twas

National Agricultural Research Laboratories

KAWANDA, UGANDA

NARL

EXCELLENCE IN SCIENCE

Profiles of Research Institutions in Developing Countries

PUBLISHED BY TWAS,
THE ACADEMY OF SCIENCES
FOR THE DEVELOPING WORLD

EXCELLENCE IN SCIENCE

Profiles of Research Institutions
in Developing Countries

EXCELLENCE IN SCIENCE
Profiles of Research Institutions in Developing Countries

Published by TWAS, the academy of sciences for the developing world

ICTP Campus, Strada Costiera 11, 34151 Trieste, Italy
tel: +39 040 2240327, fax: +39 040 224559
e-mail: info@twas.org, website: www.twas.org

TWAS Executive Director
Romain Murenzi

TWAS Public Information Office
Daniel Schaffer, Gisela Isten, Tasia Asakawa, Cristina Serra

Design & Art Direction
Studio Link, Trieste (www.studio-link.it)

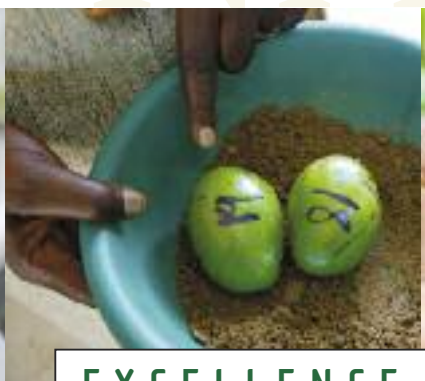
Printing
Stella Arti Grafiche, Trieste

This text may be reproduced freely with due credit to the source.

twas

National Agricultural Research Laboratories

KAWANDA, UGANDA



EXCELLENCE IN SCIENCE

Profiles of Research Institutions in Developing Countries

TWAS COUNCIL

President
Jacob Palis (Brazil)

Immediate Past President
C.N.R. Rao (India)

Vice-Presidents
Fayzah M.A. Al-Kharafi (Kuwait)
Bai Chunli (China)
Francisco J. Barrantes (Argentina)
Atta-ur-Rahman (Pakistan)

Secretary General
Dorairajan Balasubramanian (India)

Treasurer
Mohamed H.A. Hassan (Sudan)

Council Members
Adel E.T. El-Beltagy (Egypt)
Reza Mansouri (Iran)
Keto E. Mshigeni (Tanzania)
Harold Ramkissoon (Trinidad & Tobago)
Abdul H. Zakri (Malaysia)

Foreword

For more than a decade, *TWAS, the academy of sciences for the developing world*, in collaboration with several other organizations and funding agencies – including the United Nations Development Programme's Special Unit for South-South Cooperation (UNDP-SSC), the Global Environment Facility (GEF) and the Packard Foundation – has developed a large number of profiles of scientific institutions of excellence in the developing world. The profiles have been published as books (by Harvard University Press and Kluwer Academic Publishers), as articles (in *Environment Magazine*) and as news stories (in the *TWAS Newsletter*).

To date, more than 150 institutions have been examined. Each profile details how the institution has developed and how its research programmes are organized. Each explores the institution's strengths, probes its weaknesses – and, most importantly – describes how its experience can offer valuable lessons for other institutions seeking to build scientific capacity.

A major goal of this decade-long initiative has been to showcase the high level of scientific excellence taking place in the developing world and to illustrate how science is being put to work to address critical social needs in the South. In this way, we hope that our expanding series of 'best practices in the applications of science and technology' can

serve as a valuable blueprint for policy-makers and those involved in the administration and management of national policies and programmes.

The case study that follows – which examines the work of the National Agricultural Research Laboratories (NARL) in Uganda – is about one such successful scientific institution in sub-Saharan Africa.

Dismal statistics abound about the state of science and society in sub-Saharan Africa. And numerous publications detail the difficult circumstances faced by the people there. Yet, encouraging signs of progress are also emerging. Over the past decade, six of the world's 10 fastest growing economies have been in sub-Saharan Africa. These countries have been led by Angola, which has experienced an annual growth rate of more than 11%, and also include Nigeria, Ethiopia, Chad, Mozambique and Rwanda, each of which grew at an annual rate exceeding 8%.

Yet, much of this economic growth has been commodity-based and due in no small measure to China's insatiable appetite for the continent's metals and minerals. While investments in science and technology have also grown, this growth has been at a far slower pace. Indeed, Rwanda is the only country in sub-Saharan Africa that spends more than 1% of its gross domestic product on science and technology.

Nevertheless, it would be a mistake to ignore the increasing emphasis that countries throughout sub-Saharan Africa are placing on science and technology as primary engines

of sustainable growth. The trend is discernible, in part, in the increasing number of scientific institutions of excellence that are making significant contributions to their societies.

Investments, no doubt, remain too small, and the number of scientific institutions of excellence too few in number. Progress, moreover, has been uneven and fragile. And reversals in fortune are not uncommon. Moreover, the global economic crisis, which began in mid-2008, has placed the future at risk even for those African countries that have made significant strides forward. Yet, it should also be noted that many countries in sub-Saharan Africa have not only weathered the economic crisis better, but have also rebounded more quickly, than have the United States or the majority of countries in Europe.

In short, what has been happening in sub-Saharan Africa over the past decade is encouraging, and science and technology have become important tools in helping to advance these positive trends. TWAS is dedicated to exploring these developments by profiling scientific institutions of excellence that are leading the way for a better future on the continent – institutions like the National Agricultural Research Laboratories.

Daniel Schaffer
TWAS Public Information Officer
Trieste, Italy
March 2011

Contents

Sidebars

Key Personnel

Snapshots

Introduction and Issues

Uganda is an emerald country. With the exception of the arid northeast, its hills and plains are among the most fertile in Africa. Since time immemorial, human's closest relatives – the chimp and the gorilla – have stalked its lush, impenetrable forests. But today Uganda's rolling hills are coming under increasing pressure to feed a growing population.

Deforestation and climate change are adding stress to a farming population that still relies on traditional methods of agriculture. Most farmers, in fact, are subsistence farmers who depend on rainwater to sustain their crops. Moreover, a growing discrepancy exists between the country's rural poor and urban population. Young city dwellers, driving cars and working in office buildings, often view farming as an impoverished lifestyle that requires backbreaking work and offers scant prospects for a better future.

However, things are slowly changing. A century of agricultural research is finally starting to bear fruit for Uganda's rural residents. New farming techniques tailored to local conditions and challenges are being developed. Biotechnology is being harnessed to produce crop varieties resistant to pests.

