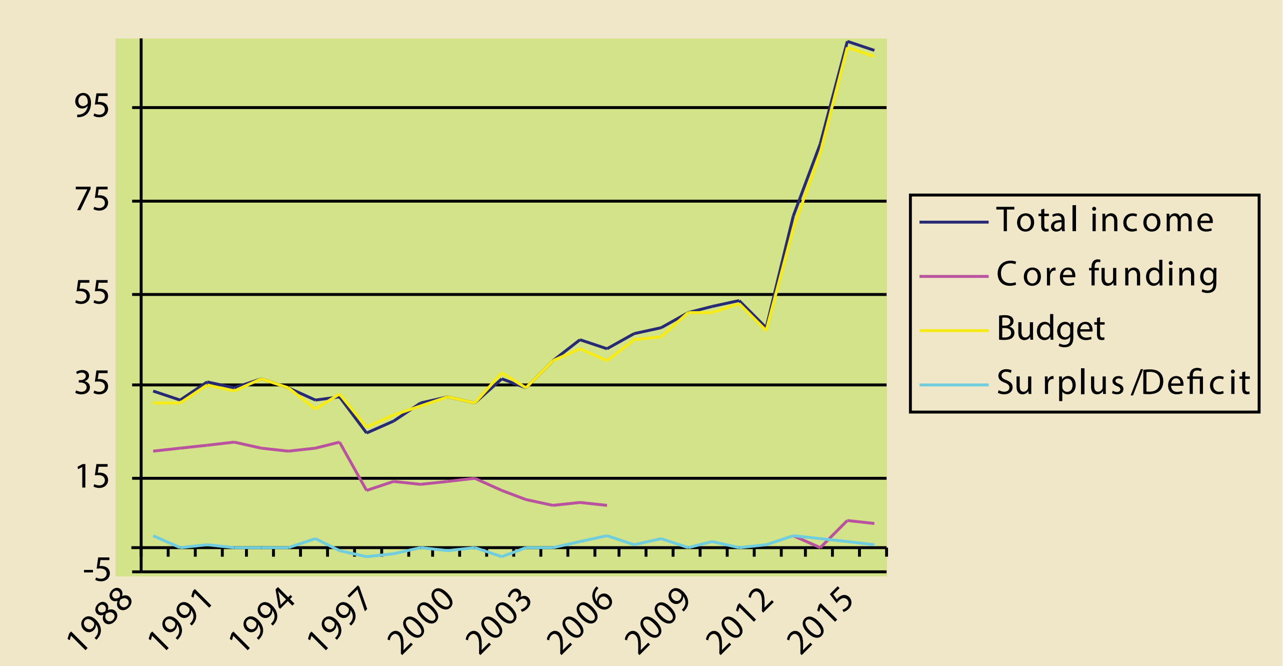


Figure 1. Total income, core funding (mostly through unrestricted grants), budget expenses, and surplus/deficit (US$ million) for IITA from the late 1980s until 2015 (after audit statements). Source: IITA Annual Reports.

[7] English writer William Shakespeare

Hartmann, as his predecessors had done, brought new ideas about the mission of the Institute and a new research management arrangement. In June 2002, the research divisions were abolished and he asked the Director of Crop Improvement, Rodomiro Ortiz, a plant geneticist, to act as Deputy Director General and at the same time appointed him to the newly created position of Director of Research-for-Development and Chairman of the Research-for-Development Council. In Hartmann's view, "*The research-for-development arrangement of the institute was changed to move leadership, resources and authority from divisional leaders to the Research-for-Development Council (RDC) members, the majority of whom are elected by their peers … the RDC is a unique set-up in the CGIAR system. In its simplest concept, five minds are better than one. When senior IITA scientists debate issues, the end product is usually better than a Director taking unilateral decisions. Ownership of the Institute is improved by the election of the councilors and it has opened more communication avenues, as scientists gradually find their 'comfort zones' of ways to express their thoughts. They now can do it directly, via their project coordinators, via any of the five councilors, or officially to the RDC directly. As the recognition of RDC's stature becomes more widespread, more institutional weaknesses are raised and identified for RDC's counsel and decision. Delicate matters, such as the difficulty some project coordinators have leading 'senior' scientists, and keeping everyone focused on the project are now addressed through a less personalized path; i.e., the RDC. Respect for the RDC is also being appreciated as its governance tools—budget, evaluation, and contract decision—are practiced.*" In 2004 the research management arrangements were fine-tuned, Rodomiro Ortiz resigned, and two regional research-for-development directors were brought into the new IITA organogram to replace a Deputy Director General (which was abolished from the staff establishment). Agronomist Stanford F. Blade took the job as Director of Research-for-Development in West Africa and plant breeder Paula J. Bramel started as the other Director of Research-for-Development in Eastern and Southern Africa. Both regional directors were ex-officio Research-for-Development Council members and one served as Chair by rotation every six months. The other three councilors were researchers, elected every two years by their peers. The two regional research-for-development (R4D) directors together with the six project coordinators reported to the RDC, which was the guardian of IITA's R4D program. The RDC addressed the program needs of the Institute and ensured that its mandate and mission were relevant to the development needs and priorities of the region it served. Its responsibilities included ensuring the quality of research, technical exchange and public awareness activities, recruitment and evaluation of scientists, allocation of resources, and collective mentoring of staff.

An end user driven research–for–development approach to nourish Africa

From mid-2002 throughout 2004, Hartmann and Ortiz shared their views on R4D with IITA staff, clients, partners, investors, and other stakeholders. In an early write-up—which was included among the annexes of the FARA-led sub-Saharan Africa Challenge Program—they indicated that '*any strategy for eliminating food shortages and accelerating the evolution rate from household production to more commercial farming entrepreneurs needs two interdependent pathways in sub-Saharan Africa: developing* *commercial 'windows' for the less vulnerable farmers through enhancing the marketing pathways of agricultural produce with high levels of added value, and increasing food security by broadening the reliance on cereal (mostly maize) monoculture into diversified crop–livestock systems, which are more environmentally resilient and nutritionally superior. Such a strategy follows a 'research-for-development end user-driven' approach that replaces the old disconnecting concept of research and development, in which researchers deal with technology generation and developers test this technology with potential end users. Research-for-development needs society-conscious, committed scientists who accept being transformed into developers by bringing a technology focus to their work. The research products ensuing from this work are demand- not supply-driven, by end users and not by 'ivory tower' scientists. Hence, this new approach closes the gap between research and development, and ensures from the start of the research process (i.e., planning) that development goals drive the agenda. Two phrases: 'from thinking to acting' and from 'research to decision' define this new research-for-development approach, in which research institutes, development organizations, the private sector, development investors, and national governments are partners, sharing the aim of accelerating agricultural diversification and commercialization for the small-scale agricultural sector."*

They listed four key elements in this research-for-development end user-driven approach:

1. Trade and marketing to encourage rural economic growth.
2. Crop diversification to avert famine and strengthen food security.
3. Enhanced governance to build ownership between investors and implementing actors, catalyzing development.
4. Partnerships to attain win-win synergies.

This R4D philosophy considers a "small landholder development trajectory"[8] from subsistence to commercial scale in which the farmers are not homogeneous and research products help them to move along the trajectory[8]. Opportunity and vulnerability factors determine what technology may be the most appropriate in the landholder development trajectory. Farmers with relatively good access to markets, who are educated and who have financial assets and access to water, prefer interventions which tend towards high income generation; i.e., a high-risk strategy that will focus on competitive and comparative advantages and will build entrepreneurial skills for wealth development, thereby leading to multiplier effects such as job creation. Small landholders with low income, who have poor market access, low education, limited assets, and who may be affected by HIV/AIDS, are reliant on rainfed farming systems, in marginal or fragile environments with a history of food relief. They tend towards a low-risk strategy which aims to build on livelihood coping mechanisms and places priority on more resilient long-term mixed cropping systems. Furthermore, agriculture provides the means, and sometimes perhaps the only means, for reconstructing, rehabilitating, and resettling people in war-torn and environmentally degraded zones. The rural development that follows peace may need a low-risk strategy emphasizing crop technology to rebuild livelihood coping mechanisms for resettled inhabitants. Research for development, keeping in

[8] Initial thoughts about the "small landholder development trajectory" ensued after exchanges of ideas between Ortiz and Winslow during their tenure as program directors at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, Patancheru, Telangana, India) in the late 1990s. They were inspired by early views shared by Fischer while he was Deputy Director General of Research at IITA.


Adding value to cassava processing: pressing fresh cassava. Photo by IITA

mind the end users, also operates within a continuum that uses a "means" (research) for an "end" (development), thereby leading to impact on both people's livelihoods and science. With this new approach, a new working culture evolves in which management internally rewards the top performers following this framework, and externally encourages staff to broaden alliances or partnerships for development in their community of practice. Networking becomes, therefore, a must because organizations that do not always share the same goals see the advantage of teaming up for succeeding in their objectives in a target area.

The new paradigm in crop and natural resource management for sustaining agrobiodiversity and making impact on livelihoods

Agricultural sciences provide a means of closing the gap between actual and potential yield in stressed environments through genetic manipulation, crop protection, and resource management. Crop technology or cultivars within each cropping system are replaced with others showing better fitness along an environmental gradient arising from the physical or naturally limiting uncontrolled factor(s). Hence, farmers and scientists search for new technology along these gradients to address specific stresses. For example, plant breeders know well that cultivars with a high yield potential are not able to outyield stress-resistant cultivars (i.e., a crossover interaction) in a stressful environment. These high-yielding cultivars may even perform poorly in stressful environments. Researchers, farmers, and policymakers should also keep in mind the following paradigm, in which economic phenotype performances (P) are influenced by many factors and their interactions, as indicated below:

> P = Genotype × Environment × Crop Management × Policy (affecting both people and markets) × Institutional Arrangements × Social Demographics

Decentralized (through networking) and end-user participatory research with local partners provides a means for working in marginal, low-input, stressful environments. This decentralization requires refining target areas, targeting local research partners for crop and resource management, and shifting responsibility from a central research station to local undertakings (which may include not only technology testing but also new material generation through specific research for further selection and testing). In this way, individual research programs (irrespective of their size) will deliberately maintain diversity across locations.

Such an approach should be driven by the needs of the rural poor to ensure that such work has a positive impact on their livelihoods. To become cost-effective and efficient in Africa, agricultural research, must follow an agroecosystem approach—farmers working together with professional researchers in developing locally adapted technology and relying on responsive local systems for its dissemination to the farming community. This technology needs to assemble a set of characteristics that reduces yield loss and confers greater yield stability in the target areas. Input and output traits are included in a market-driven research agenda. Input traits such as resistance to insect pests, diseases (bacteria, fungi, viruses), and parasitic weeds such as *Striga,* or acceptable performance in stress-prone environments (e.g., liable to drought, heat, or salinity) lead to yield stability, while output traits affecting quality and end uses provide new options for generating or improving people's incomes. Decentralized country level research programs are mandatory because teams in such programs can operate efficiently only when close to the various targeted agroeco zones for each crop.

Pursuing impacts by building upon an old tradition for success

The impact of any research-for-development program can be judged only over relatively long periods, covering technology development, release, distribution, and adoption. For example, through the introduction of more productive cultivars resistant to prevailing pests and the effective biological control of the cassava mealybug and other pests, large-scale famine was avoided in sub-Saharan Africa. Without these research-for-development efforts, 25 percent less maize would currently be produced in sub-Saharan Africa; equivalent to 8 million tons per year or the food requirements of 40 million people. Cassava production would be halved or worse, amounting to a loss of over 13 million tons of dry cassava per year, equivalent to the caloric requirements of 65 million people. Just for these two crops, research-for-development by IITA and partners means that over 100 million more people are fed; i.e., one out of six inhabitants of sub-Saharan Africa! As Sir Isaac Newton pointed out, great researchers were able to see further than others in their distinguished careers because they stood on the shoulders of others. It was therefore not surprising that two of the newest impacts of IITA, which were shaped with the beginning of the new millennium, built upon early research on Crop Improvement and Natural Resource Management in the African savanna and, by using new tools beyond the farm gate, bringing wealth to rural areas.

Sustainable resource management coupled with resilient germplasm

Local farmer with big yam tubers. Photo by IITA

to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. With the start of the new millennium, the CGIAR gave to Bernard Vanlauwe—then an IITA soil researcher—the 2000 Promising Young Scientist Award for bringing into practice the concepts of integrated plant nutrient management. Indeed, the accumulated knowledge on soil management gathered over the last 10 years, combined with solid crop improvement and plant health research at the farmers' level, brought IITA research on sustainable research management to its present stage of technology exchange through best-bets in the West African savannas. IITA researchers and partners were able, therefore, to address with confidence the intensification of cereal–grain–legume-based cropping systems in the dry savanna of West Africa in a sustainable and environmentally friendly manner. Two sustainable farming systems that greatly enhance the productivity and sustainability of integrated livestock systems were developed and implemented in the dry savanna of Nigeria. These were maize–promiscuous soybean–rotations that combine high nitrogen fixation and the ability to kill large numbers of *Striga hermonthica* seeds in the soil; and pearl millet and dual-purpose cowpea. Improvement of the cropping systems in the dry savanna was also driven by the adoption of promiscuously nodulating soybean (in particular TGx 1448-2E) and dual-purpose cowpea cultivars. The rate of adoption was very high, even in the absence of an efficient seed distribution system. The number of farmers using the improved cultivars increased by 228 percent from 2000 to 2002. Increased production of promiscuous soybean was stimulated by increased demand from industries and home utilization. Preliminary economic analysis of these systems demonstrated that there was a 50 to 70 percent increase in the gross incomes of adopting farmers compared with those still following the current practices, most commonly continuous maize cultivation. Furthermore, increases in legume areas of 10 percent in Nigeria (about 30,000 ha in the northern Guinea savanna) and increases of 20 percent in yield translated into additional fixed nitrogen valued annually at US$44 million. This reflects, at the same time, an equivalent increase in land-use productivity. With further spread of the improved crops, there were excellent prospects for additional economic and environmental benefits from a very large recommendation domain across West Africa.

Unleashing the power of markets for Africa's small farmers

In the past, most research in Africa focused on increasing the productivity of small-scale farmers. With this focus, various levels of success were achieved through the adoption of yield-enhancing technologies. However, these gains did not lead to proportionate gains for small-scale farmers who, in most instances, are poor and unable to participate in a particular market as buyers and sellers. IITA researchers and partners started in the new millennium two pilot undertakings in market development—one in East Africa (FOODNET) and the other in West Africa (RUSEP)—to show how markets can contribute to enhancing growth and providing opportunities and security among small-scale farmers. Working from the concept that markets are institutions, the two pilot projects were able to show that by developing markets, profitability, efficiency, and growth in incomes can be increased through reducing the transaction costs involved in exchange and allowing prices to reflect scarcity and information. In each of the pilot projects, market development was a key aspect which involved the identification of commodities with market opportunities, and the organization and training of clients, including farmers, processors, and traders. This provides them with the necessary skills and information to respond to the demands of market opportunities. Markets were facilitated through effective and active market information systems that provide increased access to, and use of, improved agricultural inputs. This aims to generate effective business linkages and agricultural trade. The two pilot undertakings on market development provide a coordinated and synergistic approach with existing public and private support (input and credit) institutions to increase the effectiveness and impact of research. Their goal was to expand opportunities in output markets beyond their present capacity to transform the rural economy from subsistence to commercial agriculture. For example, a new scheme of small farmer groups of between 5 and 10 persons proved successful in the four pilot states of RUSEP in Nigeria. About 4300 farmers who belonged to 550 groups linked up with private seed companies, 960 with banking institutions, and 860 with tractor-hiring services for sustainable access to modern agricultural inputs. Similarly, RUSEP facilitated in 2003 the supply of raw materials by farmers' groups to agro-industries worth about US$2.7 million. This amounts to an increase of about 20 percent in farmers' income and a reduction in cost of 15 percent for the agro-industries. FOODNET improved the market information systems in Uganda, including 2 to 3 radio broadcasts per week and the use of a local SMS service provider became available to enable text messaging for 17 commodity prices via mobile phones. Similarly, RUSEP facilitated the broadcasts of market information

Researcher showcasing IITA products to partners. Photo by IITA on 20 agricultural commodities in Nigeria through local radio and a website. There were also about 100 entrepreneurs benefiting annually from training on agroenterprise and product development in Nigeria and Uganda. Both pilot projects for linking markets to farmers left some lessons learned: the need of small-scale farmers and traders to have accurate and timely market information, for which access may be facilitated by radio, mobile phones, email, and the Internet. Hence, market information systems make markets operate more efficiently by providing reliable price data that help by raising farm-gate prices.

