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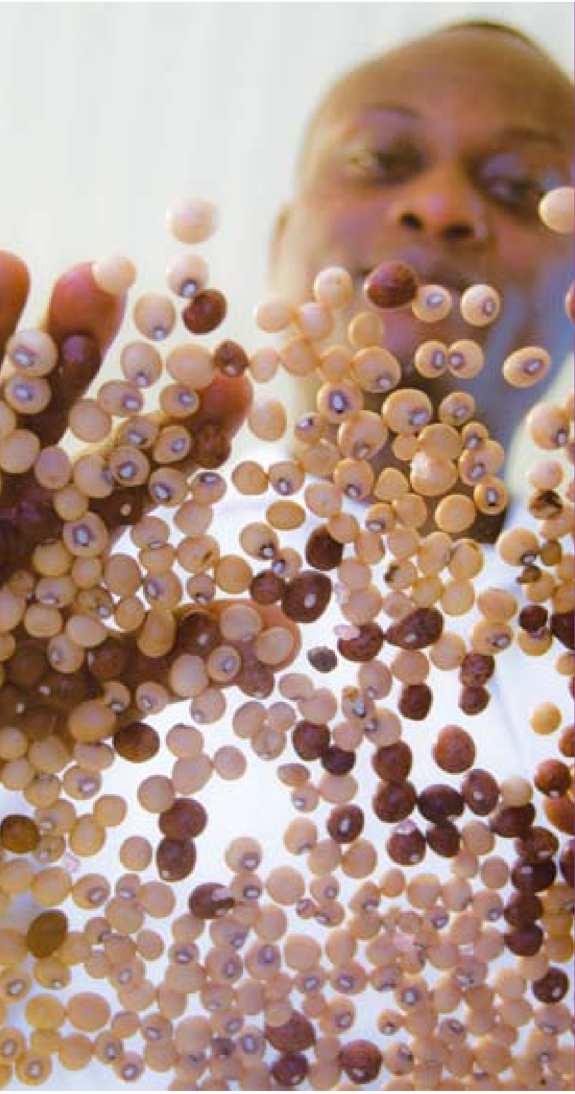

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Diversity of bambara groundnut seeds, IITA genebank. Photo by Jeffrey Oliver, IITA.

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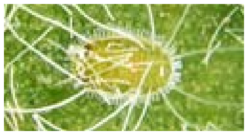

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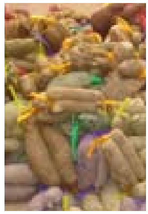

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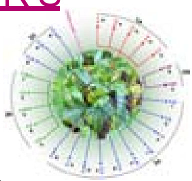

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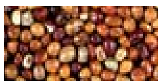

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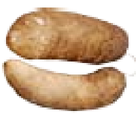

A tough puzzle: Biodiversity and natural resources management

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In the past, natural resources management covered approximately half of all activities and funds of IITA and similar institutes in the Consultative Group on International Agricultural Research (CGIAR). Most often, it did not include the conservation of wild biodiversity. The other half of funds and personnel were allotted to crop plant biodiversity, mainly the varieties available worldwide in genebanks. Increasingly, however, farmers' varieties and wild relatives of crop plants became important and the biodiversity of pathogens and witchweed were investigated in view of their use for resistance breeding.

Thanks to new technologies, breeding barriers between species could be overcome and foreign genetic material was incorporated into so-called genetically modified organisms (GMOs). These are being tested at a relatively small scale in some African countries. They are the source of real worries and polemical distortions, while countries such as the USA, China, Argentina, Brazil, and India have chosen to grow some GMOs on vast areas. Today, GMOs are at the center of a heated debate in an unnecessarily antagonistic manner, pitting the ideals of biodiversity conservation against the need to feed the world.

Since the end of the 1980s, the importance of biodiversity in general for a sustainable future of Planet Earth has been increasingly publicized. At the Rio Conference in 1990, global warming and the loss of biodiversity were singled out as the two most important issues facing mankind. The climate conference in Copenhagen last year was supposed to reach goals on halting and mitigating climate change. The conference is generally considered to have been a failure; nevertheless, great efforts to avoid a climatic disaster are being taken by many governments, even without the wished-for strict regulations.

And here we are in 2010, the "International Year of Biodiversity". International nongovernmental organizations such as the International Union for Conservation of Nature (IUCN), BirdLife International, and many others are highly active in conservation and their efforts are showing successes. Most countries have subscribed to their ethics, signed the international treaties, and established focal points for the Convention of Biodiversity. For the CGIAR, though, biodiversity

> *"The contribution to sustainable agriculture and conservation that IITA can make is by improving the tools and by significant advances in research and its application to real world needs."*
>
> \- Peter Neuenschwander, IITA Scientist Emeritus

Diversity of forest seeds found at IITA. Photo by John Peacock, IITA.

Meristem excision under aseptic conditions (laminar flow workstation) using stereomicroscope, IITA genebank. Photo by IITA.

conservation mostly remains germplasm conservation. It is the world leader in the conservation of genetic material of crop plants and their wild relatives (for instance, yam and cowpea, of particular interest in West Africa). It is instrumental in the development of rules and regulations about the ownership of germplasm under the umbrella of the Food and Agriculture Organization (FAO).

IITA is also co-developing best practices and tool kits for collecting germplasm and houses important pathogen collections. Generally though, conservation of other forms of biodiversity is treated rather timidly. The general antagonism between agriculture and nature conservation thus persists. Yet, it probably need not be so: In 2001, IUCN and Future Harvest came together to publish a policy paper outlining 'The common ground and common future, how eco-agriculture can help feed the world and save wild biodiversity'. While some of the claims might be overwrought, enough is known to allow progress towards the twin goals of saving the bulk of biodiversity while feeding the human population.

Insects are the majority of all described species. On a worldwide level, BioNET INTERNATIONAL organizes and stimulates the coordination of taxonomic research (of all taxa, but with special emphasis on insects). The IITA biodiversity collection of insects, housed in IITA-Bénin, serves as the network center for West and Central Africa. This collection, the largest in the CGIAR, is instrumental in providing basic information about the biodiversity of natural enemies used in all types of biological control.

In addition, the insectary at IITA-Bénin houses numerous live beneficial insects and mites. IITA-Bénin can respond to the changing situations of ever more invading insects and mites. Thus, in the last few years and in West Africa alone, we have seen the invasion and sometimes the control of spiraling whitefly, a new invading fruit fly (Sri Lanka fruit fly), and very recently the papaya mealybug. Last year, when the cassava mealybug invaded Thailand, IITA was able to provide effective parasitoids without delay.

Many more natural enemies are out there in the wild, suppressing their hosts or their prey. Most concern agricultural pests, but increasingly, conservation biological control is becoming important to save natural habitats from invaders. IITA is participating in these international efforts through its biological control of floating water weeds across Africa.

To assess the elusive so-called "ecosystem services", sophisticated biodiversity studies are required. IITA's historic classical biological control projects were against cassava and mango mealybug and cassava green mite, three formidable agricultural pests. The first two were not even known to science before they appeared in new habitats. These examples from South America and India illustrate how the 'ecosystem services' provided by pests' natural enemies in the home environments remain hidden until harmful insects and mites get dissociated from their predators. Important services are also provided by microbials and pollinators, but these become visible to farmers and policymakers only when their function is impaired. Examples are lack of conservation because of wanton destruction or by bad agricultural practices, such as those that lead to the depletion of nutrients in soils or the destruction of suppressive soils.

The contribution to sustainable agriculture and conservation that IITA can make is by improving the tools (GIS, sociological, etc.) and by significant advances in research and its application to real world needs. We can thus establish an intellectual agenda for discussion and change within IITA, collaborating organizations, and society at large. Comparing this claim for action with the actual situation at IITA, we find that traditional biodiversity conservation in the form of crop plant germplasm is rather well implemented; but the conservation of nonplant biodiversity is weakly institutionalized and would need better support. Natural resources management offers the intellectual platform to integrate the different disciplines in a sustainable manner. Unfortunately, the inclusion of all biodiversity activities in a holistic natural resources management remains a dream.

Within the period of 20 years, biodiversity conservation has moved from being a specialized field to becoming an urgent task to be carried out before it is too late and extinction takes away the organisms we might one day have to rely on for survival. Even where we do not completely understand the benefits of biodiversity in providing stability to ecosystems, conservation should be implemented for the good of future generations. Apart from research, this also takes the form of providing refuges for biodiversity for future studies, as is the case with the IITA-Ibadan forest or the rehabilitated forest at Drabo Gbo in Bénin. Our national partners have many more examples; they might cherish our leadership in this matter.

Researcher monitoring cowpea seeds kept in cold storage room in the IITA genebank.
Photo by Jeffrey Oliver, IITA.

NEWS

New varieties boost output, food security

The Nigeria National Variety Release Committee released several improved maize varieties developed by IITA with partners, the Institute for Agricultural Research (IAR) of the Ahmadu Bello University in Zaria and Institute of Agricultural Research and Training (IAR&T) of Obafemi Awolowo University in Ile Ife, Nigeria.

The varieties address many of the major constraints to maize production such as drought, low soil fertility, pests, diseases, and parasitic weeds. They are expected to boost maize production and food security in West and Central Africa.

Researchers developed the varieties through conventional plant breeding by tapping naturally-available traits.

The released maize include 13 open-pollinated varieties of extra-early, early, intermediate, and late maturity with resistance to the parasitic weed *Striga hermonthica* and stem borers, tolerance for drought, and with good adaptation to suboptimal soil nitrogen. Four hybrids with drought tolerance have also been released.

The committee also approved two *Striga*-resistant and two white and yellow productive hybrids developed at IITA in partnership with Premier Seeds Nigeria Ltd. The company will commercially produce and market these hybrids.

A maize field in Nigeria. Photo by IITA.

Yam vine, IITA field. Photo by IITA.

EU funds yam research

The European Union-African, Caribbean and Pacific Science and Technology Program (EU-ACP) will support research to improve and promote yam in West and Central Africa (WCA). The program will benefit six WCA countries: Cameroon, Bénin, Côte d'Ivoire, Ghana, Nigeria, and Togo.

The project, tagged "Strengthening Capacity for Yam Research-for-Development in Central and Western Africa (SCYReC)," aims to improve the capacity for yam research-for-development in the region. It will help find sustainable solutions, through science and technology, to the challenges facing the crop and exploit its tremendous potential for food security and poverty alleviation.

It will also build and increase the capacities of partners, and provide a platform for increased documentation and dissemination of information from yam research and development.

The EU support confirms the renewed global interest on yam as a vital income and food security crop in Africa.

IITA will manage and implement the project in collaboration with a team of national partners in 13 research institutions in the six countries.

World Cowpea Conference

IITA and partners will host the 5th World Cowpea Research Conference in Dakar, Senegal from 27 September to 1 October 2010. The meeting will tackle research issues to enhance the profile of cowpea as a viable income-generating and food security crop.

The conference will cover a wide range of topics—from cowpea genetic improvement and use of molecular tools, to human nutrition and processing and enterprise development.

Known as "black-eyed peas," cowpea (*Vigna unguiculata* L. Walp.) is an annual legume and is one of the most ancient crops known to man.

Worldwide, it is grown on about 10.1 million ha, with an annual grain production of approximately 4.99 million tons (FAO 2008). The largest production is in Africa; Nigeria and Niger are the biggest producers. The largest areas under cultivation are in Central and West Africa. Brazil,

Cowpea seller in local market. Photo by IITA.

Haiti, India, Myanmar, Sri Lanka, Australia, the US, Bosnia, and Herzegovina also have significant production.

Conference partners include the Dry Grain Pulses Collaborative Research Support Programme (Pulse-CRSP), Purdue University, and the Institut Senegalais de Recherches Agricoles.

Fight against cassava disease

IITA is partnering with the Agricultural Research Institute (ARI), Tanzania, and the National Agricultural Research Organisation (NARO), Uganda, to identify and use molecular markers for faster and more accurate breeding of cassava varieties resistant to Cassava Brown Streak Disease (CBSD).

The disease, caused by the Cassava Brown Streak Virus (CBSV), results in a dry rot that renders the tuberous roots inedible. It is one of the greatest threats to food security in sub-Saharan Africa.

Cassava is an important staple food from which over 200 million people derive over 50% of their carbohydrate intake.
IITA and ARI have identified a few varieties with some level of resistance to the disease.

The four-year project, funded by the Bill & Melinda Gates Foundation, aims to identify the DNA markers associated with the resistance genes in these varieties and integrate marker-assisted selection into cassava breeding programs.

Cassava brown streak disease symptoms on cassava roots. Photo by IITA.

Biodiversity conservation is key

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Biodiversity or biological diversity is the variety of life on earth; it includes all living forms, animal, plant, or microbial. It is accessible at three levels: ecosystems, species within the ecosystem, and genes within the species. Today, 65 million years after the fifth and largest notable extinction of species (that wiped away the dinosaurs), alarming reports state an unprecedented rate of biodiversity loss—maybe the sixth extinction (Eldregde 1999).

The loss of spectacular trees in the rainforests or of polar bears at the North Pole is well-publicized and of great concern. However, equally worrying but so much less acknowledged is the loss of agricultural biodiversity. Agrobiodiversity refers to the part of biodiversity that feeds and nurtures people—whether derived from the genetic resources of plants, animals, fish, or forests. The diversity of these genetic resources is the foundation for sustainable agriculture and global food security. It enables plants to adapt to new pests and diseases as well as to climatic and environmental changes.

Germplasm data management using a microcomputer (data logger), IITA genebank. Photo by Olusegun Adebayo, IITA.

There are two complementary methods to conserve plant genetic resources: *ex situ* (in an artificial environment) and *in situ* (in a natural environment). Both approaches have pros and cons. *In situ* conservation allows further evolution of germplasm in natural conditions, but *ex situ* conservation allows ready access to clean germplasm.

Since its establishment in 1967, IITA has devoted considerable resources to *ex situ* conservation. In 1975, the Genetic Resources Unit was created to collect, conserve, and study food legumes, roots and tubers, and their wild relatives. Today, IITA's Genetic Resources Center (GRC) maintains over 28,000 accessions of six main staple crop collections: black-eyed pea (cowpea), maize, soybean, cassava, yam, and banana. The biggest collection is of cowpea, with over 15,000 accessions collected or acquired in or from 89 countries, mainly in Africa. This biodiversity is very valuable for further genetic improvement and food security. It is maintained in trust for the international community and is available to all.

