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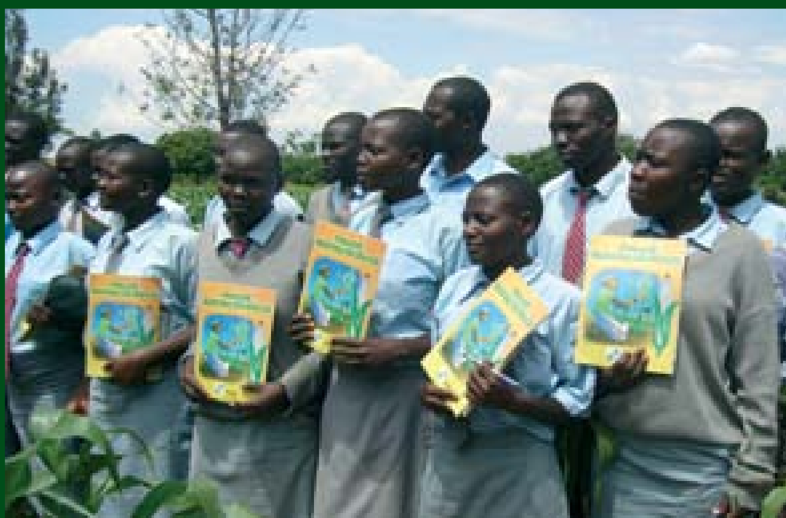
African Insect Science for Food and Health

Planting for Prosperity

Push–Pull: a model for Africa's green revolution





Planting for Prosperity. Push–Pull: a model for Africa's green revolution

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Last, but not least, we thank all the farmers who cheerfully related their 'push–pull' experiences.

Dedication

This publication is dedicated to the thousands of East African farmers who, through their entrepreneurial spirit, hard work and determination, have helped make push–pull the success story it is today.

Contents

Foreword

The International Centre of Insect Physiology and Ecology (*icipe*) is immensely proud of the 'push–pull' programme's achievements. During the past 15 years, push–pull has become a true platform technology that addresses the most critical constraints for poor cereal farmers simultaneously, i.e. poor soils and correspondingly low yields, high pest pressure, and the parasitic weed *Striga hermonthica*.

Push–pull is a science-based technology that focuses specifically on the problems facing smallholder and subsistence farmers. Because of its holistic approach it has enabled over 40,000 farmers to lift themselves and their families out of poverty. This scale of impact means that it is having a dramatic effect on entire rural communities and economies.

I learned about the push–pull programme, led by Dr Zeyaur Khan, before joining *icipe* in 2005 and actually used it as an example for a highly successful, holistic and scientifically cutting-edge approach to agricultural improvements in Africa in several of the graduate courses I taught at Leibniz University Hannover (Germany). One of the first field excursions I did after joining *icipe* was visiting push–pull farmers in the Vihiga and Siaya districts of Western Kenya together with Dr. Khan. What struck me most was the sense of ownership I got from the discussions with the farmers. They were clearly very proud of their push–pull fields, and saw it as their own technology. Moreover, the superiority of their fields compared with those of their neighbours was stunning. Many of the farmers told me that with push–pull their maize harvest had increased three- to five-fold, figures that were subsequently corroborated by several independent impact assessments.

Moreover, because the system introduced Napier grass and desmodium fodder, the majority of the farmers I visited had ventured into zero-grazing animal husbandry. And they told me that since starting with push–pull, both the stemborers that used to eat away their maize and the parasitic striga plant had simply vanished from their plots.

This success has been built on the dedication of the *icipe* team – and its numerous partners – to help African farmers, to learn from them, and also to conduct cutting-edge science. The holistic nature of push–pull is also reflected in the many disciplines of science the technology touches upon, which include applied entomology, chemical ecology, organic chemistry, modelling, eco-system analysis, socio-economics, agronomy and weed science, among others.

Project successes have been documented in numerous high-impact publications including *Nature*, *Annual Review of Entomology*, *Annual Review of Phytopathology*, *Proceedings of the Royal Society*, *Journal of Experimental Botany*, and *Biology Letters*, as well as in many practical guides, leaflets and manuals, often translated into regional languages and dialects. Many graduate students, funded by the German Academic Exchange Service (DAAD), and World Food Prize Interns have worked with the push–pull project.

Our next goal is to reach the target of one million push–pull farmers by 2020 and, with current rates of adoption, I believe we will achieve this. I also believe that push–pull is just the kind of technology needed to support a 'green revolution' for Africa, which requires increased productivity based on technologies that are more environmentally friendly and people-centred than those that fuelled the Asian green revolution. Push–pull demonstrates that this concept can work well and is worthy of support by all who wish to see Africa's declining yields and rising poverty levels reversed.

Professor Christian Borgemeister
Director General
International Centre of Insect Physiology and Ecology
March 2011

1. Push and pull: plants versus pests

The Were family are subsistence farmers who eke out a living on the Kenyan side of Lake Victoria. It is not an easy life; their farm is small and rainfall is often unreliable. Yet the Weres are better off than many of their neighbours: fields of tall, strong maize plants promise ample food for the next six months; three crossbred dairy cows enjoy a plentiful supply of fodder brought to their stalls; the children drink milk every day; and sales of milk, maize and fodder grass bring in vital cash to spend on daily necessities and to invest in farm and household improvements.

Only two years ago, the scene was dramatically different. Years of cereal cropping without inputs had reduced soil fertility and the maize plants were being attacked by insect pests and parasitic weeds. The family's thin zebu cows produced little milk, and herding them along the roadside to find forage was a full-time job for the children. Meanwhile, Christine Were was constantly engaged in the backbreaking, seemingly fruitless task of weeding the fields. The granary was empty, the family frequently went hungry, and there was no maize left over to sell. That meant no money to invest in fertilizer or other inputs to improve the situation. The family seemed trapped in a downward spiral of declining yields and deepening poverty and hunger.

Christine Were shows *icipe* technician, Dickens Nyagol, her traditional maize plot. Only two years ago all her fields looked like this: the maize was devastated by dual enemies - the stemborer *Chilo partellus* and the parasitic weed *Striga hermonthica*.

Christine Were inspects her healthy push–pull maize crop.

How were the family's fortunes turned around in such a short time? The answer lies in a novel approach to crop management that exploits the natural relationships between plants and insects. When scientists investigated the ecology of a widespread cereal pest, they discovered that introducing a carefully selected mix of forage plants into maize fields had a dramatic effect on cereal yields and total farm output. The so-called 'push–pull' technology that emerged from their research (see box on next page) makes use of natural plant chemicals that drive insect pests away from the crop and attract them to other host plants, which withstand attack better than maize. Along the way, the scientists discovered intriguing new properties in the forage legume, desmodium. Besides being nutritious for dairy cows, it repels insect pests of maize and substantially reduces damage from striga, a destructive parasitic weed. In short,

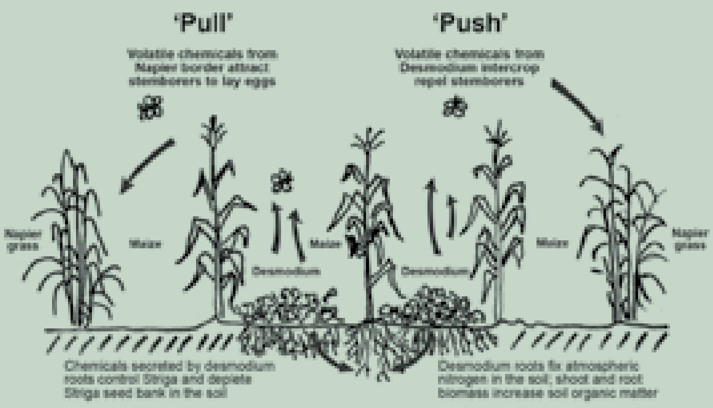
Maize field with border rows of Napier grass and an intercrop of Desmodium uncinatum.

What is push–pull?

The technique known today as 'push–pull' (or stimulo-deterrent diversion) was first documented as a potential pest control strategy in 1987 in cotton and 1990 in onion. However, neither of these studies exploited natural enemies, using instead an added chemical deterrent or toxin to repel or kill the pest. In contrast, the push–pull system described here uses no manufactured deterrents or toxins. Instead, it exploits natural insect–plant and insect–insect relationships.

"Push–pull is not something scientists have invented," says Push-Pull Project Leader Dr Zeyaur Khan, Principal Scientist at the International Centre of Insect Physiology and Ecology (*icipe*). "We have discovered several cases of integrated use of the forces of attraction and avoidance by different arthropods in their search for suitable hosts, feeding areas or egg-laying sites."

Insect behaviourists and chemical ecologists tend to agree that promising integrated pest management (IPM) tactics based on plant chemicals frequently fail because they are too narrowly based. They often target a single chemical and a single phase in the life cycle of an individual pest species. The *icipe*–Rothamsted approach makes use of a wider range of behaviour-affecting chemicals produced by both plants and insects. It introduces nature's built-in checks and balances into a man-made environment – such as a maize field – by manipulating the habitat, relying on a carefully selected combination of companion crops planted around and among the maize plants.



Farmers using push–pull for pest control not only reap three harvests (maize, Napier grass and desmodium); when they plant a desmodium intercrop they also dramatically reduce the devastating effects of the parasitic weed *Striga hermonthica*. Furthermore, the desmodium enhances soil fertility by 'fixing' nitrogen, and it acts as a cover crop to retain soil moisture. See www.push-pull.net for more.

the push–pull system can improve food security and farm income in an environmentally friendly way, making it an ideal ingredient in the long-term struggle to reduce hunger and poverty in Africa.

This publication describes the development of the push–pull technology and its dissemination to farmers in eastern Africa. We illustrate – through the eyes of some of the participating farmers – the benefits the project has brought, together with the obstacles that impede more widespread impact and the strategies that are helping to overcome these hurdles. Finally, we examine why the project has been so successful.

The large stems of maize plants provide an ideal habitat for the stemborers *Busseola fusca* and *Chilo partellus*.

Starting with stemborers

The story begins in 1994, when researchers at the Kenya-based International Centre of Insect Physiology and Ecology (*icipe*) and Rothamsted Research in the UK began to investigate the ecology of stemborers. These are the larval stages of various species of moths and the major insect pest of maize and sorghum in eastern and southern Africa.

Stemborers naturally feed on wild grasses, but when maize became a cultivated crop across vast areas of Africa, the insects began to feed on it as well. Lack of defence mechanisms in maize allowed insect populations to flourish and become a problem of economic importance. In maize – Africa's most important food crop – losses to stemborers average 20–40% but can reach 80%. As a control method, pesticides are expensive and harm the environment. Since they cannot reach insects inside the maize stem, they are often ineffective; moreover, they kill the stemborer's natural enemies. Preventing crop losses from stemborers could increase maize harvests by enough to feed an additional 27 million people in the region.