A high quantity and quality of dry and safe products with a long shelf life were necessary to support the development of cassava-based agro-industries. IITA research therefore included postharvest technology for cassava that led to having improved processing technologies and to developing new products. Lateef Sanni Oladimeji—working both in the University of Agriculture in Abeokuta and as IITA Postharvest Specialist—received the 2008 CGIAR Regional Award for Outstanding Agricultural Technology in sub-Saharan Africa. The cassava drying technology he devised has significantly contributed to income and employment gains for many small and medium-scale enterprises in Nigeria and West Africa. His first rotary dryer increased the production of cassava flour to 300 kg every 8 hours. While working within IITA's Integrated Cassava Project, he assembled a team of engineers that designed a "flash" dryer capable of drying 250 kilograms of cassava flour per hour. This work increased the use of locally manufactured flash dryers in Nigeria from 2 to over 60 units within half a decade.

40 years later: CGIAR acknowledged impacts mostly from IITA

As noted by an evidence-based assessment to the then CGIAR Science Council[9] the largest development impact in sub-Saharan Africa came via support of long-term crop improvement and integrated pest management research dealing with biological risks. This impact report indicated that about 80 percent of the impact of the CGIAR in sub-Saharan Africa estimated at US$17 billion (until the mid-2000s) ensued from the biological control of pests by IITA and national partners across the region. The prerequisites for this achievement were both a very knowledge-intensive program and the nature of investor support and financing. It would have been difficult to implement biological control options successfully without long-term commitment to knowledge generation. Likewise, there were a broad range of actors deserving acknowledgement: scientists who were on target with their ideas and translating them into research undertakings, stakeholders (or "clients") who guided the priority setting, managers who supported the scientists and sought the resources for implementing their research, and development investors who were convinced by the arguments from managers and scientists in IITA and were then willing to fund the agenda put forward by the Institute. The impact research compiled in this report to the CGIAR Science Council proved also that West and Central African farmers benefited by growing crops bred by IITA and partners in the subregion owing to edible yield increases (Table 3). Pan-African partnerships throughout the commodity chains led to impacts on crop output because of the significant gains in the fields grown by African

[9] Maredia M.K. and D.A. Raitzer. 2006. *CGIAR and NARS Partners Research in Africa: Evidence of Impact to Date.* Science Council Secretariat, Food and Agriculture Organization of the United Nations, Rome, Italy

Table 3. Successful plant breeding endeavors of IITA in sub-Saharan Africa.

Crop	Main trait(s) and impact(s)	References
Cassava	Host plant resistance to bacterial blight and cassava mosaic disease. African programs incorporated these bred-materials in 80% of their cassava bred-germplasm, which led to 50% gains in cassava root yields. The improved cultivars raised per capita output by 10% continent-wide, benefiting 14 million farmers	Hahn et al. 1979, Nweke *et al.* 2002, Nassar and Ortiz 2007
Cowpea	Cultivars that have enhanced host plant resistance to various pathogens and pests and are dual-purpose (food-feed) provide both grain for human consumption and fodder for livestock in the dry season, thereby ensuring food supply during a critical period of the year, plus providing cash income, fodder, and *in situ* grazing after harvesting during periods of grain price peak and when good quality fodder is scarce	Ortiz 1998, Sanginga *et al.* 2003, Singh 2007
Maize	Breeding high-yielding open pollinated and hybrid cultivars for resistance to *maize streak virus*, the parasitic weed *Striga*, insects, downy mildew, and other pests led to their adoption in about 60% of maize area in West and Central Africa in the mid-2000s and to more than one million people per year being moved out of poverty since the mid-1990s. Early maturing cultivars allowed the crop to be grown in the semi-arid tropics of Burkina Faso, Guinea, Mali, Niger, and Senegal	Efron *et al.* 1989, Brader 2002, Alene *et al.* 2009
Plantain	Hybrids resistant to black Sigatoka or black leaf streak provide more income to farmers owing to the reduced cropping cycle and increased bunch weight	Vuylsteke *et al.* 1993, Ortiz *et al.* 1997, Lemchi *et al.* 2005
Rice	While early maturing upland cultivars resistant to blast and drought tolerant were adopted in drought-prone inland valley swamp ecosystems and upland areas with moderate rainfall, widely accepted rainfed cultivars for Nigerian fertile lowlands, and paddy rice cultivars with high yield potential and grain quality became popular in both Cameroon and Nigeria. *AfricaRice* (then known by its former *WARDA* acronym) assumed full responsibility for rice breeding for West and Central Africa by the end of 1991. IITA former scientist [1987-1990] Monty Jones got the 2004 World Food Prize for his achievements in breeding new rice cultivars for Africa (NERICA)	Matlon *et al.* 1998
Soybean	High yielding, resistant to pod shattering, and promiscuously nodulating cultivars increased production in Nigeria by nearly 3 times within a decade though the crop area was enlarged only by 26%. Rust-proof soybean was bred to replace cultivars susceptible to *Phakopsora pachyrhizi* that causes 60 to 80 percent yield loss	Sanginga *et al.* 2003, Singh *et al.* 2003b
Sweet-potato	Until 2005 IITA led the release of orange-fleshed sweetpotato (OFSP) cultivars to alleviate vitamin A deficiency in rural households of southern Africa, particularly in rural Mozambique. The *Centro Internacional de la Papa* (CIP) took over thereafter. In 2016, IITA former scientist [1995-2005] Maria Isabel Andrade was given the World Food Prize for her research-for-development on micronutrient and vitamin biofortification through OFSP. About 26% of all sweetpotato grown in 2013 in Mozambique was OFSP and more than one million households have received improved high yielding OFSP planting materials since 2001	Low *et al.* 2007

farmers. The examples noted in Table 3 point out the benefits of having a CGIAR ecoregional center doing crop breeding, and together with many continental partners delivering the new seeds with an impact on African livelihoods. African plant breeding can be built on these previous and successful endeavors, some of which seems to remain "best-kept secrets" outside the continent. They are contributing significantly to the African diet and also to improving rural household earnings owing to surplus harvests or propelling entrepreneur development through agroprocessing undertakings. The multinational private sector has, however, done little research on crops that are grown with low inputs by poor farmers in their marginal environments.

Trees are back in IITA agenda through an international public–private coalition

The Sustainable Tree Crop Program (STCP) was launched with the new millennium as a coordinated and innovative effort made by industry, producer organizations, public-sector institutions, social and research groups, as well as development investors and conservation organizations, to facilitate the improvement of smallholder agricultural systems based on tree crops in Africa. Their interests and concerns were to improve the well-being of the smallholder farmer and the rural household, to guarantee the environmental sustainability of tree crop systems, and to ensure that viable and efficient institutional and policy frameworks are in place to serve the needs of the entire system, from producers to consumers. To achieve the goal, a public–private sector partnership was established (the STCP Alliance) to provide stakeholders with an organizational framework and policy environment to improve the performance and efficiency of the system. Productivity of tree crop farms and enterprises was raised, with an emphasis on rehabilitating and reclaiming deforested lands. Efficiency in the marketing chain was improved to deliver fair prices to farmers and quality products to end users. On the social and labor front, STCP engaged in preventing and eliminating the worst forms of child labor, thereby improving standards on farms and in communities. The aim of these efforts was a more sustainable global economy for the focal tree crop systems, characterized by increased rural incomes, reduced risk, and greater stability in the supply of quality products to end users, increased demand for and use of tree crop products, better working conditions on farms, and an improved status of environmental resources for current and future generations of Africans to pursue their interests. A regional program was therefore required to enhance the synergies to be gained by working across institutions and countries to successfully develop sustainable tree crop production. The four largest African cocoa producers (Cameroon, Côte d'Ivoire, Ghana, and Nigeria) were included in the program and accounted for approximately two-thirds of total world production. The fifth member of the program was Guinea whose diversified agricultural economy includes cocoa, cashew, and robusta coffee as major subsectors.

In 2002, a series of STCP pilot projects started in West Africa; three of the initially selected pilot projects were in Côte d'Ivoire, and one in each of the other four countries (Cameroon, Ghana, Guinea, and Nigeria). The objectives of these pilot activities were to compare, test, and validate different approaches and interventions to develop sustainable and integrated cocoa production systems, and to concurrently address child labor concerns in a coherent and systematic method (see next subsection). The ultimate goal of these pilot activities was to improve the rural livelihood of cocoa producers in West Africa by improving their ability to respond to the demands of global markets. Farmers in the pilot sites were trained in improved production technologies, farmer organizations were strengthened to provide efficient key services to their members, marketing and information systems were tested for their ability to increase farmer income, and rural communities were briefed on important social issues such as the use of child labor, HIV/AIDS, and farm safety. The Farmer Field School Curriculum on Cocoa (FFS-CC) included integrated pest management strategies, rehabilitation of old cocoa farms, and postharvest quality management, as well as child labor issues potentially associated with cocoa production. About 90 facilitators selected from farmer organizations and 40 from public extension services were trained in the four countries for implementing the FFS-CC. Over 160 schools were established through which more than 125,000 farmers were trained in West Africa. The level of enthusiasm and demand for FFS was extremely high among the rural community as well as local authorities. IITA received the 2008 CGIAR Science Award on Outstanding Communications for training farmers in West African countries to use digital video cameras as a way to share knowledge on sustainable cocoa production. Farmers participated in the filming, editing, pretesting, and final production of the videos with the support of media specialists. Groups of 20 to 25 farmers got together weekly to watch and learn from the videos, illustrated guidebooks, guided discussions, and field demonstrations. Farmers adopting the crop and pest management practices promoted by these video viewing clubs could increase yields by at least 20 percent and decrease pesticide use by up to 20 percent. Production training with marketing interventions also increased household income. For example, collective sales attracted 5 to 10 percent additional revenue for farmers in Cameroon and Nigeria, and 2 to 10 percent in Côte d'Ivoire, depending on the sales strategy, i.e., timing.

Labor practices in the cocoa farms of four West African nations. In September 2000, Britain's Channel 4 TV in a documentary on child slavery

Farmers in a meeting. Photo by IITA

Cocoa farmers field school. Photo by IITA

broadcast the claim that up to 90 percent of the cocoa in Côte d'Ivoire was produced using child slaves. Côte d'Ivoire's ambassador to the United Kingdom called the program "wildly inaccurate, unsubstantiated, and damaging to the people of Côte d'Ivoire." In July 2001 the story landed in the USA when Knight Ridder newspapers ran a series of investigative articles that further uncovered issues of child labor on Côte d'Ivoire cocoa farms. In response to these reports the Chocolate Manufacturers Association (USA) signed the so-called "Harkin-Engel Protocol" witnessed by the US Congress for the growing and processing of cocoa beans and their derivative products in a manner that complies with International Labor Organization (ILO) Convention 182. In Step 6 of the protocol action plan, the industry was committed to *"develop and implement mutually acceptable, voluntary, industry-wide standards of public certification consistent with applicable US federal law that cocoa beans and their derivative products have been grown and/or processed without any of the worst forms of child labor."* In May 2001, the United States Agency for International Development (USAID), ILO, and IITA initiated a collaborative undertaking under the "umbrella" of the STCP, which was aimed at addressing the issue of child labor in the cocoa sector of West Africa. The first step was to conduct investigations into the extent, nature, and causes of child labor. In Nigeria, Cameroon, and Ghana, the STCP baseline survey originally designed to examine constraints facing cocoa production and marketing systems for cocoa and coffee was amended to better address the issue of child labor. In Côte d'Ivoire after discussions with the highest officials in government, two studies were conducted, focused on the issue of child labor in the cocoa sector. Over 6000 households in the major cocoa-producing areas of these countries were visited and interviews were conducted with the household heads. The surveys did not substantiate the media assertions of widespread child slavery on cocoa farms. However, other social issues regarding the employment of children on cocoa farms were uncovered. The STCP alliance, in conjunction with the ILO, fostered both direct and indirect interventions to address the findings including technology dissemination to enhance productivity, education interventions, briefing on hazardous work, and trade and information systems to enhance farmer incomes.

Cassava mosaic disease: Changing a threat into an opportunity for rural development

In view of the importance of cassava as a major source of calories for Nigerians and potential source of large scale agro-industry uses in the country, the Federal Government of Nigeria asked IITA in 2002 to implement a cassava mega-project to preempt an outbreak of a more virulent strain of the cassava mosaic disease. This call was the result of a timely warning by IITA researchers on the potential attack by new strains of cassava mosaic disease in Nigeria, which could combine to form a more destructive strain of the virus. IITA, therefore, took immediate preventative action to avoid a repetition of the devastation that had occurred in Uganda during the 1990s. Since the launching of this mega-project, IITA has produced thousands of new, disease-resistant plantlets and cuttings and delivered them to Nigerian farmers. The improved plants not only resisted the disease but also slowed its spread to non-resistant cultivars, acting as a barrier to its advance. Moreover, IITA-bred cultivars produced more tuberous roots per plant and their distribution led to increases in total Nigerian production. As part of the unique preemptive strategy, IITA and its partners from both the public and private sectors in Nigeria established value-added industries and postharvest processing

Cassava processing received a boost during the Presidential Initiative on Cassava. Photo by IITA to ensure markets for the increased production that is expected. Hence, this Nigerian Presidential Cassava Initiative, which in 2003 brought the strong funding commitment of a Global Development Alliance between the largest oil company in the country and the major aid investor of the CGIAR, improved technology transfer to address cassava mosaic disease and to develop cassava processing that provided greater incomes to farmers in 11 States, mostly in the southern "cassava belt". Likewise, it assisted in identifying commercial markets for cassava, such as ethanol production and use in livestock feed and baking. In addition to being a staple food, starch from cassava was used in other industries including textile manufacturing. The Initiative, whose policy mandated flour millers

Presidential Initiative on Cassava

The Cassava Presidential Initiatives paved the way for Unleashing the Power of Cassava in Africa (UPoCA), which was a project in the 2000s that increased production by at least 30 percent and improved the competitiveness of cassava value chain actors through capacity building and by mobilizing, facilitating access to, and applying field-proven agricultural technologies in Democratic Republic of Congo, Ghana, Malawi, Mozambique, Nigeria, Sierra Leone, and Tanzania. The Chairman of the local chapter of the Nigerian Cassava Growers Association in Ido community Bashir Adesiyan said, "*I now harvest more than 20 t ha-1 using the improved varieties. With local varieties, I used to harvest 10 t ha-1.*" Furthermore, Maria Borbor – a member of Tongea Women's Development Association in Sierra Leone – described the establishment of the cassava micro-processing center in Sandeyalu as a "living bank". She added "*… now we can fulfill our financial obligations to educate our children and improve our livelihoods. We will do all within our power to sustain the micro-processing center, which provided a financial window of opportunity to us farmers, as a viable asset.*" Likewise, Peter Mtoi who was among those farmers who benefited significantly from UPoCA in Tanzania where their earnings increased 10-fold, declared, "*… with the money I made from the sale of cassava planting material and the dividends I received from the group, I have finished constructing and equipping a video den and also installed a solar system to run the TV and DVD player. I will charge the villagers a small fee to watch news and movies.*" His wife Mary further acknowledged that they purchased a commercial charcoal oven to bake bread and cakes made of mixed cassava and wheat flour to sell in their village and at the nearby shopping center. Moreover, Manunga Jeanne of the Femmes Rurales pour Développement in Kwilu District (FRUD, Bandundu Province, DRC), noted "*… each year we got less and less cassava. We did not know it was a disease and were worried because for us, no cassava means no food. If you have no cassava, it is like a death sentence; you are going to die.*" FRUD working with UPoCA selected the cassava cultivars Obama and Nsasi ("help to raise children") from IITA, and Butamu ("the sweet one") from the Institut National pour l' Etude et la Recherche Agronomiques. She told a reporter "*these varieties are not only giving us big roots and many leaves, but they are not getting this disease … and they make very tasty* chikwangue", a popular local dish made from fermented and pounded cassava.

to include 10 percent of cassava flour, boosted production by 10 million tonnes between 2002 and 2008. An impact study revealed that production increased by 17 percent in villages involved in the Initiative but by only 10 percent in those not involved. The adoption rates of bred cultivars was 74% in intervention villages (and up to 94% if farmers participated in training) and 65% for others. Furthermore, the use of processing machines such as the grater and the presser was 60% in those villages involved and up to 76% if they attended training. Gross margin and the cost:benefit ratio were higher for bred-cassava cultivars (US$ 4090/ha) than for local landraces (US$ 1500). About two-thirds of the enterprises that were fabricating processing machines were small, and 79% of them were owned by sole proprietors. Encouraged by IITA research impacts on the crop, the Integrated Action Program for Cassava Starch Production and Export was launched by the President of the Republic of Ghana for developing the cassava starch industry in his country as a major vehicle for job creation and poverty reduction in rural areas.