At the centre of this development is a research centre perched on a hill northwest of the country's capital Kampala. The hilltop has housed agricultural research since the mid-1930s. Through the years it has taken on many different roles. Until recently, it garnered renown as the Kawanda Agricultural Research Institute, with a strong reputation in

NATIONAL AGRICULTURAL RESEARCH LABORATORIES (NARL)

- *13 km Bombo Rd., Kawanda, Kampala, Uganda*
- *tel: +256 414 567649, 574073*
- *fax: +256 414 567649, 567226*
- *e-mail: karidir@imul.com*
- *website: narl.go.ug*

NARO AND NARL

• NARL is a part of Uganda's National Agricultural Research Organisation (NARO). NARO was created in 1992 as a semi-autonomous institution consolidating Ugandan research in crops, livestock, fisheries and forestry. In 2005 the institution was re-structured as an umbrella organization for all institutions that conduct agricultural research in Uganda using public funds. The NARO secretariat is based in Entebbe, southeast of Kampala, on the shores of Lake Victoria, about a 40-minute drive from NARL's Kawanda headquarters.

Nearly 900 people work for NARO; approximately 250 are scientists. The organization receives funding from the Ugandan government, donor agencies and international research funders. Its research budget for 2010/2011 totalled nearly UGX75 billion (Uganda Shilling) or USD31.5 million.

NARL is by no means Uganda's only crop research institute. It works closely with the National Crops Resources Research Institute (NaCRRI) in Namulonge north of Kampala, another NARO institute. Since 2005, NaCRRI has become the administrative home for Uganda's research programmes focusing on coffee, bananas, horticulture crops, beans, sweet potatoes, cassava and cereals. Together, the two institutes conduct research on important Ugandan staple crops. However, much of NARO's research on bananas continues to be carried out in Kawanda.

SNAPSHOTS

research on coffee, horticultural crops and bananas, a staple in Uganda. Today, it serves Uganda's agricultural research community as the National Agricultural Research Laboratories (NARL), one of east Africa's leading centres of biotechnology.

Research conducted on the hill in Kawanda has weathered Uganda's turbulent political history to become a byword for quality African science. In the early days, the colonial government concentrated on cash crops such as coffee and cotton. Later, the focus shifted to more local priorities. For example, researchers have developed a pest-resistant banana variety. And they have teamed with commercial farmers in Uganda to promote sustainable land-use practices. Now, modern biotechnology is being harnessed to develop new crop varieties.

Research based at Kawanda has also played a role in protecting Uganda's bountiful biodiversity. The country has some of the highest concentrations of species in Africa. More than 5,000 plant species are found in Uganda along with 345 species of mammals, 1,015 species of birds, 165 species of reptiles, and 43 species of amphibians.

> *Research conducted on the hill in Kawanda has weathered Uganda's turbulent political history.*

KEY PERSONNEL

AMBROSE AGONA, director of NARL

• ***Ambrose Agona*** *has been NARL's director since 2007. Before then he led the institute's post-harvest programme. As a researcher, Agona pioneered a method for using black polyethylene sheets stretched over holes in the ground to kill post-harvest grain damaging insects with the sun's rays. He has a bachelor's degree in crop science from Makerere University in Uganda, a master's degree in biology from the University of Wales in the UK and a doctorate degree in biology from the University of Zimbabwe.*

NARL is involved in projects to protect plant species that are threatened in the wild, some of which play a key role in traditional medicine – for example, the *Prunus africana* tree used to treat urinary tract disorders; the *Warburgia ugandensis* tree whose bark is used by nomads to treat venereal disease; and *Hallea rubrostipulata*, a tree whose bark and roots are used to treat malaria.

A key component of Uganda's vibrant agricultural research landscape, NARL is helping to build a brighter, healthier and wealthier future for all Ugandans.

A Century of Agricultural Research

Most visitors to Uganda arrive at the international airport in Entebbe on the shores of Lake Victoria. The airport is easily accessible from the capital city of Kampala, which is just 40 kilometres away.

Agricultural research in Uganda can be traced to the establishment of the Entebbe Botanical Gardens in 1898. At the time, Entebbe was the seat of the British protectorate government. The British were keen to maximize the return from the fertile fields of Uganda, so they founded the gardens that today stretch 1.5 kilometres along Lake Victoria's shoreline. The gardens were populated by an inventory of indigenous plants and became test-beds for introduced species.

The oldest studies on Ugandan soil types and such colonial cash crops as cotton and coffee originated in the gardens. Other plants are preserved there as well. Visitors can still admire a small patch of rainforest within the gardens – the only one that has been preserved so close to Uganda's capital. Scenes from the first Tarzan movies are said to have been filmed there in the 1930s.

A LEGACY AT RISK

• *Charcoal burning, increasing cultivation and a growing population are threatening Uganda's bountiful biodiversity. At-risk species include wild-growing indigenous fruit trees and plants that are used in traditional medicine by more than 80% of Ugandans.*

The Entebbe Botanical Gardens are an important line of defence in the fight to conserve threatened plant species in Uganda. The 40-hectare gardens house nearly 400 plant and tree species. An in-garden nursery propagates threatened plant species, and researchers encourage their planting throughout the country.

"Local communities often take local plants for granted," says Catherine Kiwuka, in-situ *conservation officer at the gardens. Indigenous fruits, such as those from the* Garcinia buchananii *tree, are nutritious but not tended to by farmers. Meanwhile, medicinal plants are becoming rare in the wild due to over-exploitation. These include two evergreen trees:* Warburgia ugandensis, *which is believed to have anti-malarial properties, and* Prunus africana, *which is thought to be effective against prostate cancer. Both are grown in the gardens.*

"Deforestation is a big problem," says Kiwuka. "People are cutting down the wild plants that could encourage crop improvement."

SNAPSHOTS

> *"The institute's transfer from Entebbe to Kawanda marked the beginning of serious agricultural research and development activities in Uganda."*

Having a natural genetic variety to draw on can help crops cope with threats posed by pests and climate change, she explains. Yet, a 2010 survey in Kisoro district in southwestern Uganda found no wild relatives of millet, a grain used to make beer and porridge.

Kiwuka and her colleagues try to sensitize villagers to the importance of keeping the forests around them healthy. "We go out into the field and empower farmers. We explain to them the principles of good field management and tilling practices."

The gardens are also involved in creating village seed banks where farmers can 'borrow' grain. The concept works like this: Farmers take 1 kilogramme (kg) of grain from the bank to sow their field. After harvest, they return 2 kg of grain to the bank, enabling other farmers to borrow. Think of it as paying 'interest in kind' as a way to grow a seed bank for all farmers.