Any new sample entering the genebank is given a "passport" and a unique accession number. The passport holds important information related to the background of the accession. Such data, and in particular the georeference, i.e., the exact location where the sample was collected, provide valuable information. Indeed, when searching for drought tolerance traits, breeders may want to give priority to samples collected in dry areas. The analysis of georeferences of accessions also shows any potential ecogeographical gaps in the collection. Finally, the genetic erosion of a crop can be assessed during recollecting missions based on vernacular names and georeferences of already collected accessions. Unfortunately, for most collections, passport data are far from complete; the country of origin may be known, but the georeferences are missing. This lack of information is partly because the importance of passport data was underestimated in the past.

A collection of biodiversity is traditionally measured at the accession level using phenotypic characterization and evaluation descriptors. The former category generally refers to highly heritable, easily seen, measured, and expressed descriptors. The second includes descriptors that are more sensitive to the environment, such as yield or pest and disease resistance. Among the 52 international descriptors used to describe cowpea diversity, some quantitative traits show a high rate of diversity. Cowpea pod length varies from as little as 5.6 cm up to 49.9 cm, depending on the accession.

Vegetative trait diversity can be equally spectacular. Depending on the accession, the number of days required to harvest the first mature pod varies from 49 to 129 days after planting. In the context of global climate change and the shortening of the rainy season, such a descriptor is of high interest to the breeding community. Although it is important to capture diversity for today's breeding interests, it is equally important to capture "neutral" diversity. Something that has no direct use for improvement today may become valuable in the future.

Since the 1980s, the development of molecular tools has had a substantial impact on biodiversity characterization. This fast-evolving tool provides increasingly efficient, precise, and cost-effective methods of managing collections. Where the combination of

Diversity of crop genetic resources in the IITA genebank. Photo by IITA.

passport and phenotypic descriptors fails to identify duplicates, molecular methods provide a new tool for discriminating and identifying. It is also used to detect the potential loss of genetic integrity, whether associated to conservation or regeneration. IITA is presently fingerprinting the international collections of yam and cassava.

The genetic resources of one given crop are classified in three gene pools based on their respective compatibility/incompatibility to produce viable and fertile progeny (Harlan and de Wet 1971). Gene pool I includes the crop species itself and its wild progenitor. Gene pools II and III include other species that are related to yet different from the crop species of interest (Gepts 2006). Gene pool I is generally well represented in *ex situ* collections but gene pools II and III have often been neglected, although they represent a valuable reservoir of untapped genes as they evolved independently of human preferences.

Africa is a center of diversity for two of the crops maintained at IITA: cowpea (*Vigna unguiculata*) and yam (*Dioscorea* spp.) (Padulosi 1993, Orkwor et al 1998). IITA has devoted considerable resources for conserving the wild relatives of *Vigna*. However, efforts are still needed to further collect more wild relatives and cultivated cowpea. Although generally African biodiversity remains rich, various threats exist. Climate change attracts most attention in this matter but agriculture intensification should not be overlooked. The paradox is that research in agriculture requires diversity to build on existing traits but is one of the main threats to that vital biodiversity.

IITA is planning a collecting mission for cowpea in 2010 in regions of Nigeria where collecting had not been done and will focus on two species*: V. unguiculata* var. *spontanea* (gene pool I) and *V. unguiculata* subsp. *baoulensis* (gene pool II). Remi Pasquet, a taxonomist expert for cowpea from the International Centre of Insect Physiology and Ecology (*icipe*), will lead the expedition.

Over the last 30 years, there has been a profound change in the legal landscape with regard to ownership of biodiversity in general and crop genetic resources in particular (Gepts 2006). In the past, biodiversity was considered a common heritage of humanity, but in 1992, the Convention on Biological Diversity (CBD) assigned sovereignty over biodiversity to national governments. CBD is the first legally binding framework for the conservation of biodiversity that recognizes the "knowledge, innovations, and practices of indigenous and local communities and encourages the equitable sharing of benefits arising for the utilization of such knowledge, practices, innovation, and knowledge" (Shand 1997).

More recently, the International Treaty on Plant Genetic Resource for Food and Agriculture reconsidered the question of sovereignty over plant genetic resources. It promotes the exchange of germplasm for 64 crops in a multilateral agreement (multilateral system, MLS). Within this frame, the conservation of plant genetic resources, i.e., the future of food security, relies on shared initiatives and responsibility and the construction of a global system. Within this system, each stakeholder has a role based on comparative advantage—whether it is access to germplasm, technology, human resources, or capacity development.

The opening of the Svalbard seed vault in Norway, in 2008 is one of the building blocks of the global system. Such an initiative caught the attention of the media and, consequently, directed the attention of the world on the erosion of plant diversity. It is somehow reassuring to know that part (even a little) of plant diversity is now kept in a place that is naturally clean, cool (energy efficient),

Researcher checks tissue culture-grown cassava. Photo by Jeffrey Oliver, IITA.

isolated (as the North Pole), and protected (by polar bears). However, not all plant diversity can be conserved in Svalbard. In fact, many species producing so-called recalcitrant seeds as well as those clonally propagated cannot be maintained at low temperatures for various physiological reasons. These problematic species, which in IITA's collections include yam, cassava, and banana/plantain, are generally banked in the field or *in vitro* slow-growth conditions. The latter approach is preferred as it protects germplasm from field biotic and abiotic risks and allows easy access to distribution of clean material.

The ultimate *in vitro* conservation approach is cryopreservation (conservation at very low temperatures, generally at −196 ^{o}C). At such a temperature, all biochemical and biological processes are stopped. Thus, plant tissue can, in theory, be stored forever. IITA has recently developed such a process for cassava (Dumet et al. accepted).

Whatever the *ex situ* conservation approach, it will never be preferable to *in situ* conservation. However, whenever biodiversity preservation poses a threat to human livelihoods, comfort, or convenience, the politically expedient choice is usually to "liquidate" the natural capital (Ehrlich and Pringle 2008). It seems unlikely that more natural space will be available to ensure the safety of biodiversity in the future… This is not impossible, however, if the schools are involved in teaching the value of biodiversity to the younger generations.

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Insect biodiversity for sustainable management of natural resources

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The conservation of biodiversity and the sustainable use of natural resources are guiding principles of the CGIAR and a recognized thematic priority area. The CGIAR is a major player in the collection, characterization, and unrestricted distribution of agrobiodiversity resources and related information on a global scale. Currently, out of 15 centers, 11 house important genebanks amounting to some 650,000 accessions. These provide scientists with the genetic material needed to significantly increase agricultural productivity.

The conservation of genetic resources at IITA is particularly broad in coverage. Thus, collections encompass a wide range of organisms including plants but also associated nonplant biodiversity. Emphasis is placed on the *ex situ* preservation of plant genetic material. This is reflected in the maintenance of roughly 28,000 germplasm accessions from 19 agricultural crops and their wild relatives. More than half of the genebank's holdings represent in-trust collections of cowpea for which IITA has received the world conservation mandate. Free and unrestricted public access to this genetic material is ensured through institutional compliance with the international seed treaty developed through the Food and Agriculture Organization with the strong involvement of the CGIAR centers.

Apart from the use of genetically improved crops, agricultural productivity is also strongly influenced by a rich in-field biodiversity comprising organisms such as fungi, bacteria, viruses, nematodes, mites, and insects. Their beneficial or deleterious impact on crops is relatively well understood when interactions are based on simple associations of organisms. However, when many players are acting sometimes across several trophic (nutrition or feeding) levels, the study of ecosystems becomes complicated and knowledge-intensive.

Generally, a thorough inventory and characterization process is the requisite condition for the sustainable management of this nonplant biodiversity. Related information is primarily stored in research collections to which IITA has been giving growing attention over the last decade. Today, important nonplant collections allow safe diagnostics of plant pathogenic microorganisms used for resistance screening in breeding programs and arthropods/fungi used for biological control (see Korkaric and Beed, this issue).

A collection that has particularly expanded over the last 15 years is the arthropod reference collection at IITA-Bénin, the largest within the whole CGIAR. It encompasses currently more than 350,000 specimens collected in a wide range of agricultural and natural environments throughout West Africa. More than 5,000 species from 330 arthropod families have been identified from the sampled material, but it is estimated that about 40–50% of all known insect biodiversity of the subregion is preserved in this collection, awaiting further study. Serving as the coordination center for the West African node of the global taxonomic network BioNET-INTERNATIONAL, this biodiversity collection is well placed to provide essential services for sustainable natural resource management at the regional level.

The most important service has been the assistance in arthropod identification. Similar to the safe characterization of germplasm when plant material is transferred under the International Treaty on Plant Genetic Resources for FAO, 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.

For scientists, farmers, extension and biosecurity agents, quarantine authorities, and any other user throughout the globe, accurate and timely identification is vital. It represents the unique entry point for access to existing information about any organism. Opportunities in West Africa similar to diagnostics services for plant diseases for identifying arthropods are scarce or nonexistent and fees requested by overseas centers of expertise are not affordable for most local users. Thus, by providing the names of, on average, 1,500 submitted arthropod specimens per year, IITA has been instrumental in responding to the regional need for over a decade.

Insect diversity: Tenebrionidae family checklist. Photo by Georg Goergen, IITA.

Arthropods form the bulk of the roughly 1.8 million species that have been described until today. It is estimated that this number actually represents only a small fraction of all living organisms, the number of yet unnamed species being particularly large in tropical countries. Thanks to regular faunistic activities, IITA has contributed to the discovery and description of more than 120 arthropod species previously unknown to science. Among them are important pests and their natural enemies.

Following climate change, invasive alien species (IAS) are widely regarded as the second-greatest threat to biodiversity worldwide. They represent a growing concern for biosecurity and quarantine services, especially since increased trade and travel are expected to accelerate the rate of pest introductions. For tropical Africa, data sampled over 100 years show a rate of three introductions every two years. The failure to recognize IAS may have dire economic or ecological consequences. Prevention or early detection of such IAS requires considerable knowledge of native and exotic fauna.

For West Africa, IITA-Bénin is at the forefront of IAS surveillance with the detection of the whitefly *Paraleyrodes minei* Iaccarino, the Sri Lanka fruitfly *Bactrocera invadens* Drew et al., and lately the papaya mealybug

Immature of the whitefly Paraleyrodes minei*.*
Photo by Georg Goergen, IITA.

Infestation of the papaya mealybug Paracoccus marginatus*.* Photo by Manuele Tamo, IITA.

Paracoccus marginatus Williams & Granara de Willink (see photographs). Such monitoring also led to the recent detection of a new cashew pest, now awaiting description.

Despite the need to maintain the present services and the opportunities arising to work in new fields, the future of the collection remains unsure because of the lack of external funding. This is all the more surprising since new opportunities for the delivery of public goods are now appearing in various areas with significant impact for the sustainable use of natural resources. Thus, the comparatively young age of the collection makes it particularly well suited for the application of novel identification methods such as DNA barcoding.

Adult female of the Sri Lanka fruitfly Bactrocera invadens*.* Photo by Georg Goergen, IITA.

IITA's participation could thereby provide important additions to this publicly accessible DNA database thus advancing the goals set by the Consortium for the Barcode of Life (CBOL). Besides agricultural pests and their natural enemies, this technology will also target crop pollinators because of their vital services to ecosystems and the particular concern raised by their global decline. Thus, a full return from past collection efforts will be achieved by applying molecular techniques.

Opportunities to extend biosystematics services at IITA are manifold and crucial for the region that is known to suffer from scanty local capabilities. These include the development of web-based products, the integration of Geographical Information Systems, the provision of online identification tools using high resolution images of important West African arthropod species, and capacity building in the identification of agriculturally relevant groups at various academic levels.

IITA has already an undeniable comparative advantage in biosystematics. This advantage should be preserved in view of its vital support to the successful deployment of plant genetic material for improving food security and reducing poverty in developing countries.

Why manage noncrop biodiversity

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When it comes to the diversity of nonplant taxa, the numbers alone are highly impressive. There are an estimated 5–30 million species of microorganisms globally but only two million have been formally described. In 1 g of soil, over a billion bacteria cells can be found, but fewer than 5% of the species have been named or can be grown on artificial media. For fungi, about 1.5 million species are estimated to exist and yet only 5% have been characterized taxonomically.

Nematodes remain particularly poorly described with only a fraction of the suspected half million found in nature known to man. For insects, arachnids, and myriapods only 1.1 million have been named from a potential 9 million. These numbers compare with an estimated 420,000 seed plants of which most have been described.

Knowledge of biodiversity is uneven, with strong biases towards the species level, large animals, temperate systems, and the components of biodiversity used by people. Although biodiversity underlies all ecosystem processes, modern agriculture is based on a very limited genetic pool of crops and an even more limited exploitation of the genetic resources of nonplant taxa.

This is surprising, considering that as a consequence of their diversity microorganisms and insects play pivotal roles across ecosystems that far exceed those of plants. They provide critical functions and services for food and agriculture. They are indivisibly connected with ecosystem resilience, crop health, soil fertility, and the productivity and quality of food. Modern agriculture in the developed and especially the developing world uses only a small fraction from this rich pool of genetic resources.

Conserving and using nonplant taxa

One of the vital pillars in the work of the CGIAR is the conservation and use of agrobiodiversity and related knowledge. Over 650,000 accessions of crop, forage, and agroforestry genetic resources are stored and maintained through the centers' genebank system and distributed to researchers and breeders throughout the world.

However, scientists from different CGIAR centers are also involved in collection, conservation, and sustainable use of insects and mites, fungi, bacteria, viruses, and nematodes that are either beneficial or antagonistic to crops. These research collections are used in two main areas: (1) crop health and productivity, where the collection supports screening for resistance in breeding programs, pathogen diagnostics, and the development of biological control technologies, and (2) soil health, fertility and ecosystem resilience where

Disease symptom on lettuce leaf caused by Colletotrichum fuscum. Photo by Fen Beed, IITA.

for example, collections support the development of biofertilizers.

IITA's main collections of nonplant taxa are housed at the stations in Ibadan (Nigeria) and Cotonou (Bénin). At the headquarters in Ibadan, the collection and study of plant pathogenic fungi, bacteria, and viruses of important crops are coordinated and collections are maintained. Examples are those for yam and cassava anthracnose, cassava bacterial blight, and soybean rust pathogens.

Some of the collections contain large numbers of isolates of the same species which are often unique, not being found elsewhere in the world. International repositories might hold many different species, but tend to store fewer isolates per species and rarely prospect across the developing world. A diverse range of isolates gives a more complete representation of the genetic diversity which can be crucial for understanding evolutionary patterns, pathogen variation, and population dynamics.

Aflatoxin-producing fungus Aspergillus flavus *growing out of maize grains in a culture medium.* Photo by Joseph Atehnkeng, IITA.

It helps breeding programs to identify targets for resistance selection.