Better health and nutrition through crop genetic enhancement for micronutrients

Protein-energy malnutrition and micronutrient deficiency are among public health problems leading to learning disability, impaired work capability, illness, and death in Africa. Population growth, intensive poverty, environmental degradation, poor agricultural services, and lack of enabling policy environments are among the factors aggravating malnutrition in the continent, particularly among pregnant women, nursing mothers, and preschool children. Genetically improving the nutrient content of staple food crops represents a sustainable way to alleviate micronutrient malnutrition,

IITA's research benefits marginalized groups, including women and children. Photo by IITA

Farmers applying Aflasafe on maize fields. Photo by IITA.

e.g., iron-deficiency anemia or corneal blindness owing to vitamin A deficiency. In an effort to identify cultivars high in micronutrient content, crop cultivars grown in distinct locations can be assessed for iron, zinc, and ß-carotene content. A crop breeding program for micronutrients needs to assess the occurrence of micronutrient deficiency (e.g., vitamin A, iron, zinc or urinary iodine) in target areas and provide the best germplasm to farmers in each location to address it accordingly. Likewise, fortification with target micronutrients may be appropriate if they are available for mixing in local diets. Maize lines bred at IITA in the 2000s exhibited significant differences in iron, zinc, and ß-carotene content in the grain of one of the main staple foods in Africa. One of the maize lines grown at a location in the transition zone showed 45 percent more iron bioavailability than a control maize cultivar widely grown by farmers in northern Nigeria. The results indicate the potential to breed early maturing maize cultivars for high and stable mineral content in their kernels across diverse growing environments.

Ensuring food safety and preventing trade barriers due to mycotoxins

Aflatoxins are toxic chemicals produced by the fungus *Aspergillus flavus* and are prevalent in stored grains in the developing world. Aflatoxins are known to cause liver cancer and also suppress the immune system, and cause death in animals. A West African survey found that virtually all the children examined had elevated levels of aflatoxins in their blood. In 2003, the article "*Dietary Aflatoxin Exposure and Impaired Growth in Young Children from Bénin and Togo,*" published in 2002 in the British Medical Journal, Vol. 325, received the CGIAR Outstanding Scientific Article award. The co-authors were IITA scientists, led by plant pathologist Kitty Cardwell, and their partners at the University of Leeds and at the London School of Hygiene and Tropical Medicine (UK). Their research revealed a striking association between exposure to aflatoxin in children (from villages of Bénin and Togo) and standard indicators of malnutrition (stunting and underweight). The research-finding points to the need to address aflatoxin contamination in stored food grains, particularly maize and groundnut, in warm and humid areas of West Africa. The IITA team investigated therefore the potential of biological control agents that can act against plant pathogens through different modes of action including antibiosis, competition, and hyper-parasitism. Competition occurs when two or more microorganisms require the same resources in excess of their supply. In a biological control system, the more efficient competitor (the biological control agent) out-competes the less efficient one (the pathogen). One innovative option to minimize the development of aflatoxins in crops was by 'competitive exclusion'. The idea was to introduce and establish a fungal strain that does not produce any toxins and have it replace the strain of *A. flavus* that causes the problem. IITA researchers and partners found one such strain. The next challenge was to test this or equivalent strains in areas where aflatoxins are a threat. Another option was plant breeding. In fact, some maize inbred lines bred at IITA for resistance to aflatoxin production were better than two of the best US lines. Further tests of some of the IITA lines also showed that they had protein profiles different from those of the US lines, suggesting that there was the potential to identify new mechanisms of resistance to aflatoxin from among IITA lines. In the 2000s, IITA in partnership with the United States Department of Agriculture – Agricultural Research Service (USDA–ARS) released six new maize inbred lines with resistance to aflatoxin contamination and adapted to the lowlands. They are used by national programs as parents to accelerate breeding efforts against aflatoxin contamination in maize. The last but not the least option included traditional storage and food processing methods. Generally good storage practices are associated with levels of aflatoxin. Some methods of maize preparation such as roasting and treatment with alkali reduce levels of aflatoxin. Boiling and soaking corn in lime water could eliminate or greatly reduce the levels of aflatoxin in the final product. Selective removal or isolation of contaminated portions of the food commodity is the most widely used physical method for aflatoxin decontamination.

Agrobiotechnology to address the needs of the rural poor

Biotechnology applications in current use for improving crops grown in Africa are tissue culture, genetic transformation, DNA fingerprinting, molecular-aided analysis of genetic diversity, and DNA markers for new

IITA uses biotechnological tools to improve crops. Photo by IITA

Happy and well-nourished children in farm communities. Photo by IITA

testing tools and aided breeding. IITA has been among the most active research organizations on agrobiotechnology in Africa. While undertaking genomics and genetic transformation research, IITA has addressed these questions. (i) What kind of genomics and genetic transformation research does IITA need to fulfill its mission? (ii) Where are we and what are the applied aspects of genomics and genetic transformation research for the improvement of crops in Africa? (iii) How can IITA benefit from specific partnerships with Advanced Research Institutes (ARIs) or global initiatives involving ARIs and NARS and how can they team up to attract funding from development investors? (iv) How can IITA serve as an effective bridge to transfer knowledge and technology from ARIs to its NARS partners? IITA's role in research-for-development involving agrobiotechnology in Africa has included fostering the international sharing of knowledge and skills in biotechnology tools important to the improvement of agriculture on the continent, helping African national partners to negotiate acceptable terms on intellectual genetic, and other proprietary biotechnology assets needed for crop breeding, and launching creative and innovative approaches such as the molecular breeding of crops relevant to African agriculture. Hence, IITA has bridged gaps by linking ARIs around the world to Africa to help them share in the benefits of biotechnology. For example, DNA markers were used to tag specific segments of chromosomes bearing the desired gene(s) to be transferred (or incorporated) into breeding lines (or populations). By finding genes with a DNA marker, the power of selection in plant breeding can be magnified. Likewise, IITA and research partners worldwide have developed methods to genetically transform cassava, cowpea, *Musa,* and yam to overcome pest and disease problems and produce new diagnostic tools for identifying pests and pathogens or contaminants in food and feed. In short, IITA undertook applied plant biotechnology research to address the food and income needs of Africa; transferred, where appropriate and in collaboration with partners overseas and on the continent, biotechnology products from the laboratory to the marketplace; served as a platform for technology transfer between overseas ARIs and Africa; and enhanced the capacity of selected partners in Africa to apply and monitor biotechnology via comprehensive interactions and training-through-research programs.

In 2003, the CGIAR Promising Young Scientist was Jonathan H. Crouch, then the Global Theme Leader for Biotechnology at the International Center for Research in the Semi-Arid Tropics (ICRISAT, Patancheru, India), who in his speech accepting this award acknowledged this success to his whole tenure in the CGIAR, which started as an IITA postdoctoral fellow on plantain and banana biotechnology in the second half of the 1990s at IITA High Rainfall Station (Onne, near Port Harcourt, Nigeria).

Moving the agenda into the 21st century

Low agricultural productivity and a high percentage of poor and undernourished people, both adults and children, are common features of sub-Saharan Africa. At the beginning of this millennium, low infant weight was predominant in West and Central Africa, as well as the Great Lakes

In rural Africa, agriculture remains as the dominant factor for economic development. Photo by Africa RISING

Region of Eastern Africa. The ratio of agricultural land per rural inhabitant of sub-Saharan Africa declined from 3.7 hectares in 1970 to 2.2 hectares in 1998; and from 2.3 to 1.5 hectares in West Africa; i.e., an annual decline of –1.26 percent for sub-Saharan Africa, and –0.9 percent for West and Central Africa. In the mid-1990s, the decline slowed significantly (–0.50% and –0.1%, respectively), which shows the effects of rural migration to urban areas and, in some locations, the negative effects of pandemics affecting the health and life expectancy of rural African people. The annual demand for food kept growing (3.3%) and was not matched by the growth in agricultural production in the 2000s. Not surprisingly, per capita calorie intake remained then at low levels in sub-Saharan Africa, and below the average of the developing world. Agriculture accounted for 33 percent of GDP and 40 percent of exports for sub-Saharan Africa in the 2000s. It provided jobs to 65 percent of the labor force (versus 15% in industry and 2% in services). In short, agriculture remained the dominant factor for economic development in most of Africa and, more importantly, the rural poor depended on agriculture for their livelihoods at the beginning of this millennium. Hence, research-for-development interventions aiming to provide food, reduce poverty, and generate income should have been a must in any agenda in which science was pursued to assist development in Africa.

Women are one of the major beneficiaries of IITA's integrated research and development programs. Photo by IITA

As pointed out in several fora, poverty remains the greatest barrier to improving the quality of life. One of the most effective ways to alleviate poverty, and in turn its inseparable partner, hunger, is through agriculture and the production of more food. However, as indicated by Hartmann[10] "*a successful approach cannot only be about agriculture—it has to recognize the vital role it plays in the bigger picture. The strength of the IITA approach to local production, wealth creation, and risk reduction is its embrace of strategies that recognize that the issues that contribute to poverty are intertwined. The degree of impact from this approach depends on several factors, not the least of which is investor and implementing entity choices. The choices investors make in how activities are financed may be as important as how much. Equally, the choices made by development institutions such as IITA and its national and regional partners on problem definitions and research-for-development methods, are also critical*". IITA 2005–2007 Medium-Term Plan stated that "*... understanding the implications of these choices is one key to greater progress in meeting the Millennium Development Goals. The second key is the need to fully appreciate the impact agriculture has on health, nutrition, income, productivity, and rural development. IITA's poverty reduction strategy for*

[10] Hartmann, P. 2009. An Approach to Hunger and Poverty Reduction for sub-Saharan Africa. International Institute of Tropical Agriculture, Ibadan, Nigeria

sub-Saharan Africa is based on three, telescopic, prongs: to encourage local production in ways that create wealth and to reduce risk for farmers and both the rural and urban poor. If the development community has to choose just one activity with which to address the first Millennium Development Goal of reducing extreme poverty and hunger, we should produce more food in a way that creates wealth and addresses producer risks".

Bananas in the East African highlands: Agronomy and genetic engineering to the rescue

Banana is a very important food staple in the Great Lakes Region of Eastern Africa and produced throughout the year. Farmers sell any surplus harvest on a daily basis. Coffee is a pure cash crop, grown on over half a million coffee farms—of which 98 percent are owned by smallholders—and provides a major foreign exchange source for the Great Lakes countries, e.g., 20 percent of Uganda's foreign exchange revenues comes from coffee. Both crops complement each other regarding socioeconomic benefits to growers and their households: banana provides food security and daily cash while coffee gives a cash boom twice a year, thus helping farmers to invest in infrastructure or buy inputs, transport equipment, or pay for large social events. Furthermore, banana and coffee intercropping is more profitable than monocropping either banana or coffee, as revealed by IITA's diagnostic survey. Further research shows that shade-loving coffee plants do not compete for light with tall banana plants; both benefit from potassium when intercropped but coffee is potassium-deficient in sole cropping. It seems that the mulch resulting from the high turnover of banana biomass reduces the need for soil tillage, thereby keeping the shallow banana and coffee rooting systems undamaged, and bringing nutrients into forms that are easily

Growing healthy banana plants.

available for the plants. Hence, this intercrop system does have some strong advantages, and understanding how it works allows these findings to be used in other banana- and coffee-growing areas, particularly where land pressure and alack of credit or capital are the main constraints for smallholder farmers.

"*Matooke*" is the local word for food used in Uganda. This dish uses green banana that are cooked, wrapped in the plant's leaves, and mashed or pounded into a meal. Ugandans eat, on average, more than a quarter of a kilogram of banana in a day. Banana *Xanthomonas* wilt (BXW) emerged at the beginning of the millennium as a disease threatening the livelihoods of East African smallholder farmers. Entire banana fields can be destroyed by BXW and there are no commercial pesticides, biocontrol agents, or resistant cultivars available to control it, thus calling for solutions to be found before this pest destabilized food security in the Great Lakes Region

Confined field trials of Banana Xanthomonas Wilt-resistant transgenic plants. Photo by IITA

of Africa. Hence, Uganda's National Agricultural Research Organization (NARO), Academia Sinica (Taiwan), the African Agricultural Technology Foundation (AATF), and IITA have been working for the last 1.5 decades on producing "*matooke*" banana resistant to BXW using a transgenic breeding approach, particularly where farmers are reluctant to employ labor-intensive pest control measures. NARO and IITA jointly developed an efficient protocol using a cultivar independent transformation system that paved the way for using transgenes from sweet pepper that confer resistance against BXW by delaying the hypersensitive response induced by the pathogen. The gene involved encodes for a ferrodoxin protein that exists in all organisms and is common in human diets, thus being safe for human consumption and the environment. Hundreds of transformed plants of various banana cultivars were generated, and underwent a first screening for host plant resistance in the laboratory and the glasshouse. The most promising were thereafter evaluated for efficacy against BXW in confined field trials under different farming systems. Most transgenic plants exhibited both normal growth and fruit development, and did not show any substantial changes in morphology compared with non-transgenic plants. More interestingly, while non-transgenic control plants developed symptoms and eventually wilted completely, several transgenic plants remained asymptomatic until harvest. This partnership research provided the first field-based evidence for the transgenic control of a pest in banana and progress toward the development and release of banana resistant to BXW. Selected transgenic plants will be included in further testing for environmental and food safety, in compliance with target country biosafety regulations, risk assessment and management, and seed registration and release procedures. Research on public perception, consumer preferences, and acceptability, which may guide the commercialization and wide use of this transgenic banana, defined four consumer groups based on socioeconomic characteristics plus institutional awareness and trust[11] Consumers are more skeptical than farmers regarding any putative unknown health effects of the transgenic banana. Decision-makers, extensionists, and researchers should

[11] Kikulwe, E.M., J. Wesseler and J. Falck-Zepeda. 2011. Attitudes, perceptions, and trust. Insights from a consumer survey regarding genetically modified banana in Uganda. *Appetite* 57, 401–413

therefore consider such distinct perceptions when designing the deployment of transgenic banana in Uganda, because this country foregoes potential annual benefits ranging between US$179 million to US$365 million by delaying their approval for farming.[12]

Thomas Dubois—a biocontrol specialist at ESARC—was the recipient of the CGIAR 2006 Promising Young Scientist Award for his work to improve banana. Dubois and co-workers developed enhanced tissue culture planting materials—derived from banana's cells—intentionally infected with a beneficial fungus to offer protection against pests and pathogens. An innovative public-private partnership delivered these planting materials to farmers in Eastern Africa.

Improving agriculture-based livelihoods in Central Africa

Belgium's Directorate General for Development Cooperation issued a call for proposals in April 2004 with the aim of accelerating the impacts of agricultural research for development in the Great Lakes Region of Africa. Three projects were approved, operating largely in the same areas of Burundi, Rwanda, and the Democratic Republic of Congo including similar national partner institutes and complementing proposed activities on integrating natural resource management with resilient germplasm (mainly banana and legumes) and marketing approaches. Bioversity International, CIAT, and IITA—their proposers—agreed to ensure cooperation and complementarity, thus avoiding technical and financial duplication at the national level. The Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA) was therefore launched in 2006 with the goal of improving the livelihoods of those depending on agriculture through investments in system productivity and resilience. The Katholieke Universiteit Leuven and the Université catholique de Louvain provided support on upstream research. CIALCA used an integrated systems research and unique collaboration platforms for a better impact on poverty and ecosystems integrity. It was able to jump-start activities and mobilize networks to boost farmers' incomes from integrated systems intensification, while preserving their land for future generations. Ready-to-use technology best-bets were packaged and delivered by development partners to farmers who received technical training and capacity support, e.g., on integrated pest management for banana. Likewise, CIALCA strengthened local capacity in a region that had significantly lost its scientific capacity during the many years of conflict by training more than 50 MSc and PhD students through "sandwich" and exchange programs. Moreover, interactions and joint capacity building with projects of the Vlaamse Interuniversitaire Raad (Flanders, Belgium) catalyzed and scaled these undertakings. CIALCA has paid off, as noted through improving farm productivity in smallholder systems by more than 27 percent, raising household incomes by 19 percent, bettering nutrition security, (e.g., at least in percentage increase of protein intake), and delivering positive environmental spin-offs. Furthermore, after almost 10 years of research, capacity building, and networking CIALCA contributed to lifting about half a million people out of poverty in Central and Eastern Africa. CIALCA was integrated—as a model for linking agricultural systems with R4D impact—into the CGIAR Research Program (CRP) Humidtropics in mid-2013, and shaped Phase 2 of the CRP on Roots, Tubers, and Bananas.