Indeed the seed bank, in large measure, is an upscale version of the Uganda National Genebank in Entebbe, where seeds are dried and stored in freezers. More than 2,500 samples are being conserved in this way. The samples can be kept viable for up to 50 years. The Uganda National Genebank is part of the country's Plant Genetic Resources Centre, a unit of NARL.

SNAPSHOTS

In 1937, the colonial government's agricultural research activities moved to a rubber farm on a hill 13 kilometres northwest of Kampala. The government had acquired the farm from its Danish owners in 1934. The new headquarters were named Kawanda Agricultural Research Station.

"The transfer from Entebbe to Kawanda marked the beginning of serious agricultural research and development activities in Uganda," says Ambrose Agona, director of NARL.

KAWANDA'S MANY INCARNATIONS

1937-1992	*Kawanda Research Station*
1992-2005	*Kawanda Agricultural Research Institute*
2005-present	*National Agricultural Research Laboratories, Kawanda*

SNAPSHOTS

At first, the institute's scientific staff were entirely white. Indigenous Ugandans were only trained as technicians or data collectors. The founding father of Ugandan science was Zerubabel Nyiira who was trained as a technician at Kawanda and eventually received his PhD in bioecology and biostatistics. He would later become the first chief executive officer of the Uganda National Council for Science and Technology, serving from 1990-2005.

In the 1950s, researchers at Kawanda undertook a detailed mapping of Ugandan soils. By the time Uganda gained its independence in 1962, the research institute's focus was shifting from the cash crops promoted by the colonial rulers to a more development-oriented agenda. The late 1960s witnessed the beginning of serious training efforts for indigenous scientists. It was also at this time that the institute began to build a national reputation by focusing on the needs of local farmers.

The 1970s and early 1980s were a turbulent time in Uganda, and the institute did not escape unscathed. Although it continued to function throughout the rule of Idi Amin, it was overrun in the mid-1980s when the

National Resistance Army marched on Kampala from the west. The army camped out at the institute, which provided an important strategic advantage because of its hilltop location. The institute was looted and many of its research records were destroyed.

"The institute was abandoned for a year," says Wilberforce Tushemereirwe, leader of NARO's banana research programme, who was a young researcher at Kawanda at the time. "When we returned, we found that the place had been completely ransacked except for some books and desks. The science records were gone." It took four years for the institute to start functioning properly again. Data that had not yet been fully analysed was lost, and experiments had to be repeated. "It was a mess," Tushemereirwe says.

After the war, the new government, headed by president Yoweri Museveni, rebuilt the institute. In 1992, it became a part of the newly created National Agricultural Research Organisation (NARO). At the time, it was called the Kawanda Agricultural Research Institute (KARI). In 2005, its name was changed to the National Agricultural Research Laboratories (NARL) as part of an institutional re-organization.

Today, Uganda is nearly self-sufficient in food production. "Our food security status is very strong, especially when compared to the rest of the region," says Agona. "We don't rely on just one crop. Instead we grow a wide variety of crops. This helps make our food supply more resilient."

Research at NARL

NARL has evolved from the cotton-, sugarcane- and coffee-based research centre of the colonial era to a broad-based institute for agricultural development and farmer training.

Today NARL's efforts extend far beyond Kawanda hill. The laboratory has many collaborative activities with other NARO institutes – most notably, NaCCRI in Namulonge, which administers Uganda's research activities on such commodities as banana, millet, maize, cassava and sweetpotato.

However, NARL has the country's most advanced agricultural laboratories, and is at the forefront of a significant foray into modern biotechnology.

NARL research is carried out in eight units.

- The Plant Genetic Resources Centre and Entebbe Botanic Gardens is the only NARL unit not based in Kawanda. Its duties include characterizing Uganda's plant genetic resources and encouraging their sustainable use by farmers.
- The Natural Agricultural Biotechnology Centre not only houses Kawanda's state-of-the-art genetic engineering laboratory but also pursues research that relies on more traditional breeding technology, including tissue culture. The centre initially focused on bananas but its research now extends to beans, coffee and passion fruit.
- The Crop Post-Harvest Research Unit explores strategies for reducing post-harvest crop losses, including improvements in storage techniques, pest management and marketing systems. Additional research focuses on reducing the drudgery of traditional farming, especially for women.
- The Soil Fertility Management and Agrometeorology Unit – as the name suggests – concentrates on soil management. One of its most important tasks is to produce updated soil maps of Uganda and provide advice to farmers and land owners on the best use of their soil. It offers many services, including water and soil analysis, farm planning and courses in geographic information systems (GIS). The unit also works on issues related to the impact of climate change on agriculture.
- The Biocontrol Unit develops and promotes the use of biological control of pests, plant diseases and weeds. This involves the introduction of parasites that feed on pests and the discovery of natural pesticides.

- The Agricultural Engineering and Appropriate Technology Research Centre adapts agricultural engineering technologies to meet farmer and market demands. The centre trains farmers in the use of appropriate technologies and advises government on rural engineering. Its achievements include a small treadle pump, a hand-operated pesticide sprayer, a manual machine for shelling maize and a cassava/potato slicer.
- The Food Biosciences Research Centre conducts research on food quality, safety, nutrition, preservation, processing, storage and marketing. Its mandate encompasses many NARO research areas, including livestock and fisheries.
- The Agricultural Research Information Centre coordinates agricultural information for NARO and promotes linkages between the different parts of Uganda's agricultural research system. It is an information resource for Ugandan farmers and farming students.

"Banana, a staple food in Uganda, has its own dedicated research programme."

Bananas: Uganda's golden fruit

Banana is a staple food in Uganda. Consumption of the golden fruit reaches nearly 260 kg per person per year compared to 26 kg per capita in the United States.

Small, sweet apple bananas are a favourite with children. Ugandans drink banana juice, banana beer and even banana wine. However, the fruit is most commonly used to make 'matooke', a starchy banana mash that is steamed and eaten with meat and sauce. The word matooke literally means 'food' in *luganda*, Uganda's most widely spoken indigenous language. A meal is not a meal if there is no matooke, Ugandans say.

Uganda's National Banana Programme dates back to 1990. Before then, the research was dispersed. Research on banana diseases was carried out separately from on-farm research and breeding.

A re-structuring of Ugandan agricultural research, which took place between 1998 and 1990, led to the creation of multi-disciplinary programmes dedicated to important crops. Bananas were one of the crops that received its own dedicated research programme.