"It used to be thought that native grasses caused the stemborer problem and that getting rid of them would remove the stemborers too," says Dr Zeyaur Khan, entomologist at *icipe* and leader of the project. But, in fact, many grasses provide a habitat for the stemborers' natural enemies, so help keep the stemborer population under control No one had studied the relationship between the grasses and the borers in depth, so, prompted by Professor Thomas Odhiambo, then Director of *icipe*, Khan launched a survey.

Multiple interactions

The initial objective was to study the multiple interactions among cultivated crops, wild host plants, different stemborer species and their natural enemies. This information would then be used to develop an integrated pest management (IPM) approach to controlling the insects. The scientists studied more than 400 wild grasses and grouped them according to their efficacy in attracting female moths to lay eggs and their ability to support larval development. "We already knew that some wild grasses act as 'trap plants', enticing egg-laying females but depriving the larvae of a suitable environment," says Khan. This is often because the grasses also attract the borers' natural

Remjius Bwana Asewe, a farmer from Yenga, near Kisumu, harvests his Napier grass. Farmers plant three rows of Napier around their maize, then harvest the grass by cutting around each row in turn. That way, there is always a continuous grass border to trap the stemborers.

Before boring inside the maize stem, early instar larvae of stemborers feed on leaves causing holes on the leaf surface. This is a typical symptom of stemborer infestation.

enemies. Other grasses simply act as reservoirs for the pests and increase their populations. The survey results indicated that around 30 grass species were suitable hosts for stemborers, but only a few of them attracted both moths and their enemies. "These grasses were the ones with potential to be exploited as trap crops to draw the borers away from the maize and reduce their populations," adds Khan.

The findings were encouraging, but the team knew that farmers with small land holdings would be unlikely to plant a wild grass simply to attract pests. So farmers were consulted to find out which grasses were most useful as cattle fodder. Researchers at the Kenya Agricultural Research Institute (KARI) helped identify suitable farmers to consult.

The pull...

Two trap crop grasses appeared particularly promising: Napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum sudanense*). Grasses planted among the maize plants provide too much competition, but researchers found that when they were planted in border rows around a maize field, the stemborers were enticed to lay their eggs on the grass rather than the maize. The grasses were providing a 'pull' by releasing volatile chemicals. These grasses also have effective defence mechanisms to protect themselves against stemborer attack. Sudan grass is an attractive habitat for the African parasitic wasp *Cotesia sesamiae*; these tiny insects inject their eggs into the stemborer larvae and, when the eggs hatch, the wasp larvae eat the stemborers. Napier grass has a particularly ingenious way of defending itself: when the larvae bore into the stem, the grass secretes a sticky

A sleeping enemy

Western Kenya is the 'maize basket' of the country. In some locations, two maize crops can be grown in a year. But in many areas, as the Were family discovered, the parasitic weed *Striga hermonthica* is taking over. The seeds are so tiny that Christine could have unwittingly brought them into her field and sowed them along with the maize. Stimulated by chemicals released by the roots of the crop plants, the seeds germinate, but instead of growing roots and drawing nourishment from the soil, they parasitise the maize, weakening or even killing it.

Each mature plant produces around 50,000 seeds, which remain viable in the soil for up to 20 years, awaiting a suitable host. Recommended control methods for this 'sleeping enemy' include heavy application of nitrogen fertilizer, crop rotation, chemical germination stimulants, herbicide application, hoeing and hand-pulling, and the use of resistant or tolerant crop varieties. These have met with scant enthusiasm from farmers who have little cash or time to spare. Increased cropping frequency and deteriorating soil fertility favour the growth of striga and the survival of its seeds. Yield losses range from 30 to 100% and, in some cases, infestation has reached such a high level that farmers have no choice but to abandon the land.

The parasitic witchweed, *Striga hermonthica*

gum, physically trapping the borer and preventing most larvae from completing their life cycle. Both grasses attract additional stemborer predators such as ants, earwigs, spiders and cockroaches, which are found in significantly larger numbers in push–pull plots than in control plots.

In 1997, the scientists began on-farm trials to evaluate the benefits of Napier grass, which has the added value of being a perennial and is already grown widely for livestock fodder. Researchers and farmers worked together to identify which varieties provide both a good habitat for the stemborer and good forage. 'Bana' was an obvious choice, since it has smooth, broad leaves (an improvement on some local varieties that have rough leaves and sometimes make cows cough) and is highly attractive to stemborers. Besides increasing their maize yields, the farmers planting Napier border rows benefited from a ready supply of grass to feed their livestock or sell to other farmers.

Molasses grass planted around a zero grazing unit. Farmers like Lillian Wang'ombe have discovered that the grass not only repels stemborers, but also reduces the number of ticks attacking their cattle.

...and the push

Khan describes how he came across the repellent effects of another fodder crop, molasses grass (*Melinis minutiflora*), while visiting KARI's Kitale research station. This discovery was to become the 'push' component of the system. "Molasses grass has a very strong, sweet smell, which caught my attention. Quite by chance the KARI researchers had planted a plot of molasses grass next to one of maize. There was little stemborer damage on the maize closest to the molasses grass, but the other side of the plot was heavily infested."

Khan decided to investigate further. Trials confirmed that, indeed, molasses grass has a strong repellent effect on stemborer moths, even when only one row is planted in every ten of maize. Even more intriguing was the discovery that, like Sudan grass, molasses grass attracts the parasitic wasp, *Cotesia sesamiae*. This puzzled the scientists, who could not initially understand why the parasitoid would be drawn to a location where it was unlikely to find its host.

Meanwhile, at Rothamsted Research, Professor John Pickett (Head of the Biological Chemistry Division) and his team were helping to piece the puzzle together by investigating the nature of the plant chemicals (known as semiochemicals) that attract or repel stemborer moths. The most relevant compounds have been identified by a combination of insect electrophysiology and mass spectrometry and tested on the insects using bioassays. "We have discovered six host plant volatiles that attract female stemborer moths to lay their eggs," says Pickett.

The next step was to investigate the volatiles produced by the intercrop plants – the 'push' chemicals – and to find out why molasses grass repels stemborers but attracts their natural enemies. A nonatriene compound emerged as a key stimulus. "The nonatriene is what we call a 'feeding stress' chemical," explains Pickett. "It is normally produced by molasses grass, but maize plants produce it when they come under attack from the stemborer."

It appears that, at low concentrations of the chemical, additional pests arrive, attracted to a plant that is already weakened by pest attack; but at high concentrations the pests are repelled, taking it as a sign that the plant is already fully exploited. At high or low concentrations, parasitoids are attracted to find their hosts. "Molasses grass has evolved an ingenious defence strategy, since its release of volatile chemicals mimics that of damaged plants," adds Pickett. The use of chemicals by plants to protect themselves from attack in this way was an important discovery and was reported in the leading international journal *Nature* (14 August 1997). This work, together with recent discoveries concerning 'smart' plants (see box) have led the scientists to develop general hypotheses regarding the role of plant semiochemicals in determining insect recognition of host plants, and could lead to major new lines of defence in crop-protection strategies in many different cropping systems.

Discovering desmodium

Molasses grass is accepted by farmers as a 'push' intercrop since it provides fodder for cattle. But Khan and his colleagues were keen to find alternatives that might add a further dimension to the push–pull system. The team focused their attention on legumes, since these not only provide nutritious food and forage, but also improve soil fertility because they 'fix' part of their nitrogen requirements from the atmosphere. Cowpea (*Vigna unguiculata*) and silverleaf desmodium (*Desmodium uncinatum*) looked promising candi-

Developing 'smart' plants that warn of insect attack

Further research into the chemistry underlying the push–pull effect has revealed another suprising finding: plants can actually communicate with one another. The research team, lead by Dr Khan, made this startling discovery when further investigating the 'push' effects of molasses grass, which emits a stress chemical when it comes under attack from stemborer larvae. This chemical prevents further plant damage by discouraging the moths from laying any more eggs. When they are planted close to molasses grass, maize plants appear to pick up on this stress response and will produce the same repellent chemicals, with levels detectable after only 24 hours. It appears that the molasses grass is warning the maize to watch out for insect attack.

The fodder grass *Brachiaria* is another so-called 'smart' plant. The team has discovered that once the stemborer moth has laid its eggs, the grass stops producing attractive plant volatiles so no more eggs are laid. At the same time, the grass releases the chemicals that attract parasitic wasps and thereby prevent the larvae from completing their life cycle. "This is ideal trap plant behaviour," says Khan, "and just the kind of trait that we would like to introduce or stimulate in maize plants". In fact, the team has identified similar behaviour in maize landraces acquired from South America. "Crossing these landraces with African high-yielding varieties could potentially lead to the development of a new type of maize with built-in insect resistance", adds Khan.

Collecting plant volatile chemicals from maize plants

Further study has led scientists to discover that maize plants can detect and copy the stress chemicals released by molasses grass

dates. Cowpea had long been grown for grain and fodder in parts of West Africa, while desmodium originated in South America and had been introduced into Kenya in the early 1950s.

During this phase of the work, the Suba District Agricultural Officer visited the *icipe* team at their Mbita Point research station on the shores of Lake Victoria. Deeply concerned about the devastating effects of the parasitic 'witchweed' *Striga hermonthica* on local maize harvests (see box on page 4), he asked whether there was anything *icipe* researchers could do. Since the team were primarily entomologists and fully occupied by their stemborer research, they declined his request, little knowing they were on the verge of an important discovery that would address just those concerns.

Khan and his colleagues tested desmodium as a 'push' intercrop with maize on-station at Mbita Point. "All our experimental plots are infested with striga," he says. "So imagine our amazement when we found that maize plots with a desmodium intercrop not only had little stemborer damage but also became virtually free of striga after only on growing season." In fact, eliminating the striga had an even greater effect on increasing maize yields than controlling the stemborers. This indeed brought a new dimension to the push–pull technology and posed the question 'how?' (see box).

The effects of desmodium on striga, combined with the potential of push–pull to increase yields of food and fodder, were hugely exciting, but the team was justifiably cautious. Although farmers were already familiar with intercrops, the idea of using them to affect insect behaviour was new and the farmers would need to grasp the idea and understand how it worked. It was therefore vital for the *icipe* team to take control of the dissemination strategy and ensure it was based on providing knowledge and education alongside seeds and planting materials. Experience over the past 15 years has shown that providing farmers with knowledge has empowered them to adapt the approach to their own needs and to changing conditions in the future.

How does desmodium suppress striga?