[12] Falck-Zepeda, J., E. Kikilwe and J. Wesseler. 2008. Introducing a genetically modified banana in Uganda. Social benefits, costs, and consumer perceptions. *IFPRI Discussion Paper* 00767. International Food Policy Research Institute, Washington, D.C.

Transforming livelihoods in the extreme northeast of Nigeria

IITA and the Canadian International Development Agency (CIDA) launched in 2004 the 5-year project *Promoting Sustainable Agriculture Project* (PROSAB) *in Borno State* with the goal of improving the livelihoods of the rural communities in the State through enhancing food security, reducing environmental degradation, improving sustainable production using transfer of gender-responsive agricultural technologies and management practices, easing access to input and commodity markets, developing an enabling policy environment, and strengthening the capacity of the project's stakeholders. PROSAB operated within a sustainable livelihoods framework, thereby emphasizing increasing livelihood assets and improving the capabilities of the rural poor. Subsistence farming in the target area faced erratic rainfall, marginal soil fertility, and an underdeveloped market. The participatory research and extension approach used by the project was effective in undertaking a community analysis to identify livelihood opportunities, constraints, and entry points, and to plan interventions; participatory action planning addressed priority problems and the deployment of best-bet technologies through male/female farmer-led participatory research and trials in pilot communities. Female and male farmers selected the technologies that suited their conditions and environments from a basket of options, which included maize tolerant to *Striga* and drought, dual-purpose soybean and cowpea, early maturing groundnut from ICRISAT, dwarf sorghum, WARDA's NERICA rice, maize–soybean rotation to reduce *Striga* and improve fertility, proper and timely application of fertilizer, environmentally friendly agrochemicals, and appropriate planting density. Community based seed multiplication operations were established to provide improved crop seeds. A market information system and links to major food processors provided ready markets. As noted towards the end of this project by Mrs Bata Joshua—one of the leading members of the women's group in a community called Vinadam in the Hawul Local Government area of Borno State—"*prior to the introduction of PROSAB in our community, our harvests couldn't feed us for the whole year. We had to supplement by buying grains from the market. Presently, our harvests are sufficient to feed our families and we even have surplus for sale in the market*". She also acknowledged that "*this new building is being built from revenues realized from selling soybean. The project is making a remarkable contribution to improving our livelihoods*. Likewise, James Buba and his wife, who were among the most promising soybean farmers in Nggabu Village also had a similar success story with soybean. James said "*We harvested 4.2 tons of soybean from my 2-ha farm last year and made a profit of Nigerian ₦184,000 (then about US$1,500) on soybean sales … This year, we have doubled the soybean farm and we expect about 6 tons to make more money.*" PROSAB more than doubled agricultural productivity with the use of new cultivars and management practices. Likewise, through the partnership with ILRI crop-livestock integration improved land preparation, animal nutrition, and health care, while farmers' access to genuine veterinary drugs was ensured. After this 5-year project, farmers' incomes increased 81%, they had better access to inputs and secured social empowerment. Socioeconomic analysis shows that poverty fell by 14 percent for about 17,000 households while their food security improved by 17 percent. The government, farmers, partners, and other stakeholders agreed that PROSAB "*helped significantly increase agricultural productivity and build the capacity of thousands of farmers and* *farmers' associations in the northern Nigerian State."* This project therefore demonstrated how appropriate technologies along with farmers' endeavors add great value to research outputs.

From field to fork: Fine-tuning IITA research-for-development approach

IITA acknowledged at the beginning of this millennium that agriculture embraces a multiplicity of stakeholders and systems, thus asking for an information-intense and knowledge-based approach "from field to fork" involving producers, transporters, consolidators, traders, and retailers who finally sell the item to a consumer. Agricultural research was understood as a provider of innovations to address needs and exploit opportunities that have developed within agri-food systems (Fig. 2). In this regard, IITA engaged with partners within Africa and beyond to enhance crop quality and productivity that lead to an impact on the lives of both rural and urban poor people within the continent. This R4D agenda sought technology to address hunger and poverty in Africa rather than purely adding scientific knowledge. IITA's approach was based on long-term development needs that guided research design and choice of partners, and incorporated both a mid-process initial outcome and an explicit phase-out strategy; these are critical elements often absent in traditional models. Thus, IITA along with its research and development partners was meant to deliver research outputs to achieve an outcome, which is then used to excite and attract more partners who were envisaged to take charge of the scaling-up and scaling-out of the technology by broadening participation and increasing the chances of success and ultimate development impact (Fig. 2). Along these lines, IITA gradually phases out and devolves functions to these partners until it exits entirely because development agents should deliver the final and larger desired outcomes addressing the initially identified development needs. Ex–post assessments should be undertaken to compare with the baseline information and measure the impact on the ultimate beneficiaries.

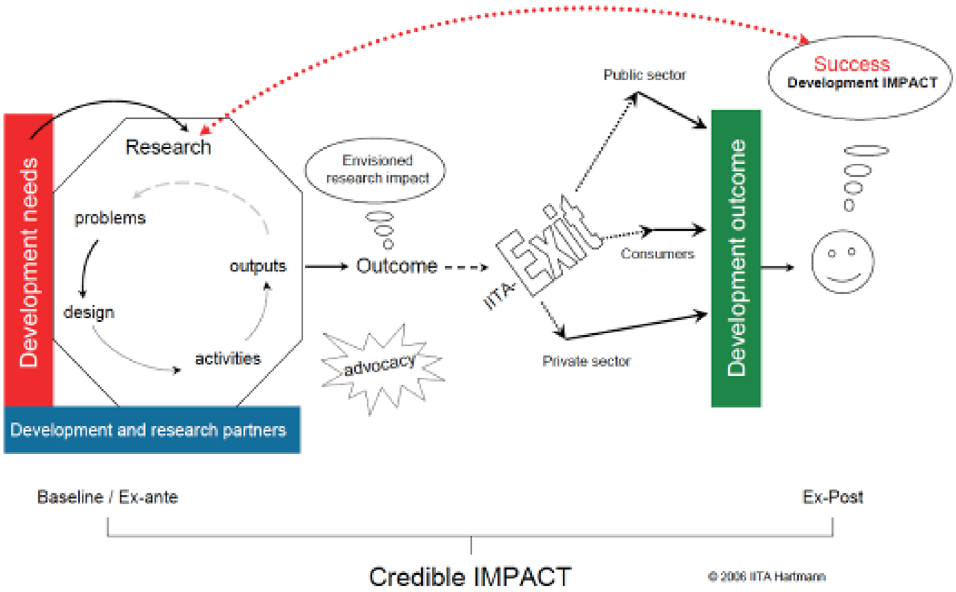


Figure 2. IITA's 2001-2011 research-for-development approach began identifying societal, producer, and consumer needs requiring research with potential impact. Research outcomes should be scalable and have partners available for adoption. Advocacy could be also pursued. Once partners embraced outcomes, IITA left implementation and changed its role to monitoring them and to undertaking ex-post assessments to measure impacts on the ultimate beneficiaries. Development impacts could bring new challenges that were referred back to development needs


Youth entrepreneur using a tablet to record data about planting. Photo by IITA

2011– present The Lead Research Partner Facilitating Agricultural Solutions for Hunger and Poverty in the Tropics

9

In May 2011, IITA's Board announced that Nteranya E. Sanginga had become the new Director General. He was then Director of CIAT's Tropical Soil Biology and Fertility but had previously spent 14 years in IITA in various capacities, including Principal Scientist and Head of the Soil Microbiology Unit and Project Coordinator. During his interview by the Board, Sanginga indicated that IITA's research and partnerships should be organized and strengthened by building on its past achievements and enhancing its scientific and administrative capacity to deliver on its mission of "*increasing agricultural production, food security, and income in sub-Saharan Africa*." A refreshed 2012–2020 strategy was released at the beginning of his tenure as Director-General for operationalizing the vision of IITA becoming "*the lead research partner facilitating agricultural solutions to overcome hunger and poverty in the tropics*" and raising by 2020—together with partners—11 million Africans out of poverty and redirecting 7.5 million hectares of agricultural land to productive and sustainable use.

This refreshed strategy has been the management tool for implementing research-for-development and maintaining a financially stable Institute. It also has provided the foundation for developing a cohesive and better-focused, high-quality research program to achieve IITA's mission, ensuring strong programmatic alignment within the CGIAR global research program portfolio. This strategy also enhanced accountability through better monitoring and evaluation of expected targets, making sure that IITA maintains and improves its comparative advantage in relevant, cutting-edge agricultural research. Hence, the values to be pursued by IITA staff were originality, excellence, collaboration, respect, professionalism, integrity, inclusiveness, equity, multiculturalism, and disciplinarity. IITA research-for-development agenda considers four impact zones that represent major agroecological zones and farming systems in sub-Saharan Africa (Fig. 3). An important operating principle was, therefore, the decentralizing of IITA from headquarters to four Hubs covering West (Ibadan, Nigeria), East (Dar es Salaam, Tanzania), Central (Kinshasa, D.R. Congo), and Southern Africa (Lusaka, Zambia) (Fig. 4). Likewise, a new organizational structure became operational in 2012 to respond to the challenges posed

Dr Nteranya Sanginga

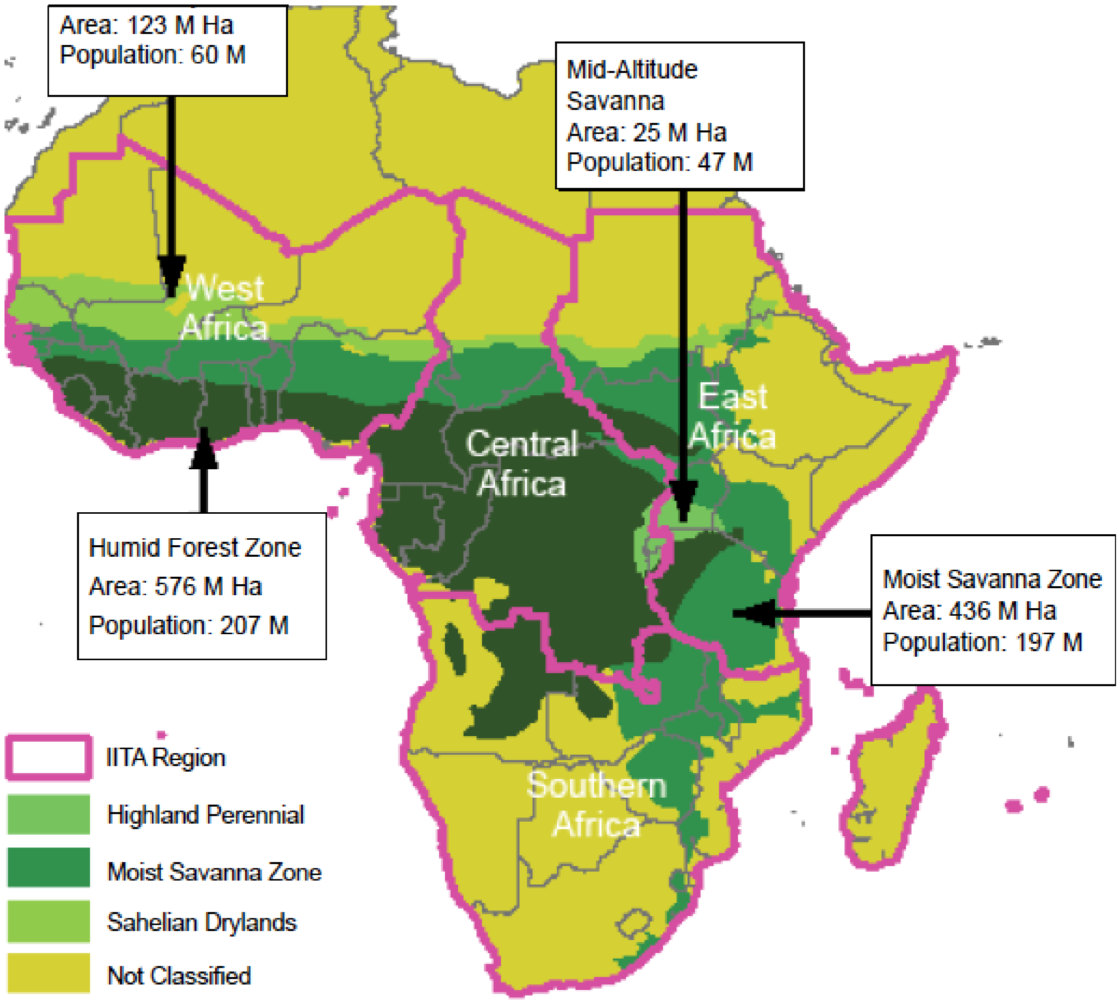


Figure 3. IITA's impact zones and major cropping systems of four agroecological zones across sub-Saharan Africa and its four hub-regions covering West, Central, East, and Southern Africa.

by the new initiatives such as the CGIAR "renewal," and to improve relationships with partners in the various multilateral and bilateral projects. As a result, there was a new research and institutional leadership that involved besides Sanginga, Ylva Hillbur as Deputy Director General for Research-for-Development, Kenton Dashiell as Deputy Director General for Partnerships and Capacity Development, and Kwame Akuffo-Akoto as Deputy Director General for Corporate Services.

The CGIAR embarked in 2010, after a review, in a new reform and restructuring aiming at renewal to "*improve the engagement between stakeholders in international agricultural research for development—namely, donors, researchers, and beneficiaries—and to refocus CGIAR on the major global development challenges.*" The main objectives of this change process were "*to integrate the work of the research centers, enhance collaboration with partners, ensure effective governance, and improve efficiency in providing and using resources.*" As a result, IITA aligned its research-for-development agenda to the CGIAR's system level outcomes (SLOs) and research programs (CRPs). The SLOs aspire to reducing poverty, improving food and nutrition security, and enhancing natural resources and ecosystem services, thus contributing strongly to the Sustainable Development Goals (SDGs) related to no poverty, zero hunger, good health and well-being, gender equality, clean water and sanitation, climate action, and life on land. Owing to its comparative advantage, the CGIAR also decided to give priority to and focus its CRPs on climate-smart agriculture, genetic improvement, nurturing diversity, natural resources and ecosystem services, gender and inclusive growth, nutrition and health, agricultural systems, and enabling policies and institutions. The goal of the multidisciplinary CRPs was to position the CGIAR to pursue innovative, comprehensive, and sustainable solutions, and to deploy available technologies. IITA was given the lead role for the CRP on Integrated Systems for the Humid Tropics (Humidtropics) that sought *"to transform the lives of rural poor in the humid lowlands, moist savannas, and tropical highlands in tropical Americas, Asia, and Africa"* … through an *"agricultural systems approach, a single research-for-development plan, and a unique partnerships platform for better impact on poverty and ecosystems integrity."* IITA used Humidtropics as an integrator of its refreshed strategy during the lifespan of this CRP (2012-2016), while participating actively in agrifood systems CRPs such as Grain Legumes; MAIZE; and Roots, Tubers, and Bananas; and integrating CRPs such as Agriculture for Nutrition and Health, Climate Change, Agriculture and Food Security; Policy, Institutions and Markets; and Water, Lands, and Ecosystems.