At the outset, the main challenge was coping with infectious diseases such as black sigatoka, a leaf spot disease caused by a fungus, that can cut fruit yields by half, and the banana weevil, an insect whose grubs bore into banana plants causing them to become more susceptible to rot and fungal disease, which stunt plant growth and cause tall-growing plants to break in windy conditions.

Using conventional breeding and tissue culture, the banana programme set out to produce varieties resistant to pest and diseases. It was 14 years before the first modified banana was released on the market, says Wilberforce Tushemereirwe, who heads up the banana programme.

"Developing varieties is a long process," he adds. "However, there are many varieties under study that should soon be released. I consider the development of new varieties to be our number-one achievement."

KEY PERSONNEL

WILBERFORCE TUSHEMEREIRWE, leader of the national banana research programme

• ***Wilberforce Tushmereirwe****, or "Tush", is a stalwart of Uganda's national banana research programme. He has been involved in this programme since its inception in 1990, and was made its leader in 1996 after completing his PhD at the University of Reading in the UK. His training is in plant pathology. He has contributed extensively to the understanding of such banana diseases as black sigatoka and banana wilt, and has co-authored articles examining the acceptance of scientifically enhanced bananas by Ugandan farmers and city-dwellers.*

A genetic revolution – embracing new technologies

Bananas are difficult to breed for genetical variety. Propagation takes place by a sort of cloning, whereby farmers replant genetic copies that plants produce of themselves, known as suckers. This means there is little genetic variation, not just to protect against disease but also to use for breeding purposes.

Due to these constraints, as well as the economic importance of the banana in Uganda, researchers at Kawanda have chosen the fruit for the starting point of its foray into modern biotechnology.

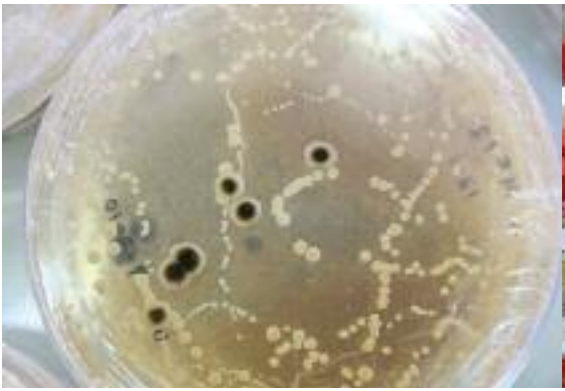
"We could see that conventional approaches were not taking us very far. So biotechnology was going to at least complement traditional approaches," says Andrew Kiggundu, who heads NARL's biotechnology laboratory, the National Agricultural Biotechnology Centre. The USD1 million centre was launched at Kawanda in 2003 by Uganda's president, Yoweri Museveni.

Today, it is one of the few laboratories in Africa with the capacity to produce genetically engineered crops. The technology is being tested in a variety of ways. NARL researchers are developing bananas fortified with vitamin A and iron to combat blindness and anaemia, both of which are common among residents in poor Ugandan communities. Field trials of the banana were performed in Kawanda in 2009.

A transgenic approach is also being tested to fight banana xanthomonas wilt (BXW), a ruinous disease that emerged in Uganda in 2001. It currently costs farmers in Africa's Great Lakes region an estimated USD500,000 each year.

The bacterial disease, which was originally found in Ethiopia, leads bananas to ripen unevenly and prematurely, causing the entire plant to eventually wilt and rot. The disease spreads quickly via contaminated cutting tools and infected plants. By January 2004, just three years after it first appeared in Uganda, outbreaks were confirmed in 14 districts in the north, east and centre of the country.

Using a gene from green pepper, scientists at NARL are hoping to produce strains of banana that are partially or entirely resistant to BXW. The green pepper gene produces a protein called HRAP that strengthens the plant's ability to seal off infected cells. The idea was pioneered by scientists at the *Academia Sinica* in Taiwan, where it has been shown to improve the disease resistance of vegetables, including broccoli, tomatoes and potatoes.



> *NARL is one of the few laboratories in Africa with the capacity to produce genetically engineered crops.*

ANDREW KIGGUNDU, research scientist, plant biotechnology

• ***Andrew Kiggundu****, who is one of Uganda's leading scientists working on transgenic crops, heads NARL's biotechnology efforts. He earned a bachelor's degree in zoology and botany in 1994 at Makerere University in Kampala. In 1997, he received a scholarship to pursue a master's degree at the University of the Free State in Bloemfontein, South Africa. His research focused on screening banana species for resistance to banana weevil, a stem-boring insect that causes a great deal of plant damage. Kiggundu returned to South Africa in 2001 for his PhD. Building on research conducted for his master's degree, he took a closer look at the banana weevil scourge to identify genes that could be introduced to bananas to help them resist this pest.*

Results, thus far, are promising. Laboratory tests of the transgenic banana showed that some strains had 100% resistance to BXW. Field trials of the strain were planted in Kawanda in October 2010.

Other NARO institutes are working on genetically modified cotton and cassava. Uganda is also participating in the Water Efficient Maize project (WEMA) with other countries. Meanwhile, NARL is preparing to use biotechnology to improve the nutritional content of millet. Groundnuts, which are susceptible to virus diseases, are also in the laboratory's sights.

However, because Uganda does not have a law to regulate the commercial growing and selling of genetically engineered crops, the future of NARL's transgenic crop varieties remains uncertain.

BIOTECH REGULATIONS

• While NARL is one of Africa's leading laboratories involved in genetic engineering, the future of genetic engineering in Uganda remains unclear. As of late 2010, Uganda's government had not passed a law to regulate the commercial release of genetically modified organisms (GMOs). This places Uganda at a disadvantage when competing against South Africa, Egypt, Burkina Faso and Kenya, all of which have functioning biosafety laws in place.

Uganda's proposed biosafety law is currently stuck in the country's legislative system. Research can continue according to the rules set by a biosafety policy adopted in 2008. But the move from the laboratory to the field cannot take place without a law regulating commercial distribution.

Although political resistance to the introduction of GM food has softened in recent years, some factions in the government remain sceptical. Few anticipate that a law will be passed before the general elections expected sometime in 2011.

So what does the public want? A thesis written in 2010 by a doctoral student in NARL's banana research programme showed that poor farmers are eager to cultivate genetically modified crops if they address problems such as disease susceptibility and increase yields. The thesis also indicated that resistance to GM food is strongest in the cities.