Collections of isolates of the same species can be used to develop appropriate biocontrol technologies. One such example is IITA's collection of *Aspergillus flavus*, a fungus that normally produces aflatoxin, a compound that is toxic to humans and animals. Over 4,500 strains have been collected from Nigeria alone and screened for toxin production and their ability to outcompete other strains when found simultaneously on foodstuffs. The atoxigenic and most competitive strains have been used to formulate aflasafe®, a biocontrol product (see R4D Review September 2009 issue).

Also in Ibadan, collections of beneficial soil microorganisms are studied and maintained. These organisms (such as *Rhizobia* spp. and mycorrhizae) enhance the nutrient uptake of leguminous crops and can be used as biofertilizers.

At IITA-Bénin, microorganisms and arthropods have been characterized and preserved for use in biological control programs to manage invasive crop pests and weeds. Plant pathogens have been identified and stored since the deployment of appropriate control measures first requires definitive identification of the causal agent of the disease. The biodiversity center maintains over 360,000 insect and mite specimens and is one of the largest reference collections in West Africa (see R4D Review September 2009).

Other IITA stations keep smaller working collections of nonplant taxa. At IITA-Uganda, collections of nematodes, bacteria, and fungi are maintained—mainly those associated with banana production. Certain *Fusarium* strains, for example, are used for endophyte-improved banana tissue culture for enhanced pest and disease resistance.

IITA is a lead organization for the conservation and use of nonplant taxa across sub-Saharan Africa. It is now characterizing nonplant taxa collections across the CGIAR as part of the World Bank-funded GPG2 project (Phase II of the Collective Action for the Rehabilitation of Global Public Goods in the CGIAR Genetic Resources System). This is the first system-wide inventory and collation of the existing global, nonplant taxa collections. The aim is to provide a coordinated and harmonized service for research and use of noncrop taxa to support durable farming systems in the developing world.

Future challenges and opportunities

There is a growing appreciation of the fact that farming occurs in an ecological context with complex interactions between crop and nonplant taxa that can be beneficial or antagonistic. There is also increasing demand for sustainable and environment-friendly solutions to manage pests and diseases, with the expectation that the biopesticide market share will increase to over 4.2% by 2010 and, for the first time, reach a market of over US$1 billion. Due to the rate of population increase the World Bank estimates that the global demand for food will double within the next 50 years. At the same time, the amount of arable land is decreasing from pressure from nonfarming activities and the unsustainable farming practices that are causing losses in soil fertility. This scenario is exacerbated by the fact that 40% of what is grown in the world is lost to weeds, pests, and diseases. In developing countries it is common for up to 70% of the yield to be lost due to attacks from insects and microbial diseases.

Therefore, agricultural production needs to be intensified and more marginal land used to produce sufficient food. This requires the deployment of improved land management techniques combined with the selection and distribution of appropriate crop and noncrop germplasm to exploit interactions with beneficial nonplant taxa and resist increased pressure from antagonistic nonplant taxa. Other factors such as climate change are likely to add new layers of complexity to these challenges. To predict risk and develop appropriate adaptation strategies, CGIAR and governments will become increasingly reliant on knowledge of and access to nonplant taxa genetic resources for food and agriculture. This will be used for research, training, or direct use in agriculture and originate, or be found, in a range of countries or centers.

This is part of 12 months of samples of insects received at the IITA biodiversity center in Bénin. Photo by Georg Goergen, IITA.

Collections form the mechanism through which information and access to nonplant taxa can be obtained, but the survival of these collections is under threat from funding constraints. Appropriate policies, investments, and collaborations among CGIAR centers and with international collections are urgently needed to recognize noncrop taxa as global public goods. This would facilitate the conservation of collections, increase their visibility, and maximize their use for the benefit of sustainable farming systems. Especially in Africa, where the biodiversity is high, but the taxonomic and technological capacity is limited, work is needed to manage the full potential of nonplant taxa for food and agriculture.

A research park for Africa

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The IITA campus is a rich center of biodiversity. Because of the protection and nonexploitation of a patch of secondary forest, lakes, and other natural resources in the area, it represents a wealth of flora and fauna that are not common in other parts of Nigeria.

IITA was established in April 1967. Earlier in October 1965, approximately 1,000 ha of land were acquired, lying between Ojo in Ibadan town and Moniya villages. The land was covered mainly with oil palms, cassava, maize, cocoyam, and a variety of indigenous trees and climbers.

Today, 43 years on, the area is taken up by research, administration, and residential buildings, lakes, experimental plots, and 350 ha of valuable secondary forest. An arboretum was established in 1979 containing 152 different tree species; 81 of them are indigenous. In addition, the residential and administrative areas of IITA were extremely well landscaped with a diversity of both indigenous and exotic trees. Many of the original hardwood trees were left *in situ*.

Although protected, the forest is still a degraded secondary forest. It is basically four layered, made up of a discontinuous emergent canopy

IITA campus. Photo from Google Maps.

dominated by *Milicia excelsa* (Iroko), *Celtis zenkeri, Terminalia superb*, and *Antiaris africana*; a tree canopy made up of *Blighia sapida*, young *Ceiba pentandra*, *Entandrophragma angolense*, and *Ricinodendron heudelotii* as the more frequent woody plants. The shrub layer is composed mainly of *Newbouldia laevis* and *Baphia nitida* with seedlings and saplings of typical canopy emergents such as *Mammea africana*. The herb layer is highly diverse containing members of the family *Orchdaceae* and some *Poaceae* and *Chromolaena* sp. in the more open areas (Hall and Okali 1978, 1979).

The IITA forest provides a good habitat for a great number of different insects and birds. It is one of the Birdlife International Important Bird Areas (IBA) with 350 species, including the Ibadan Malimbe, *Malimbus ibadanensis,* which is endemic to this region.

Knowledge about the diversity of butterfly species at IITA is incomplete. A preliminary survey conducted by lepidopterist Robert Warren in 2002-2009 has confirmed the presence of 149 species (See Warren, this issue). This figure is considered low and could be as high as 400.

In December 1987, a group of enthusiastic volunteers from IITA embarked on carving out a nature trail in the forest. Many useful plant species including herbs, medicinal plants, fiber-producing plants, and fruit and timber trees can be seen from the trail. The most spectacular is a climber with a long name and a huge (40 cm diameter and 50 cm length) dark-red flower called *Pararistolochia goldieana*, which belongs to the family *Aristolochiaceae*.

The rich biodiversity of the campus is also influenced by its nine lakes. The largest is approximately 70 ha. A dam (The John Craig Dam) was constructed in 1969 and impounds water from the Awba River which runs through the

Pararistolochia goldieana. Photo by IITA.

Gunwin watershed. This lake is home to various varieties of fish, aquatic weeds, and birds.

Currently there are many fish in the nine lakes and ponds. Records show that the largest lake was stocked with a wide variety of species. The dominant ones are the African Catfish (*Clarias gariepinnus*), Nile Perch (*Lates niloticus*), Slapwater (*Heterotes niloticus)*, and various Tilapines (*Oreochromis niloticus, Tilapia zilli*, etc.). But a wide variety of other species are present, e.g., *Gymnarchus niloticus, Hepsestes odoe,* and *Channa obscura*. There is also a diversity of aquatic weeds, *Nuphar* spp. (water lily), *Azolla* sp. (water fern), *Potomogeton* sp., *Typha* sp. (bulrush), and *Lagarosiphon cordofanus* Caspry. *L. cordofanus* Caspry is uncommon and this may be the only known occurrence in Nigeria (Adeniyi Jayeola, personal communication).

Despite the water and forest habitat, the resident level of mammalian fauna is low. The cane rat or grass-cutter, duiker, mongoose, potto, tree hyrax, civet, and the giant Gambian rat can be seen. Others are the bush-tailed porcupine, squirrels, and small antelopes. Amphibians, lizards, and snakes are also common but have not been studied or documented. However, there is a

Fruit bats flying over a Ceiba pentandra *tree* (Yoruba local name: osun papa). Photo by IITA.

large population of straw-colored fruit bats. The flying foxes (*Eidolon helvum*) form large colonies in the IITA forest. They are the second largest West African bat with a wing span of up to 953 mm. Adults can weigh up to 350 g. They roost conspicuously in the open, covering hectares of treetop branches in the IITA forest and arboretum. An important food for these bats is the fruit of the Iroko tree (*M. excelsa*). The Iroko produce finger-sized fruits that resemble mulberries. Each fruit contains an average of 80 small, tomato-like seeds which are then transported away from the parent tree. Iroko ranks as one of Africa's most valuable hardwood trees.

Why is IITA so concerned about its secondary rainforest, indigenous trees, and its rich biodiversity? Deforestation is a serious problem in Nigeria that currently has one of the highest rates of forest loss (3.5%) in the world, translating to an annual loss of 350,000-400,000 ha of forest land (See Ladipo, this issue). Since 1990, Nigeria has lost 6.1 million ha or 35.7% of its forest cover. These figures give Nigeria the dubious distinction of having the highest deforestation rate of natural forest on the planet, and the lowest percentage (2.4%) of rainforest remaining in any African country.

The IITA campus is one of the few reserves in Nigeria where valuable and rare indigenous trees, such as the Iroko, are safe from poachers. Today there is only one specimen of *Parkia bicolor* in southwestern Nigeria; this one tree is on the IITA campus.

Recently the Director General of IITA, Hartmann, announced that the IITA campus and all it contains will become an African Science Park. This decision is most timely, coming during the International Year of Biodiversity. This will create a more diverse scientific community which could include agriculturalists, ornithologists, lepidopterists, ecologists, foresters, botanists, invasion biologists, and conservationists.

In the future, the IITA campus could be used as a research site for reconciling increasing agricultural production in the tropics and the conservation of biodiversity. IITA has embarked on seed collecting and propagation of indigenous trees to develop an *in-situ* conservation program for indigenous trees of West Africa. It is also working with scientists at the A.P. Leventis Ornithological Research Institute (APLORI); Centre for Environmental, Renewable, Natural, Resources Management Research and Development (CENRAD); Forestry Research Institute of Nigeria (FRIN); the University of Ibadan; and the Royal Botanical Gardens, Kew to ensure that its rich biodiversity will be conserved for many generations to come. This new initiative at IITA will be used to educate and encourage others in Nigeria to preserve these valuable rainforests.

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The butterflies of IITA

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IITA boasts a wide range of butterflies. Knowledge about the diversity of these species, however, is incomplete. For instance, a preliminary survey conducted from 2002 to 2009 has confirmed the presence of 149 butterfly species. The actual number could fall somewhere in the range of 250 to 400.

A survey carried out in a directly equivalent location (Olokomeji Forest Reserve) in the late 1960s found 267 species, with quite limited collecting inputs (estimated total >450). A more complete survey at Agege, near Lagos in southwestern Nigeria, found more than 380 species. This location is in the moist evergreen forest zone, and is fairly comparable to the secondary nature of the IITA forest.

Completing a survey at IITA would yield information useful for conservation. The fact that the IITA forest is small and now isolated would allow the assessment of pressures on extinction. Despite the enormous destruction of West African forests to date, records show that butterfly extinction has yet to occur when viewed on a regional scale.

While the primary consideration for survival will be the presence of the host plants, there is also a consideration of the range required for survival. Knowledge of the total species population within IITA and specific species present could be likely to provide answers on the cut-off point where the range is too small for survival of certain species groups.

The IITA forest is also an important conservation target itself because of its location. It is quite possibly the westernmost representative of semi-deciduous forest on this scale before the Dahomey gap. Attempts to locate equivalent forests within Nigeria to the west of IITA, guided by satellite imagery, yielded only one small, unprotected patch (5 km west of Tapa). Forest reserves have all but disappeared. Several butterfly species (e.g., *Liptena ilaro, Euriphene kiki, Axiocerses callaghani*) found near IITA have not been seen elsewhere, pointing to the biogeographical importance of such habitats. If results eventually show that the IITA forest is indeed too small to allow the survival of all the species that should be present in an equivalent forest type, it will nonetheless remain an important refuge.

Display cases of all but a handful of the 149 species observed to date have been donated to IITA to promote further interest.* A specimen of the very rare species *Melphina noctula* was found at IITA (there are only three in the Natural History Museum), and has been donated to the African Butterfly Research Institute in Nairobi, Kenya.

An in-depth study of the IITA butterflies would be of international interest and importance because very few such surveys have been completed in Africa. Comparison with our knowledge of the fauna of western Nigeria could shed light on the importance of a forest such as IITA's for the long-term survival of species. It could be one of the localities proposed for studying the survival of the butterflies between now and 2100. Finally, it could show if new species are added as the forest matures from its secondary status over time.

*Specimens were collected, identified, mounted, and donated recently by the author to IITA. These are currently on show at the IITA International School in Ibadan, Nigeria.

Ed's note: Robert Warren is a butterfly expert who came to Nigeria at the age of 4 months. He has been surveying butterflies all over Nigeria and at IITA since 2002. He recently gave a lecture at IITA with two other experts on African butterflies, Szabolcs Sáfián and Oskar Brattström.

A classical approach to saving life's variety

The beginning of the tragedy to come wasn't so clearly understood, but it became more visible as scientists studied the demise of the dinosaurs and came to consider, over the centuries, the reduction of species. The destructive trend is clear and fast encroaching on domesticated plants and wild animals alike, putting some species such as the whales and panda bears on the endangered list and threatening food security.

Consequently the world is losing biodiversity at rates not seen before.

In Nigeria, for instance, the country has lost some 6.1 million hectares or 35.7% of its forest cover since 1990. Worse, Nigeria's most biodiverse ecosystems—its old-growth forests—are disappearing at an even faster rate. Since 2000, Nigeria has been losing an average of 11% of its primary forests every year, twice as fast as in the 1990s.

Adeniyi Jayeola, a Senior Lecturer in plant systematics, Department of Botany and Microbiology, University of Ibadan, says, "The deterioration we find worldwide today is unprecedented. Unless we act together, and quickly too, we may sooner than later induce a global ecological crisis far beyond the control of any technology. It is a multi-faceted challenge requiring all hands to be on deck."

Areas visited in Nigeria in particular and the world in general have shown that man has demonstrably failed to accord the environment the respect it deserves, whether this is the air, sea, or land.

Consequently, out of more than 10,000 species in the past people today depend on only 12 species for 80% of all their food.

To stem the loss of biodiversity, in 2002, 10 years after the Convention on Biological Diversity (CBD), 193 nations participating in the treaty had agreed to "achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional, and national level as a contribution to poverty alleviation and to the benefit of all life on earth."

This year, parties are converging to take stock of the journey so far but the general assumption is that more action needs to be taken.

What is biodiversity worth?

