The Push–Pull Farming System:
Climate-smart, sustainable agriculture for Africa






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Susan Parrott of Green Ink conducted the field research and literature review, wrote the original text, supplied most of the photographs and, together with other members of the Green Ink team, completed the edit, layout and proofreading. Additional photographs were supplied by *icipe*. In 2014, Karen Brock of Green Ink revised and updated the original text to reflect new developments in push–pull technology. And then in 2019, Guy Manners of Green Ink carried out a similar exercise, also supplying new photographs. The publication was printed in Kenya by Regal Press.

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 African farmers who, through their entrepreneurial spirit, hard work and determination, have helped make push–pull the success story it is today.

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Foreword

The International Centre of Insect Physiology and Ecology (*icipe*) is immensely proud of the 'push–pull' programme's achievements. During the past 25 years, push–pull has become a true platform technology that simultaneously addresses the most critical constraints faced by poor cereal–livestock farmers: poor soils and correspondingly low yields, high pest pressure, the parasitic weed *Striga hermonthica*, and shortage of high-quality livestock fodder.

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 236,000 such 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.

Through new research initiated in 2011, *icipe* scientists – working together with Rothamsted Research and national partners – developed a 'climate-smart' variant of push–pull, which includes two new drought-tolerant companion plants. Climate-smart push–pull is currently being extended to drier agro-ecosystems and applied to a wider range of cereal crops, including sorghum.

The success of the push–pull programme is built on the dedication of the *icipe* team – and its numerous partners, including *icipe*'s donors – to helping and learning from African farmers, at the same time as conducting cutting-edge science. The holistic nature of push–pull is reflected in the many scientific disciplines the technology touches upon, which include applied entomology, chemical ecology, organic chemistry, modelling, ecosystem analysis, socio-economics, agronomy and weed science.

Programme 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*, *Ecology Letters* and *Biology Letters*, as well as 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 programme.

Our goal to help one million people in Sub-Saharan Africa to be food secure by 2020 has been met ahead of schedule: assuming an average household size of six, 236,000 adopters of push–pull equates to over 1.5 million people. 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 reversed.

Dr Segenet Kelemu
Director General and Chief Executive Officer
International Centre of Insect Physiology and Ecology
December 2019

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.

Yet, only two years previously 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 fertiliser 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 previously 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.

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.

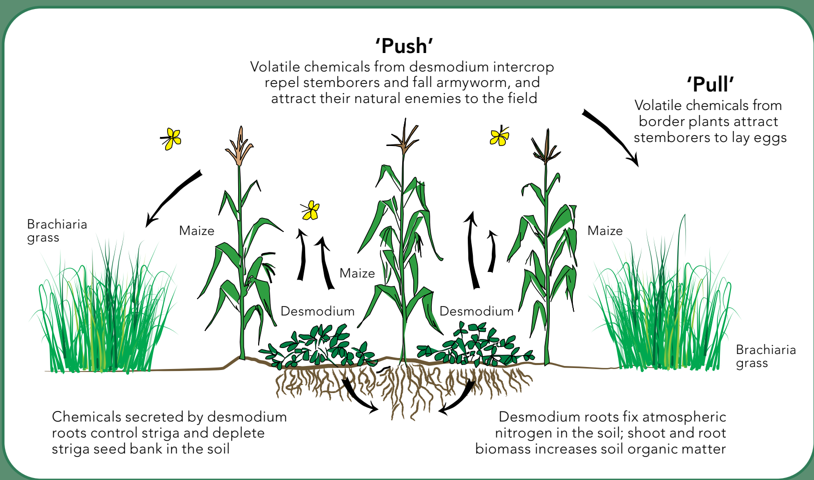
"Push–pull is not something scientists have invented," says push–pull programme leader Professor Zeyaur Khan, principal scientist at the International Centre of Insect Physiology and Ecology (*icipe*). "We have discovered several cases of integrated use of the forces of attraction and avoidance by different 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 human-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, fodder grass (Napier or brachiaria) 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.

Maize field with border rows of Napier grass and an intercrop of silverleaf 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, 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.

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

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

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 caterpillars (larval stages) of various species of moths and constituted the major insect pest of maize and sorghum in Sub-Saharan 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 eastern Africa.

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

"It used to be thought that native grasses caused the stemborer problem and that getting rid of them would remove the stemborers too," says Professor Zeyaur Khan, entomologist at *icipe* and leader of the programme. 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 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 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 stemborers away from the maize and reduce their populations," adds Khan.

Remjius Bwana Asewe, a farmer from Yenga, Kisumu County, harvesting 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.

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, now known as the Kenya Agricultural and Livestock Research Organization, KALRO) helped identify suitable farmers to consult.

The pull...

Trap crop Napier grass (*Pennisetum purpureum*) appeared particularly promising. 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. Napier grass has a particularly ingenious way of defending itself: when the larvae bore into the stem, the grass secretes a sticky gum, physically trapping the borer and preventing most larvae from completing their

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 Were 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.*

life cycle. It also attracts 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 perennial and is already grown widely for livestock fodder. Researchers and farmers worked together to identify which varieties both effectively attract egg-laying stemborer moths away from maize and provide 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 such as 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 (now KALRO) 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 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 (then scientific leader of chemical ecology, and now at Cardiff University) and his team were helping to piece the puzzle together by investigating the nature of the plant chemicals (known as semio-chemicals) 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, p.6) have led the scientists to develop general hypotheses regarding the role of plant semio-chemicals 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 like promising candidates.