SNAPSHOTS

> *"Most Ugandan farmers do not know how to best manage their soil. They use just 1 kg of fertilizer per hectare per year."*

Soil science and climate change

Agriculture starts with the soil. However, most Ugandan farmers do not know how to best manage their soil, says Drake Mubiru, senior research officer and head of NARL's soils, soil fertility management and agrometeorology unit. Recent studies indicate that soil, especially in central Uganda, has been severely degraded.

"Ugandan farmers use just 1 kg of fertilizer per hectare per year, which is among the lowest levels in the world," he says. This average, moreover, is skewed by high fertilizer usage in the large estates. Surveys show that small-scale farmers frequently use less than 0.25 kg per hectare of fertilizers per year.

Such data illustrates the low level of technology on which most Ugandan farmers operate. Yet, current conditions also create an opportunity. By using such simple technologies as fertilizers, farmers won't need to open new tracts of land to cultivation to increase agricultural output and meet the needs of a growing population.

The unit is updating the country's recommendations for fertilizer use. "The current recommendations were issued in the 1960s. Many things have changed since then," says Mubiru, "including the introduction of high-yielding crop varieties."

The type of farming that is done has changed as well. People who were subsistence farmers now cultivate cash crops. And crops that were once viewed as subsistence crops, such as maize, beans, bananas and cassava, are becoming cash crops as farmers export them to Sudan, Kenya, the Democratic Republic of Congo and South Africa.

The unit is also digitizing the country's soil maps. Soil maps were introduced in the 1960s, but the digital versions have more detailed layers of information and also lend themselves to much more sophisticated data analysis. The updated maps, for example, help identify erosion hotspots, the spread of disease and forest encroachments. "The maps will aid planning in the districts. Planners will be able to use them to detect demographic trends and identify productive agricultural areas that are under stress," says Mubiru.

The soils unit is also examining the effects of climate change. The country's rainy seasons are already in flux. Climate variability has always been a problem in Uganda, but it is getting worse, says Mubiru. "Droughts are becoming more serious and rains more intense." Intense floods struck eastern Uganda in 2007. And, in 2010, there were devastating storm-induced landslides in the eastern parts of the country. "These events," says Mubiru, "were due to climate change."

The unit is researching which crops are at risk from climate change. A rise of 2° C in global temperatures would likely devastate East Africa's coffee plantations. "Climate research shows that temperatures are increasing across the globe. But it also shows that temperatures are climbing more rapidly in high-altitude regions. If the temperature goes beyond a certain point, the coffee crops will disappear," says Mubiru.

Looking ahead, the unit will continue to promote conservation agriculture to help farmers cope with climate variability. Such a strategy is based on three principles. First, don't disturb the soil by ploughing; rather drill into the soil to plant the seeds. Second, cover the soil with leguminous plants to help stabilize it, keep it cool and add nitrogen. Third, rotate crops to help break pest and disease cycles.

"We have done an on-farm pilot study on conservation agriculture. In 2011, we plan to upscale it, " says Mubiru. Demonstrations in communities will be financed in full for three years. Incentives covering 20-30% of the material cost of converting to conservation agriculture will be provided to farmers who want to participate. Thereafter, all costs are expected to be met by the farmers themselves.

KEY PERSONNEL

DRAKE MUBIRU, senior research officer, soil research programme

• ***Drake Mubiru*** *heads up NARL's soil research programme. He earned an undergraduate degree in chemistry and master's and PhD degrees from the University of Kentucky, USA. His dissertation traced how* E.coli*, a bacterium that spreads in animal and human waste and can cause food poisoning, moves through the soil. In Kentucky, as in Uganda, the use of livestock and poultry waste as fertilizer, which can contain* E.coli *bacteria, creates a possible route for contaminating the groundwater. "Right now most of the water in Kampala is contaminated," Mubiru says.*

> *"Climate variability has always been a problem in Uganda, but it is getting worse."*

Fruit flies, an imported problem

An important aspect of NARL's responsibility entails being responsive to the needs of farmers. For instance, when mango fruit farmers complained that fruit flies were destroying more than half of their crops, the institute felt compelled to respond.

Ugandan farmers have been encouraged to grow fruit since the mid-1990s. However, a decade later, farmers began to observe that fruit coming from NARL developed fruit fly infestations. Working jointly with researchers in Kenya, NARL researchers discovered that the infestations were caused not by local fruit flies, but by an invasive species from Asia.

Caroline Nankinga Kukiriza moved from the banana research programme to head up a project on ways of dealing with Uganda's fruit fly epidemic. The project began in 2010. "Everybody wanted the answers two or three years ago, so you can imagine the pressure we face."

KEY PERSONNEL

CAROLINE NANKINGA KUKIRIZA, research scientist, biological control

• ***Caroline Nankinga Kukiriza*** *is an expert on controlling pests using biological agents. She received her bachelor and master's degrees from Makerere University in Kampala. Her PhD from the University of Reading, UK, examined ways of using fungal pathogens to control the wicked banana weevil. She recently was awarded funding from the country's Millennium Science Initiative to battle the scourge of an invasive species of fruit fly that is decimating mango crops in Uganda.*

"There are so many things that we don't know about the fruit fly," she continues. "What species of fruit flies do we have? Why are they here? What are the physical factors that influence fruit fly infestations?"

The invasive fruit flies likely arrived with exotic mangoes imported from South Africa and India and spread to farmers. These are more susceptible to fruit fly infestation than local varieties, notes Kukiriza. "We want to know what is making these local mangoes less susceptible to infestation than the imported mangoes. It could be physical features or it could be things inside the mango."

The three-year fruit fly project has received USD250,000 from Uganda's Millennium Science Initiative. The project employs one PhD student and three master's students. Kukiriza loves her new challenge. "There are so many unanswered questions. Everything you deliver is new and important," she says.

> *"An important aspect of NARL's responsibility entails being responsive to the needs of farmers."*

NaCCRI

• The National Crops Resources Research Institute (NaCRRI), another of NARO's public research institutes, is an important collaborative partner of NARL. It is situated in Namulonge, some 30 km north of Kampala.

Formerly the Namulonge Agricultural and Animal Production Research Institute, NaCCRI was launched in 1949 by the Empire Cotton Growing Corporation of Britain. As the name suggests, it focused on problems related to cotton production throughout the British empire. Uganda was chosen to host the institute since it was centrally located. With the exception of India, Uganda is the largest producer of cotton in the British Commonwealth.

The institute was handed over to the government of Uganda in 1972. In the 1980s, its mandate expanded to include other crops – for example, maize, cassava, sweet potato, rice, soybean, sunflower, groundnuts and wheat. It also conducts research on feed for livestock.