As the world prepares to take a retrospect on set targets, we can, however, no longer expect nature to provide us with a free lunch. Efforts to protect natural resources could depend on our putting a price tag on the goods and services they provide us. The United Nations Environment Programme's 2007 Global Environment Outlook 4 report states that the pollination of crops by honeybees alone is worth US$2–8 billion, and the global herbal medicine market was worth US$43 billion back in 2001.

In addition, the tropical forests provide a whole variety of leaves, fruits, barks, roots, and nuts which form the mainstay of the modern pharmaceutical industry. We depend totally on the variety of life for our food security. The loss of biodiversity therefore presents us with one of the toughest puzzles, and concrete steps are needed to slow down the tide.

Innovative approaches to contain biodiversity loss

Despite the decline in species, which are currently disappearing at 50–100 times the natural rate, a regenerated forest on

IITA's campus in Ibadan has proved that indeed we can restore nature if we so desire. The forest, located on the west bank in IITA, sits on 350 ha of land and was initiated from abandoned farmland.

Forty three years after its establishment, this swathe of securely protected trees stands out as one of the least disturbed patch of forest in Nigeria with floristic characteristics ranking almost at par with a natural forest. The regeneration of the forest has brought appeal from the scientific community as researchers are seeking to uncover and understand the variation in plant species, composition, and structure of a forest regrowing from abandoned farmland and the causes of the variation.

David Okali, Chair, Nigerian Environmental Study/Action Team, who plans to do the study on the IITA forest with other colleagues, says such long-term studies are rare. The results on the rate of growth will be used in calculating directly the rate of carbon storage in the forest.

As the world marks the International Year of Biodiversity, Okali says deliberate efforts to conserve nature are important to stem biodiversity loss, stressing that the reestablishment of the IITA forest presented a good scenario for conservation.

Apart from forest regeneration, Okali says local communities could adopt other initiatives to curtail the loss of biodiversity. These include a return to traditional practices that made it a taboo for people to cut some species of trees or kill sacred animals. Also traditionally regulating hunting practices, and planting and protecting shade-providing fruit trees that adorn the village squares will help.

The success of the regenerated forest at IITA has reinforced the possibility that the opportunity is still within our reach.

Based on this experience, it is clear that the plan by parties to the CBD to create a global network of terrestrial and of marine protected areas can be done if there is the will and the means. How this will happen and funded is a question that all Governments must answer.

The IITA Lake and forest have been well preserved for the last few decades. Photo by Jeffrey Oliver, IITA.

The state of Nigeria's forests

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The IITA forest. Photo by Katherine Lopez, IITA.

Nigeria is blessed with a large expanse of land and variable vegetation, but this important resource is not sustainably used or managed. Many rural dwellers in the past have treated our forest resources as inexhaustible.

Today the story is different. The average rural dweller now realizes that the forest is "finished," but poverty continues to force people to exploit even the relics of remaining forests.

The Federal Government has, over the years, attempted to generate baseline data on the state of our forests including their use. These studies have provided data for a better understanding of the state of forest resources, the rate of environmental degradation, and the rate of forest depletion.

They also emphasize that present-day forest cover is under pressure as a result of human activities such as agricultural development where vast lands are cleared without conservation considerations, large-scale peri-urban housing project development, fuelwood generation, uncontrolled forest harvesting including poaching for logs and poles, and urbanization.

In Nigeria, deforestation or loss of vegetation or the selective exploitation of forests for economic or social reasons is very common. In most areas major losses have been recorded in vegetation, forest complexity (diversity), or in germplasm (quality).

The deforestation rate in the country is about 3.5% per year, translating to a loss of 350,000–400,000 ha of forest land per year. Recent studies show that forests now occupy about 923,767 km^2 or about 10 million ha. This is about 10% of Nigeria's forest land area and well below FAO's recommended national minimum of 25%. Between 1990 and 2005 alone, the world lost 3.3% of its forests while Nigeria lost 21%.

In addition, some state governments are removing the protected status from forest estates without regard for the environment. The State Forest Departments have been unable to curtail the spate of requests to establish large-scale oil palm plantations in forest estates. The unfortunate impression that has thus been created is that the forest estate exists as a land bank for other sectors as demands continue nationwide.

As the forests are exploited, so too is the biodiversity.

Plant and animal genetic resources are also lost with this important genetic resource, vital for breeding in future. Conserving the wild relatives of cultivated crops is also needed.

What factors continue to threaten biodiversity and contribute to poverty? These include deforestation, desertification, habitat alteration, invasive alien species (plants and animals) importation, poor land management (fire and agricultural systems + grazing), climate change, unilateral development decisions, poor political accountability, and poor budget allocation, release, and implementation.

We cannot afford not to conserve our forests and thus lose the vital ingredients of rural development. The situation is getting worse every day and the need for forest conservation and restoration is becoming critical.

With the new National Forestry Policy and the National Document on Biodiversity Conservation Action Plan, a new approach is needed now on forestry resources conservation in Nigeria. Enforcement and a community approach will produce positive results.

All stakeholders need to understand that biodiversity is critical to the maintenance of a healthy environment. Its role is enormous in meeting human needs while maintaining the ecological processes upon which our survival depends. Biodiversity not only provides direct benefits such as food, medicine, and energy; it also affords us a "life support system."

Biodiversity is required for the recycling of essential elements. It is also responsible for mitigating pollution, protecting watersheds, and combating soil erosion. Controlling deforestation will ensure that biodiversity exists and can help reduce the impacts of climate change and thus act as a buffer against excessive variations in weather and climate. It can then protect us from catastrophic events.

Increasing our knowledge about biodiversity can transform our values and beliefs. Knowledge about biodiversity is valuable in stimulating technological innovation and providing the framework for sustainable development. Let us protect our forests as a start.

Ed's note: David Ladipo is the Principal Consultant and CEO of the Centre for Environmental, Renewable, Natural, Resources Management Research and Development (CENRAD), Ibadan, Nigeria.

Inside the IITA forest. Photo by Christine Peacock, IITA.

Unlocking the diversity of yam

The International Year of Biodiversity (IYB) has emphasized the need for global action that will unravel the genetic diversity of yam, a root crop that provides food security to 300 million people in sub-Saharan Africa.

Yam is grown in about 51 countries in the tropics and subtropics, with yields averaging about 11 t/ha in the major producing countries of West Africa (Nigeria, Cote d'Ivoire, Ghana, and Bénin). However, little is known about the tuber crop's diversity.

"This aspect is important for yam improvement to meet the demand of people depending on this crop for food and livelihood," says Ranjana Bhattacharjee, IITA Scientist working on fingerprinting the yam germplasm collection.

Yam provides calories and puts money in the pockets of farmers. The tuber-bearing climbing plant from the genus *Dioscorea* also plays a major role in sociocultural activities in West Africa including traditional marriages and the New Yam Festival (see page 28).

Globally, there are over 600 species of yam but only a few are cultivated for food or medicine. Scientists fear that some species are threatened and might become extinct as a result of climate change and genetic erosion. This prompts the calls for conservation.

The major edible species of African origin are white Guinea yam (*D. rotundata* Poir.), yellow Guinea yam (*D. cayenensis* Lam.), and trifoliate or bitter yam (*D. dumetorum* Kunth). Edible species from Asia include water

IITA scientists inspect yam plants in the field gene bank. Photo by Olusegun Adebayo, IITA.

or greater yam (*D. alata* L.), and lesser yam (*D. esculenta* [Lour.] Burkill). Cush-cush yam (*D. trifida* L.) originated from the Americas. White Guinea yam and water yam are the most important in terms of cultivation and use.

This preferred staple is usually eaten with sauce directly after boiling, roasting, or frying. The tubers may also be mashed or pounded into dough after boiling, or cooked with sauces and oils. They can be processed into yam balls, chips, and flakes.

Fresh yam tubers are peeled, chipped, dried, and milled into flour that is used in preparing dough called *amala* (Nigeria) or *telibowo* (Bénin). Commercial products based on dry flakes or flours from the tuber are produced in Nigeria, Ghana, and Côte d'Ivoire for export and sale in urban areas.

Though millions depend on the crop, especially in sub-Saharan Africa, not many outside of Africa know about the tuber's potential for commercialization, and its role in enhancing food security in the region, according to Robert Asiedu, Director of the Program on Root and Tuber Systems at IITA.

"We talk about yam tubers as a food staple of millions of Africans to donors or investors who don't even know what yam is, how it looks or tastes. So the question is: How would they even think of investing in research in a 'little-known' staple like yam?"

Perhaps yam's low profile in the developed countries or in the West is the major limitation in attracting funding for research, but this hardy tuber is an important "part of man" especially in Africa, the Caribbean, Asia, and the South Pacific Islands where it is widely eaten. According to Asiedu, it is the "preferred and most appreciated staple food and calorie source" in areas where it is grown.

Yam faces constraints that include the high costs of planting material and of labor, decreasing soil fertility, the inadequate yield potential of varieties, and increasing levels of field and storage pests and diseases associated with intensive cultivation.

To tackle some of these constraints, work at IITA for the last few years has focused on improving the tuber, primarily white and yellow Guinea yam, and water yam.

The breeding program uses the 2,216 accessions of Guinea yam and 816 of water yam in IITA's genebank to study resistance to anthracnose and virus diseases. Improved populations have been developed with partners in the national agricultural research and extension systems (NARES), who have released varieties in Nigeria (National Root Crops Research Institute, 7) and Ghana (Crops Research Institute, 3).

Despite the success in yam improvement, new challenges keep on coming, prompting researchers to use other tools, such as molecular characterization to unlock the genetic diversity of yam.

Recently, the Global Crop Diversity Trust funded a project in IITA to duplicate, document, and distribute the germplasm of yam to other partners in accordance with the International Treaty on Plant Genetic Resources for Food and Agriculture. Such support is indeed a milestone in yam research. The project also aims to fingerprint the entire germplasm collection at IITA. This will help in understanding the extent of genetic diversity present in the collection. From this, the genes for important traits can be determined through association mapping, a tool that could be used successfully to improve and sustain the crop.

As the world marks the IYB, serious attention from other donors is necessary to keep the crop as a "part of man."

Yam festival

The Yam Festival is a popular holiday in Ghana and Nigeria, two countries in the yam belt in West Africa. It is usually held in the beginning of August at the end of the rainy season. The festival is named after yam, which are the first crops of the season to be harvested. It marks the end of one farming season and the beginning of another, a season of plenty.

In West Africa, yam cultivation is associated with a wide variety of beliefs and taboos which govern planting, harvesting, and consumption. Sacrifices are offered to the gods at various stages of growth from planting to harvest. These are also performed in various yam-growing areas of the Pacific.

Nigeria
The New Yam Festival is a 2-day cultural festival in southern Nigeria. Dancers wear masks that reflect the seasons or other aspects of nature. It is chiefly celebrated by two large cultural groups: the Ibo or Igbo of the southeast, and the Yoruba of the southwest. The Ibo call the festival *Iri Ji*; *ji* means yam. The Yoruba call it *Eje*.

Various communities celebrate Iriji in different ways. But all have a parade, songs, dancing, and drumming. Because a good yam harvest is important for survival, the people give thanks to the spirits of the earth and sky. The New Yam Festival is celebrated by gathering, blessing, and then feasting on the new yams.

Ghana
The Yam Festival is called the Homowo or "To Hoot at

Hunger" Festival. The people hope for a good harvest so that no famine will hit in the coming year. This festival takes place in many rural communities. Women dig up the yam and carry them home in baskets on their heads. Villagers gather together as the women and young girls prepare the feast, with the yam as prized food. They choose a young boy to carry the best yam to the festival dinner, and another boy follows him beating a drum. Other young people from the village march to the beat of the drum and the sound of a woodwind instrument, and sometimes musket fire. Chiefs, under umbrellas and wearing robes made from the famous, brightly colored Ghanaian Kente cloth, follow the yam, and the young people dance. Other activities include singing, wearing animal masks, and displaying fetishes.

Outside Africa
In Indonesia, the traditional yam festival occurs once every 4 years. A big seed yam weighing 2-3 kg is planted near a tree which is stripped of its bark to provide the yam vine with sturdy support. The yam is watered during the dry season and harvested after 4 years for the festival. Similar festivals are celebrated in the Pacific Islands, especially in Papua New Guinea.

History and legend
The New Yam Festival in Nigeria also has religious meaning for those who still practice the native tribal religions. Although most Nigerians are either Muslim or Christian, many still honor the spirits of the land and the souls of their ancestors in their everyday lives and in their ceremonies.

According to Ibo myth, a man named Ibo, or Igbo, gave the tribe its name. A very old legend explains how the yam and the cocoyam, another starchy root vegetable, became such important foods for the Ibo.

During a time of terrible famine, a tribesman named Ibo was told by a powerful spirit that he must sacrifice his son Ahiajoku and daughter Ada to save his other children from starvation. After Ahiajoku and Ada were killed, the spirit told Ibo to cut their bodies into many pieces and to bury the pieces in several different hills of soil.

Ibo did these, and, in a few days, yam leaves sprouted from the hills containing pieces of Ahiajoku's flesh, and leaves of the cocoyam sprouted from the hills where Ada's flesh was buried. The spirit told Ibo and his living children to farm these two crops. They did so, and when the yam and cocoyam were harvested, they provided food that kept the family from starvation. Because of this, Ahiajoku is worshiped as the god of yam. He is greatly honored during the New Yam Festival.

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Safeguarding local varieties ensures food security

Cassava is a food security crop to more than 600 million people in the developing world, providing incomes to resource-poor farmers, improving their livelihoods, and serving as a buffer against food crises.

The strategic importance of cassava, however, is being threatened, especially in Africa, as local varieties are in danger of disappearing because of genetic erosion and other human and natural factors.

"In Guinea, for instance, about seven local cassava varieties are fast disappearing. This is risky, especially for cassava since it is a clonal crop," according to Paul Ilona, IITA Senior International Trials Manager. Clonal crops are those propagated through cuttings or other plant parts, not by seeds.

Genetic erosion is a process whereby the already limited gene pool of an endangered species of plant or animal diminishes even more when individuals from the surviving population die out without getting a chance to breed within their endangered low population.

Both local and improved cassava varieties alike create a robust gene pool, offering choices for breeders in future breeding programs. However, the loss of genes from the extinction of some local varieties could limit future improvement programs. The endangered varieties may hold key traits that could offer possible solutions to hunger and poverty in the future.

Cassava pile after harvest. Photo by Olusegun Adebayo, IITA.

To prevent the genetic erosion of cassava, IITA and the Institut de Recherche Agronomique de Guinée (IRAG) have stepped up efforts to save native African varieties with the collection of 73 local varieties from Guinea, West Africa.