Most legumes act as false hosts of striga in that they stimulate germination but do not support growth of the weed. However, field trials showed that when legumes were intercropped with maize, far less striga was seen with desmodium than with other legumes such as cowpea, soybean and sun hemp. In addition, desmodium progressively reduced the number of striga seeds in the soil. Experiments revealed that the desmodium roots were releasing chemicals that undermined the growth of the weed, a so-called allelopathic effect.

Work to identify the chemicals responsible was conducted by *icipe* in collaboration with Rothamsted Research in the UK. The research team has discovered three new isoflavanone compounds (uncinanone A, B and C) and a previously known isoflavanone (genistein). They now know that desmodium not only stimulates germination of striga seeds but also inhibits post-germination growth of the parasite's radicle – the part that attaches to the host plant. This is known as 'suicidal germination' and explains why desmodium can actually reduce the number of striga seeds in the soil.

The research work is time consuming. Khan at *icipe* reckons it will take another five or six years to isolate and characterise all the compounds produced by desmodium roots and to understand their roles in post-germination inhibition of striga. Nevertheless, the range of potential applications is broad and encouraging. Striga threatens the staple food of more than 100 million Africans. Of the 23 species prevalent in Africa, *Striga hermonthica* is the most significant, parasitising a range of crops including maize, sorghum, millet, rice and sugarcane.

Investigating the effect of desmodium on striga. Plants on the right have little striga infestation since they have been exposed to root exudate from desmodium, but those on the left (controls supplied with water only) are heavily parasitised.

2. Uptake and impact: knowledge is the key

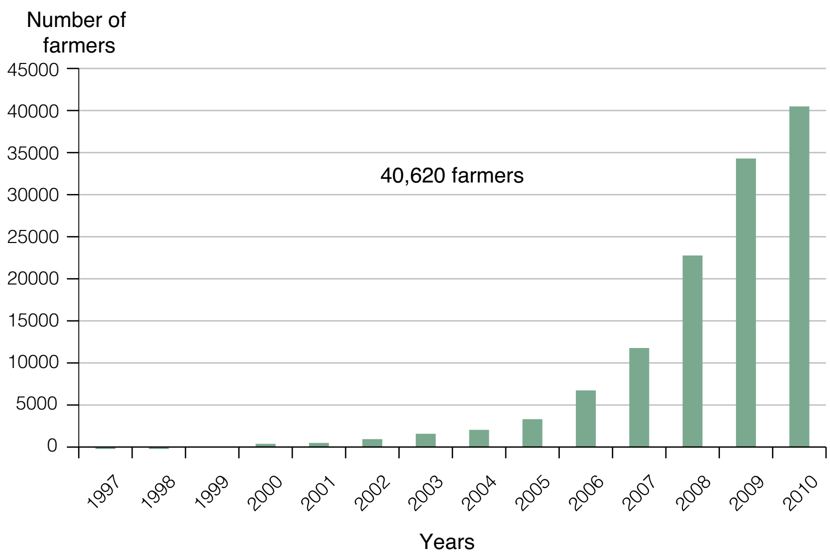
In early 1997, Khan and his colleagues began disseminating the push–pull or habitat management technology to farmers, aiming to transfer both the technology and the knowledge of how it worked. Training in scientific methods encouraged farmers to experiment further, gain ownership of the technology and pass on their new knowledge to others. By training a network of farmer–teachers, helping establish farmers' groups, and facilitating farmer field schools and field days, the team have established a mechanism for rapid adoption, which is the key to widespread impact. Over 40,000 farmers have now adopted the technology (see graph) and most of them can relate stories of major upturns in their fortunes and living standards.

The push-pull garden at *icipe*'s Thomas Odhiambo Campus at Mbita Point, Kenya

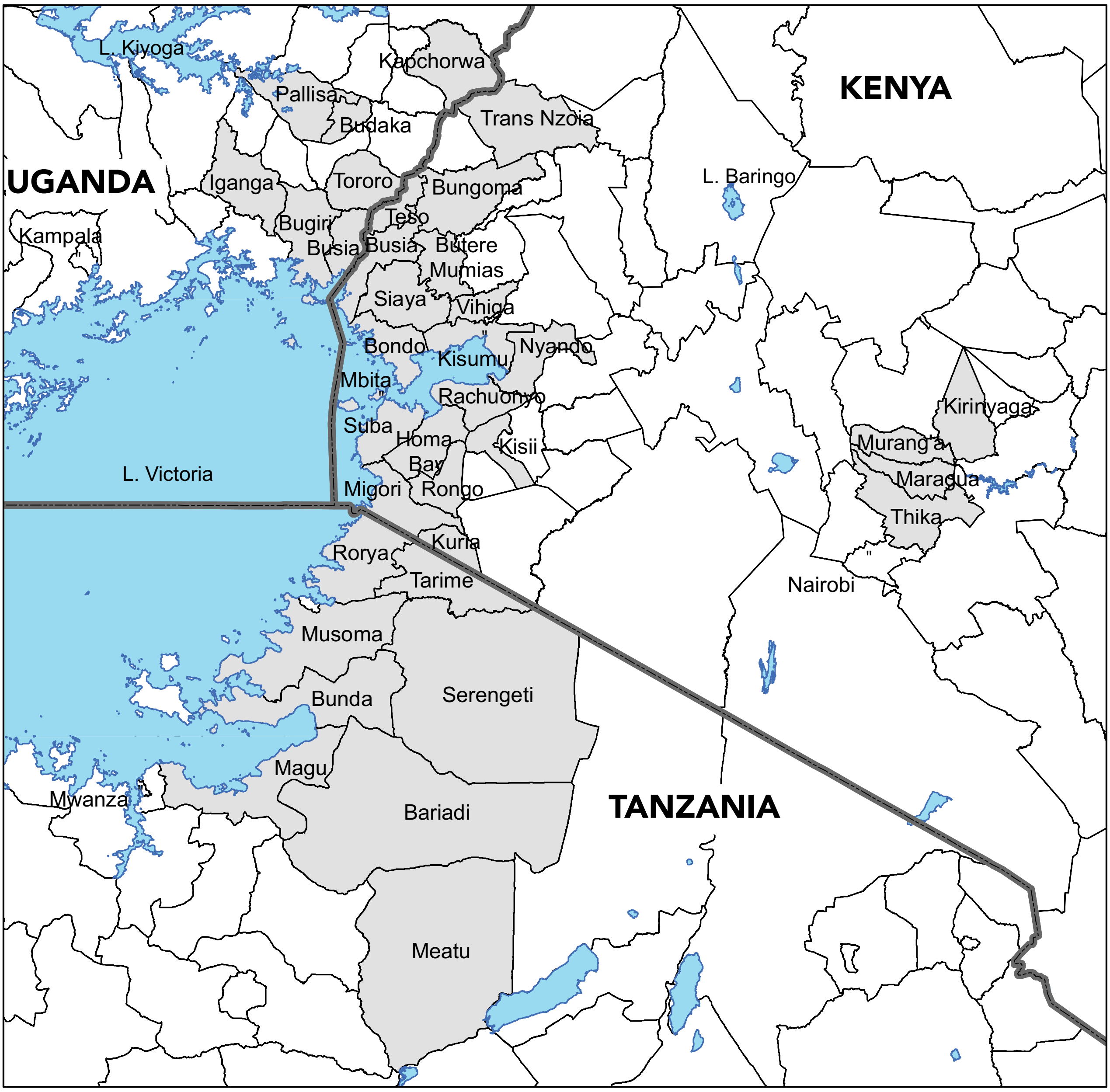
Seeing is believing

Although the researchers could explain the technology with confidence, they soon discovered that farmers remained highly sceptical unless they could see a push–pull plot for themselves. The first step, then, was to establish a push–pull garden at Mbita Point, which farmers and others could visit. Next, the researchers began to establish trial and demonstration plots on selected farmers' fields.

Researchers from KARI and government extension staff helped identify suitable areas for on-farm trials. The team chose two districts for the initial trials: Suba, on the eastern shores of Lake Victoria, and Trans Nzoia, further north. In both areas, there is a high reliance on maize and a lack of food security. Livestock ownership is also widespread but good quality fodder is in short supply.



Adoption of the push–pull technology in East Africa, 1997–2010.



Map of East Africa showing districts where farmers have adopted push–pull

The success of the dissemination tactics employed in the first two districts led the team to replicate the system elsewhere. In each new location the researchers begin by inviting local farmers (individuals or groups) to a *baraza* (public meeting), publicised through local chiefs, district agricultural officers and church leaders. The researchers listen to farmers' problems and explain the benefits of the push–pull technology. Based on criteria such as willingness to experiment, having enough land and cattle, availability of Napier grass and extent of the stemborer and/or striga problem, the farmers then nominate several individuals who will trial the technology on their own fields.

After the first season, most trial farmers are keen to expand their push–pull plots, while field days and informal contacts attract additional local interest. If farmers can show a degree of commitment to the project by planting border rows of Napier, the project will supply the initial seed required to establish the desmodium intercrop. In all areas, *icipe* and KARI technicians and Ministry of Agriculture staff are available to advise and help with keeping records.

The demonstration plots proved to be a powerful advertisement for the technology and word spread quickly. Despite recruiting additional technicians, the researchers realised they needed to provide more extensive help and support if new project farmers were to acquire sufficient knowledge to apply the technology correctly. The solution was to recruit some of the more experienced farmers as teachers to help their colleagues (see box). An internal review of the farmer–teacher

Farmer–teachers spread the word

Peter Koinange is a respected elder in his village of Wamuini, 10 km southeast of Kitale in Trans Nzoia, Kenya. Although there is no striga here, stemborers cause considerable damage and the soils are poor and lack nitrogen. Koinange was one of the first farmers to host on-farm trials in 1997, when he planted Napier grass around his maize plot. “It was incredible,” he remembers. “Before, I had to spend a lot of money on insecticide and fertilizer. Adding the grass meant I could use fewer inputs and still get a better yield.” He later added a desmodium intercrop and established a seed multiplication plot.

Koinange is one of a rapidly growing number of farmer–teachers who are spreading the word about push–pull. When he had successfully managed his push–pull plot for three years, he was given a bicycle, a notebook and some training. He visits five farmers every two weeks to give advice and guidance. Visits and progress are recorded by both teacher and students and regularly reported to *icipe* technicians.

Training in scientific methods has encouraged farmer–teachers to experiment further, equipping them with new skills so they can expand the range of options they offer to other farmers. For example, Koinange has experimented with molasses grass, discovering that it not only repels stemborers from maize but also keeps ticks off his cattle. He has since planted a border of molasses grass around his zero grazing unit and some of his neighbours have copied the idea.

Analysis of the farmer–teacher impact concluded that, on average, each farmer–teacher influenced some 34 other farmers over a two-year period and that the training given to the farmer–teachers gave them sufficient knowledge to train others effectively.