Through its refreshed strategy the Institute embraced during Sanginga's first tenure as Director General (2011-

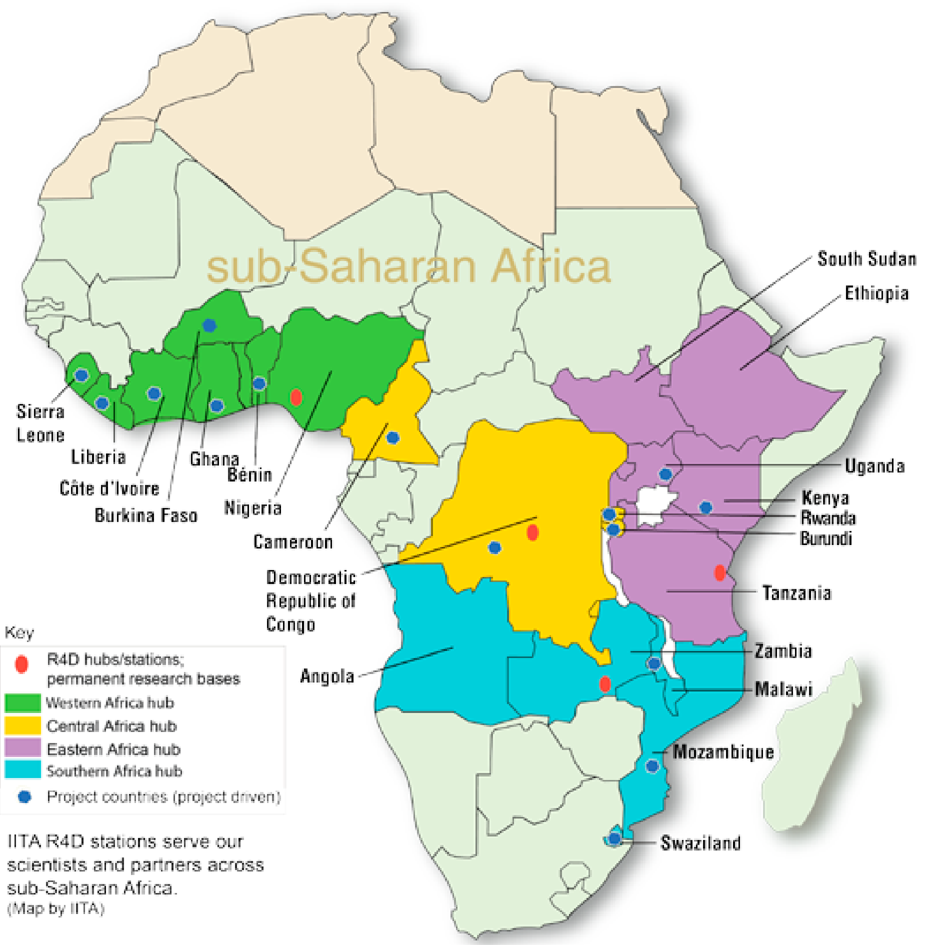


Figure 4. IITA Hubs and related Project Country Offices in sub-Saharan Africa at the beginning of the 2010s [see their addresses at the end of this publication]

2016) a results-oriented approach based upon innovation, efficiency, equity, performance, results, and transparency, and supported by a results-based management system. It also achieved the doubling of both funding (Fig. 1) and staff (to about 200 scientists). Likewise, IITA advanced the SLOs of the CGIAR in four defined agroecological impact zones in Africa —Sahelian drylands, moist savannas and woodlands, mid-altitude savannas and forests, and humid forests— by increasing edible yields of major staples banana/plantain, cassava, cowpea, maize, soybean, and yam, increasing average farm incomes, and reducing the number of malnourished children. Hence, 50 percent of IITA efforts in the refreshed strategy were given to improving food security and availability while increasing the profitability of foods, feeds, and other agricultural products had 20 percent and ensuring the sustainability of natural resources management had 30 percent.

Humidtropics

There are about 3 billion people— most of which are poor farmers on about 3 billion ha of land—living in the world's humid tropics that show the biggest gap between its ecological and economic potential and human welfare. A typical system in the humid tropics has the farmer— in the center—who utilizes, water, land, labor, cash, and knowledge to grow, process, and market various crops and livestock to meet livelihood needs such as income and nutrition. The productivity of such a farming system is, however, often poor, while natural resources are degraded and flawed markets and institutions are unable to tap into the potential that exists in the wider system to meet their needs. Likewise, access to and benefit from the limited systems resources often differ between men and women at all ages, being more detrimental to women. Hence, Humidtropics, which was one of three system CRPs in the 2012-2016 CGIAR portfolio and led by IITA, sought to transform the lives of the rural poor in tropical America, Asia, and Africa using an integrated systems research and unique partnership platforms for better impact on poverty and ecosystems integrity. Humidtropics— unfortunately ending in 2016 due to the launching of the CRP II portfolio—is a systems research program comprising all lowland humid and subhumid ecologies (between drylands and aquatic systems), drawing on research in commodity CRPs, and integrating technologies and forecasting ability from other CRPs (Fig. 5). Most of its work was done through two principal channels: strengthening the systems research dimension in various research activities of the CGIAR and other core partners; and establishing a number of projects in integrated systems research in various action sites focusing on the sustainable intensification of farming systems and including the improvement of social and ecological resilience as well as the maintenance of ecosystem integrity therein.

Humidtropics pursued the analysis of systems to identify entry points for interventions. This CRP also did research on gender dimensions and its mainstreaming and analyzed options for institutional innovation and scaling. Furthermore, it included instructional design approaches and traditional postgraduate research fellowships on systems research, thus contributing to capacity building. Partnerships and strategic alliances were important mechanisms for implementing Humidtropics.

Several CRPs adopted the multi-stakeholder platform approach because this is a promising vehicle for agricultural innovation and development. The objective of a

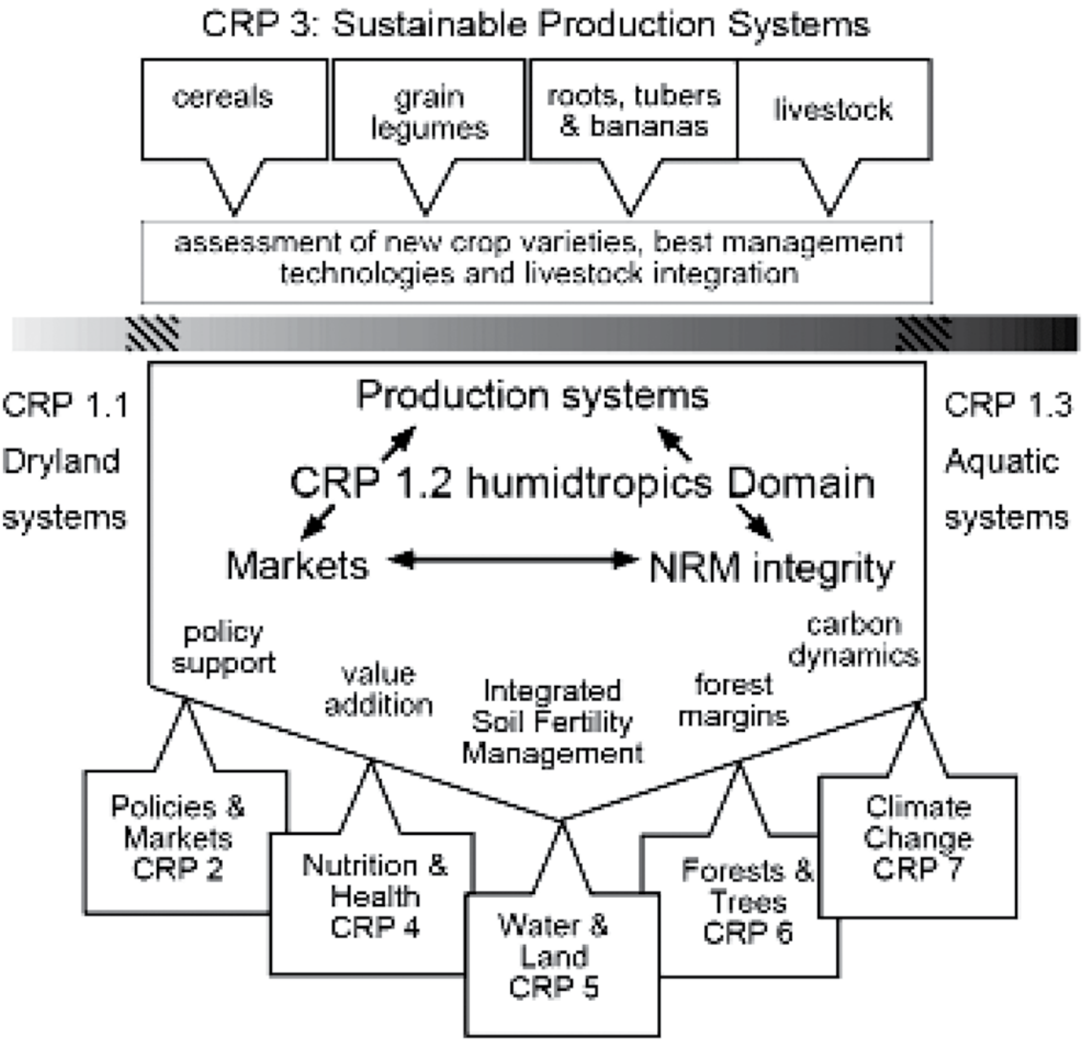


Figure 5. Interactions between Humidtropics and other CGIAR Research Programs (CRP).

multi-stakeholder platform is to foster technological and institutional innovation by facilitating continuous interaction and collaboration in networks of farmers, extension officers, policymakers, researchers, the private sector, and others who are relevant to the agricultural system. It also offers a space for learning and negotiation, thus strengthening the "capacity to innovate" in and across stakeholders' networks. Humidtropics adopted this approach for achieving its research-for-development outcomes across sub-Saharan Africa, tropical America, and Southeast Asia. The multi-stakeholder platforms are still young but their participatory, demand-driven approach is already contributing to the advance of coherent and integrated R4D strategies and to the promotion of strong multi-stakeholder partnerships. A private sector representative said after attending a meeting, *"The platform can help in identifying markets and in learning how to access markets. It can also provide training for farmers to add value to their products so that they can increase their income."*

Investing in soil for sustainably increasing productivity

"The soil is the farmer's lifeline" wrote Sanginga in the foreword to

Table 4. Selected impacts of Resource and Crop Management by IITA.

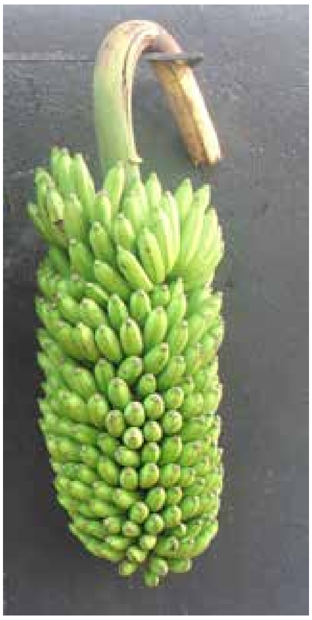
Management	Reference
Alley cropping: IITA researchers developed an improved fallow technology to replace slash-and-burn systems in African agriculture. Maize production under agroforestry-based systems may be socially profitable and financially competitive when compared with maize production relying only on chemical fertilizer	Kang et al. 1990, Adesina and Coulibaly 1998
Cover crops: Farming systems with Mucuna provides a higher benefit:cost ratio than those without this cover crop technology, which provides yield gains, reduces labor, and restores soil fertility	Manyong et al. 1999
Integrated soil fertility management to increase farming productivity through sustainable resource management coupled to resilient germplasm: Maize-promiscuous soybean rotations that combine high nitrogen fixation and the ability to kill large numbers of Striga hermonthica seeds in the soil and millet-dual purpose cowpea. Adopting farmers increased their gross incomes by between 50 and 70% compared with those maintaining their practices, namely continuous maize cultivation. Legume areas increased in Nigeria – particularly in its northern Guinea savanna – and surplus yield translated into additional fixed nitrogen valued annually at several dozen million US$	Sanginga et al. 2003

one of IITA's annual reports. It is not surprising, therefore, that a pillar of IITA's research has been anchored in protecting and improving this vital agricultural asset research that led to impacts throughout its lifespan (Table 4). There was, of course, an evolution on the approach and targets in this half-century of research; i.e., moving from technology generation to multi-stakeholder research in development. For example, in the early years the research focus was on land clearing, soil erosion, zero tillage, fertilizers, and mulching; it switched towards agroforestry and cover crops within farming systems in the 1980s, and moved further on developing dual-purpose crops and integrated soil fertility management in the 1990s. IITA embraced the research-for-development paradigm in the 2000s and engaged proactively on a demand-driven approach, in which research associated itself increasingly with development partners for addressing the needs of existing farmers. Today, IITA does its research on natural resource management as a partner in the development process, through joint activities with other stakeholders, pursues adaptive research with and by farmers, and participates in development platforms with the aim of bringing underutilized, marginal, and degraded lands to more productive and sustainable use.

Two major ongoing Natural Resource Management projects, in which IITA proactively participates are Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa (N2Africa), and the institutionalization of quality assurance mechanisms and dissemination of top quality commercial products to increase crop yields and improve food security of smallholder farmers in sub-Saharan Africa (COMPRO). The goal of N2Africa is to increase biological nitrogen fixation and the productivity of grain legumes among African smallholder farmers, contributing to enhanced soil fertility, improved household nutrition, and increased cash income; COMPRO aims at improving crop yields of smallholder farmers in sub-Saharan Africa through the identification, promotion, and adoption of effective agricultural commercial products and the institutionalization of regulatory procedures to guarantee quality of these products. One of the areas on which both N2Africa and COMPRO are working is to develop a set of standardized protocols for the collection, evaluation, and quality control of effective nitrogen-fixing rhizobium strains that form nodules on the roots of leguminous plants.

NARITAs: Matooke banana hybrids for food security in African Great Lakes

Breeding triploid bananas is challenging, slow, and expensive due to low fertility, meagre seed set, and poor germination rates, thus meaning that it is difficult to produce large hybrid offspring for testing. Moreover, banana plants require large testing plots and up to three years to accomplish two fruiting cycles. Nonetheless, Uganda's National Agricultural Research Organization (NARO) and IITA initiated in the mid-1990s the breeding of the East African highland banana hybrids using some of the banana germplasm IITA bred at its High Rainfall Station (Onne, Nigeria). These first-ever East African highland banana hybrids—named NARITAs (NARO–IITA)—were developed at the National Agricultural Research Laboratories in Kawanda and at IITA's research station in Sendusu. NARITAs ensued from the work of three generations of IITA banana breeders. These NARITAs are secondary triploid hybrids for food ("matooke") and for juice obtained after crossing selected tetraploid hybrids with IITA diploid-bred germplasm. The tetraploid hybrids were derived from crossing female-fertile East African highland banana and diploid banana used as a source of host plant resistance to black leaf streak. The newly bred hybrids were assessed along with local East Africa highland banana for their performance, adaptability, and stability. NARITAs performed better than the local cultivars, used as checks, across all traits evaluated, e.g., 96 percent of NARITAs had a bunch weight higher than that of the local cultivar. These secondary triploid hybrids show potential to increase banana production in Uganda, Tanzania, and the highlands of East Africa, where they are undergoing further testing across multiple locations and involving farmers to assess performance on farmers' fields. IITA and partners started in 2014 a new banana breeding project through a grant from the Bill & Melinda Gates Foundation with the aim of significantly upgrading existing banana breeding efforts in Tanzania and Uganda, where banana production only achieves 9 percent of its potential. This partnership project supports the on-farm testing of NARITAs, strengthens technical capacity of banana breeding programs in the Great Lakes of Africa, reinforces partnerships with local farmers, and develops local research capacity by supporting PhD and MSc projects. Farmers will benefit by having rapid access to high-yielding NARITAs showing host plant resistance to the main pathogens affecting East African highland banana and having satisfactory quality traits for the consumers.



NARITA banana developed by NARO in Uganda and IITA. Photo by IITA

An ecofriendly approach against the violet vampire

The parasitic weed *Striga* (witchweed) reduces yields or destroys entire harvests of crops such as cowpea and maize after attaching to their roots and sucking out nutrients. Witchweed affects about 4 million hectares of maize grown mostly by African smallholders, who cannot afford costly herbicides for fighting this parasitic plant. The most widespread Striga species leads to yield losses of up to 80 percent, thus causing US$1.2 billion losses every year. IITA and public or private partners such as CIMMYT, the International Centre of Insect Physiology and Ecology, and BASF Crop Protection have released methods of Striga control such as resistant cultivars, "push-pull" technology that involves intercropping with forage legumes that inhibit the germination of Striga seeds, herbicide-coated seeds, and biocontrol using a

naturally occurring host-specific fungal pathogen that kills the weed at all stages without affecting other crops. The most widely used fungal isolate that met all requirements for a potential bio-herbicide for witchweed is *Fusarium oxysporum* f. sp. *strigae*, which is highly virulent, attacks Striga in all growth stages (from seeds to germination, and from seedlings to flowering shoots), protects the current crop yield, and prevents seed formation and dispersal. *F. oxysporum* f. sp. *strigae* is highly host-specific to *Striga* and does not produce any known mycotoxic compounds, thus it does not pose any health risks to farmers, input suppliers, traders, or consumers, or threaten crops or the environment. Imazapyr is a herbicide that kills the *Striga* seedlings after its seeds germinate and before they can cause any damage. Imazapyr-resistant maize cultivars with host plant resistance to *Striga* are known to produce more grain yield under witchweed infestation, sustain less *Striga* damage, and support fewer emerged *Striga* plants than the check cultivars. IITA research shows further that the combined use of *Striga*-resistant maize cultivars in rotation with legumes caused witchweed seeds to germinate but fail to latch on to the host, thereby increasing crop productivity by an average of 88 percent. Integrated witchweed control interventions generate additional maize and cowpea grains that lead to increased incomes, better nutrition, and reduced poverty, as well as providing employment from surplus grain production to food markets.