These varieties are now conserved under *ex situ* conditions at IITA's Genetic Resources Center (GRC) in Ibadan, Nigeria. They form part of a collection to safeguard the continent's plant genetic resources. The collecting mission in that West African country last year was funded by the Global Crop Diversity Trust, IRAG-Guinea, and IITA.

"The conservation of local varieties provides hope for future cassava breeding programs and helps to guarantee food security in Africa," says Dominique Dumet, GRC Head and coordinator of the collecting mission.

Ilona says the loss of native cassava varieties might limit the number of genes available for breeders. "For breeders, any time we lose (crop) genes, it hurts. That is why the conservation of local cassava varieties at GRC is important to us," he says.

Apart from cassava, IITA's GRC holds over 25,000 accessions of major African food crops, including cowpea, yam, soybean, bambara groundnut, maize, and plantain/banana. IITA shares these accessions without restriction for use in research for food and agriculture.

The collecting mission makes Guinea the fourth country, after Angola, Togo, and Bénin, to allow IITA to collect and share their germplasm with other countries, since the International Treaty on Plant Genetic Resources for Food and Agriculture went into force in June 2004.

Cassava selling and processing provide women in Nigeria with gainful employment. Photos by Olusegun Adebayo, IITA.

BEST PRACTICE

Cassava: improving sustainability of farming systems

Anneke Fermont, a.fermont@cgiar.org

Throughout Africa populations are growing fast and pressure on land is steadily increasing. To maintain productivity, farmers are constantly adapting their management of natural resources. Farming systems are thus changing from ”slash and burn systems” to ”natural fallow” systems into ”continuous cropping” systems without external inputs and ultimately into more ”intensive” systems using agricultural inputs.

Cassava-maize systems in East Africa

A principal crop in Africa’s farming systems is cassava, with a total production that has quadrupled in the last five decades to about 118 million t/year. Cassava is a major crop in East Africa, where it is often produced together with maize by smallholder farmers. Such cassava–maize-based systems are found around Lake Victoria and in Burundi, Rwanda, and eastern DR Congo. Apart from being dominated by cassava and maize (on average one-third of cropped land is planted with cassava and one-quarter with maize) these systems have a high self-sufficiency in food. Sixty percent of all households sell cassava and maize; each crop generates an average of US$90 per year.

Due to its widely varying levels of land pressure, this region allows an interesting study of natural resource management and opportunities to improve both the productivity and the sustainability of cassava-based farming systems.

Pauline Auma of Busia district (western Kenya) proudly shows her cassava harvest. Photo by Anneke Fermont, IITA.

Cassava is widely grown in East Africa today, but this is a recent development. Only three decades ago cassava production was limited to the odd corner in farms as enforcement of its production during colonial times had given the crop a very bad image. The remarkable change in the importance of cassava has been driven by sharply increasing land pressure. No longer having the land available to restore soil fertility through natural fallows, farmers replaced fallows with cassava.

Does cassava improve soil fertility?
Jacinta Ouma, a farmer in Teso district, western Kenya, explains: "Cassava drops its leaves on the soil while it grows. This improves the soil, so if I plant maize after cassava it grows better." Jacinta is not alone in this belief. A similar practice, known as *jachère manioc* or 'cassava fallow', exists in West Africa.

Almost 90% of farmers interviewed in Uganda and Kenya had the same opinion. Farm surveys in Uganda and Kenya showed that farmers plant cassava on all soil types to maintain soil fertility. If land pressure increases and soils consequently become more acidic (pH <5.8) and deficient in phosphorus (P) (available P <4-5 mg/kg), farmers increasingly plant cassava in the poorest fields in their farm. In Siaya district, western Kenya, with nearly 400 people/km^2, farmers planted nearly twice as much cassava on infertile soils than on fertile soils.

Women in Teso district (western Kenya) peel cassava for eating. Photo by Anneke Fermont, IITA.

Modeling to substantiate farmers' claims
To understand farmers' observations, we used a modeling approach. Our results suggest that planting maize on an infertile soil will result in slowly declining levels of soil organic matter, while planting cassava will slowly increase soil organic matter over time. The difference is explained by the fact that cassava grows much better than maize on infertile soils. The large amounts of easily available nitrogen (N) in its crop residues likely give cassava its reputation as a soil improver.

The model estimated that cassava returns about four times more N to the soil than maize. Through its deep rooting system and its association with mycorrhizae, cassava can pump up nutrients from the subsoil and absorb nutrients from less easily accessible pools. Nutrients from its N-rich litterfall are then redistributed to more labile pools in the topsoil.

But all is not sunshine and roses. Continuous cropping systems without external nutrient inputs deplete the soil's nutrient pool. On the highly weathered soils found in large parts of Africa, this will unavoidably result in nutrient limitation and declining crop yields. In East Africa, N and P limitations for cereal crops are widely documented. A series of field trials with over 100 farmers demonstrated that cassava production is often limited by N and P, and commonly by potassium (K).

Cassava grows better on good soils
Cassava is known for its ability to produce fair yields where other crops fail. This has led many to believe that soil fertility is not important in cassava production. Our field trials show that this is a misconception. On the contrary, using improved varieties but no fertilizer, low soil fertility was the principal constraint to production and caused farmers an average loss of 6.7 t/ha with respect to an attainable yield

The field of Nikirima Arajabu in Iganga district (Uganda) shows a very strong response to NPK fertilizer. Photo by Anneke Fermont, IITA.

of 27 t/ha. Drought caused a loss of 5.4 t/ha and poor weed control 5.0 t/ha, whereas pests and diseases caused an average loss of 3.8 t/ha.

The farm surveys showed that Kenyan and Ugandan farmers harvested on average between 7 and 10 t/ha using farmer practices. This is far below the maximum yield of 35 t/ha that was observed during the two-year on-farm fertilizer trials and clearly shows the potential for improving yields.

Using an integrated management package that consisted of an improved genotype, recommended planting practices and NPK fertilizer, average yields in farmers' fields more than doubled from 8.6 to 20.8 t/ha. About 30% of the yield increase was due to the use of improved genotypes, while a whopping 60% was the result of fertilizer use. These findings reinforce the idea that soil fertility/nutrient availability is a principal production constraint for cassava.

Options to improve system sustainability

Though fertilizer use may be the easiest way to improve cassava productivity and improve system sustainability, high prices limit the adoption of fertilizers, unless strong markets develop. Farmers have, however, other options to improve cassava productivity, increase nutrient availability, and reduce nutrient losses within their farming system. These include: (1) better weed control and drought avoidance strategies; (2) improving cassava's efficiency as a soil fertility improver; (3) returning cassava stems to the field after harvest to reduce nutrient losses; and (4) planting cassava in rotation/intercrop with (cash) crops that receive manure/ fertilizer.

Dealing with the challenges from increasing land pressure and related sustainability issues while substantially improving crop yields requires R4D teams with a strong interdisciplinary character. African farmers have shown great resourcefulness in maintaining system productivity by introducing cassava as a soil fertility improver. Now, IITA and its partners have the challenge to come up with innovative strategies to maintain or further improve system sustainability and crop productivity in increasingly stressed farming systems.

Participatory strategies of conserving yam biodiversity in Bénin

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Yam (*Dioscorea* spp.) is an important tuber crop in Bénin. Its production is intensive in Collines (Center), Donga and Borgou (North), but marginal in Atakora (Northwest), Plateau (Southeast), and in Alibori (far north). Four species are cultivated (*D. alata*, *D. cayenensis-rotundata* complex, *D. dumetorum*, and *D. bulbifera*). Among these, the native African *D. cayenensis-rotundata* complex remains the most important, preferred, and widely cultivated.

Yam production in Bénin is seriously hampered by numerous constraints including pest and disease pressure, poor soil, and changing climate. Strategic use of existing genetic diversity is thus an appropriate option for addressing these constraints in an affordable and sustainable way. For this diversity to be well studied, conserved, and used, the International Foundation for Science (IFS), Gatsby Charitable Foundation (UK), IITA, Bioversity International, and more recently the Global Crop Diversity Trust (GCDT) sponsored several research projects in Bénin between 1997 and 2009. Within the framework of these projects, different yam germplasm collection surveys have been conducted that led to a unique collection of 1,017 accessions conserved in the field by the Crop, Aromatic and Medicinal Plant

Yam tuber seeds of different accessions ready for transport to IITA genebank for ex situ conservation.
Photo from Alexandre Dansi, IRDCAM.

Biodiversity Research and Development Institute (IRDCAM) in northern Bénin.

The landraces collected were fully documented (origin, agronomic traits, and technological characteristics) and a database was constructed. With the help of farmers, the collected landraces have been fully characterized based on plant morphology and classified into 210 morphotypes. The equivalence of the diverse vernacular names that cause confusion among users has been clearly established. The geographical distribution of the morphotypes, together with genetic diversity analysis, led to the identification of four different zones of diversity. These are Zone 1: Atakora (far Northwest); Zone 2: Bariba cultural area (Northeast); Zone 3: Donga (Northwest); and Zone 4: South-Center.

Analysis at the community level within each of these four zones revealed the high yam diversity in Bénin in Zone 2 (20–82 varieties per village; 40 on average) and in Zone 3 (13–48 varieties per village; 24 on average). Zone 1 (8–27 varieties per village; 17 on average) and Zone 4 (6–-51 varieties per village; 20 on average) had less diversity. Early maturing (double-harvested) varieties dominate Zones 1 and 4, while Zone 3 is dominated by late-maturing (single-harvested) varieties. Both late- and early maturing landraces appeared in almost equal proportions across villages in Zone 2.

Within each of the four diversity zones and at community level, several varieties are disappearing or being abandoned. High rates of genetic erosion (32–48% on average) were recorded almost everywhere. This highlights the necessity and urgency of developing strategies to conserve the existing diversity both *in situ* and *ex situ* for use by present and future generations. With the financial support of GCDT, Bénin yam germplasm is already fully regenerated and safely

Germplasm collection points in Bénin.

duplicated in IITA's Genetic Resources Center at Ibadan (Nigeria) where it will be conserved both *in vitro* and in a field bank.

The causes of the ongoing genetic erosion are diverse (technological, biotic, abiotic, and cultural) and vary in relative importance according to production zones. In the far Northwest (Zone 1), for example, environmental factors, particularly poor adaptation to climate change and susceptibility to poor soils, are the most important. In the Northeast (Zone 2) susceptibility to pests and diseases and cultural beliefs are the principal reasons.

To compensate for the loss in diversity and cope with the environmental (biotic and abiotic) constraints, farmers use different strategies to exploit the existing diversity. In the dry zone of Atakora where climate change is more perceptible, farmers adopt new varieties to adapt production to actual local conditions that are characterized by increasing frequency of drought. They also alter the timing of planting and other agronomic practices. In central Bénin, farmers increasingly neglect *D. cayenensis-rotundata* varieties in favor of those of *D. alata* since these are better adapted to current agroecological conditions (poor soil, pest and disease pressure, low rainfall, etc.).

To assist farmers with this option for using the genetic diversity, a program for intensive variety exchanges between villages and producers in different diversity zones was launched in 2009 within the framework of the GCDT project. Of 20 to 30 participating villages in each zone, 15 villages have already received new varieties (40 to 50 per village). This year, 15 other villages will also benefit from this program.

Alexandre Dansi (right) and some farmers from Tchakalakou (North Bénin) in a discussion during the participatory yam characterization and classification exercise. Photo from Alexandre Dansi, IRDCAM.

The exchanges have been conducted, taking into account the preference criteria determined for each zone. This exchange of varieties is a strategic way of conserving diversity on-farm through utilization. It has a multidimensional importance that includes strengthening yam production, food security, poverty alleviation; improvement of household income generation; strengthening diversity, conservation, and use; and improvement of sociocultural conditions of rural women. The results will rapidly become more evident in Zone 1.

In the northern part of this zone negatively affected by climate change, only one to two varieties out of eight to ten are tolerant of drought. The weather is suitable for the production of dry yam chips, which are in high demand and more expensive than fresh yam, but the late-maturing varieties used for this purpose were almost absent. In the south of the zone (Toucountouna and Natitingou region) dominated by lowlands, flooding is a challenge and only a few varieties were reported to be tolerant of high soil moisture.

We believe that by using, through exchanges, a large number of the Bénin yam varieties available, farmers in these regions will have a chance to find at least 50 that will be suitable for their local conditions. A strong network of yam producers in Bénin is actually being organized by IRDCAM to sustain the effort. The farmers highly appreciate the effort.

Cultivated yam are all domesticated from wild relatives co-evolving with the cultivated forms via gene flows. Because these species are sources of useful genes, participatory strategies have also been developed to preserve their diversity *in situ* while encouraging the domestication process developed by farmers.

Made to measure: smart natural resources management approaches

Coffee-banana intercropping demo, Uganda. Photo by Piet van Asten, IITA.

Coffee and banana yields in the East African highlands are often only 10 to 30% of those achieved in commercial farms in Latin America and Asia. This is the result of a mixture of biotic stresses on the crops such as pests, diseases, and weeds, and abiotic constraints such as poor soil quality and drought.

Poor crop management practices that do not sufficiently address these constraints prevent farmers from reaping maximum benefits from their efforts.

However, the importance of these yield-limiting factors differs from region to region. The natural resources management (NRM) approach therefore starts with identifying the gap between the actual, attainable, and potential yields for each location.

Diagnostic surveys and analytical tools such as the boundary line analysis are used to rank and quantify the causes of low yields. This then guides the development of tailor-made measures and actions for farmers.

Smart use of mineral fertilizer and organic matter

Poor soils are one major cause of low yields in the East African highlands. Much of Africa's soils are old and poor, situated on very old continental plates. Only a few places have soils that still have substantial nutrient stocks, such as those derived from young volcanic material and metamorphic rocks.

Years and years of soil erosion and poor farming methods that mine minerals have worsened the situation.

IITA is working with farmers to combine organic manure and mineral fertilizer to replenish soil nutrients to meet the needs of banana and coffee.

Piet van Asten, IITA systems agronomist based in Uganda, says the approach stresses the judicious use of mineral fertilizer that is moderate in quantity, applied at the right time and in the right way, and combined with locally available organic matter.

"The combination of fertilizers and organic matter provides much-needed additional nutrients that are efficiently used up by the crops. The organic matter helps to retain mineral fertilizers applied in the topsoil and reduces losses from leaching," he says. "It also improves the soil physical properties which help to retain soil humidity and control the temperature. Plants thrive in such humid and temperate environments as the roots are better able to take up nutrients."

Sources of local organic matter are mulch, urine, manure, and compost.

Research has shown that adding mineral fertilizers and mulch to both coffee and banana nearly doubles their yields. However, the fertilizer type and dose have to supply the nutrients that are lacking.