Today, NaCRRI is Uganda's main crop research institute. It is the administrative home of all the country's commodity-based research programmes, including the banana research programme that began at Kawanda. Among its many achievements, NaCRRI helped restore cassava production in Uganda by breeding strains resistant to the cassava mosaic disease, which stunts plant growth. It has also played a key role in the control of the water hyacinth, a waterweed that threatens Ugandan lakes.

SNAPSHOTS

NARL Training

NARL plays a key role in training the next generation of Ugandan agricultural scientists. A few decades ago, most scientists at Kawanda received their degrees from foreign institutions. Today, however, there is a drive to train as many scientists as possible in the country. Nevertheless, the lion's share of PhD students at Kawanda still obtain their degrees from abroad.

The institute has links with many universities in the developed world, and some in emerging economies. Since the end of apartheid in 1994, South Africa has become a popular destination for PhD students. Earning a degree there is less costly than in Europe or the United States.

Funding for training comes through dedicated programmes, such as the Agricultural Research and Training Programme sponsored by the World Bank, or as part of grants allocated for research. "We try to include a training component in every grant proposal," says Ambrose Agona, director of NARL. However, training opportunities are scarce, and there are waiting lists for the degree courses.

Finding the staff to supervise students is a challenge. There is a lack of mid-career researchers at NARL. When NARO was created in 1992, a hiring freeze had been in place for several years. As a result, many researchers are now approaching retirement and there are few candidates ready to fill their shoes.

Brain drain is another problem. There is competition within Uganda for agricultural scientists and many staff are offered better paying jobs in neighbouring Rwanda. "The sad thing is that we use our resources to train these people, and then they take off," says Agona.

Realizing that Uganda needs its scientists to stay home, the government raised public sector scientists' salaries by 15% in June 2010. However, money is not everything, says Agona. The cost of living in Kampala is low compared with many neighbouring countries such as Kenya. And the improved security in Uganda compared with neighbouring Kenya has helped to stem the flow of brains to the east.

Retaining educated and skilled workers, in short, remains one of the biggest challenges facing Ugandan science.

"Retaining educated and skilled workers remains one of the biggest challenges facing Ugandan science."

TOMORROW'S RESEARCH STARS

• ***John Adriko*** *is pursuing a 'sandwich' PhD through the University of Copenhagen in Denmark. Basing his fieldwork at Kawanda, he is studying molecular diagnostics to detect pathogens in plants. He expects to graduate in 2011 and hopes to return to Uganda when his degree is completed. "Our diagnostic systems are very poor. We can only detect disease by observing symptoms; we can't do tests on healthy-looking plants. I want to be at the forefront of finding solutions to the problems of my country," he says.*

• ***Annette Namuddu,*** *a research assistant at NARL's biotechnology laboratory, is pursuing a master's degree at Makerere University in Kampala. Her fieldwork involves checking for nematode resistance among plants developed at NARL. She has bought a piece of land near Kawanda where she hopes to show others in the community how to apply agricultural science to improve yields and manage pests. "I love farming," she says. "I want to help farmers manage these pests and diseases."*

• ***Winnifred Aool****, a research assistant in NARL's fruit fly project, is studying for her master's degree at Gulu University in northern Uganda. She went into science to be like her aunt, who was a doctor. "Here, you provide solutions to many people's problems. Farmers often put all of their capital in the seedlings they buy. If the crops are bad they suffer. We feel like we can make a difference," she says.*

Funding Matters

Agricultural research receives more funding from the Ugandan government than any other area of science. In 2008-2009, it accounted for more than half of the government's UGX76 billion (USD32 million) science and technology budget.

However, NARO also obtains funding from international donors and foreign research funders. Its total budget for 2010/2011 was just under UGX75 billion (USD31.5 million), of which development partners contributed nearly UGX40 billion (USD17 million). NARL's annual budget reached USD5 million in 2010, of which only USD1 million came from the government of Uganda.

NARL scientists have to actively seek and apply for grants to supplement the institute's core funding. "Our scientists are proactive in writing project proposals," says Ambrose Agona, director of NARL.

FREDERICK KAYANJA, Chairman of NARO Council

• ***Frederick I. B. Kayanja*** *studied veterinary sciences in London before conducting medical research at the University of Oxford, UK. He received a 'sandwich' PhD from the universities of Cambridge and East Africa. The latter was split into four national universities in 1970, including Makerere University in Uganda. His research interests range from bone blood supply to mammalian reproductive biology. He has been the vice-chancellor of Mbarara University of Science and Technology in western Uganda since its creation in 1989. In 2004, the French government awarded Kayanja the* Commandeur de l'Ordre des Palmes Academiques*. Kayanja was also a recipient of a lifetime achievement award from the British government in 2007. He is a TWAS Fellow (1988) and delivered a TWAS Medal Lecture in 2000.*

DENIS KYETERE, director general of NARO

• ***Denis Kyetere****, director-general of NARO, earned his PhD in plant breeding at Ohio State University, USA. He also holds a diploma in project planning and management from the Uganda National Chamber of Commerce and Industry. His research has focused on identifying and mapping the MSV1, a gene that enables maize to tolerate streak virus disease. He also developed several maize varieties that are now grown in Uganda and surrounding countries. He has chaired the Forum for the Agricultural Research in Africa (FARA) and the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). He holds several honours, including the 2008 International Alumni Award from Ohio State University's College of Food, Agricultural and Environmental Sciences.*

> *"Agricultural research receives more funding from the Ugandan government than any other area."*

THE MILLENNIUM SCIENCE INITIATIVE

• In 2007, the government of Uganda launched a five-year partnership with the World Bank to bolster science and technology. The bank agreed to lend the country USD33 million at a low interest rate to kick-start its knowledge production.

The Uganda National Council for Science and Technology published the first call for proposals for MSI funding in 2007. Since then, several additional calls have followed. As of December 2010, the MSI reported that it has supported 22 research projects and the training of more than 3,660 scientists and engineers, 102 at master's and PhD levels. It has also lent support to the development of four new undergraduate courses in science and engineering at various Ugandan universities and the upgrading of seven existing courses. In addition, MSI has provided funds for developing programmes designed to help policy-makers appreciate and apply scientific information to their decision-making efforts.

At the time this booklet went to press, it was not clear if the MSI loan would be renewed when it expires in 2011. The government of Uganda has indicated that it wants to take control of the country's science budget, and so it may assume responsibility for funding the grant programmes currently supported by MSI.