Ensuring food and feed safety through entrepreneurship

Aflatoxin contamination undermines public health by suppressing the immune system, stunting growth in children, and causing cancer and

Aflasafe production at the Business Incubation Platform, Ibadan, Nigeria. Photo by IITA.

death due to acute poisoning through liver cirrhosis or necrosis. Aflatoxins also affect feed, thus causing slow growth or death in livestock, and are used as non-tariff barriers in the global trade of contaminated crops if above the limits set for importing them. Ranajit Bandyopadhyay (IITA), Peter J. Cotty (USDA–ARS), and partners were able to produce Aflasafe™, a fungus-based biocontrol product against aflatoxin contamination in major African food crops. Aflasafe has proved to significantly reduce aflatoxin contamination by 50 to 99 percent in maize field trials in Nigeria. A single application of Aflasafe 2 or 3 weeks before maize flowering sufficed to prevent aflatoxin contaminationthroughout and beyond a cropping season and even when the grains were in storage. At the end of the last decade, Nigeria's National Agency for Food and Drug Administration and Control provisionally registered Aflasafe™ and authorized the treatment of up to 100 ha of farmers' fields. Farmers treating their maize fields with Aflasafe™ achieved a reduction in aflatoxin of nearly 80 percent in grains at harvest. Likewise, poultry fed with maize grains treated with Aflasafe experienced reduced mortality in addition to other benefits such as dropping feed intake and an increase of the feed conversion ratio. An Aflasafe manufacturing plant was built at Ibadan to show how an initial investment pays off due to the high demand for quality grain in Africa. This project emphasized the development of a viable business plan for the production, adoption, and distribution of the biocontrol product to ensure sustainability of efforts. Priority was also given to raising public awareness about aflatoxins and their biocontrol, as well as to building the human capacity of national partners, and developing facilities that allow them to have their own versions of Aflasafe. Advocacy led to the establishment of the Partnership for Aflatoxin Control in Africa (PACA), which was endorsed by the Partnership Platform of the Comprehensive Africa Agriculture Development Program (CCADP), thus underscoring the need to address aflatoxin contamination in Africa.

The International Forum for the Governments and Central Bank Governors from 20 major economies (G20) announced in its 2012 summit in Los Cabos, Mexico, the AgResults initiative that included promoting Aflasafe for producing 260,000 tons of maize grain (i.e., in about 200,000 ha) in Nigeria. This "pull-mechanism" is a results-based financial incentive rewarding successful innovations and their adoption that are designed to overcome market failures and to encourage private and public sector innovators to develop products and services that they would not otherwise bring to the markets. A pilot was designed to demonstrate a successful model for increasing smallholder adoption of biocontrol technology in Nigeria by reducing barriers to the widespread adoption of Aflasafe through a premium per-unit payment for maize verified to contain a high prevalence of Aflasafe. On the launching of a project to support the commercialization of the cost-effective Aflasafe in 2011, Wilson Songa, then the Agricultural Secretary in Kenya's Ministry of Agriculture, said, "*Kenya has become a hotspot of aflatoxin contamination. Since 2004, nearly 150 people have died after eating contaminated maize.*" He, on behalf of his country, further welcomed this development after the loss of lives and millions of tons of maize grains due to aflatoxin contamination. To pave the way for its unrestricted use in Kenya, the Pest Control Products Board granted to Kenya Agricultural and Livestock Research Organization (KALRO) in mid-2015 the full registration to Aflasafe KE01™, which was jointly developed by KALRO,


Yellow maize free from aflatoxins. Photo by IITA

IITA, and USDA-ARS. In 2013, country coordinator Charity Mutegi received the Norman Borlaug Award for Field Research and Application as a member of the IITA research team in Kenya.

IITA also released Afla-ELISA, which is an enzyme-linked immunosorbent assay (ELISA) for the quantitative estimation of aflatoxins. Afla-ELISA because of its simplicity in performance offers sensitive detection that is convenient for adoption in sub-Saharan Africa. It is a suitable, low-cost alternative to official monitoring methods for routine aflatoxin surveillance in crops and other commodities.

Climate-resilient, nutritious maize

IITA and African partners have bred high-yielding cultivars showing host plant resistance to various pathogens and pests, and enhanced adaptation to abiotic stress, such as drought, thus contributing to making maize a significant food and cash crop in West and Central Africa. Nowadays, IITA provides about 70 percent of the bred maize germplasm in the subregion with very little or no further improvement before the cultivar is released in a country. An impact study reveals that more than 60 percent of maize farming areas in Nigeria in the mid-2000s was planted to modern cultivars, which account for about half of the maize grown in the region. In Nigeria, the total maize area increased from about 1 million hectares at the end of the 1960s to nearly 6 million in 2014. Modern cultivars rose sharply from being grown in 111,000 hectares in 1981 to 4.2 million in 2005, which suggests a steady adoption growth. It was also estimated that between 35,000 and 50,000 people were lifted out of poverty for each US$1 million invested in IITA maize research. Furthermore, the Total Net Benefit from maize research in the region between 1981 and 2005 was estimated at US$6.8 billion or equivalent to 12 percent of the present value of total maize production over the same period. The Annual Net Benefits increased from US$43 million in 1981 to above US$400 million in 2005. IITA research in maize improvement had a benefit-cost ratio of 21; i.e., each US$1 invested in research generated additional food worth US$21.

About 650 million people living in sub-Saharan Africa eat maize, whose productivity is severely threatened by frequent droughts and irregular rainfall. For example, there were more than 12.5 million people who in 2011 were distressed by the worst drought in the last half-century in the Horn of Africa; more than 35 percent of maize-growing areas may be affected by drought in West and Central Africa because farmers grow most maize without irrigation and rely solely on rainfall. CIMMYT and IITA then implemented a Drought Tolerant Maize for Africa (DTMA) project for nine years across 13 African countries with funding from the Gates Foundation, the Howard G. Buffet Foundation, the Department for International Development (DFID) of the United Kingdom, and USAID to assist African farmers to lessen the negative effects of drought by providing them with drought tolerant maize cultivars. These include hybrids and open-pollinated cultivars that yield, on average, 20 percent more than the widely grown commercial hybrids and farmer-preferred cultivars, thus giving farmers high grain yields regardless of climatic constraints in good years or in bad years. Mr Bakary Touré from Kolokani (Mali) said, "*In September 2011, I had nothing to eat, so I sold my goats and chickens to feed my family …* [but] *maize saved me*." He—following the advice from fellow farmers—bought 20 kg of seeds of a DT maize cultivar in May 2012. After harvesting 1.6 tonnes of maize grains, he stated, "*I gave three bags to friends who will pay me back later …* [because] *with the 13 bags I have, I can feed my family for six months*." At the end of this project (December 2015), 233 DT maize cultivars were released across the target countries. More than two million farmers acquired and grew the new DT cultivars in Angola, Bénin, Ethiopia, Ghana, Kenya, Malawi, Mali, Mozambique, Nigeria, Tanzania, Uganda, Zambia, and Zimbabwe. Many DT maize cultivars also show host plant resistance to witchweed and are nitrogen-use efficient. DTMA provided germplasm and technical backstopping for seed production, as well as funding to popularize the new cultivars to local small and medium-

A bumper maize harvest—thanks to IITA and partners in the Drought Tolerant Maize in Africa project. Photo by IITA sized seed enterprises using exhibitions, field days, and the media. Most DT maize cultivars have been commercialized or are in the process that depends largely on when they were released. The largest areas growing DT maize cultivars in 2013-2014 were noted in Nigeria (>23%), Bénin (~22%), Malawi (~22%), Uganda (~20%), and Zambia (> 10%). Four DT maize cultivars exceeded 100,000 ha in 2015, namely BH661 in Ethiopia, Pan53 in Zimbabwe, Sammaz15 in Nigeria, and ZM523 in Angola. A household survey conducted in Nigeria from November 2014 to February 2015 found a 21 percent poverty point reduction as a result of the adoption of DT cultivars; i.e., an estimated 370,000 households (equivalent to 2.7 million individuals) managed to move out of poverty as a result of adoption of the DT cultivars.

Over 100 million Africans who rely on maize-based diets—particularly pregnant women, lactating mothers and their young children—have suboptimal vitamin A uptake, thus a high risk of visual impairment and blindness, and increased susceptibility to anemia, diarrhea, measles, malaria, and respiratory infections. IITA had begin breeding maize for high β-carotene and provitamin A content in the 2000s using temperate germplasm as a source for this trait. Several maize inbred lines containing 15 to 23 $\mu g\ g^{-1}$ of provitamin A adapted to the savannas of West and Central Africa have been bred in the last few years. The most promising inbred lines were used to develop 10 synthetics and nine hybrids with 40 to 70 percent of the current breeding target provitamin A content set under the HarvestPlus Challenge Program and producing grain yields comparable to

Research helps ensure food security for Africa's teeming millions. Photo by IITA or better than the farmer-preferred maize cultivars. Provitamin A cultivars have been released in DRC, Ghana, Mali, and Nigeria in collaboration with partners in the NARS of each country.

Yellow cassava released in Nigeria

The Government of Nigeria in November 2011, through its National Variety Release Committee, released vitamin A-enriched "yellow" cassava cultivars bred by IITA and partners, particularly the National Root Crops Research Institute (NRCRI) at Umudike and CIAT, under the aegis of CGIAR HarvestPlus. The high content of carotenoids gives this yellow color to the tuberous roots, which are most often white. The human body converts the consumed β-carotene into vitamin A, thereby tackling malnutrition. This yellow cassava is cost effective for delivering vitamin A in Nigeria, where deficiency of it afflicts about 20 percent of pregnant women and 30 percent of children five years old and below. The average Nigerian consumes daily about 600 g of cassava—particularly from *gari*, which is a creamy-white, granular flour with a fermented flavor and sour taste made from fermented, gelatinized fresh tuberous roots. These high- yielding, pest-resistant, yellow-fleshed cassava cultivars may provide up to 25 percent of the daily vitamin A requirement for both children and women. The consumption of provitamin A cassava tuberous roots could help Nigeria reduce economic losses in GDP estimated at about US$1.5 billion.

The 2016 Al-Sumait Food Security Prize for Development in Africa, which was designed to promote development in Africa and administered by the Kuwait Foundation for the Advancement of Sciences, was awarded jointly to CIP and IITA for their groundbreaking research on the causes of undernourishment and for providing their solutions. Al-Sumait Prizes are given to individuals or institutions that help to advance economic and social development, human resources development, and infrastructure in Africa through their sustained research and/or innovative projects that result in a major impact on the lives and welfare of the people of Africa, especially the poor and underprivileged. CIP was acknowledged for working on orange-fleshed sweetpotato to address vitamin A deficiency. The citation for IITA said: "*The International Institute of Tropical Agriculture is a leading African crop center and a member of the CGIAR, focusing on research and development of the key African food crops: banana and plantain, cassava, cowpea, maize, soybean, and yam. The team's efforts developed and deployed safe and more nutritious food crops such as legumes, cereals (vitamin A maize), with the first released orange maize varieties from it, and tubers (cassava) through biofortification, use of efficient and affordable biocontrol products against aflatoxins, and made these available to smallholder farm families in the region to balance calories, diversify diets, and safeguard health and nutrition.*"

Improving plant breeding through the use of genomic tools

Advances in genetic enhancement research are being used by IITA to bring innovations in its plant breeding methods. High throughput phenotyping, dense DNA markers, and data computerization are used for marker-assisted selection and for selection based on genomic estimated breeding values (GEBV). For example, the goal of the ongoing Next Generation Cassava Breeding (NextGen) partnership project is

Biotechnology lab in IITA, Ibadan, Nigeria. Photo by IITA

to increase significantly the rate of genetic gains in cassava breeding. NextGen led by Cornell University and with co-funding from the Gates Foundation and DFID (UK) involves IITA, NRCRI, NARO, the Ministry of Agriculture, Livestock and Fisheries of Tanzania, the West African Centre for Crop Improvement (Ghana), and Makerere University (Uganda) as partners in Africa. Genotype-by-sequencing technology led to mapping host plant resistance genes for CMD, and was used to reveal non-additive effects that may affect the prediction of total genetic value, both of which have implications for breeding cassava cultivars. IITA and partners are testing GEBV models for increasing genetic gains per unit time in East African highland banana breeding. Preliminary results show that selection based on GEBV could be feasible for characters that are easy to measure.

Forging the chains for development

The African Development Bank (AfDB) approved a grant to IITA in 2011 for the project Support to Agricultural Research for Development of Strategic Crops in Africa (SARD-SC), whose aim is to improve food and nutrition security and contribute to poverty reduction in 20 African countries by working on the value chains of cassava, maize, rice, and wheat. These were defined by the

African Heads of State as strategic crops in CAADP. SARD-SC plans to reduce food imports from other continents, and to offer African farmers better access to markets, to improve their livelihoods, and to tackle poverty through enhanced beneficiary capacity, thus achieving sustainable development for Africa. The project, led by IITA with AfricaRice and ICARDA, uses innovation platforms within each commodity value chain to bring together all concerned stakeholders to collectively identify the problems, and together come up with suitable and relevant solutions. SARD-SC introduced innovations ranging from generating new cultivars and novel technologies for production and processing to enhancing the capacity of farmers and other stakeholders, and the development of related infrastructure and efficient project management. After 1.5 years, the project was already able to identify and nominate for release several high-yielding wheat cultivars bred by ICARDA and partners both in Nigeria and the Sudan and began the building of various postharvest handling facilities for the cassava value chain in most of the project countries. The main achievement so far relates to the wheat value chain: in Nigeria, wheat areas increased from 50,000 hectares in 2012 to 100,000 in 2016, and wheat production rose from 100,000 tonnes in 2012 to 250,000 in 2016. In the Sudan, wheat areas were enlarged from 135,000 hectares in 2013 to over 254,000 in 2016, and wheat production was augmented from 265,000 tonnes in 2012 to 787,400 in 2016.

Encouraged by these early results IITA through SARD-SC organized in 2016 workshops to discuss the new AfDB initiative, known as "Africa Feeding Africa" or the Technologies for African Agricultural Transformation (TAAT) program. This is a critical strategy for transforming agriculture on the

Processing facilities built through the SARD-SC project. Photo by IITA

continent with the goal of ensuring that Africa will be able to feed itself through agriculture. TAAT will be implemented in 35 African member countries of the AfDB and along 24 specified value chains. The workshops were able to identify priority intervention areas to achieve rapid agricultural transformation across Africa through raising agricultural productivity. In its inception Phase 1 (2017–2019) TAAT will operate through raising agricultural productivity and processing and marketing operations along seven priority value chains, namely self-sufficiency in rice production, increasing Africa's wheat production, cassava intensification, maize production and intensification, soybean for Africa, modernizing poultry production, and achieving self-sufficiency in inland fish production. FARA and the CGIAR support this AfDB initiative to revitalize and transform agriculture through the TAAT program in the shortest period while restoring degraded land and maintaining or strengthening the ecosystems supporting agriculture. This initiative will be led by IITA in partnership with FARA, CGIAR, NARS, and the Alliance for a Green Revolution in Africa (AGRA).

Africa RISING

Wikipedia says that *Africa Rising* was "*coined to describe the rapid economic growth in sub-Saharan since 2000 and the belief in the inevitability of further, rapid development on the continent.*" Acknowledging this happening, IITA and partners have been transforming African agriculture through sustainable intensification using action research and development partnerships. In this regard, IITA leads two of the three regional projects of the Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) program through a grant from USAID as part of the US Government's Feed the Future initiative. IITA and partners deal with the sustainable intensification of cereal-based farming systems in West Africa and with cereal–legume–livestock integrated farming systems in East and Southern Africa. ILRI leads the third project for crop–livestock systems in the Ethiopian Highlands, while the International Food Policy Research Institute leads the overall program's monitoring and evaluation. According to Jerry Glover, USAID Senior Sustainable Agricultural Systems Advisor, "*… the most important outcome so far has been developing the highly skilled research networks of partners and platforms. We have come together as a complex and diverse set of people to address a wide range of agricultural research issues in some fairly remote, poorly supported communities. We are developing an infrastructure, a network of expertise that involves national partners who can help support these communities do what they want to do. Building together this partnership has been perhaps the most rewarding component of Africa RISING.*" Nonetheless, in Year 3 of implementation, the joint technology scaling project already obtained some very impressive outcomes. For example, an indicative cost: benefit analysis shows that farmers in northern Ghana got superior economic returns when using Africa RISING technologies. The mean benefit: cost ratio was 4.2, thus indicating that the farmers earned three times their total expenditure when using technologies brought by Africa RISING. On average this can also generate a daily net return to labor nine times higher than the amount farmers can earn in a day if they are involved in casual work in the project intervention areas. Furthermore, profits seem to be more sensitive to changes in output prices than to changes in input prices and wages, suggesting that technology adoption was most affected by policy interventions affecting output prices.