Through mapping soil and plant nutrient status, IITA identified the missing nutrients in each region. Subsequently, it developed region-specific recommendations for using fertilizer and organic mulch in parts of Uganda.

Training materials were also developed to teach farmers how to identify nutrient deficiencies in their own farms by observing plant leaves. This should ultimately help them to localize their fertilizer needs down to the farm level.

Halting and preventing soil erosion by placing contour bunds stabilized by forage/mulch grasses and leguminous plants are also important to conserve and improve soil quality.

Smart intercropping systems

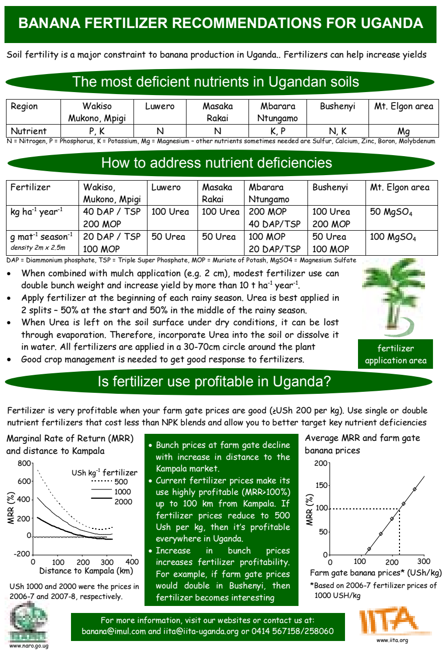
IITA has been working on promoting the intercropping of banana/plantain and coffee as research has clearly shown that intercropping works better than monocropping either crop.

Coffee, a shade-loving plant, performs well when grown under banana/plantain. Research findings showed that creating space for the banana/plantain does not reduce the yield of coffee but instead, the farmer gets bonus income from the banana.

Such intercropping systems, says van Asten, spread the socioeconomic risks of farmers as they become less vulnerable to the price fluctuations of a single crop.

"The two intercrops provide farmers with permanent piecemeal harvests from banana and annual or biannual cash booms from coffee," he said.

Intercropping has other benefits. It leads to sharing of inputs, such as fertilizers purchased through the cash crop system, such as coffee farmers' cooperatives. It also improves



BANANA FERTILIZER RECOMMENDATIONS FOR UGANDA

Soil fertility is a major constraint to banana production in Uganda.. Fertilizers can help increase yields

The most deficient nutrients in Ugandan soils

Region	Wakiso Mukono, Mpigi	Luwero	Masaka Rakai	Mbarara Ntungamo	Bushenyi	Mt. Elgon area
Nutrient	P, K	N	N	K, P	N, K	Mg

N = Nitrogen, P = Phosphorus, K = Potassium, Mg = Magnesium – other nutrients sometimes needed are Sulfur, Calcium, Zinc, Boron, Molybdenum

How to address nutrient deficiencies

Fertilizer	Wakiso, Mukono, Mpigi	Luwero	Masaka Rakai	Mbarara Ntungamo	Bushenyi	Mt. Elgon area
kg ha^{-1} $year^{-1}$	40 DAP / TSP 200 MOP	100 Urea	100 Urea	200 MOP 40 DAP/TSP	100 Urea 200 MOP	50 $MgSO_4$
g mat^{-1} $season^{-1}$ *density 2m x 2.5m*	20 DAP / TSP 100 MOP	50 Urea	50 Urea	100 MOP 20 DAP/TSP	50 Urea 100 MOP	100 $MgSO_4$

DAP = Diammonium phosphate, TSP = Triple Super Phosphate, MOP = Muriate of Potash, MgSO4 = Magnesium Sulfate

- When combined with mulch application (e.g. 2 cm), modest fertilizer use can double bunch weight and increase yield by more than 10 t ha^{-1} $year^{-1}$.
- Apply fertilizer at the beginning of each rainy season. Urea is best applied in 2 splits – 50% at the start and 50% in the middle of the rainy season.
- When Urea is left on the soil surface under dry conditions, it can be lost through evaporation. Therefore, incorporate Urea into the soil or dissolve it in water. All fertilizers are applied in a 30-70cm circle around the plant
- Good crop management is needed to get good response to fertilizers.

fertilizer application area

Is fertilizer use profitable in Uganda?

Fertilizer is very profitable when your farm gate prices are good (≥USh 200 per kg). Use single or double nutrient fertilizers that cost less than NPK blends and allow you to better target key nutrient deficiencies

Marginal Rate of Return (MRR) and distance to Kampala

USh 1000 and 2000 were the prices in 2006-7 and 2007-8, respectively.

- Bunch prices at farm gate decline with increase in distance to the Kampala market.
- Current fertilizer prices make its use highly profitable (MRR>100%) up to 100 km from Kampala. If fertilizer prices reduce to 500 Ush per kg, then it's profitable everywhere in Uganda.
- Increase in bunch prices increases fertilizer profitability. For example, if farm gate prices would double in Bushenyi, then fertilizer becomes interesting

Average MRR and farm gate banana prices

*Based on 2006-7 fertilizer prices of 1000 USH/kg

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Training material for farmers. Poster courtesy of Piet van Asten, IITA.

fertilizer-use efficiency, as fertilizer applied to the cash crop also benefits the food crop.

Intercropping improves the biophysical efficiency of the systems by providing better and more permanent canopy and soil cover that reduce erosion. It improves soil organic carbon stocks (carbon sequestration) through the biomass produced.

Another benefit, says van Asten, is that intercropping can sometimes increase the quality of some crops. For instance, under suboptimal growing conditions, shade-grown coffee is often of better quality and thus could fetch more money on the market.

Linking to input and output markets
In a study of the factors that limit farmers' usage of mineral fertilizers for their banana plants, Uganda farmers cited lack of access as one constraint. Moreover, they said it was not available in smaller packaging and more affordable sizes. IITA is working to encourage farmer cooperatives that are organized around postharvest handling, sorting, and bulking to organize the supply of inputs such as fertilizer for their members.

According to van Asten, cooperatives have better access to input/output markets and improved powers of negotiation. They have improved access to market information, bulking and storage facilities, savings and credit schemes through collaboration, and agreements with input/output dealers. They can also facilitate the exploration of niche markets through the certification of products in terms of quality, production, and techniques.

Smart extension services
To meet the information needs of farmers, IITA and partners are exploring options to make location-specific information accessible. This includes the use of extension publications, videos, and mobile phone services.

Coffee plants perform better when grown under the shade of banana plants. Photo by Piet van Asten, IITA.

Together with Grameen Foundation, IITA is exploring how information can be tailored to the location of the farmer through a (decision-tree) series of questions. The more information a farmer can provide, the more precise the recommendations will be.

The NRM work on coffee and banana shows that there are practical, readily available measures that farmers can use to increase yield and contribute towards the fight against poverty and hunger. However, they have to be region- and crop-specific for maximum impact.

"For all these measures to be successful, they must start with using clean and resistant planting materials. Investing in fertilizers for use on diseased plants is a futile exercise," concludes van Asten.

Dominique Dumet:

Safeguarding agrobiodiversity for the future

As the head of IITA's Genetic Resources Center (GRC), Dominique Dumet says she is something between a curator and an administrator. She is involved in conservation (field bank, seed bank, and in vitro bank, which includes cryopreservation for clonal crops), checking inventory, improving processes and workflows, transferring technology, and computerizing the system. In addition, she is involved in recruiting staff and selecting students, germplasm distribution and acquisition, research in plant genetic resources, staff management, research project development and proposal writing, and communication to donors on special projects and about germplasm at IITA during scientific meetings.

She is primarily interested in ex situ conservation and particularly low temperature biology and its application to conservation systems (cryopreservation, sanitation). She has an overview of all domains of germplasm conservation and takes part in various research projects as a collaborator to "add value to the germplasm." She no longer considers herself a researcher, since she spends most of her time administering the genebank and planning or writing proposal or reports. This International Year of Biodiversity, she explains what GRC plans in support of promoting biodiversity conservation.

Why is biodiversity conservation important? What are your priorities?

Our work is very important. We try to reduce the rate of irreversible loss in the biological diversity that is used in agriculture. All conservation aspects are important, but maybe the conservation *sensu stricto* comes first if we have to choose as we have a responsibility towards the international community and if we do not work well, all may suffer from our mistakes.

What do you like about working in Africa? In your field of specialization?

I am proud of my job. I hope I contribute to improving the well being of the poorest even if for one iota. I also like being in an environment very different to the one in which I grew up.

In vitro biology and cryopreservation in particular is my field of specialization. Cryopreservation fascinates me as I find it amazing that we can stop the life of a tissue and bring it back again whenever we want to do so. In the frozen stage, all biochemical or biological processes stop—that means that everything stops moving at one moment—and then the magic of life makes it start again so long as physical and chemical parameters are adequate (cooling and thawing temperature, osmotic pressure, light, growth regulators, etc.).

What are your challenges and constraints at work?

The challenges are to maintain the bank at international standards and to keep all the accessions alive. Some constraints include unforeseen requests which make us work under pressure as we still have our routine activities, and new concepts that make our system obsolete.

How do you make the many visitors to GRC understand and appreciate what you are doing?

I give information on the basic concepts of diversity, I explain why we need to conserve it *ex situ* (out of the natural environment) because of the genetic erosion taking place in the field. Then I explain how we maintain it via seeds or field and *in vitro* banks, depending on the crop. I also show some examples of diversity, e.g., cowpea seed collection and the variation observed at seed coat. I provide some background on the gaps in the collection based on GIS. And I generally conclude with the International Treaty and access to plant genetic resources for food and agriculture (PGRFA).

Please cite some concrete steps being taken by IITA in biodiversity conservation.

IITA was involved in collecting genetic resources as early as the 1970s so we do have a long history in investing in biodiversity conservation. Many collecting missions have been organized and germplasm has been also acquired from many national collections. The majority of the collections have now been described at agromorphological level, but we are still working on it for maize, for example. We have to characterize any new accessions coming into the bank.

Recently we organized a meeting and survey to develop the cowpea global conservation strategy (Trust-funded). We will have the same strategy developed for yam in 2010 (we are

Collection recording with barcode inventory system, IITA genebank. Photo by Olusegun Adebayo, IITA.

also organizing the Trust-funded expert meeting for this). We are developing more efficient conservation processes such as cryopreservation (this lowers costs but also limits genetic variation during storage). We are fingerprinting the collections of clonal crops to identify germplasm at accession level. This will further guide our collecting missions.

Do you think governments everywhere are serious about biodiversity conservation?

That depends on the country. The richer ones certainly take more serious action—but the poorest (or the less organized) do not have this 'luxury'. I think all understand the value of biodiversity but as it is a long-term investment to store and as the return on investment is not guaranteed, countries either ignore it or do little about it.

What is the state of agrobiodiversity in Africa?

It is not too bad, compared to other continents—my view on this is that Africa has not yet undergone its Green Revolution (but this opinion may be controversial). However, things may change very quickly, especially now that Africa is seen as a big field where agriculture can take off. Somehow, if we are successful in producing high-yielding crops the adoption rate of such high potential crops may quickly wipe away natural diversity, including (but not only) the landraces (varieties developed by farmers over thousands of years). When the elite genotype replaces older varieties it makes the low performing one obsolete and it increases the rate of planting (as it can generate higher revenue). We have to be vigilant about this since we, as breeders of improved varieties, are partly responsible. There is a conflict of interest between agriculture intensification and conservation of biodiversity.

Do farmers understand the need to conserve seeds or genetic resources for future generations?

In general I would think they are the first one to know about biodiversity but they may not be aware of the amplitude of the “erosion” of species. Some are already organized in community based genebanks and there are participatory conservation projects within the CGIAR but I do not know enough about the topic. This may be an important complementary approach, but participatory conservation may be difficult to sustain. Besides in community based conservation, the incentive is cultural preference. That means only materials of immediate interest for the farmers are kept.

What is the status of IITA’s seed shipment to Svalbard in Norway?

We had planned on sending more than 20,000 accessions of cowpea and its relatives, bambara groundnut, maize, and soybean in the next few years. Cowpea makes up the majority of the accessions that we are sending. There is a bit of deviation from the original plan but we are more or less on track.

Being the lead person in agrobiodiversity conservation in the Institute, how do you plan to mark the UN International Year of Biodiversity?

We plan to raise awareness about biodiversity among the youth, i.e., high school students and adults in the local community. We will organize quiz contests, tree planting activities, excursions to the IITA forest and to the genebank; produce information materials (videos, flyers, handouts) and set up roaming exhibits and posters.

We also plan to organize seminars and a field or biodiversity/community day for students, farmers, and residents in the local community. We will be coordinating with partners from the University of Ibadan, local schools, Alliance Française, and other organizations, such as National Center for Genetic Resources and Biotechnology, Nigeria Institute of Horticulture, and University of Abeokuta.

What would be your message to colleagues about biodiversity conservation?

Don’t just conserve; educate as well.

Robert Asiedu:

Advancing the development of Africa through science

Robert Asiedu is a plant breeder, whose main research interest is on tropical root and tuber crops, especially yam and cassava. From the International Maize and Wheat Improvement Center (CIMMYT) he joined the Root and Tuber Improvement Program of IITA in 1989. His initial research was on cassava and its wild relatives but he spent most of his time on yam research. He has held various leadership or management roles in IITA since 1991. He is Director, Research for Development (R4D), West Africa, and Program Director, Agrobiodiversity and Root and Tuber Systems Programs. In this interview, he talks about research on root and tuber systems, and on agrobiodiversity initiatives.

What inspires you at work?
The potential to advance the development of Africa through agricultural research is a major inspiration for me. IITA offers an excellent platform for achieving this so it is a great pleasure and a privilege to work here.

What do you like about your work as director?
I enjoy the broader opportunities and challenges the position offers to contribute to the development of the subregion through science.

How do you feel about IITA's work in West Africa and in those areas that you are in charge of as program director?
West Africa is the subregion in which the Institute has worked longest. It is fascinating to reflect on the changes in our modes of operation and interaction with partners in response to the changes in our environment. We have done well so far but there is still a lot to do.

What is your work philosophy?
To do the best I can every time.

You talk about yam as being a "part of man". What is so special about yam?
My thoughts on the links between man and yam are based on several fascinating articles by anthropologists and ethnobotanists that I have read on the subject. From West Africa through the Caribbean to the Pacific region, yam is respected and celebrated through major annual thanksgiving festivals in areas where it is cultivated as a staple.

How is progress on IITA's R4D on roots and tubers/ Agrobiodiversity?
The R4D work on tropical root and tuber crops continues to focus on genetic improvement, crop and pest management, food science and technology, and agroenterprise development.