Peter Koinange, a farmer-teacher.

Laurence and Joseph Odek, farmer-teachers, pictured with Lord David Sainsbury and farmer Boaz Nyaten’g. Laurence Odek adopted push–pull in 1997 and his yields have remained high, allowing him to start a dairy goat enterprise and build an entire new house.

system suggests it is working well, but needs close supervision from *icipe* or KARI technicians to ensure the teachers visit their students regularly and give good advice. Some farmer–teachers already have long waiting lists of prospective students. Indeed, Musa Aluchio in Butere Mumias District has 87 farmers queuing up for his services.

Building on the success of farmer-to-farmer dissemination, the *icipe* team have developed training materials and encouraged the inclusion of push–pull in the curricula of farmer field schools. They have also helped set up many new training groups. Farmer field schools confer much wider benefits than just education. By forming farmers into groups, a field school gives the group cohesiveness and they are much more attractive to other government organisations and NGOs offering support and services. They also promote farmer exchange visits, helping to share knowledge. "A field school is a farmer's resource centre for new ideas," says Vincent Okumo, a field school facilitator in Bungoma District. "When our eyes are opened to new knowledge, we start to see many more possibilities." The field schools also integrate many different aspects of farming, helping farmers develop a strong business base for their farm enterprise.

Farmer field schools have proved a highly effective means of disseminating the push–pull technology. Empowering farmers with knowledge boosts their self-esteem and confidence and several field school facilitators and group leaders have become village chiefs or leaders within their communities.

Farmers respond well to messages from other farmers and the push–pull play has been very successful in encouraging new groups of farmers to adopt the technology.

Information and awareness

Every Thursday and Sunday evening, more than five million Kenyan farmers listen to '*Tembea na majira*' ('Follow the path'), a rural 'soap' broadcast on national radio. Like the original concept for the UK radio programme 'The Archers', the storyline introduces new ideas and technologies for improving agriculture. Habitat management or push–pull features regularly and many farmers who have adopted the system heard about it here. The use of drama to convey educational messages is popular in western Kenya and can be highly effective. Some of the younger community members in Vihiga and Butere Mumias Districts have written a push–pull play, which they perform for their peers, entertaining and educating at the same time. Researchers hope to spread the idea to other districts.

Analysis of the flow of information about push–pull indicates that multiple communication channels are involved in spreading awareness of the technology. In addition to *icipe* and KARI field technicians, these channels include non-government organisations (NGOs), community-based organisations, traders and fertilizer or seed sellers, particularly in the more remote areas. To ensure consistent and correct messages, KARI and *icipe* have jointly produced a range of information booklets, brochures and comics in English and local languages. These are being widely distributed as part of the educational dissemination strategy.

A basket of options

A striking aspect of push–pull is the wide range of benefits it provides farmers and its adaptability to individual needs. In addition to raising crop yields, it addresses issues of soil fertility, erosion and moisture conservation, and provides a reliable source of good-quality fodder. With push–pull, farmers struggling to make ends meet on as little as 0.25 ha of land can grow enough to eat, build a livelihood and start to accumulate assets.

Although dissemination efforts focus mainly on small-scale farmers, where the need for food security and income generation is greatest, the technology has been enthusiastically adopted – and adapted – by medium-scale farmers too (see box). Some farmers plant only border rows of Napier grass around their maize plot, utilising the 'pull' part of the technology. Those adopting both 'pull' and 'push' can choose to plant either desmodium or molasses grass between the rows of maize. The planting scheme can be varied too – desmodium can be planted either in alternate rows (the most effective way to deal with striga) or, if there is no striga, in one row for every three or five of maize, to allow for easier ploughing by ox or tractor. Molasses grass can be planted at a range of densities and provides an effective 'push' even at only one row in ten of maize. In response to farmer demand, the *icipe* team has investigated the planting of edible beans as an additional intercrop (see page 23). While this practice increases labour demand, it appears that yields of maize are

Simana Farmer Field School in Bungoma District was formed to teach push–pull. Its activities now include fish ponds and a small tree nursery, which supplies seedlings for members' woodlots. The tree enterprise is managed entirely by the youth of the village, giving them status and an income.

Meeting different needs

At first glance, the Gumo family farm in Kiminini (Trans Nzoia) has little in common with that of the Chapya family, who live in Ebukanga (Vihiga). The Gumos have 40 ha, keep ten crossbred dairy cows and earn money by selling milk. The Chapyas, with ten people to feed, have to survive on only 0.25 ha of land.

Josephine (a farmer-teacher) and Charles Gumo grow desmodium as a sole crop, harvesting fodder and seeds.

Both families, however, have adopted push–pull and have seen a dramatic increase in their farm output. Due to shortage of desmodium seed, Livingstone Chapya planted only a small plot (measuring 35 x 15 m) with the technology but was amazed at the result. "Before, the farm was purple with striga," he says. "But after planting push–pull, I harvested two sacks (180 kg) of maize. I was only getting a quarter of that from the same area before." He has since expanded the size of his push–pull plot and feeds the Napier grass and desmodium to his zebu heifer. He also sells forage when he has enough. He no longer has to buy maize or seek off-farm work; instead, he can invest time and resources in improving his farm and household assets.

Livingstone Chapya currently has a zebu heifer but will soon have sufficient forage to support a crossbred animal.

Josephine Gumo is relieved she no longer needs to apply expensive fertilizer and pesticide to get an adequate maize yield. "With push–pull, I get a bigger harvest – even without using inputs – and the stemborers have all gone." She plants border rows of Napier and one row of desmodium to every five of maize, to allow for mechanised ploughing. Despite having a relatively large farm, she used to struggle to feed the cows in the dry season. Now that she has solved her fodder problem, she keeps new heifer calves and has noticed an increased milk yield – from 8 litres per cow per day to 12. Within five years she hopes to have 20 cows and will need to employ six full-time staff to manage the workload.

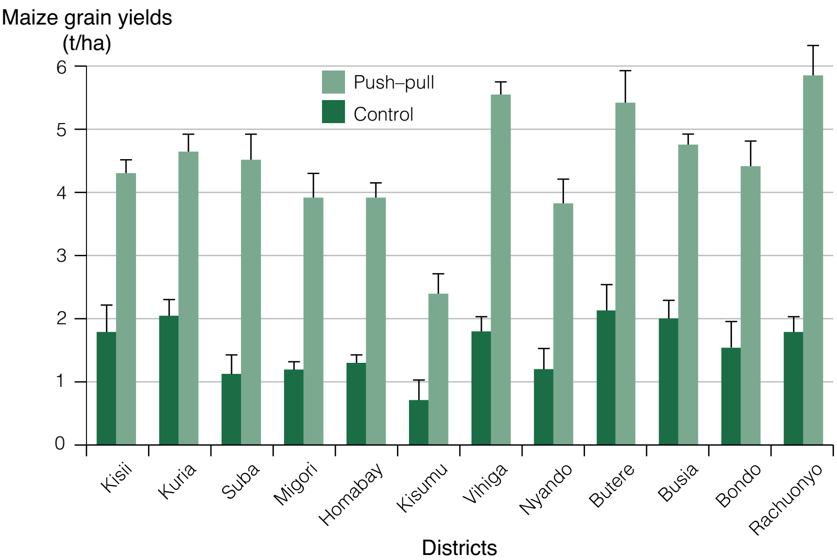
The contrasting stories of these two families show that the push–pull technology is widely applicable across a range of farm sizes and socio-economic circumstances.

not affected and the farmers benefit from being able to produce a source of protein without needing more land.

The robustness and flexibility of the system is demonstrated by successful adoption in different agro-ecologies. The system is used, for example, in the lakeshore region, where two rainy seasons allow two crops of maize and where striga is the main threat to food security. It is also highly effective in the highlands of Trans Nzoia, where there is no striga but farmers experience serious stemborer and soil fertility problems. Furthermore, push–pull has proven effective in boosting yields and eliminating pests in sorghum, millet and upland rice crops (see Chapter 4).

Food to eat, money to spend

Most farmers adopting push–pull have increased their maize yields by over 100% (see graph). The Were family now harvest two bags of maize (180



Average maize yields in push–pull fields (and maize monocrop fields) in 12 districts of Western Kenya in 2009.

Napier grass being sold by traders (KSh 50 per bundle) on the roadside in Luanda, western Kenya.

kg) from a push–pull plot of only 20 x 30 m, while the same area before would have given them only half a bag (45 kg). This scale of yield improvement is not unusual and many families, even on quite small farms, are now self-sufficient in maize and some may even be able to sell part of their harvest. Yield gains are due not only to the control of pests; the desmodium intercrop also improves soil fertility (see 'Safeguarding the environment'). Furthermore, the Napier border rows help prevent soil erosion as well as protecting the maize from lodging (falling over) in strong winds.

Market forces play a large part in the adoption of any new agricultural technology. Although farmers recognise the value of the push–pull approach in controlling stemborers and striga to boost maize production, many cite the additional income-generating opportunities offered by growing forage as their main incentive to switch to the new system. Sales of Napier grass and desmodium to neighbours with stall-fed cattle provide a new source of income and, since the forage can be harvested regularly, this brings in money when there are no other crops to sell. Having home-grown forage also means they no longer need to spend many hours each day either gathering forage for stall-fed cattle or herding the animals as they graze.

Some farmers have made enough profit from the sale of forage to buy a dairy cow or goat; others now have sufficient fodder to upgrade their cows by crossing their native zebus with exotic breeds (such as Ayrshires and Friesians), thereby increasing milk yields. A regular supply of milk not only raises farm income, it also improves the nutritional status of the farming family, especially the children (see box).

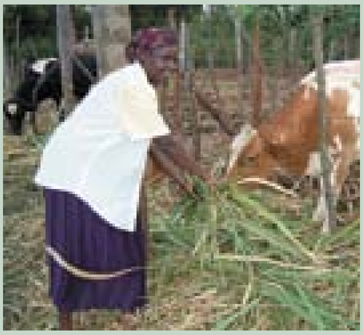
In East Africa, most farmers keep indigenous zebu-type cattle, which are hardy and can survive on little feed, but produce only small quantities of milk (around 300 ml per cow per day). This partly explains why, in most districts, milk demand by far outstrips the available supply. The major constraint to keeping crossbred, higher-yielding dairy cattle and goats is the seasonal shortage and generally poor quality of available feed. Farmers who adopt push–pull not only achieve a year-round supply of good quality fodder, they also satisfy one of the criteria demanded by Heifer International. Farmers like Litunya (see Chapter 3) can now qualify to receive a dairy cow or goat as part of the Heifer International scheme and the NGO also promotes push–pull widely within its knowledge transfer mandate.