A success story

Ms Masheshe Salum—a small-scale maize and legume farmer in Ngipa village, Kiteto District, in central Tanzania—said, "My life changed thanks to the Africa RISING-NAFAKA-TUBORESHE CHAKULA scaling project". She further noted, "We learned about planting drought-resistant maize varieties, line spacing, fertilizer application, and the use of tied-ridges to conserve soil water. I implemented all the best practices I learned, and I am grateful it has paid off in such a big way!" and happily concluded "… thanks to the technologies of Africa RISING, I now have more than enough to feed my family! And with the postharvest knowledge that I gained from training, I intend to store my surplus and sell later at the best time and price so that I can pay my children's school fees."

MIRACLE in Southern Africa

There are about 22.4 million African people living with the human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS), which in rural areas leads to reduced farm productivity due to labor shortage, delay in farm operations, decline in livestock production, and loss of agricultural skills. IITA with funding from the Swedish International Development Cooperation Agency (SIDA) launched the 3-year project "Making Agricultural Innovations Work for Smallholder Farmers Affected by HIV/AIDS in Southern Africa" (MIRACLE), whose aim was improving productivity and helping to ensure sustainable livelihoods of people living with HIV/AIDS (PLWHA) and depending on agriculture in Malawi, Mozambique, Swaziland, and Zambia. MIRACLE pursued a participatory and extension approach, and used an innovation systems framework to establish its platforms that encouraged stakeholders to interact and participate in the innovation process,

Changing lives

Mr Henrique Hilário Avela was among the farmers in the Malema District (Nampula Province, Mozambique) who agreed to work on and host demonstration and participatory varietal selection trials in his farm. He was growing cash crops such as vegetables twice a year and never had any interest in trying other crops. Because of MIRACLE, Mr Avela decided to try soybean, and after its harvest he said, "*My joy was immeasurable as I was seeing this huge amount of money for the very first time in my entire life. I couldn't believe it was mine.*" He and his wife built a 3-bedroom house in a piece of land his parents had given him long before. Mr Paulo Potocosse also shared the same joy because after harvesting soybean he was able to buy a motorbike and built two more bedrooms in his house. Other lead farmers and community leaders such as Celestino and Bonifacio stated that after about two years MIRACLE "*changed the entire Malema district. Until 2011, people thought only of maize, onion, and a few vegetables. After seeing and experiencing the benefits from soybean both economically and in health people have become wiser. Most of us are now growing maize only for home consumption and devote the rest of the land to soybean. Most farmers are now trying to legalize their lands because even a small parcel with soybean can improve their lives.*" Celestino declared, "*Before, we just cultivated our land. Now, we have seen that soybean production can change our lives and we are now treating it as a serious business. Not many of us have the financial resources to cultivate bigger land sizes. If we really want to go into the soybean business, we need to borrow from the bank, where DUAT[13] is required as a collateral. This is the reason why many of us are now in the process of legalizing our lands.*" Bonifacio continued saying, "*Women have also become highly interested in producing the crop for themselves after learning what they can do with soybean. They might have shown you those skin-and-bone children our women are working with. A few months after being fed with soybean porridge and milk, they look healthier. To us these things that are happening are truly miracles. This improvement in the lives of farmers will not happen had IITA not introduced this project.*"

[13] The Direito do Uso e Aproveitamento da Terra (DUAT) is a certificate issued by the Government of Mozambique giving the holder the right to use the land for specific and authorized purposes but with certain limitations enforced by the Land Law.

thus allowing them to achieve their respective objectives. The project's key interventions included production, consumption, and marketing of nutritious crop and livestock products, as well as lobbying for supportive agricultural and health policies and strengthening stakeholders' capacity. MIRACLE promoted the production, value addition, and utilization of high-yielding, nutrient-dense cultivars of cassava, cowpea, maize, soybean, and sweetpotato at both small and medium-scale commercial levels. Furthermore, this project encouraged the production, marketing, and consumption of indigenous nutritious vegetables such as amaranths and other leafy vegetables, and promoted the production of small livestock through research on feed formulation using dual or multipurpose legumes and cereals, or by improving animal housing, and seeking better ways of disease control, particularly of chickens.

Tracking poverty reduction associated with IITA research-for-development

Improving livelihoods across sub-Saharan Africa remains IITA's top priority, because it is where research meets the real world. Indeed, agricultural research contributes significantly to productivity growth, which in turn raises per capita incomes and reduces rural poverty. For example, an IITA impact study shows that the adoption of cassava technology contributed to an estimated 10 percentage point reduction in the poverty rate in four African countries (Tanzania, DR Congo, Sierra Leone, and Zambia). Disaggregated data further indicated that the adoption of the same technology benefited female-headed households. A similar study conducted in Nigeria has also shown that the adoption of cassava technology increased asset ownership and improved household calorie intake, thus reducing the probability of stunting among children.

Recent impact assessment results across countries revealed that at least 4.3 million people had been lifted out of poverty in sub-Saharan Africa by 2016 (out of the target of 11.6 million to be lifted by 2020 in its Refreshed Strategy). Impact assessment research by IITA is also identifying factors affecting technology adoption decisions that will change smallholder farmers' welfare. In Zambia, for example, a study showed that the adoption of maize—legume rotation, residue retention, improved maize varieties, and their combinations, which raised both maize grain yields and smallholder's incomes and consumption expenditures, was related to both household- and plot-level characteristics.

The above findings demonstrate that investing in agricultural research for development appears to be a socially profitable investment. However, such research and technology impacts cannot be realized without efficient extension, credit, and input supply systems.

Revisiting intellectual property rights policy and joining Open Access

IITA's Board of Trustees on 28 November 2012 approved a new IITA IP policy, which is fully in line with, and based on the CGIAR Intellectual Assets Principles to ensure compliance with them. IITA regards the results of its research and development activities as international public goods (IPGs) and is committed to their widespread diffusion and use to achieve the maximum possible access, scale, and scope of impact and sharing of benefits to advantage the poor, especially farmers in sub-Saharan Africa. IITA also recognizes the indispensable role of farmers, indigenous communities, agricultural professionals, and scientists in conserving and improving genetic resources. IITA seeks, therefore, to be respectful of national and international efforts to protect and promote farmers' rights.

IITA considers that excluding others from accessing IITA research products and results is contradictory to its mandate and mission. Thus, IITA does not seek to secure patents or plant breeders' rights unless such protection is deemed necessary to keep IITA materials or technologies available and freely accessible to its beneficiaries. IITA requires recipients and users of data, knowledge, and any technology originating from the Institute, to publicly acknowledge IITA as the source of the original information, material or research product. In, addition, IITA respects the intellectual property rights of others, and will acknowledge and obtain appropriate permission for the use of other's data, knowledge, and technology. Open Access (OA) is also an important practical application of IITA's commitment to IPGs as it means the immediate, irrevocable, unrestricted, and free online access by any user worldwide to information products, and unrestricted reuse of content subject to proper attribution. IITA has put, therefore, in place a set of OA tools that shows promise in fully unlocking research potentials and giving research efforts more visibility. IITA abides by both the CGIAR Open Access and Data Management Policy and its own Data and Information Management Policy to be OA compliant.

Starting them young: Researchers simplifying science for young kids. Photo by IITA

Aflasafe demonstration-scale manufacturing plant in Ibadan, Nigeria

What IITA Offers Today

IITA and partners locate its R4D projects where most of African rural poor people are living today (Fig. 6), with the aim of increasing major staple food yields by 60 percent, raising average farm income by 50 percent, lifting 15 percent of the poor households above the poverty line, reducing the malnourishment of children by 30 percent, and restoring 40 percent of degraded farms to sustainable resource management. IITA also continues strengthening other areas to ensure that its research results, knowledge, and products get into the hands of African farmers and end users. Furthermore, the Institute remains committed to capacity building and to conserving agrobiodiversity in Africa.

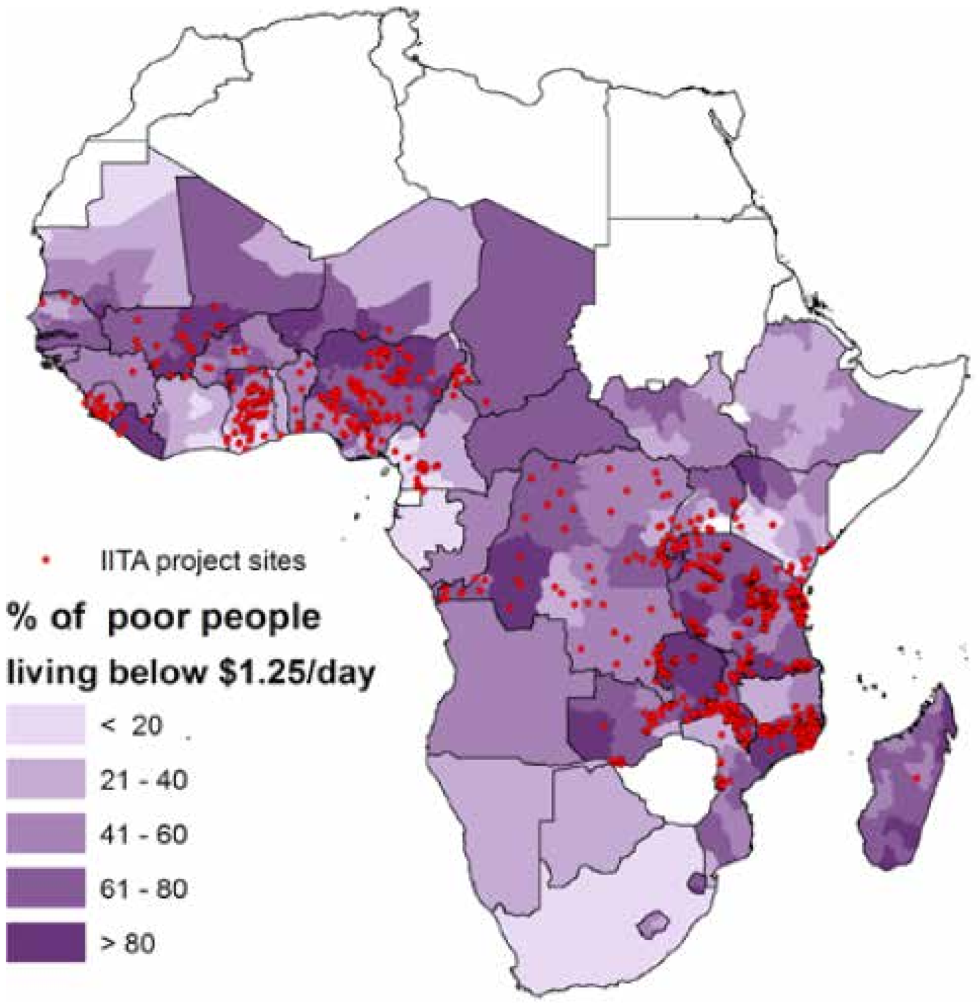


Figure 6. Distribution of poor people in Africa (%) and IITA project sites.

Agribusiness and multi-stakeholder platforms through innovative partnerships

IITA's Business Incubation Platform (BIP) was established in 2013 and bridges research and dissemination by accelerating the commercial development of the Institute's proven and profitable research-based technologies. Its mission, which fits into IITA's mandate to deliver CGIAR system-level outcomes, is "*to create jobs and boost the income, nutrition, and health of poor rural women and men by providing better access to improved agricultural technologies, products, and services that will enhance their agricultural productivity while sustaining natural resources.*" It ensues from two findings, namely, African agribusiness recognizing the importance of research—and—development but also acknowledging shortcomings in fully using its outputs owing to insufficient capacity and resources, and to product development being seen as secondary by scientists who think their research ends after demonstrating their pilot technology successfully.

BIP has two avenues for commercial development: IITA's scientists develop innovative products with the potential for commercialization, or initiate and build a network of public and private sector partners that will support the activities of small to medium-scale agribusiness entrepreneurs, initially within Nigeria and later on elsewhere. Hence, BIP translates relevant findings from IITA R4D into commercially viable products, thus serving as a better mechanism for technology transfer to both private and public sectors, and then on to farmers. For example, GoSeed is a Business Unit of BIP producing and marketing quality breeder and foundation seeds or planting materials of IITA mandate crops to private seed companies for production, distribution, and sale of quality certified seeds or planting materials to farmers, while the 240-m^2 NoduMax plant at IITA produces and markets quality grain legume inoculant of rhizobium for soybean in Nigeria, or a prototype manufacturing facility at IITA is used to produce Aflasafe™ to treat tens of thousands of hectares of smallholder farms. IITA has also set up AgriServe to support its strategic objectives by providing advisory services and technical backstopping for the planning, development, and implementation of start-up agribusiness opportunities, and linking these services to innovative investment.

Youth in Agriculture

Two important features of the ongoing IITA strategy are the profitability of the farm enterprises and employment generation particularly for the youth because Africa has the world's youngest population (364 million between 15 and 35 years old), but the average age of its food producers is worryingly high for a continent aiming to feed itself and eradicate malnutrition by 2025. IITA alumnus Kanayo Nwanze, during his first visit as President of the International Fund for Agricultural Development (IFAD) in 2012, planted a tree at headquarters that symbolizes the birth of the IITA Youth Agripreneurs. His visit was also a wake-up call to the serving youth corpers at the Institute asking them to turn to agriculture as a lifeline and develop profitable agribusiness that brings wealth and employment. He advocated investing in young people in the rural areas as a "*... simple solution to some of the world's most pressing problems such as poverty and hunger, and to curtail migration to urban centers.*" The Institute launched IITA Youth Agripreneurs to empower the youth to use agriculture as a tool to tackle youth unemployment across sub-Saharan Africa through training and by supporting them to carry out various agribusinesses. IITA Youth Agripreneurs is a group of young graduates involved in agribusiness with the aim of serving as a model to other young people planning to venture into agribusiness and becoming the trainers of trainers. In mid-2014, Nwanze visited again and was surprised that IITA Youth Agripreneurs had moved on by starting and expanding various enterprises on staple crops and livestock, fish farming, packaging, marketing, training other young people, and replicating the group in Nigeria, the Democratic Republic of Congo, Kenya, Tanzania, Uganda, and Zambia. In Nigeria, their efforts cut across the value chains of cassava, maize, plantain/banana, and soybean. They are working on stem multiplication and root production of cassava, certified and foundation maize and soybean seed multiplication, and sucker multiplication and fruit production of plantain/banana.

In 2014 IITA Youth Agripreneurs began in Tanzania and engaged in processing soymilk and high quality cassava flour with a brand name, selling maize, and growing tomato. AfDB adopted the IITA Youth Agripreneurs model forits Empowering Novel Agri-Business-Led Employment (ENABLE) Youth Program being implemented in 31 African countries. AfDB—whose President since September 2015 has been Akinwumi Ayodeji Adesina, another IITA alumnus and Nigeria's former Minister of Agriculture and Rural Development—intends through ENABLE to mitigate serious social issues such as rural and trans-Atlantic migration, soaring youth unemployment, and the associated risks to society by supporting young unemployed graduates to go into agribusiness or a well-paying career in the process to generate wealth and subsidiary employment. IITA participates in country-level ENABLE projects by providing services related to policy analysis, knowledge management, program briefing and outreach, capacity development at several levels, and monitoring and evaluation.

IITA Youth Agripreneurs with IFAD President Kanayo Nwanze. Photo by IITA

Table 5. IITA training by category and gender.