For yam, improved options for the mass production of affordable and healthy seeds are a major component of our agenda. We have been investigating nutrient use efficiency and the role of mycorrhizal fungi in yam mineral nutrition. The research on food science/ technology is focused on understanding the functional properties required in yam tubers and products for household and industrial purposes, development of new competitive products from yam, and screening of germplasm for textural and nutritional attributes.

We continue to improve on our efficiency and effectiveness in conserving the germplasm of banana/plantain, cassava, cowpea, maize, soybean, and yam. Core collections and reference sets are being defined. These collections are characterized using molecular tools and several are being preserved in the form of DNA available for delivery to requestors. Documentation of information has been improved and are now available online. There has been a significant increase in the accessions of clonally propagated crops that are preserved *in vitro*, in addition to the field banks.

What are the challenges in working on roots and tubers? Agrobiodiversity?

The limited history of research on the tropical root and tuber crops, such as cassava and yam, has left huge gaps in the knowledge of their basic biology. This affects the pace of advancement in research, compared to that of other major staple crops. This is exacerbated by the limited pool of researchers on these crops worldwide. Research funding is very low compared with the importance of these crops in sub-Saharan Africa.

In Agrobiodiversity, the major challenges are the lack of clarity in the interpretation of various international conventions, increasing protectionism in the sharing of crop germplasm, and the apparent lack of international agreements governing the status of collections of nonplant taxa.

What can you advise colleagues?

We should constantly keep our focus on the status, needs, and expectations of those who will benefit from our work.

How could we make the partnership with national programs, donors and policymakers, the private sector, or the growers work better?

Successful partnerships are built on good foundations. Establishing partnerships involve the joint setting and common understanding of the objectives, sharing of responsibilities, and clarity of roles. Periodic and objective assessment of progress is necessary, followed by effective action on the findings. There should be mutual respect and trust in the relationship as well as regular, effective, and open communication. It is important to monitor the changing circumstances of the various partners, including institutional and policy environments, and the needs of some partners for capacity building to play their roles effectively. Good cooperation also depends on fairness in acknowledging the contributions of partners and equity in sharing results, credits, or benefits.

How would you assess IITA's efforts in agrobiodiversity conservation?

IITA has played and continues to play a key role in conserving germplasm of staple crops, underutilized crop species, and nonplant taxa that are important to African agriculture. Most national programs in sub-Saharan Africa have difficulty in providing the facility and personnel required for long-term conservation of these materials, especially the clonally propagated crops. The duplication of national collections of selected crops in our genebank is a major contribution to the assurance of long-term security. IITA works with a range of partners to continually improve the methods of preservation and characterization of the conserved germplasm.

How can we promote agrobiodiversity conservation among our audiences?

We can increase information dissemination using the print and electronic media and stakeholder consultative workshops to highlight the benefits of sustaining diversity in the food and farming systems and hence in the genetic resources on which these depend. The long-term conservation of nonplant genetic resources, such as beneficial insects and bacteria, requires even more explanation. Taking advantage of our political neutrality and links with relevant international agencies, we can engage in more consultation with policymakers in Africa to allow more freedom in making new collections of germplasm and facilitating international exchange.

Scott Miller:
Guardian of life

Photo from Scott Miller

As Deputy Undersecretary for Science at the Smithsonian Institution (SI), Scott Miller helps oversee the work of SI's science units, including the National Museum of Natural History, National Zoological Park, Smithsonian Tropical Research Institute, and others. He is also Chair of the Executive Committee of the Consortium for the Barcode of Life (CBOL), and Co-Chair of the US Government Inter-Agency Working Group on Scientific Collections, where he works on science capacity building activities on national and international scales. He maintains an active research program in the systematics and ecology of moths, and the application of that information to conservation and agricultural issues in New Guinea and Africa.

How did you become interested in biodiversity?
I grew up fascinated by nature as a child, and was able to get involved early in insect research projects at a local natural history museum, leading to a career in biodiversity. As I gained a broader perspective, I became especially concerned about helping developing countries to develop the capacity to manage their biodiversity wisely. They lead to my work in Africa.

What will the International Year of Biodiversity achieve?
This is an important opportunity to raise the profile of biodiversity issues. But we have to remember that our reliance on biodiversity is constant, and so must be our attention to understanding and wise management.

Many studies show that biodiversity is declining at an alarming rate worldwide. Could you comment on this?
I agree that biodiversity is being degraded at an alarming rate. While the exact rate can be debated, it is clearly not sustainable.

What is the value of lost biodiversity?
We need much better economic models and data for biodiversity and ecosystem services, but some studies give an idea of the economic importance [Costanza et al. 1997, Pimentel et al. 2000]. One-third of global crop production relies on insect pollinators, valued at some US$ 117 billion. Natural biological control is valued at some $400 billion. Soil arthropods that maintain soil fertility provide trillions of dollars in value to agriculture.

How can Africa reduce biodiversity loss?
Action is needed at all levels, from wise government policies, enlightened management of industries that use natural resources, through the empowerment of local people to conserve and benefit from their own natural resources. Wise management requires understanding biodiversity, and valuing conservation to maintain the benefits to society over the long term. The economies of most African countries are based on natural resources, and sustainable development requires wise management. I have always been impressed by the "Working for Water" program in South Africa as a model for integrating landscape scale conservation, invasive species management, economic development and job creation, but there are many other success stories across Africa.

You worked in the International Center for Insect Physiology and Ecology (*icipe*) in Kenya some time ago. Tell us about your experiences in conservation and sustainable development.

My time in Kenya was a tremendous learning experience for me, and I hope I was able to help build programs that will have lasting impact. I am still involved in Kenya through collaborations with *icipe*, Mpala Research Centre, and the National Museum. We tried to help local people understand the value of their biodiversity, how to restore degraded landscapes, and how to benefit from the biodiversity resources. Among other things, I was involved in an integrated conservation development project at Kakamega Forest in western Kenya that involved many synergetic components. These included strengthening forest management, replanting degraded lands, reducing the use of wood as fuel (through promoting efficient cooking stoves), developing sustainable income sources (especially "low tech" uses of natural products, and ecotourism), providing microfinance facilities, and enhancing the accessibility of health care and family planning.

What do you think of IITA's efforts in agrobiodiversity conservation/ sustainable agriculture?

Historically, IITA has played a very important role in agrobiodiversity conservation efforts. While some of those efforts remain strong, I am concerned that financial pressures threaten some of them, such as the collections that support biological control research and application in insects and fungi. The institutional infrastructure for understanding biodiversity is very weak in West and Central Africa, and as an international organization, IITA can play a vital role in filling the gap, and building national capacity. I am pleased to see IITA's leadership in the CGIAR study of biomaterial collections beyond plant germplasm, which recognizes these collections as Global Public Goods.

Do you see the investment in conservation well spent?

IITA's investment has been critical in the past, and needs to be enhanced to support future agricultural development and pest management. Climate change will bring new challenges to agriculture in Africa, and crop germplasm will be crucial, as well as knowledge of crop relatives, pest organisms, and beneficial organisms. The native forest on IITA's Ibadan campus is an important biodiversity resource, and the protection that IITA has provided it for many years has been an important service.

What is the contribution of insect diversity to agriculture?

Insects provide vital ecosystem services to agriculture, including pollination, biological control of pests, and the maintenance of soil fertility. A recent study on the impact of CGIAR research in Africa (Maredia and Raitzer 2006) found that 80% of the impact (valued at $17 billion) resulted from four biocontrol programs using insects and mites. All those programs had to solve significant taxonomic problems (e.g., understanding the biodiversity) before they became successful, underscoring the importance of research and documentation.

How does the Consortium for the Barcode of Life contribute to the conservation and protection of biodiversity?

DNA barcoding is a species diagnostic system using short sequences of DNA (www.barcoding.si.edu), and the Consortium is an international organization promoting the development of standards and the building of the reference library of sequences. Understanding species, being able to identify them, and being able to communicate about them are basic to managing and using biodiversity. Thus, CBOL contributes through allowing fast and accurate identifications in difficult situations such as the immature stages of plant pests, the wood or roots from medicinal plants, or parts of butchered wildlife or fish in the illegal trade.

CBOL works closely with organizations with similar interests, such as BioNET INTERNATIONAL and the Global Taxonomy Initiative of the Convention on Biological Diversity. We are communicating with organizations such as the International Plant Protection Convention to help establish formal protocols for the DNA-based identification of agricultural pests.

Ken Neethling:
Biocontrol champion

Ken Neethling is the chief executive officer of Biocontrol Products (BCP) based in South Africa. An engineer by training, he started working for BCP 13 years ago. Commercial biocontrol was a relatively new concept then, he says. Along the way, he became exposed to commercial fermentation and the world of microbes. Today, he manages the business and works with a "very competent team".

BCP started as a biocontrol company, initially producing a fungal nematicide (egg stage) to work alongside those targeted at adult nematodes in an IPM program. In 1997, the Biological Control of Locusts and Grasshoppers (LUBILOSA) project approached BCP to commercially produce Green Muscle®, a flagship product, for the control of locusts, relates Ken. BCP has subsequently used its platforms of research, registrations, and production to bring other microbes to a commercial level. BCP's range today includes many bacteria, fungi and plant extracts—for a diversity of uses in agriculture, including growth promotion, insecticides, nematicides, fungicides, and nutrition.

What are the prospects of biological control products in Africa?

BCP's corporate slogan is "restoring nature's balance". In many respects this sums up the case for biocontrol products: They're natural, generally safe to nontargets and already found in nature; they have a smaller environmental footprint and work in harmony with nature; they restore balance; this recognizes that the way we have historically treated our

Ken Neethling (right) and colleague Sifiso showing off one of BCP's industrial fermenters. Photo from Ken Neethling, BCP.

environment was out of balance. Restoring balance also implies sustainability and "subeconomic threshold" control strategies.

Biocontrol products are not a silver bullet—they're part of a solution. When considering the growing global population that needs to be fed, the fertile soils of Africa are also part of the solution.

If Africa's decision makers are receptive, then I believe biological control has a bright future in this continent.

IITA was part of the team that developed Green Muscle® years ago. The technology is one product of research that has proved quite successful. Tell us more about Green Muscle®.

I have a very high regard for IITA's researchers…The development of Green Muscle® was truly a multidisciplinary, multicultural and multinational success story. BCP's contribution to the development of Green Muscle® was in the areas of production, stability, formulation, costing, packaging, and providing product for trials. Over the years, BCP has also provided training on aspects of quality control and standard operating procedures. We advise on storage and provide analytical services to our Green Muscle® customers. BCP has also contributed to the registration process in some of the affected countries.

Why did it take Green Muscle® almost 10 years from development to deployment to get into the market when it was so obviously a very effective product?

BCP is but one of the many champions of Green Muscle®. We worked tirelessly over the last 10 years. There were, and still are, many challenges.

The technology had to break new ground. For example, biocontrol has a completely different mode of action to the commonly used synthetic chemicals—it is slower acting on the knockdown, but with a longer residual and less environmental effect. In the case of Green Muscle®, the locusts stop feeding after 2 days. They become lethargic and, due to predation (they're safe for birds and mammals to eat) they are quickly picked off. So the challenge was to show that <u>not</u> having hundreds of poisoned locust cadavers lying around was a good result!

The other challenge was cost—I'm sure many can appreciate that a biocontrol product, produced initially in small quantities, would have a very hard time competing in terms of price or cost against chemicals churned out in massive factories. Make no mistake, cost is important and especially in locust control, every dollar needs to be stretched to extract maximum benefit.

However, cost is a much bigger picture than simply the price of the active ingredient per hectare. Recent studies have indicated that the lifecycle cost of chemical control (including disposal of obsolete stock, soil decontamination, loss of pollination services, etc.), is higher than that of biocontrol.

I believe that there is still scope for even wider deployment—for example, preventative treatment campaigns in eco-sensitive breeding grounds that could prove more cost-effective than an emergency response to an outbreak.

What have been your challenges and opportunities in marketing Green Muscle®?

Our main marketing challenge is that we have so many different "customers" to consider.

First and most importantly the general population, who risk losing their food and livelihood to locust swarms of sometimes biblical proportions; the governmental plant protection departments of the various countries, who manage smaller campaigns within their borders; regional (i.e., cross border) emergency outbreak management bodies that largely depend on external funding; the United Nations, which coordinate and disperse donor funding for locust control; and the donor community, who ultimately hold the purse strings that need to be opened in large emergency campaigns.

How much is the demand for Green Muscle® in Africa?

Demand is obviously directly linked to locust outbreaks and contingent donor funding. To be honest, it has been frustratingly sporadic. This is not ideal from a production perspective, as it is more cost-effective to run continuously, with regular planned off-takes. To date, supply has been able to keep up, but we have also had to burn the midnight oil a few times in an emergency.

Is there any interest in the product outside Africa?

Yes there is interest outside Africa. My interpretation of this is that "good news travels fast". But finding the right partners, doing trials, establishing market potential, drawing up agreements, licensing and all the other factors mean that this type of product can never be expected to be an "overnight success".

What is the outlook of biocontrol, in general, in Africa? The world?

In summary, I would say the outlook is good, but this needs work and commitment from all stakeholders before it can have a meaningful impact on Africa. The same would apply to the rest of the world, except that consumer awareness (and hence demand) is higher in the developed world.

Do you think biocontrol would become competitive enough against chemical-based control measures?

Historically it can be argued that biocontrol hasn't challenged chemical-based control measures, but that was partly due to the way we viewed this notion of control. What we have seen is that novel strains and human ingenuity are helping to make biocontrol a worthy alternative to chemicals. We've experienced this first hand with Green Muscle® in large-scale control operations, where we have had control comparable to that of the chemicals. In some extreme situations, such as in Algeria, we saw exceptional control, a level greater than 90%.

What would help to popularize the adoption of biocontrol technologies?

This challenge requires total commitment from many diverse stakeholders. But the basic principle, "Use it or lose it," applies. Biocontrol technologies must be used and must make a difference in areas that count; otherwise they will forever remain in the research domain.

Green Muscle has gone the way of traditional R&D (i.e., research/ science -> product development -> commercialization). When should the private sector come in?

Necessity is the mother of invention, so while I lean towards the commercial sector as being more in touch with the needs of the market, there is nothing to say that scientists can't also fulfill this role. What is important is that there is a clear path to market, with early involvement of a commercial partner and good communication among all stakeholders during the development cycle.

What is needed to push agricultural technologies, such as biocontrol, from the research shelves to the market and eventually to the intended end-users?

A lot of money, for starters! Much more than I think anyone ever estimated. And a lot of time too. It needs product champions across the board: in government, in research, in the media, and in the procurement and purchasing channels.