SNAPSHOTS

Additional income is generated by providing services to Ugandan commercial farmers. The institute's soil science unit sells its field surveys to large-scale farmers, and is working on a business model to enable poor farmers to access these services as well.

The funding situation has improved in recent years. The country has received an injection of cash from the Millennium Science Initiative in the form of a five-year, low-interest loan provided by the World Bank to build capacity in science and technology. Several research projects at Kawanda, including the fruit fly project (see page 32), receive MSI funding.

The president of Uganda, Yoweri Museveni, has also promised that some of the wealth derived from the country's newly discovered oil fields will be used to strengthen the science base. In June 2010, the country's public sector scientists received a 15% pay raise.

Nevertheless, funding remains a constraining factor, says Andrew Kiggundu, who heads NARL's biotechnology laboratory. Yet, at least the money is becoming more consistent and predictable, he adds. "The feeling is good now. I think our budget will grow."

> *"The funding situation has improved in recent years."*

From Lab Bench to Farm Field

Since independence in 1962, Ugandan agriculture research has focused increasingly on the needs of poor farmers. Today, extension services are a cornerstone of NARO's operations – and also one of its biggest challenges.

The political and social turbulence that marked the 20th century has left scars on Uganda's farming community. When the country was a protectorate of the UK, the colonial government told farming communities what to grow. If farmers refused, they were punished. Coffee has a local name, *kibooko*, which literally means 'canes' or 'caning' and is derived from colonial history when the government would cane people for refusing to grow it.

Towards the end of the colonial period, it became popular for farmers to organize co-operatives. The co-operatives allowed subsistence farmers to sell some of their crops and to use the revenues to invest in education and better equipment. The British and Ugandans jointly ran courses at a co-operative college in Kampala. The co-operatives settled disputes, opened banks and devised marketing strategies for a population that largely had no experience in accounting and sales.

Each co-operative had 100 to 150 farmer members who elected their own committees. However, over time, the co-operatives became increasingly ineffective and corrupt. Today, only Uganda's tea growers organize themselves into co-operatives. Their produce is sold at auction and the co-operatives serve the purpose of inhibiting farmers from undercutting each other's prices.

The current government liberalized Uganda's economy in the early 1990s. Within a few decades, Ugandan farmers went from being told what to do to being given the freedom to plant anything they like. Today, however, farmers obtain advice from many different players, including development agencies, the 'green' lobby and, of course, scientists.

The National Agricultural Advisory Services (NAADS) has managed the government's extension services since their introduction in 2001. NAADS's mandate is to develop a demand-driven, farmer-led agricultural service delivery system that targets poor subsistence farmers. It also develops programmes designed to help meet the needs of women, youth and people with disabilities.

The effort, however, has fallen short of its goals. A NAADS survey done in 2008 concluded that just 14% of the households had received a visit from an extension worker over the past 12 months. Female-headed household fared even worse – less than 7% had met extension officers.

A World Bank survey published in 2011, *Science, Technology and Innovation in Uganda: Recommendations for Policy and Action*, found that even those farmers who received visits from NAADS officers often failed to change their behaviour.

"The people who have done well are people who have listened carefully to the information that has been provided and have used it in ways that have made them more innovative and entrepreneurial. They have learned that this is an investment that pays off if they apply what they have learned. More people have come to understand this, but we still have a long way to go to ensure that every farmer benefits from our efforts," says Andrew Kiggundu.

NARO launched a new five-year project beginning in 2010 to strengthen the linkages between research and extension services. The World Bank and the government of Uganda will fund the Agricultural Technology Agribusiness and Advisory Services (ATAAS) project to the tune of UGX240 billion (USD100 million) per year.

The ATAAS project will coordinate the activities between NARO and NAADS. Among other things, the partnership is expected to promote agro-business.

One problem facing extension services is that Ugandan science is dispersed. "A lot of research has been funded by donor projects that do not have a centralized data deposition policy," says Andrew Kiggundu. A new act of parliament now requires every Ugandan to deposit copies of publications in national repositories. However, many Ugandan scientists are unaware of this obligation, Kiggundu says.

SILIM NAHDY, executive director of NAADS, Uganda's research extension organization.

• ***Silim Nahdy*** *is the executive director of Uganda's National Agricultural Advisory Services (NAADS). He earned his PhD in agriculture from the University of Reading in the UK. He was also the director of Kawanda Agricultural Research Institute, the forerunner of NARL, from 1996-2001. Before becoming director, he worked in the institute's post-harvest programme. Nahdy owns his own farm in Mukono district in central Uganda where he grows bananas, oranges and passion fruit, among other crops.*

The Agricultural Research Information Centre, which is part of NARL, coordinates agricultural information for NARO and promotes linkages between the different parts of Uganda's agricultural research system. It serves as an information resource for Ugandan farmers and farming students, as well as for other researchers.

NARO also carries out its own outreach. "We use the media, most notably radio, and agricultural forums to present our research to the public," says Robert Anguzu, public relations officer at NARO. The biggest challenge is getting in touch with the poor, remote farming communities, he says. Radio has proven to be the best medium for reaching poor people, since programmes go out in local languages, he says.

The organization arranges competitions to promote the use of technology in farming communities. "We might run a contest for the 'best village' or for the most 'complete farmer'," says Anguzu. Prizes range from fertilizer to watering cans and wheelbarrows. "It's a teaching opportunity and fun too," Anguzu says.

> *"We use the media, most notably radio, to present our research to the public."*

Policy Interface

As a government-funded institution, NARO is expected to furnish the government of Uganda with scientific advice. "Our politicians have a great deal of confidence in us," says Robert Anguzu, public relations officer at NARO.

The Millennium Science Initiative (MSI) sponsors an annual Uganda Science Week that brings together policy-makers, scientists, school children, entrepreneurs and the public to raise awareness and appreciation for science and technology and its role in national development.

Getting policy-makers to listen requires a different tactic than reaching poor farming communities, says Anguzu. "These guys are busy. So you develop policy briefs for them that summarize the key scientific issues. We may present our findings and insights to policy-makers during short breakfast meetings or afternoon briefings in their offices."

UGANDA'S NATIONAL DEVELOPMENT PLAN

• Uganda's National Development Plan for 2010/11–2014/15 was approved by the government in April 2010. It identifies eight priority growth sectors: agriculture, forestry, tourism, mining, oil and gas, manufacturing, information and communication technologies and housing development.

Science is one of the complementary growth sectors identified in the plan. The goals are to:

• Reduce the ratio of science to arts graduates from 1:5 to 1:3 by 2015.

• Boost the number of researchers to 10 researchers per 1,000 labour force.

• Increase public spending on R&D.