Category	Female	Male	Total
Group training	40793	97610	138403
BSc	69	102	171
MSc	375	753	1128
PhD	239	633	872
PostDoc	1	46	47
NARS Short-term	181	685	866
Internship/Volunteers	1251	943	2194
Visiting scientists	25	228	253
Total	42934	101000	143934

Knowledge sharing and training: a track record of excellence

IITA gave training to over 140,000 individuals (Table 5) from 68 countries[14], of which in excess of 40,000 are women. These professionals (mostly from sub-Saharan Africa) advanced their knowledge and acquired skills directly through IITA's training, and many others indirectly through the knowledge the former in turn have passed onto them. A core function of IITA's capacity development approach is the provision of facilities to graduate students to conduct field and laboratory research under the supervision of its staff, but in association with degree-granting universities. A wide range of research topics have been addressed in graduate studies, with a total of 2,000 students; 1128 MSc (67 percent male and 33 percent female) and 872 PhD (73 percent male and 27 percent female). Likewise, more than 2000 interns have benefited from the experience of an experienced member of IITA staff. Undergraduate students also benefited from this training scheme.

IITA has pursued a demand-driven, action-oriented, integrated capacity development for research-for-development. The Institute has therefore facilitated the sharing of knowledge and information exchange through various approaches, individual short-term and long-term courses and ,group training. Its courses—organized to help large numbers of agricultural research and extension workers and farmers—have dealt with various aspects of agricultural production in Africa, thus allowing trainees to meet their goals and cope with problems as they arise.

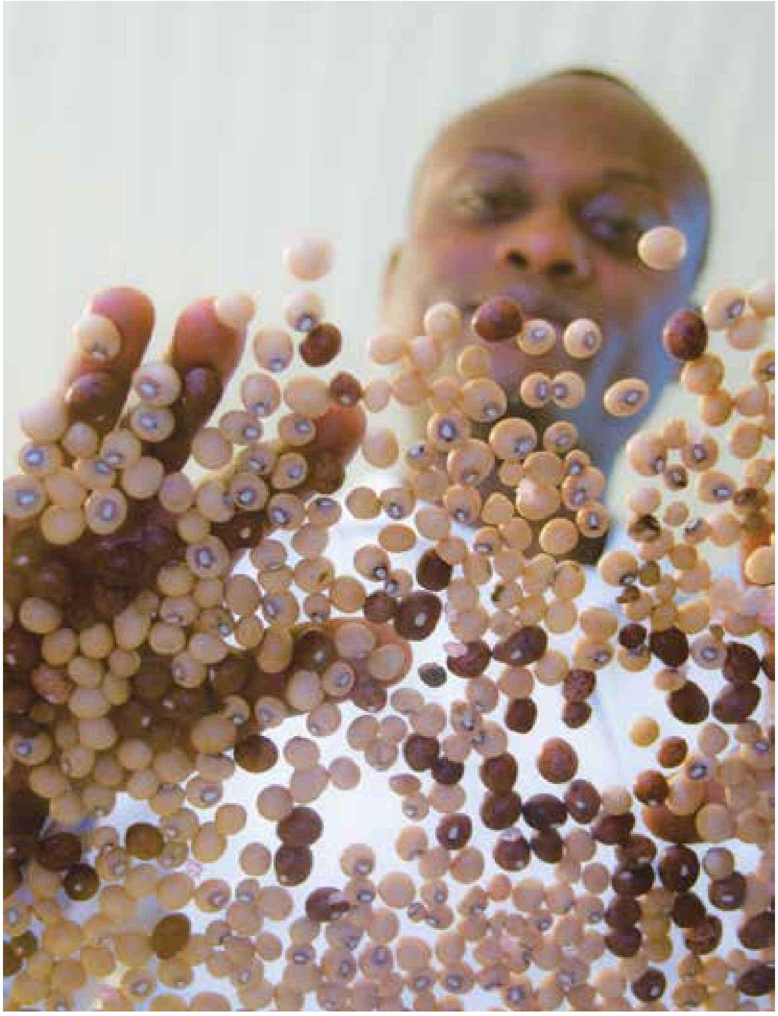
[14] Australia, Austria, Belgium, Republic of Benin, Botswana, Brazil, Britain, Bulgaria, Burkina Faso, Burundi, Cameroon, Canada, Cape Verde, Central Africa Republic, Chad, China, Colombia, Comoros, Costa Rica, Côte D' Ivoire, Cuba, Democratic Republic of Congo, Denmark, Dutch, Ethiopia, France, Germany, Ghana, Honduras, India, Italy, Japan, Kenya, Liberia, Malagasy Republic, Malawi, Mali, Morocco, Mozambique, Namibia, Nepali, the Netherlands, Niger, Nigeria, Norway, Rwanda, Senegal, Sierra Leone, South Africa, South Sudan, Spain, Sri Lanka, Swaziland, Sweden, Switzerland, Tanzania, Thailand, Togo, Turkey, Uganda, Union of Soviet Socialist Republics, United Kingdom, United States of America, Vietnam, Zambia, Zimbabwe

IITA's Capacity Development Program includes the Professional Capacity Advancement Program targeting partner national research institutions and universities; the Graduate Research Fellowship Program enabling promising professionals to develop the necessary research skills, attitude, and confidence for a successful career in agriculture; short-term courses and non-degree group training for scientists and extension or NGO workers; and interns or volunteers who are students enrolled in their first degree or fresh graduates wanting experience (1–6 months) to help them with their career decisions or to complete requirements for their university degrees. Throughout its lifespan, the Institute has enhanced the skill-set of stakeholders in regional locations through constantly developing different training strategies and delivery methods to meet the requirements of targeted beneficiaries. IITA has also organized, with partners a number of research-themed seminars and workshops undertaken to support knowledge exchange. To further its training-education agenda, IITA produces a range of training materials and communication media. The range of educational materials includes printed manuals, field and laboratory guides, audiovisuals and photo collections, and field products. The Institute also facilitates knowledge sharing through its web platform on training events and materials, and supports the exchange of experience and knowledge sharing to enhance professional expertise.

Capacity development remains a core priority for the Institute, because of the important role it plays in research and rural economic growth and development as well as addressing the rapid changes in the biophysical, sociocultural, technological, and policy environments of the agricultural innovation systems in sub-Saharan Africa. In November 2013, the Board of Trustees approved the Capacity Development Strategy 2014–2018. This Strategic Plan sets out the Institute's approach to addressing key challenges in areas such as IITA staff development and NARS capacity in agricultural research fordevelopment. The strategy is largely informed by the Institute's own experience as well as those of other CGIAR Centers and partner institutions in capacity development, and the lessons they have generated. It is expected that the implementation of the strategy will contribute to strengthening IITA's position as a leading international agricultural research institution in sub-Saharan Africa while enhancing the effectiveness of its operations. The objectives of this strategy are to contribute to the creation of employment, businesses, and markets, through the provision of agricultural, entrepreneurship, and management training; and to enhance the human, technical, and institutional capacity of NARS in research, technology dissemination and adoption, and scaling-up.

Managing plant health by surveillance and germ-free germplasm conservation and distribution

IITA gives priority in its R4D agenda to making and keeping crops healthy. To achieve such an aim, IITA provides farmers with access to the latest information on pathogen and pest threats, as well as giving them economical, environmentally sustainable mechanisms to deal with such threats, thus enabling farmers to leverage their own solutions. Coupled with this approach is the production and distribution of high quality seeds, which help to deal with some of these issues before they are a problem. For example, the Open Access platform Cassava Disease Surveillance (CDS)


Diversity of seeds in the IITA genebank. Photo by IITA

is a virtual network for the rapid preliminary diagnosis of cassava diseases using a visual inspection of symptomatic plants submitted as digital images through an Internet-enabled device such as a smart phone, touch pad, or computer, among others. In this way, CDS protects the cassava crop from destructive pests using early diagnosis, allows the implementation of plant health management to safeguard and improve cassava tuberous yields in farmers' fields, and facilitates identification of invasive pathogens, thus preventing them from becoming established in new areas. The CDS has been integrated into the Nigerian Agricultural Quarantine Services (NAQS) for the surveillance of emerging risks.

IITA Germplasm Health Unit continues using safeguards and procedures to produce, maintain, and export healthy germplasm following FAO–International Plant Protection Convention regulations and specific regulations of the recipient country, particularly to avoid risks related to the entry, establishment, and spread of plant pests. It also facilitates the production of pest-free planting material and transfer knowledge and capacity to partners. For example, the Cassava Seed Tracker™ (CST) Web app allows the real-time tracking of cassava stem cutting production, including preplanting planning, registration of cutting fields, crop management, harvesting, quality assessment, and quality assertion. CST can be also used as a digital platform for communication and networking of cassava seed producers and service providers. The CST is set to become a formal tool for cassava seed quality monitoring and certification in Nigeria.

Key role in preserving African genetic resources

Biological diversity embraces all varieties of life on earth, i.e., animals, plants, and microbes. IITA, since its establishment in 1967, has allocated resources to collect, conserve, and study plant genetic resources. This agrobiodiversity—kept in trust for humankind—serves in the genetic betterment of crops. The Institute was involved in collecting genetic resources as early as the 1970s, thus showing a long history in investing in agrobiodiversity conservation.

IITA inaugurated at Ibadan in 1975 its Genetic Resources Center (GRC), which today maintains almost 30,000 accessions of the six mandate crops; being those of African crops such as cowpea (over 15,000 accessions including 70% of African landraces) and yam (about 3,000 accessions), the most important worldwide (Table 5). Clonal crops (yam, cassava, and banana/plantain) are conserved in the field and in vitro with cryopreservation now developed for cassava. Most of the accessions have been described at the agromorphological level and some underwent DNA fingerprinting to characterize them further and identify duplicates for better genebank management. Core subsets—which are a smaller sized but manageable representation of the diversity of the entire collection—were defined for both cowpea and yam in the 2000s for widening their use in both genetic resource research and breeding. Relevant information is available online for GRC databases and GENESYS, a portal developed by the Global Crop Diversity Trust to make the information on its accessions more widely accessible. The collection is held "in trust" for the global community and operates as part of the multilateral system under Article 15 of ITPGRFA with distribution using the standard multilateral transfer agreement (SMTA). Considerable emphasis is given to enhancing use of germplasm including genotyping and evaluation with breeders. GRC also works closely with IITA Germplasm Health Unit to ensure conservation and distribution of genebank accessions free of pathogens and pests, thus reducing the phytosanitary challenges to sharing germplasm with bona fide users.

The potential impact framework of Local Average Treatment Effect (LATE) with the instrumental variable approach and economic surplus models was used to assess the economic and social impact of cowpea germplasm conservation at, and improvement by IITA. About 37,000 cowpea accession-shipments from IITA genebank were received by scientists who were affiliated to 49 research and academic institutions in Nigeria. A large percentage was used by IITA's scientists and their national partner to develop breeding lines. Furthermore, an adoption study conducted in Kano State, the largest cowpea-producing State in Nigeria, and the DNA fingerprinting test conducted on adopted cowpea samples linked five bred-cultivars to the conserved germplasm in the IITA genebank. The adopters of these bred-cultivars increased their cowpea productivity by 254 percent on 58 percent of cowpea farmlands cultivated in 2012. They also increased significantly their per capita income. The total benefits (to consumers and producers) and the internal rate of return (IRR) over 31 years of investments on cowpea germplasm conservation at, and improvement by IITA were estimated at US$3.6 billion and 54 percent, respectively. As a result, 884,241 farmers would have been lifted out of poverty over the same period of time. Under the 50–50 percent general rule of thumb, then

The IITA genebank conserves more than 30,000 of accessions of food crops in trust for humanity. Photo by IITA half of the estimated impact could be attributed to IITA through the conservation of cowpea germplasm.

At the beginning of this decade, IITA engaged in a global initiative to preserve yam biodiversity. About 3000 yam landraces and cultivars gathered from all over the world through were sent to GRC for sanitation and *in vitro* introduction, with the further aim for them to be frozen at ultra-low temperatures (–196 °C); i.e., cryopreserved for long-term storage. Their DNA fingerprinting will further reveal sample uniqueness and avoid the maintenance of duplicates in the collection, as well as providing information on total collection diversity, thus assisting on identifying valuable traits to fight pathogens or adapt to climate change. IITA has also sent samples of most of its cowpea accessions and its wild relatives, Bambara groundnut, maize, and soybean, to the Global Seed Vault, which is a secure seedbank on the Norwegian island of Spitsbergen near Longyearbyen in the remote Arctic Svalbard archipelago. This "Doomsday Vault"—as it is commonly referred to—was built by the Government of Norway as a service to the global community and inaugurated on February 2008. It is the world's largest collection of crop diversity and receives seeds shared under the multilateral system, or under Article 15 of the ITPGRFA, or seeds that have originated in the country of the depositor. The Global Seed Vault ensures that these seeds will be available for bolstering food security should a human-made or natural disaster threaten agricultural systems or genebanks at any point in the future. IITA still controls access to the seeds deposited because in this "black box system" the depositor is the only one who can withdraw the seeds and open the boxes.

IITA includes associated non-plant biodiversity in its conservation of genetic resources because agricultural productivity is strongly influenced by other comprising organisms such as fungi, bacteria, viruses, nematodes, mites, and insects. The arthropod reference collection kept in Cotonou (Benin Republic) encompasses more than 350,000 specimens that were collected across various agricultural and natural environments throughout West Africa. This biodiversity collection provides essential services for sustainable natural resource management, e.g., arthropod identification. Users need reliable and valid entity names for biodiversity monitoring, pest management, biological control, conservation, and compliance with trade-related controls under the prevailing Sanitary and Phytosanitary regulations of the World Trade Organization. IITA has also contributed to the finding and description of more than 120 arthropod species that were previously unknown to science. Some of them are important pests and their natural enemies.

The IITA campus at Ibadan is in itself a rich center of biodiversity, particularly due to the protection and non-exploitation of a patch of secondary forest (350 ha), lakes, and other natural resources therein. Hence, it saves a wealth of flora and fauna that are not always found in Nigeria.

The largest lake (70 ha) is home to various types of fish, aquatic weeds, and birds. The IITA forest offers a suitable habitat for many different insects and birds, and is among the Birdlife International Important Bird Areas with 350 species. Volunteers embarked on carving out a nature trail in IITA forest in December 1987, which allows many useful plant species such as herbs, medicinal plants, fiber-producing plants, and fruit and timber trees to be seen. With funding from the Leventis Foundation Nigeria, IITA has continued to restore the existing forest by removing invasive exotic species, protecting it against disturbance and theft, cataloging the biodiversity of the forested areas, replanting the east bank of the lake with indigenous tree species, engaging in conservation educational activities, especially with young people, and forming local, regional and international partnerships in tropical forest conservation, research, and education. An arboretum—established at Ibadan in 1979—contains 152 different tree species, of which 81 are indigenous. In addition, the residential and administrative areas of the campus are also well shaded with various exotic and indigenous trees, e.g., many original hardwood trees were left *in situ*. IITA campus in Ibadan provides an example on how a research site reconciles increasing agricultural production sustainably while preserving its surrounding biodiversity.

The monkey sanctuary of Drabo Gbo was founded by Peter Neuenschwander in 1995, when he bought 2.5 hectares of teak forest and agricultural land from the elders of Drabo Gbo, 30 kilometers north of Cotonou, and 12 kilometers from the spreading town of Calavi. Today the sanctuary covers 14 hectares of small old-forest islands and rehabilitated forest adjacent to the villages of Drabo Gbo, Drabo Fanto, and Dodja.

The rights to all plots were given in January 2014 to IITA, which accepted the responsibility of maintaining the forest and using it for research while respecting the existing forest cover.

This sanctuary holds 50 out of the 100 species on the Benin Red List of endangered plant species and serves as a fertile breeding ground for the still critically endangered red-bellied monkey. It also serves as a site for strengthening research capacity in nature conservation by demonstrating standardized procedures for observing monkeys.

The IITA lake and forest in Ibadan, Nigeria. Photo by IITA

Research results are shared and disseminated to a wide audience. Photo of IITA

Acknowledgements: IITA Partners, Donors, and Investors

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IITA has always engaged in partnerships with national, regional, and international institutes, national governments, civil society organizations, farmers, and the private sector to conduct research and ensure that its research results benefit agriculture growth and development, particularly in sub-Saharan Africa. IITA throughout a half-century has partnered with over 800 different organizations worldwide to advance research-for-development undertakings. IITA acknowledges that its close collaboration with partners is necessary to ensure the optimum use of resources, knowledge sharing, access to technology and cutting-edge science, mutual learning and for making a positive impact on the on the livelihoods of African farmers.

IITA headquarters at Ibadan. Source: Google Maps

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IITA partners work with both private and public sectors to achieve its development goals. Photo by IITA

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Charity Mutegi of IITA Kenya won the 2013 Norman Borlaug Award for Field Research and Application. Photo by IITA

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