What would you tell scientists or research organizations, such as IITA, working on biocontrol development?

There is a lot of good work being done by scientists around the world—biocontrol technology development is one of the many exciting and challenging areas with so much potential. The aim of science is to increase knowledge for the purposes of serving humanity and protecting our planet—whatever we research, develop, and commercialize must have these values as their foundation.

Bambara groundnut seeds from the IITA genebank. Photos by IITA.

DNA barcodes for pathogens of African food crops

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Diagnostic tools play an important role in the accurate and timely identification of the pathogens involved in disease etiology, also in disease surveillance, the development of host plant resistance, and quarantine monitoring. They also support safe conservation and the exchange of germplasm. Detailed knowledge of pathogen population structure and genetic diversity is a prerequisite to developing unambiguous diagnostic tools and is critical in establishing disease management tactics. Increasingly, modern diagnostic tools are being based on the DNA characteristics of the pathogen as they are neutral to growth stage and environment; offer adequate diversity to distinguish species, strains, substrains, isolates, and even individuals; and offer convenience of detection using modern bio-techniques such as polymerase chain reaction (PCR).

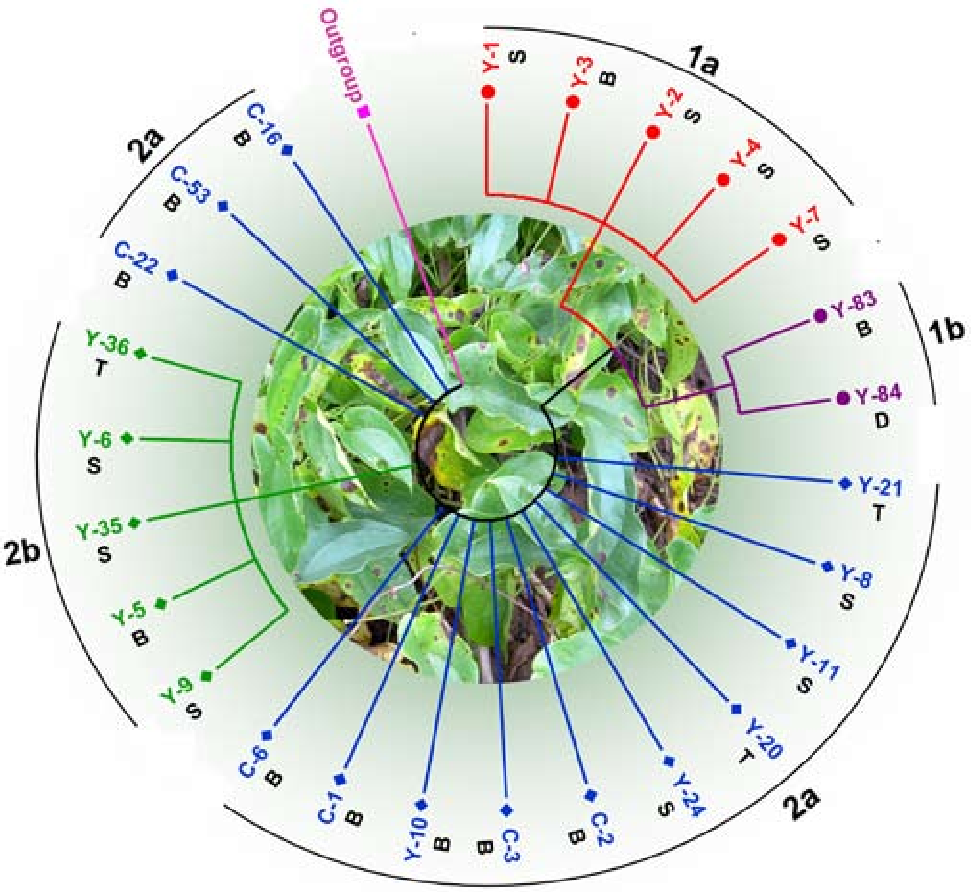
At IITA, we undertook a new initiative to characterize pathogen populations and recognize unique stretches of sequences—known as ”DNA barcodes” —that can be used as genetic markers for the rapid diagnosis of the pathogens and pests affecting the African food crops on which we work. DNA barcodes, otherwise also known as DNA markers or DNA fingerprints, are essentially a short stretch of nucleotide sequences that aid in the specific identification of species strains or substrains. They are used to resolve pathogen taxonomy and phylogeny.

The work focuses on economically important fungal, viral, and bacterial pathogens, insects, and nematodes. The information is used to gain ”barcode” designation in global sequence databases such as BOLD (the barcode of life data system) or NCBI (National Center for Biotechnology Initiative), and to assemble these into a database for public access.

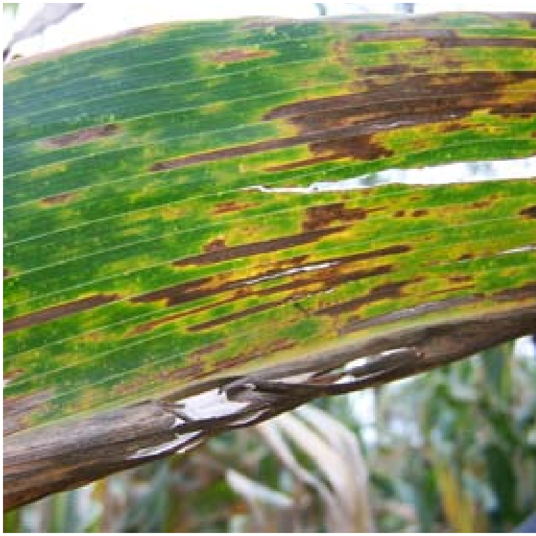
This approach—a combination of conventional biology, biotechnology, and bioinformatics—involves the selection of targets, amplification of target genes using universal or generic primers, sequencing of target genes and identification of unique barcodes, and development of PCR-based diagnostics for specific detection of barcodes. This approach is particularly useful in identifying pathogens that are difficult to distinguish either by morphology or other properties. It offers high accuracy in identifying quarantine pathogens and reduces the risk of spread. In addition to diagnosis, it also contributes to the fundamental understanding of pathogen phylogeography and relationship with host and contributes to the development of management tactics.

We are using this approach to characterize the fungal pathogen(s) causing anthracnose—the most destructive disease of yam and cassava in West Africa. The disease causes severe yield losses in both crops and often kills the plant. The causal fungus, *Colletotrichum gloeosporioides* Penz., is widespread in West Africa. We identified various isolates of this fungus differing in morphology, growth characters, and pathogenicity, then investigated their genetic relatedness and diversity through molecular analysis of a set of 25 reference isolates (17 from yam and 8 from cassava) using multilocus gene targets. They were grouped into spot (S) and blight (B) isolates based on symptoms they induce. Both types of isolates infect yam, but only B isolates infect cassava. We assessed the genetic diversity in these isolates by nucleotide sequencing and cluster analysis of the ~540 base pair (bp) nuclear ribosomal internal transcribed spacer region (ITS1, ITS2 and the 5.8S gene) and partial gene sequences of actin (~240 bp) and histone (~370 bp).

Phylogenetic cluster analysis grouped the 25 isolates into two major clades (a clade is a group that shares features from a common ancestor) and two subclades within the major clades. Both the S and B isolates were distributed between the two clades (see figure). All the isolates in clade 1 were unique to yam. Seven of these isolates (YA08-1, YA08-2, YA08-3, YA08-4, YA08-7, Y-83, Y-84) formed a genetically



Clustering of 25 yam isolates based on rDNA sequences. Isolates from yam are indicated as 'Y', and cassava as 'C'. Isolates causing blight symptoms are indicated as 'B' and spot symptoms as 'S'. Gibberella moniliforme *is the outgroup.* Courtesy of Lava Kumar, IITA.



Left: Severe anthracnose symptoms on cassava stem. Photo by Ranajit Bandyophadyay, IITA.
Right: Gray leaf spot lesions in maize. Photo by Anu Aregbesola, IITA.

distinct lineage, indicating that they could be new strains unique to yam. Isolates in clade 2 infect both cassava and yam, suggesting their capability to infect a wide range of plants. It is plausible that clade 2 isolates could be those most frequently occurring on yam and cassava because of their ability to survive on weeds and other crops. We recognized unique sequence motifs and designed diagnostic PCR primers directly from infected plant tissues for the specific amplification of *C. gloeosporioides* infecting yam and cassava.

Using a similar approach, we characterized the fungal agent associated with gray leaf spot (GLS), the most destructive disease of maize. We found that GLS in Nigeria is caused by a distinct species of *Cercospora*, but not *C. zeae-maydis*, a previous conclusion derived from conventional analysis. This work, in addition to confirming the GLS etiology, allowed us to establish a unique set of primers for the specific identification of the GLS pathogen prevalent in Nigeria.

Through comparative genomics, we identified common genome regions in cassava mosaic begomoviruses occurring in sub-Saharan Africa. We developed a simple multiplex PCR assay that can detect all the major viruses in cassava mosaic disease etiology. This test has been adopted for virus indexing of cassava propagated in vitro.

To aid us in diagnostics research, we developed a simple and cost-effective procedure suitable for extraction of DNA from seeds, leaves, stems, tubers, and even roots. The resultant DNA is suitable for PCR-based diagnoses of fungi, bacteria, and viruses in the infected tissues of a wide range of plant species. It is handy for the quarantine monitoring of germplasm. We are establishing a repository of diagnostic protocols in an approach we call the ”Diagnostic Basket®” and will make it available to users.

Barcodes and diagnostic tools provide a solid base for the understanding of the taxonomy and diversity of pathogens infecting African food crops.

African yam bean: a food security crop?

Daniel Adewale, d.adewale@cgiar.org

Biodiversity assures the evolutionary continuity of species. The collection and conservation of diversity within species are a safeguard against the loss of germplasm. They provide a buffer against environmental threats and assure continual and sustainable productivity. Global food security is becoming shaky with increasing dependence on a few major staple crops. This has resulted in an alarming reduction not only in crop diversity but also in the variability within crops.

The conservation and maintenance of agrobiodiversity of neglected and underutilized plant species such as African yam bean (AYB) in seed banks aim at contributing to food security and preventing a potential food crisis. Increasing the use of underutilized crops is one of the better ways to reduce nutritional, environmental, and financial vulnerability in times of change (Jaenicke and Pasiecznik 2009); their contribution to food security is unquestionably significant (Naylor et al. 2004, Oniang'o et al. 2006). Among other things, the consumption of a broader range of plant species ensures good health and nutrition, income generation, and ecological sustainability.

Diversity in color, color pattern, structure, texture, brilliance, etc. of African yam bean seeds. Photo by Daniel Adewale, IITA.

Potentials of African yam bean

The plant *(Sphenostylis stenocarpa)* is one of the most important tuberous legumes of tropical Africa. It is usually cultivated as a secondary crop with yam in Ghana and Nigeria. A few farmers who still hold some seed stocks, especially the white with black-eye pattern, plant it at the base of yam mounds in June or July. The crop flourishes and takes over the stakes from senescing yam. It flowers and begins to set fruits from late September and October. The large bright purple flowers result in long linear pods that could house about 20 seeds.

The seed grains and the tubers are the two major organs of immense economic importance as food for Africans. This indigenous crop has huge potential for food security in Africa. However, there are cultural and regional preferences. In West Africa, the seeds are preferred to the tubers but the tubers are relished in East and Central Africa (Potter 1992). The crop replaces cowpea in some parts of southwestern Nigeria (Okpara and Omaliko (1995). Researchers (Uguru and Madukaife 2001) who did a nutritional evaluation of 44 genotypes of AYB reported that the crop is well balanced in essential amino acids and has a higher amino acid content than pigeon pea, cowpea, and bambara groundnut.

Apart from the use of soybean as an alternative to animal protein, protein from other plant sources is not often exploited. The protein content in AYB grains ranged between 21 and 29% and in the tubers it is about 2 to 3 times the amount in potatoes (Uguru and Madukaife 2001, Okigbo 1973). AYB produces an appreciable yield under diverse environmental conditions (Anochili 1984, Schippers 2000). Another positive contribution of the crop to food security is the identification of the presence of lectin in the seeds, which could be a potent biological control for most leguminous pests.

Biodiversity

Although the vast genetic and economic potentials of AYB have been recognized, especially in reducing malnutrition among Africans, the crop has not received adequate research attention. Up to now, it is classified as a neglected underutilized species or NUS (Bioversity 2009). Devos et al. (1980) stressed that the danger of losing essential germplasm hangs over all cultivated food crop species in tropical Africa, especially those not receiving research attention. The quantity and availability of AYB germplasm is decreasing with time. At one time, Klu et al. (2001) had speculated that the crop was nearing extinction; its inherent ability to adapt to diverse environments (Anochili 1984, Schippers 2000) may have been responsible for its continual existence and survival. Nevertheless, scientists think that the genetic resources of AYB may have been undergoing gradual erosion.

IITA keeps some accessions of the crop, but otherwise, its conservation in Nigeria is very poor and access to its genetic resources is severely limited. Seeds of AYB seem to be available in the hands of those who appreciate its value, i.e., the elderly farmers and women in a few rural areas in Nigeria. The ancient landraces in the hands of local farmers are the only form of AYB germplasm; no formal hybrid had been produced as yet.

Improvement of the crop is possible only when the intraspecific variability of the large genetic resources of the species is ascertained. The genetic resources of AYB need to be saved for use in genetic improvement through further exploration in tropical Africa and for conservation.

Understanding AYB

Eighty accessions (half of the total AYB collection under conservation in the IITA genebank) were assessed for diversity using morphological and molecular methods. Thirty selected accessions were further tested in four ecogeographical zones in Nigeria to understand their productivity and stability. The breeding mode was also studied.

Findings show that each of the 80 accessions of AYB has a unique and unmistakable genetic entity, promising

Tuber yield per stand of AYB accession TSs96 at Ibadan, 2006. Photo by Daniel Adewale, IITA.

to be an invaluable genotype as a parent for crop improvement. Morphologically, two groups have evolved: the tuber forming and the nontuber forming.

Grain yield differed among individual accessions and across the four agroecologies. The average grain yield across the four diverse environments in Nigeria (Ibadan, Ikenne, Mokwa, and Ubiaja) was ~1.1 t/ha; however, grain yield at Ubiaja was well above 2 t. Most agronomic and yield-determining traits had high broad sense heritability and genetic advances, assuring high and reliable genetic improvement in the species. AYB is both self fertilizing and an outcrosser; the latter trait is exhibited at about 10%.

The good news is improvement through hybridization is possible within the species.

An African yam bean plant showing mature pods ready for harvest. Photo by Daniel Adewale, IITA.

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