• Create a Ugandan ministry of science and technology.

• Establish four science park and technology incubation centres to provide innovation support for young scientists.

• Encourage the private sector to invest in R&D.

SNAPSHOTS

NARO's researchers have been instrumental in drawing up many recent policies. They served as advisors in the drafting of the biotechnology bill, which awaits approval from the country's cabinet. NARO researchers also had a hand in advising the recent National Development Plan (see above), the poverty eradication plan in 1997, the plan to modernize agriculture in 2000 and Uganda's national science, technology and innovation strategy in 2009.

Future Prospects

Research in NARO is still settling into the new institutional structure established in 2005. In the years to come, each of the agricultural institutes will grow into their new roles. For NARL, this includes being a high-technology resource partner for other institutes, including NaCCRI.

With its century-old, deeply rooted history, agricultural research receives the most funding from the Ugandan government out of all research sectors. However, this situation may change as the government turns its attention to national efforts to exploit its recently discovered oil resources. Already, one of the foremost priorities for the government is setting up petroleum engineering courses. Health research is also likely to get a boost, as are information and communication technologies.

That is not to say that agricultural research funding will shrink. If the government keeps its promise to increase its commitments to research, all sectors will be winners. Yet, the onus will be on all agricultural research centres to demonstrate their impact on social well-being. This will require an even stronger focus on outcomes, especially in terms of getting the research results to farmers.

The country's agricultural researchers will not only be obliged to provide services for farmers but also to make sure there is a market for those services. "Market issues became a priority around 2005," says Robert Anguzu, NARO's public relations officer, after a reorganization placed increased focus on service delivery and market opportunities.

NARL already sells information to large-scale farmers. But the market has to include small-scale farmers, says Drake Mubiru, head of the soil science division at NARL. "We are trying to market ourselves to small-scale farmers. This is difficult. Even fertilizers are hard to market to small-scale farmers because they are reluctant to change their ways," he says.

"Nevertheless," says Andrew Kiggundu, head of NARL's biotechnology laboratory, "the government's commitment over the past several years has begun to level the playing field and ease our efforts in reaching small-scale farmers. Policies are finally lining up and it feels as if most people are moving in the same direction."

"We're starting to feel the impact of this commitment," he adds. "A large number of agricultural technologies are becoming increasingly relevant. Even poor people are moving from subsistence agriculture to growing commodities they can sell. I feel confident about the future," he says.

> *"The next few years could see a significant improvement in the financial status and public impact of NARL."*

Conclusions

With political support for science growing, and renewed effort going into extending agricultural technologies to poor farmers, the next few years could see a significant improvement in the financial status and public impact of NARL.

The challenges facing Ugandan science, however, remain daunting. Climate change will increase the variability of the climate, putting pressure on farmers – in particular poor farmers with no savings to dip into if crop yields are disappointing. Water management will become increasingly important to make up for variations in rainfall. A growing population will place increasing pressure on food crops and medicinal plants. Land management will have to become more sophisticated to stem biodiversity loss and conserve agricultural land. New pests could arise requiring urgent action.

The good news is that Uganda has built the capacity to conduct the research required to meet these challenges head-on. A century of nearly continuous focus on agricultural science has paid off. What are needed are sustained commitments and increasingly sophisticated ways of communicating the knowledge to farmers. But the basics are already in place.

Some regulatory challenges remain. In particular, the country's biotechnology policy is long overdue. The government's investment in genetic engineering at NARL's biotechnology laboratory will not pay off unless the fruits of the research have a way of reaching consumers. Far from endorsing genetically modified food wholesale, a workable biotechnology law would enable the country to exploit the technology in a responsible way.

Some 50 years after Uganda's independence, the country's agricultural researchers are leading the way to a better future for all Ugandans. With adequate support from the government and increasing ingenuity, Uganda's farmers stand a good chance to fulfil the high hopes that have been placed on them to ensure adequate food supplies in the years ahead.

Acknowledgements

Linda Nordling, a Cape Town based journalist, the author of this booklet, and Daniel Schaffer, TWAS public information officer, would like to thank the National Agricultural Research Laboratory's (NARL) staff at Kawanda for their dedication and patience in helping in its production.

A special 'thank you' goes out to Andrew Kiggundu, head of NARL's National Agricultural Biotechnology Centre, for his assistance in setting up interviews in Kawanda. Thanks also to Catherine Kiwuka and the staff at Entebbe Botanical Gardens for an unforgettable tour of the gardens.

Additional thanks go to Ambrose Agona, director of NARL, and the entire staff at both NARL and NARO for helping with the inquiries that fed into this booklet as well as to the staff at TWAS – Tasia Asakawa, Gisela Isten and Cristina Serra – for their valuable editorial contributions. Lastly, we warmly acknowledge the staff at the Uganda National Council of Science and Technology (UNCST) for providing advice and context about Ugandan science.

TWAS

- *ICTP Campus, Strada Costiera 11, 34151 Trieste, Italy*
- *Tel: +39 040 2240 327*
- *Fax: +39 040 224 559*
- *e-mail: info@twas.org*
- *website: www.twas.org*

TWAS

TWAS, the academy of sciences for the developing world, is an autonomous international organization that promotes scientific capacity and excellence in the South. Founded in 1983 by a group of eminent scientists under the leadership of the late Nobel Laureate Abdus Salam, TWAS was officially launched in Trieste, Italy, in 1985, by the secretary-general of the United Nations.

TWAS has nearly 1,000 members from more than 90 countries, over 85 percent of whom live and work in developing countries. A Council of 13 members is responsible for supervising the Academy's affairs. TWAS is assisted in the administration and coordination of programmes by a small secretariat, headed by the executive director. The secretariat is located on the premises of the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy. UNESCO is responsible for the administration of TWAS funds and staff. A major portion of TWAS funding is provided by the Ministry of Foreign Affairs of the government of Italy.

The main objectives of TWAS are to:

- recognize, support and promote excellence in scientific research in the South;
- provide promising scientists in the South with research facilities necessary for the advancement of their work;
- facilitate contacts between individual scientists and institutions in the South;
- encourage South-North cooperation between individuals and centres of scholarship.

To achieve these objectives, TWAS is involved in various activities and collaborates with a number of organizations, especially UNESCO and ICTP.

For additional information, see www.twas.org.

EXCELLENCE IN SCIENCE

This series of booklets – published by TWAS, the academy of sciences for the developing world – highlights successful scientific institutions in the South and explains how their research has both been sustained over a number of years and how it is helping their host nations achieve sustainable economic development.

twas