Milk to spare

Lillian Wang'ombe farms 1 ha in Wamuini, near Kitale in Trans Nzoia with her husband John. As her maize crop used to be infested with stemborers, there was barely enough to feed the family and none left over to sell. She heard about push–pull from her mother and was impressed by the way the technology got rid of the stemborers without using insecticide.

After planting Napier grass and desmodium, Wang'ombe found she had enough maize to feed her five children for the whole year and still had a surplus for market. Within one season she had enough Napier grass to give some to her mother, in return for milk. Before long, it was obvious that there was enough fodder to keep a cow and, after selling the surplus maize, she was able to buy her first crossbred cow and pay a deposit on a second.

Wang'ombe now has three cows, two of which are due to calve. When they do, there will be enough milk for the household and to sell. The children eat well and the family has been able to buy schoolbooks, medicines and furniture. "Some people laughed at us when we first planted Napier grass without cows on such a small farm, but now they come to us for advice!" she says.



Lillian Wang'ombe feeds her crossbred dairy cows with home-grown Napier grass.

Heifer International Kenya Director, Alex Kirui, pictured with a dairy goat stall-fed on Napier grass. Dairy goats can produce two kids per year instead of one as well as higher milk yields (3 litres per day compared with 1.5 litres from local breeds).

Sale of desmodium seed is another income-generating opportunity. This came to light when the speed of adoption of the push–pull technology led to a serious seed shortage. Seed multiplication has now developed into a commercial enterprise (see Chapter 3).

Asset acquisition

Making the difficult transition from subsistence farming to earning a cash income allows farmers to start acquiring assets and so to increase the income-generating potential of their farms still further. Accumulating assets also gives farmers some insurance against hard times or for when family needs arise. For example, Samuel Ndele, who lives on a 1.2 ha farm in Ebukanga, Vihiga, was experiencing diminishing maize yields due to the combined effects of stemborers, striga and declining soil fertility. When he heard about push–pull on *Tambea na majira* he thought it might help him. He tried it and was delighted when he harvested twice as much maize from his first plot than he had previously. With the money he earned from selling Napier grass and maize, he bought a sow and fed her on maize and desmodium forage. When she farrowed, he sold all six piglets and bought a zebu heifer and a new roof. Now that he has plenty of forage, he can return more of his crop residues (and the manure from the pig's stall) to the soil, improving the fertility of his farm. This year he hopes to build a bigger house and next year he will buy a crossbred cow. "Now every year gets better instead of worse," he says.

Safeguarding the environment

Many farmers comment on the beneficial effects of push–pull on soil fertility, soil erosion and soil moisture. In addition, the improved availability of forage allows them to return crop residues to the soil instead of feeding them to livestock. Zero grazing units are an excellent source of farmyard manure that farmers can use to enrich the soil either by applying it directly or using it to make compost. Many apply farmyard manure to their Napier grass, which grows faster allowing more frequent harvesting. Improving soil fertility is especially important in Trans Nzoia, where non-push–pull farmers have to use inorganic fertilizer and pesticides if they are to obtain a reasonable maize yield. Farmers like the Wang'ombes and the Gumos have discovered that with push–pull they can get sizeable yields without using inorganic fertilizers and pesticides.

Monocropping and the use of chemical inputs are strongly correlated with the loss of biodiversity. By introducing a mixture of crop species into the farm environment and reducing the need to use pesticides, push–pull reverses that trend. In addition to increased numbers of natural enemies of stemborers, researchers found significantly more beneficial soil organisms in maize–desmodium fields than in maize crops alone. Reducing the use of pesticides and inorganic fertilizers has important benefits for human and environmental health and, of course, releases farmers' cash for other purposes. Another benefit with far-reaching implications is the ability of the system to improve livelihoods on even very small farms. This has the potential to reduce human pressure on the land, thereby slowing human migration to the cities and to marginal or protected areas.

Sale of piglets and, eventually, milk will allow Samuel Ndele to continue to invest in his farm and improve his income over the longer term.

Bilia Wekesa shows researchers how she makes compost in her zero grazing unit. Farmyard manure, household waste and crop residues are piled up and covered with maize stover and will make good compost after about three months.

Push-pull is particularly beneficial to women farmers. Once the plots are established, it reduces labour demand because weeding becomes much easier and there is no need to gather fodder for the animals. A supply of milk and additional household income also benefits the health and welfare of the women and children.

Extending the benefits

The *icipe* team has linked up with national scientists to introduce the technology in Tanzania and Uganda. Since the dissemination strategy in Kenya has proved so successful, the Ugandan and Tanzanian researchers are adopting a similar approach, identifying farmers' problems and arranging exchange visits with Kenyan farmers. Field days held on-farm have increased the farmers' knowledge of striga and stemborer biology and have given them more confidence to adopt the technology and explain it to other farmers.

Work on outscaling push–pull was initiated in the striga-infested districts of Eastern Uganda in 2001. By 2010, through farmer-to-farmer dissemination, the technology had been adopted by over 4000 subsistence farmers, on a total of over 3000 hectares of land, with yields of maize rising from less than 1 tonne to nearly 4 tonnes per hectare; an impressive increase of 400%.

Similarly, in Tanzania over 6,000 farmers have adopted the technology and the majority have at least doubled their maize yields.

New zones, different crops

Although developed initially for maize, push–pull also benefits farming systems based on sorghum, millet and upland rice. These cereals are more tolerant of drought than maize and are grown in areas where rainfall is scant and unreliable. Striga and stemborers can also be severe constraints in such areas. Researchers have found that, when these cereals are intercropped with the drought-tolerant greenleaf desmodium (*Desmodium intortum*) and bordered by rows of Napier grass, the effects of striga and stemborer can be greatly

Addressing aspects of climate change

With arid areas on the increase due to climate change, drought-resistant sorghum is likely to become an increasingly important staple crop in many parts of sub-Saharan Africa.

Zeyaur Khan is presently working towards adaptation of the push–pull technology to drier areas of Africa to ensure its sustainability under the increasingly adverse conditions associated with climate change. His research group is identifying new drought- and temperature-tolerant trap and intercrop components for the technology, which will widen the scope for further expansion, especially in the more arid areas of sub-Saharan Africa that are most vulnerable.

Khan is exploring the possibility of breeding edible beans and cowpeas that have the powerful striga-controlling properties of desmodium built in. These will be suitable for intercropping with maize and other cereals to respond to a broader profile of farmer practices. In the long term, he also visualizes a possibility of transferring appropriate striga-inhibiting genes to the cereals themselves, creating a new generation of parasitic-weed-free cereals.

Project Leader, Zeyaur Khan, illustrates the beneficial effects of push–pull on sorghum crops in a trial at *icipe*'s Thomas Odhiambo Campus at Mbita Point, Kenya

New Rice for Africa (NERICA) is an upland, non-irrigated rice, which is a cross between Asian and African species. High yielding and drought tolerant, it can be grown without irrigation and is well suited to African smallholder farming systems. It is also highly susceptible to *Striga hermonthica* (left). However, when planted with an intercrop of desmodium (right), it is not attacked by the parasitic weed.

reduced and crop yields increased by at least 50%. "This adaptation of the technology will be particularly applicable for arid and semi-arid regions throughout Africa," says Khan.

The importance of this research was recognised in 2010 when *icipe* secured a 3 million Euro research grant from the European Union. This will fund further work to enhance the resilience of the push–pull technology, including the biology of plant signals related to water stress. The aim is to extending its appeal to farmers and improve its long-term sustainability in different agro-ecologies throughout Africa.

A good return?

Although the long-term benefits are clear, the early stages of establishing a push–pull plot place heavy demands for labour on participating farmers. (This and other constraints are discussed in Chapter 3.) So, does the technology offer farmers a good return on their investment?

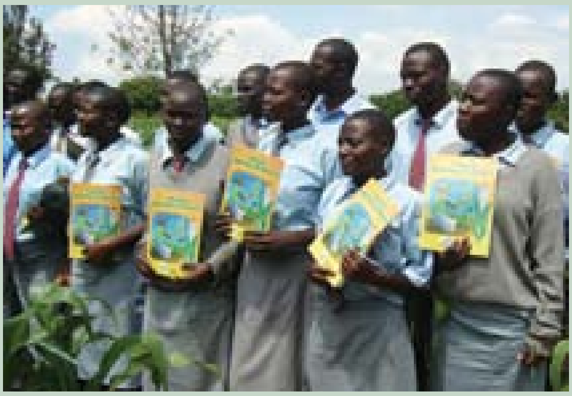
icipe has commissioned several studies to help answer this question, including an independent analysis (see box). Another formal cost–benefit analysis measured farmers' income, expenditure, use of inputs and labour. The results indicated a benefit-to-cost ratio in excess of 2.5 when evalu-

Impact on farmers: an independent assessment

A recent independent impact assessment study by the Swiss organisation, Intercooperation, in Kenya and Uganda confirmed the push–pull technology is widely accepted and adopted by smallholder farmers because it addresses their major production constraints. The assessment report concluded that the technology contributes significantly to reducing the vulnerability of farm families by ensuring higher yields of maize (increased from 1.2 t/ha to 4.2 t/ha) and milk (increased from 1.5 l/day to 3.8 l/day). Perhaps even more importantly, push–pull confers better yield stability. The study further concluded that the technology forms a 'springboard' for diversifying the farming system, especially by incorporating dairy operations. Increased food security, higher income, better education of children and health of the family, greater knowledge and a higher status in the village are factors that all contribute to an overall improved livelihood situation amongst smallholder farmers adopting push–pull.

The study estimated the annual additional gross benefit generated by push–pull compared with a traditional maize crop in 2009 to be in the range of about US$ 100 per family or US$ 2–3 million nationally. Study author Martin Fischler concludes that push–pull is "probably the single most effective and efficient low-cost technology for removing major constraints faced by the majority of smallholder farmers in the region, resulting in an overall and significant improvement in their food security and livelihoods".

Source: Fischler, M. 2010. Impact assessment of push–pull technology developed and promoted by *icipe* and partners in eastern Africa. Nairobi, Kenya: International Centre of Insect Physiology and Ecology. ISBN 92 9064 215 7.



Income generated by push–pull allows many children to attend school up to secondary level. *icipe* is also bringing push–pull into schools through an information booklet designed to educate the farmers and agricultural scientists of the future.

ated over several years. This indicates that it is efficient and consistently gives farmers a good return on their investments. Economic gains are greatest in areas where both striga and stemborers pose a constraint to growing maize. Returns are good even for farmers who have small plots and little money to invest – and these, after all, are the ones who need help the most.

It is important to emphasise that the high labour inputs for establishing the Napier border rows and desmodium intercrop are a one-off, while the benefits continue for many years. Hence, the benefit-to-cost ratio is likely to increase as time goes on. Consequently, another study assessed the economic performance of push–pull in comparison with conventional maize monocrop and maize–bean intercrop systems in six districts in western Kenya over 4–7 years. The researchers found that maize grain yields and associated gross margins from the push–pull system were significantly higher than those in the other two systems.

Although push–pull plots had higher production costs for the first two seasons, these reduced to either the same level or significantly lower than in the maize–bean intercrop from the second year onwards in most locations. Similarly, the net returns to land and labour with push–pull were significantly higher than with the other two systems. Push–pull consistently produced a positive net present value (NPV) when the incremental flows of its benefits compared to those of the two conventional systems were discounted at 10–30%, indicating that push–pull is more profitable than the other two systems under realistic production assumptions. "The technology is therefore a viable option for enhancing productivity and diversification for smallholder farmers who largely depend on limited land resources", says Khan.

A collaborative project between *icipe*, the International Maize and Wheat Improvement Center (CIMMYT) and the Tropical Soil Biology and Fertility (TSBF) Programme has revealed that the gross margins of push–pull can be greater than those of other striga control strategies. The scientists studied combinations of desmodium, soybean or sun hemp and local maize or imazapyr herbicide resistant (IR) maize, developed by CIMMYT. IR maize has a low dose (30 g/ha) of imazapyr herbicide added as a seed coat to herbicide-resistant maize. The herbicide attacks the striga seedling before or at the time of attachment to the maize root and any imazapyr not absorbed by the maize seedling diffuses into the soil, killing non-germinated striga seeds. The various options were tested with or without fertilizer.

The results showed that push–pull with local maize and no fertilizer gave the best return. Adding fertilizer is inappropriate in dry areas since drought frequently affects crop growth and the investment cannot be recovered. The high gross margins of push–pull are related to the low input costs, since Napier and desmodium are perennial crops and, once planted, provide income for several years.

Christine Were has compared these options on her farm. Although she found that a combination of push–pull with IR maize and fertilizer provides the best control of striga, her preferred option is to grow local maize in a push–pull plot. "With this system I don't have to buy fertilizer or seed," she explains. "And I get more maize when I plant a desmodium intercrop than I do with the other legumes." Indeed, additional studies over six seasons concluded that the push–pull system is highly profitable, providing a better return on investment than using fertilizer or IR maize.

Rosemary Onduru lives near Onyatta village in Bondo District, where striga is a serious pest. She planted her first push–pull plot at the end of 2010 and is looking forward to a far better harvest this year than the meagre 8 kg maize she got last time from her traditional plot. While she found it hard work to establish the push–pull plot, she was encouraged when she saw her neighbour harvesting big bags of push–pull maize. She also knows that future seasons will be easier with less time spent weeding, freeing her labour for more productive tasks like taking the Napier to market and, when she has saved enough for a cow, selling milk.

3. Challenges and constraints: from seeds to policy

As they start to be adopted, new technologies often encounter obstacles, some of which may have been unforeseen at the outset of the project. Hurried dissemination, without first addressing these obstacles, may lead to failure. For example, desmodium is labour-intensive to establish since the plot requires frequent and thorough weeding if the emerging seedlings are not to be overcome by weeds. Until farmers have seen desmodium seedlings growing, they cannot tell the weeds from the crop. This is where visits to Mbita Point, help from farmer–teachers and farmer field schools prove invaluable. The high incidence of HIV/AIDS in some areas is another factor contributing to shortage of labour. Here too, farmer–teachers or farmer groups may be able to help by mobilising support within the local community.

Harvested desmodium seed before (left) and after on-farm processing.

The need for seed

As word spread about desmodium's ability to suppress striga, farmers throughout the trial districts began clamouring for seed, creating a serious shortage. Although the Kenya Seed Company was importing seed from Australia, the price was high and availability limited. *icipe* therefore began a farmer-based seed multiplication project, which also gave farmers the opportunity to develop an additional income stream. Initially, this was implemented by informal groups of farmers, who planted desmodium bulking plots primarily for the seed harvest. The activity proved lucrative, with seeds fetching a high price in the market – between US$10 and 15 per kg.

The quantities produced, however, were rather small and in 2003 Khan sought help from the private sector. He approached the Kitale-based Western Seed Company to undertake commercial seed production through contracts with local farmers and community groups. The initiative began with 300 farmers in Bungoma and Trans Nzoia, who were trained in seed production and preparation and given 250 g of certified seed each to multiply (see box overleaf).

Western Seed undertakes to buy the harvest from all its contract farmers. It then cleans the seed, checks germination and viability, and packs and stores the seed. In 2004 the number of contract farmers increased to 450 and, by the end of 2005, there were over 700 farmers involved. Now the number has increased to over 1500. While the company initially sold most of its packaged seed to *icipe* (for distribution to new project farmers), after 2005 it has also sold seed on the open

Western Seed markets certified desmodium seed produced by contract farmers

Turning a tidy profit

A worsening stemborer problem and the high cost of fertilizer and insecticide meant that Bilia Wekesa could no longer rely on maize as the main source of income from the 1.6 ha she farms near Kitale in Trans Nzoia. She heard about push–pull on the radio and thought it sounded 'too good to be true'. But after attending a *baraza* she decided to try the system.

Wekesa collected enough seed from her initial desmodium intercrop to plant her own bulking plot and is now a contract producer for Western Seed. She harvests weekly and prepares the seeds by placing them on a large stone and threshing them with a piece of rubber. "Establishing the plot and collecting and cleaning the seed are hard work and take a lot of time, but the profit is good, so it's worth it," she says. "I make more money from selling desmodium seed than from maize or Napier grass, from a much smaller area of land. And the money is available all year round."

Bilia Wekesa harvesting desmodium seed. Her homemade overall prevents the hairy seed pods sticking to her clothing.

market. In conjunction with *icipe*, the company has started a promotional scheme, whereby a 50g pack of desmodium seed is given away with every purchase of a bag of hybrid maize seed. This scheme could reach up to 3000 new farmers each year, considerably expanding the market for desmodium seed. The package contains sufficient information to enable farmers to adopt the technology and make contact with Western Seed and *icipe*, together with suggestions for contacting local farmer–teachers or field schools.

Farmers are constantly thinking up new ideas and several have tried establishing new desmodium plants by means of vegetative propagation, planting desmodium vines or stems in the same way they propagate sweet potato. The *icipe* team is helping to spread this idea through farmer-trainers, field schools and demonstration days.

Although busy with his own maize development programme, Saleem Esmail, Chief Executive of Western Seed, was keen to assist because he was convinced of the benefits of push–pull. But did it make good business sense to become involved? "Yes, probably there will be long-term benefits," he replies cautiously. "There is an element of risk." In fact, profitability is not the immediate reason for his involvement. "There is a need to address the whole sustainability of farming in Africa," he continues. "We cannot sell to farmers who have no cash – first we have to help put money in their pockets." Esmail believes that, by raising farmers out of poverty, his company can lead them into the cash economy so that they become tomorrow's seed buyers.

Linking a commercial seed company with numerous small-scale farmers has great potential and additional private seed companies have shown interest in producing desmodium seed. Such competition will help keep the seeds affordable.

Credit and cows

The second major constraint preventing farmers from capitalising fully on the push–pull technology is the lack of cash or credit to buy crossbred dairy cattle. Although some (like the Wang'ombes) have saved money from sales of forage, this is not possible for all farmers, particularly those with large families and small farms. *icipe* has therefore worked hard to establish strong links with appropriate development schemes and programmes. After working together for several years, formal Memoranda of Understanding have been signed with both Heifer International and the Ministry of Agriculture's National Agriculture and Livestock Extension Programme (NALEP). Both organizations work with farmer groups to improve livelihoods and both are now promoting the push–pull technology to their clients. Heifer International is working with 2700 farmers in Kenya, all of whom are receiving training in push–pull, while all NALEP extension agents are learning about the technology and promote it as a priority to all their clients.

"Push–pull fits well with our philosophy," says Titus Sagala, Heifer International Regional Coordinator for Western Kenya. "We help farmers use their on-farm resources to become more productive in a sustainable way, by diversifying their livelihoods." Heifer works with selected farmers' groups to make them more food secure and resilient before training them in livestock options, including dairying. Then the farmers must build a zero grazing unit and have a reliable source of year-round fodder before they are given a dairy cow or goat. They then undertake to pass on an in-calf heifer (or pregnant goat) to the next farmer in the scheme. (Further benefits associated with partnerships and group schemes are discussed in Chapter 4).

When adapting push–pull to sorghum- and millet-based farming systems in the drier areas, an obstacle that has yet to be overcome is the need to protect the intercrop and border rows from herds of cattle, which traditionally graze freely on crop residues after the grain has been harvested. Here, farmers will incur additional input costs (for fencing and/or labour) to protect their forage crops. Socio-economic studies may be needed to determine whether this issue is likely to deter adoption. In current project areas involving maize cropping systems, most cattle are stall-fed, tethered or herded and free-grazing cattle are uncommon.

A farmer buying desmodium seed at a field day in Rongo organised by Heifer International. *icipe* staff work closely with those from Heifer, the Ministry of Agriculture, Ministry of Livestock and other NGOs to ensure the correct knowldege is passed on with the seeds.

The gift of hope

A cow named Zawadi (meaning 'gift') represents Joseph Litunya's aspirations for the future of the farm he shares with his parents and five brothers. Since adopting the push–pull technology, his family has not only doubled its maize yield but also satisfied the criteria for Heifer International.

Zawadi is 75% Ayrshire, and when she calves, Litunya hopes she will give over 6 litres of milk per day, which will provide the family with much-needed income. As a farmer who would otherwise have had no opportunity to obtain a crossbred cow, Litunya is only too glad to fulfil the project criteria and help someone else in his situation by offering them his first in-calf heifer and sharing his knowledge of dairying with them.

Thanks to a plentiful supply of forage and a home-built zero grazing unit, Joseph Litunya has met the criteria for Heifer International, an NGO that provides crossbred dairy cows to farmers who lack the cash or credit to buy them from market sources.

Litunya helped found the Busia Farmers' Group, which is helping all its members to acquire crossbred dairy cows. Registered with the Ministry of Social Services, this formal group has introduced group savings schemes and has better access to other development support than individuals would. The members hope to win a contract for commercial production of desmodium seed and, in time, could form a cooperative for selling milk.

Harvesting desmodium seed is time-consuming, but the profit is good. However, at present, the harvest from an intercrop can only be sold through unofficial channels.

Storing the surplus

Overcoming the major constraints to growing maize is certainly a good starting point, but it is frustrating for farmers when they cannot store the surplus grain. Post-harvest losses caused by pests and diseases are extremely high in maize. Together with acute cash shortages, the risk of such losses often forces farmers to sell their crop immediately after harvest. Improved storage conditions would not only increase the amount of maize available to eat but also enable farmers to sell their surplus later, when prices are higher. While research institutes such as CIMMYT are investigating this problem generally, the *icipe*–Rothamsted team is hoping to secure additional funding for research into potential solutions that would be particularly appropriate for push–pull farmers.

Pest defence strategies

Because it increases crop diversity on the farm, push–pull might be expected to minimise the risk of pest and disease attack. However, the success of both desmodium and Napier grass as cash crops means that many farmers are planting them as sole crops, increasing the risk of pest and disease outbreaks. Indeed, throughout East Africa, Napier grass is already being attacked by a disease that causes the plants to become yellow and stunted. Working with Rothamsted, the *icipe* team have identified the culprit as a phytoplasma bacteria transmitted by the leaf hopper, *Recilia banda*. They have developed a PCR-based method for detecting the phytoplasma in the insect and plant. Now they know the cause of the disease and can identify affected plants, they are able to screen varieties of Napier and other fodder grasses for resistance and identify sources of resistance genes that could be useful in the event the disease is transferred to crop plants. Working with national partners, *icipe* staff are seeking to identify resistant Napier germplasm and other alternative fodder grasses .

Potential insect pests on desmodium include pollen beetles (*Mylabris* spp.) and a pod borer (*Maruca vitrata*). These insect pests are becoming an economically significant problem and the project team is investigating control measures to combat the threat of attack. Scientists at *icipe* and Rothamsted are working on a defence strategy targeted on these insects, which involves traps baited with floral volatiles. The idea is that farmers could make their own traps using the appropriate flowers.

Investing in knowledge

Lack of capacity is a common constraint to technology dissemination. However, the project's partnership model and focus on knowldege dissemination ensures a two-way transfer of knowledge among *icipe* staff, farmers, extension services, NGOs and national research centre scientists.

In addition, the project is investing in the international scientists of the future by hosting the World Food Prize Summer Intern Programme. Four young scientists have spent their summer break working at *icipe* with the aim of acquiring a

Napier stunt disease on the farm of Consolata James in Vihiga. The project team needs to be proactive in investigating control measures to combat the threat of attack from this and other diseases and pests.

first-hand view of real and pressing food security issues and nutritional problems in poverty-stricken areas. The students have become an integral part of the project, spending time in the laboratory as well as in the field conducting research and gathering data. The goal is to inspire young people to pursue careers in food, agriculture and natural resource disciplines.

Promoting change through champions

Push–pull can already count some 40,000 farmers as technology champions, who promote its benefits to others. Several high-profile Kenyans can be added to this number, including the Directors of KARI, NALEP, Heifer International and a former Member of Parliament. Further internationally acclaimed scientists are adding their voices and creating a volume of opinion that will influence a more enabling environment for push–pull.

Julius Arungah, former MP, is lobbying to get push–pull accepted as part of Kenya's formal agriculture strategy. Interested politicians like Arungah may also be able to tackle long-standing policy constraints, such as regulations concerning seed supply and certification.

Seed supply regulations have placed several obstacles in the project's path, but the team made a major breakthrough when they influenced a change of policy regarding the distribution of seed that was the product of KARI research. Until 2000, such seed could only be distributed through the Kenya Seed Company. The problem was that this public sector organisation did not perceive a demand for desmodium and was unwilling to distribute the seed. Since the change of policy, the private sector (Western Seed) has been allowed to distribute seed originating from KARI and the project team has begun to address the desmodium seed supply problem.

Sydney Schrider, World Food Prize Intern for 2010, interviews farmers for her research project on push–pull, gender, irrigation and food security. Sydney was the fourth World Food Prize Intern to work with the push–pull project. Before her were Bian Li (2000), Megan Srinivas (2004) and Anne Seccor (2006). Bian and Megan received the Chrystal Award for their outstanding work.

In areas of lower rainfall, poorer soils or where tsetse is a problem, dairy goats are a more appropriate option than cows. Working with Heifer International and NALEP, *icipe* is helping farmers acquire the knowledge and resources they need to run a successful enterprise based on improved breeds of dairy goat like the Saanen.

The team has had less success with seed certification regulations. Seed must receive certification from the Kenya Plant Health Inspectorate Service (KEPHIS) if it is to be sold commercially. Current rules state that all certified seed must be grown as a sole crop. This precludes seed from desmodium intercrops from being sold through approved channels. Although seed yields from sole crops are often better than from intercrops, there is greater risk of pests and diseases. Farmers do harvest intercropped desmodium for seed – for their own use and to distribute informally. But if they could sell certified seed, their profit would be greater and this would represent another significant benefit for the push–pull system. The project team and the Chief Executive of Western Seed are working hard to change these regulations.

4. Across the spectrum: learning from experience

The story so far is one of success. Some 300,000 people in more than 40,000 farming families have already adopted the push–pull system, benefiting from enhanced health, education and quality of life, as well as reduced levels of poverty, hunger and malnutrition. Most farmers report a doubling of their maize yields in the first season and, in striga-infested areas, yields have even tripled. The first adopters have maintained these improved yields for over 13 years, with minimal inputs, many becoming food-secure for the first time in their lives.

Furthermore, the research team and the farmers they have worked with have learned a great deal about plant and insect chemistry and the principles that underlie environmentally friendly pest control. Constraints to adoption have been identified and strategies for addressing them have been devised.

Training in scientific methods has helped Mary Rabilo (pictured with Ministry of Livestock technician George Genga) to develop her own forage ration for dairy cows, which contains ground maize and *dagaa* (small fish from Lake Victoria) mixed with chopped desmodium leaf. She has evaluated different combinations of ingredients and developed a mix that costs less than bought concentrate feed, yet gives a higher milk yield.

A question of scale

The key question now is how widely can the technology be applied elsewhere in Africa? Experience shows that out-scaling of projects in African agriculture is difficult and requires considerable investment of time, money and other resources. Local adaptation is also essential if new technologies are to reach their full potential in different areas.

The push–pull technology is flexible and can be successfully adapted and introduced to new cropping systems and agro-ecologies. Push–pull strategies can be developed and adapted for a range of cereal crops and farming systems. Most importantly, the technology points the way to a much broader approach to integrated pest, weed and disease management than previously attempted – an approach that sets pest and disease management in the context of the health of the whole agro-ecosystem.

From science to impact

A striking aspect of the project, and one that sets it apart from the majority of international agricultural research centre initiatives, is that it addresses the entire research and development spectrum, from strategic and applied research (building scientific knowledge and developing new technologies), through adaptive on-farm research (fine-tuning technologies to local conditions) to dissemination efforts with a range of partners.

The push–pull project provides a good illustration of the need to base new agricultural technologies on sound science. Detailed knowledge of the chemical mechanisms responsible for the push–pull effect helps to ensure the continuing efficacy of the system and allows it to be adapted to new situations. As Pickett says: "Science-based solutions are more robust. Understanding the underlying mechanisms means that if the technology ceases to work, we will be able to find out why and take appropriate action." Knowledge also gives researchers and farmers confidence to experiment further with the technology.

Dr Ephraim Mukisira, Director of KARI, is a strong advocate of push–pull because it is based on science but puts the farmer first, being easy to adopt and improving many different aspects of the farming system. "It provides a good illustration of how an international research centre can work with a national system to make a real difference at ground level." he says. "I believe this project provides us with a strong model that should be followed by other development research institutes, and our own Outreach and Partnership Department will be learning from this success story".

Margaret Oroko grows edible beans as an additional intercrop alongside the maize and desmodium on her farm in Rachuonyo District. Farmers are continually experimenting and the *icipe* project team backs them up with scientific trials to test the efficacy of their ideas. Planting beans between the maize plants or in the same hole as the maize has little impact on the harvest of maize or desmodium while, at the same time, providing an important source of protein for the farm family.

A flexible agenda

In 1994, when *icipe* first sought funding to support research on maize stemborers, push–pull was little more than a promising idea in the minds of an informal global network of chemical ecologists. That it has now become mainstream thinking in several national research systems is due in large part to the freedom enjoyed by the scientists involved to pursue new research directions as these arose – and in particular the links between the environmental aspects of the technology and its implications for poverty eradication. When Professor Odhiambo and his colleagues at *icipe* decided to focus on developing a strategy to attract stemborers away from maize, they never anticipated that one of the 'push' plants would also suppress the parasitic weed striga and that a major benefit of the technology would be improved livestock production. The flexibility of the project's funding mechanisms was a key factor in maintaining the open-ended nature of the work.

Investing in farmers

Although a knowledge-intensive technology is expensive to disseminate, the project's focus on farmer participation and training has sown the seeds of widespread and self-sustaining impact.

Projects need 'Champions'

The importance of 'project champions' – individuals who drive a project or process forward by means of their own personal commitment and energy – is well-known. Push–pull project leader, Zeyaur Khan, is just such an individual. He has spent the past 17 years working tirelessly to drive the project. A committed and talented scientist, Khan has ensured the push–pull technology is based on sound science. He has also taken a leadership role in dissemination efforts. Known by project farmers as 'Dr Push–pull', he is a vital part of the project's success.

Zeyaur Khan dicussing push–pull with 'Mama' Sarah Obama, grandmother of the President of the USA, at her home in Kenya. Mama Sarah has a push–pull demonstration plot on her farm and has agreed to become a goodwill ambassador, to further champion the project and broaden its scale of impact.

Zeyaur Khan has been elected a Fellow of the Entomological Society of America. In December 2010 he was presented with the Nan-Yao Su Award for Innovation and Creativity in Entomology by Dr. David Hogg, President of the Entomological Society of America.

Khan's achievements have been widely recognised. In July 2008 he was invited to present a plenary talk entitled "Push-pull – a chemical ecology-based IPM strategy for smallholder farmers in Africa" during the XXIII International Congress of Entomology held in Durban, South Africa and, in 2009, he was presented with the International IPM Excellence Award. In 2010, the Entomological Society of America honoured Dr. Khan with triple awards: Fellow of the Entomological Society of America, the Nan-Yao Su Award for Innovation and Creativity in Entomology, and the Distinguished Scientist Award.

Peter Wafula, Chairman of Bungoma Umbrella Farmer Field School Network, sees his job as "to oversee and empower". Since 2006, his field school network has trained over 5,000 farmers on push–pull and each of them is now training others, creating a sizeable ripple effect. In addition, several of the field school facilitators have achieved leadershiop positions (e.g. chiefs, village elders or field officers) in their communities.

Participating farmers have a sense of ownership and feel pride in what they have achieved, which encourages them to learn more and pass on their knowledge to others. They also have increased confidence and this is demonstrated when they form farmer groups, which have a louder 'voice' and can attract more resources than individuals. Teaching farmers to experiment and innovate makes them inherently more adaptable and resilient in the face of changing conditions – whether these are economic forces, such as from globalisation, or ecological, as a result of climate change.

The team has high hopes that farmer–teachers will eventually accept much of the responsibility for passing on knowledge. Currently there is still a need for technical backstopping from trained *icipe* or national scientists. Indeed, Pickett believes the project will need careful stewardship for some time to come. "Push–pull is a highly self-reliant technology and it is really up to the farmers to make it work for their own situations," he says. "But because it is so flexible, it needs some kind of anchor point. For example, if farmers start planting field beans in the space between the maize and the Napier, someone has to remind them that this may interfere with the 'pull' of the Napier grass and upset the balance of the system. It is also important at this stage to spot new challenges quickly, for example the dangers of disease in Napier grass or insect pests on desmodium." The need for backstopping also extends to quality control, for example the monitoring of desmodium seed produced by farmers to prevent a shift in its genetic make-up and/or loss of the active chemical stimuli.

Building partnerships and institutions

Adopting a partnership approach to R&D increases motivation and speeds up progress. It can also allow for a gradual exit of the initial funding and managing institutions, which can pass on responsibility to national organisations. The *icipe*–Rothamsted collaboration has worked well, due mainly to good communication. The lead scientists talk to each other regularly via a dedicated low-cost telephone line installed between their desks in Kenya and the UK. They do not compete for funds and neither organisation considers itself the leader, but each has a clearly defined role. The partnership is based on mutual benefit: while *icipe* researchers benefit from Rothamsted's advanced equipment, Rothamsted scientists rely on the *icipe* team's local knowledge and field experience. Both sides appreciate the exchange of experience and the challenging of existing ideas that the partnership entails. "Science today is highly interdisciplinary," says Khan. "We can no longer work in isolation. When people are asked to contribute intellectually they develop more enthusiasm and motivation." The two institutions have also fostered close links through exchange visits of research students.

The team have succeeded in involving a wide range of stakeholders. They have conducted

Rachel Agola proudly shows the 'One World Award' she received (along with Hans Herren and BioVision) for her courage and entrepreneurship in adopting the push–pull technology and forming the Yenga Push–Pull Farmers' Group to help others. She is keen to become a role model for smallholders throughout Africa.

Partners in prosperity

It's a big day for Rongo farmer Natiashon Ajieko. He is hosting a field day for Heifer International, who have invited 60 farmers as well as staff from *icipe*, the Ministry of Livestock, Catholic Relief Services and Plan International. During the day, the farmers will learn about planting push–pull, keeping dairy goats and poultry, growing organic vegetables, using manure and crop residues to make organic fertilizer, forage harvesting and how to store forage in the form of desmodium hay and Napier grass silage.

All four organisations are working together to build sustainable farming systems that increase farmers' self-reliance and adaptability. At the same time, the staff of each organisation are building their own capacities to train farmers. The focus is on the most vulnerable: those with small land holdings, people with HIV, widows and orphans. By working jointly, each organisation can benefit from the synergy and achieve far more than they would on their own. They can also disseminate push–pull and knowledge to many more farmers and encourage the formation of farmer groups and field schools, which in turn help farmers to learn other agro-enterprises and access support systems, including micro-credit.

As a result, thousands of small-scale farmers are forming mutually supportive networks, which help them to make the most of the multiple benefits of the push-pull technology and forge links with a range of support systems including national extension networks and technology providers. The result is a new generation of farmers who have a reliable income and/or employment, and entire communities are beginning to move from subsistence agriculture to the cash economy.

Natiashon Ajieko proudly displays one of his Saanen dairy goats

Farmers learning how to make Napier grass silage

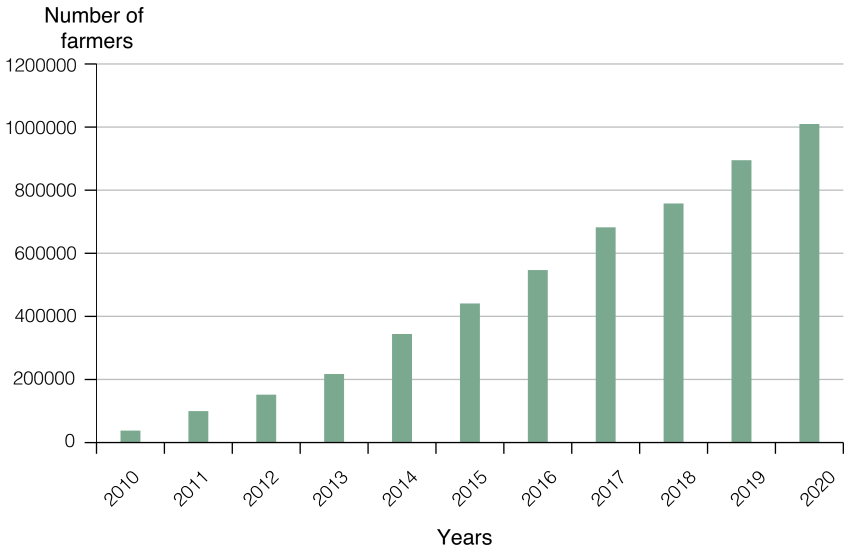
workshops at Mbita Point for government extension officers, farmers, teachers and community opinion leaders such as chiefs and church ministers. And they work closely with staff from Heifer International, NALEP, Catholic Relief Services and other NGOs through joint field days, farmer field schools and other dissemination activities.

The project experience highlights the need to recognise the interdependent but separate roles of scientists, extension workers and farmers. Although farmers can and should be active partners in research, they will often need continued support from trained researchers. The national agricultural research systems, government extension services and NGOs are taking on more and more responsibility for technology transfer in Kenya, Tanzania and Uganda, creating a critical mass of farmers and catalysing spontaneous farmer-to-farmer dissemination. *icipe* will continue working closely with these organisations, helping to build capacity through training and collaborative research. This process has already been given a boost when the KARI team involved with the project won the KARI 'Best Scientific Programme' award in 2004.

'Transformational' technology

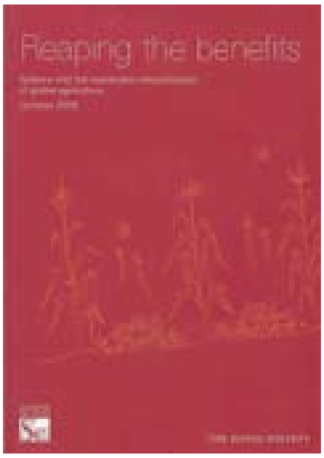
The experience of the push–pull project confirms that science can successfully support the interests of small-scale farmers and promote food security and sustainable livelihoods. With the essential ingredients of commitment, drive and enthusiasm, much can be achieved. Thanks to push–pull, more and more families like the Weres are finding a means to escape from the trap of diminishing yields and deepening poverty and hunger, and completely transform their lives.

That is not to say that the technology will continue to spread unchecked. Issues such as a continuing under-investment in national agricultural research and development, the lack of agricultural credit for small-scale farmers and the frailty of public sector seed supply systems could well frustrate widespread impact if they are not dealt with soon. In addition, poor market access and inadequate post-harvest protection and processing are likely to cause problems in the future when districts become self-sufficient in commodities such as maize. All too often in the past, these factors have led swiftly to the collapse of prices once surpluses have been achieved in a given area.



Assuming current rates of dissemination continue, over one million farmers will be growing push–pull by 2020.

If these problems can be tackled, the push–pull technology will make a substantial contribution to the 'uniquely African green revolution' called for by Kofi Annan, former United Nations Secretary-General. Furthermore, in its October 2009 report 'Reaping the benefits: Science and the Sustainable Intensification of Global Agriculture', the UK's Royal Society has identified push–pull as a readily available technology that could do much to achieve the massive increase in food production required by 2050 to meet Africa's food demands without damaging the environment and without bringing additional land into cultivation.



The Royal Society of the UK champions push–pull in its 2009 publication.

Global opinion is now united in the belief that efforts to improve Africa's agricultural productivity must be based on technologies that are highly environmentally friendly and people-centred, in comparison to those that fuelled the Asian green revolution. Push–pull is one of these technologies: it is a new and much healthier approach to pest management; it teaches farmers how to become food-secure and build a livelihood on just a small piece of land, without demanding inputs of cash or labour that are beyond their resources; in providing forage for livestock it contributes directly to poverty eradication, since it enables farmers to meet Africa's rapidly rising demand for milk and meat; and in protecting and enhancing soil fertility it tackles what is perhaps the most fundamental constraint of all to the development of African agriculture.

Push–pull Project Leader, Zeyaur Khan talking with members of the Yenga Push–Pull Farmers' Group, whose efforts have been recognised through winning several awards and shown on international television. Current rates of adoption suggest the target of one million push–pull farmers by 2020 is achievable.

As push–pull continues to spread and achieve a positive, long-term impact, it will start to play a vital part in helping African countries reverse their backward slide and set themselves on the path towards achieving the Millennium Development Goal of halving poverty and hunger by 2015. Push–pull also contributes to the MDGs relating to health, education and nutrition. Continuing to work towards and beyond these goals, Khan and the *icipe* team have set themselves the target of one million push–pull farmers by 2020, and that target looks completely achievable.

The International Centre of Insect Physiology and Ecology (*icipe*) is a tropical organisation with a tropical agenda. But why study insects? Because in the tropics, insects are a fact of life to be reckoned with. Insects pose a great risk to food production, often causing the loss of entire crops and destroying about half of all harvested food in storage. The 'old' tropical vector-borne diseases of malaria, dengue, kala-azar and the like are making a dramatic comeback, and frightening new ones are emerging. Livestock succumb in their millions to insect- and tick-borne diseases, resulting in loss of milk, meat and traction power. Underlying all of these issues is the fundamental poverty of most tropical countries and inability to harness their natural resources for themselves.

Established in Kenya in 1970, *icipe*'s founders recognised that the mainly developing countries in the tropics had special problems that were not being adequately addressed by scientists and organisations in the North. Furthermore, there was a serious lack of indigenous expertise to resolve these problems. It should come as no surprise therefore that *icipe*'s objectives for this millennium are essentially the same as they were three decades ago:

- to help ensure food security and better health for humankind and its livestock;
- to protect the environment; and
- to conserve and make better use of natural resources.

icipe
African Insect Science for Food and Health

icipe—African Insect Science for Food and Health
P.O. Box 30772-00100
Nairobi, Kenya
Tel: +254 (20) 8632000
Fax: +254 (20) 8632001/8632002
E-mail: icipe@icipe.org