During this phase of the work, the then Suba district agricultural officer visited the *icipe* team at their Mbita

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 inhibit 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. The research team 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 is time consuming and *icipe* continued to work with Rothamsted Research scientists to characterise the chemical compounds produced by desmodium roots, including drought-tolerant desmodium species, to quantify striga seed bank elimination timescales and economic benefits. 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.

Professor Khan explains the mechanism of striga suppression by desmodium root exudates to *icipe* Director General Dr Segenet Kelemu. In the row of plants on the left in the background, the striga has been supressed by the desmodium, while the plants on the right, supplied with water only, are heavily parasitised by striga.

Point research station. He asked if there was anything *icipe* researchers could do about the devastating effects of the parasitic 'witchweed' *Striga hermonthica* on local maize harvests (see box on page 4). Fully occupied by their stemborer research, the team declined his request, little knowing they were on the verge of an important discovery that would address his 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 one growing season." In fact, eliminating the striga had an even greater effect on increasing maize yields than controlling the stemborers. This brought a new dimension to the push–pull technology and posed the question 'how?' (see box on page 5).

Dissemination of a push–pull package of silverleaf desmodium and Napier grass began in 1997, and the number of adopters began to grow, steadily increasing for the next 15 years. Research continued alongside the transfer of the technology, and the *icipe* team began to search for new varieties of trap plants and intercrops that would adapt the technology to hotter, drier agro-ecosystems. They collected 43 accessions of 17 desmodium species from across Africa, eventually discovering that greenleaf desmodium (*Desmodium intortum*) not only shares silverleaf's ability to control striga and stemborers, but also tolerates higher temperatures and fixes more nitrogen. In combination with a new trap plant, brachiaria (*Brachiaria brizantha*) 'Mulato II' – selected by farmers from a range of new stemborer-controlling grasses identified by scientists – a new climate-smart push–pull package was launched in 2012, greatly expanding the potential reach of the original technology.

Dying hearts: the arrival of fall armyworm

In December 2015, fall armyworm (*Spodoptera frugiperda*) was found for the first time in Africa in western Cameroon. Within two years it had spread over much of the continent. Fall armyworm is the caterpillar (or larva) of a medium-sized moth; it is native to tropical and subtropical South and North America and has great capacity for migration (up to 2,000 km in a year in North America). While its arrival in Africa may not have surprised scientists, it spelled disaster for African maize farmers.

Brachiaria: a drought-tolerant 'smart' plant that warns of insect attack

The search for drought-tolerant trap and intercrop plants led *icipe* and Rothamsted Research scientists – together with national partners in Ethiopia, Kenya and Tanzania – to collect and test 500 drought-tolerant grasses for stemborer control. Having identified 21 that were suitable, they carried out participatory selection trials so that farmers could choose the trap plant that suited them best. They selected *Brachiaria* 'Mulato II' for its palatability to livestock and soft, bulky foliage which is easy to harvest. Crucially, it can also survive for up to four months without rainfall and withstand temperatures in excess of 30°C.

Collecting plant volatile chemicals from maize plants.

Brachiaria: a 'smart', drought-tolerant trap plant.

The team discovered that, like molasses grass, brachiaria emits plant volatiles which attract female stemborer moths. Once the moth has laid her eggs, however, the grass stops producing the volatiles, and instead begins releasing chemicals that attract parasitic wasps that kill the caterpillars, preventing them from completing their life cycle. "This is ideal trap plant behaviour," says Khan.

Further research into the chemistry underlying the push–pull effect has revealed that brachiaria is also a so-called 'smart' plant. When it comes under attack from stemborer larvae, it emits a stress chemical, which neighbouring maize plants appear to pick up on, and begin to produce the same repellent chemicals themselves within 24 hours. It appears that the brachiaria is warning the maize to watch out for insect attack. Building on this natural behaviour could potentially lead to the development of maize with in-built insect resistance.

While the caterpillar has a widely varied diet, those that arrived in and spread across Africa have a marked preference for maize. Hundreds of eggs are laid on maize leaves at any stage during the plant's development, though cannibalism tends to reduce infestation to just one or two per maize heart in the latter stages of development. However, that is more than enough: the caterpillars happily eat the heart out of the maize, and will also eat both fresh and dry cobs. Complete crop loss has been recorded in farmers' fields of monocropped maize throughout Sub-Saharan Africa.

But there is good news for push–pull farmers and, by extension, all maize farmers: "Neighbours probably had fall armyworm very bad, but not here," says Mama Molly Odhiambo Ossita of Migori County, western Kenya, who has used push–pull maize to fund the establishment and operation of a school, originally for AIDS orphans. And the story is the same across Kenya: "Push–pull effects 80–90% control of fall armyworm in Kenya and 65–75% control in Uganda," says Girma Hailu, *icipe* country coordinator for Uganda.

The control is primarily via the 'push' effect of desmodium, but some farmers, such as Eunice Atieno Ongow of Homa Bay County, have experienced suicidal egg-laying of fall armyworm on Napier grass (an unsuitable host plant). Meanwhile, Allan Metho of Kisumu West, Kenya, "found armyworms dead on the desmodium." Clearly, more research is required – and is underway – into the complexity of control mechanisms acting against fall armyworm in push–pull.

In recognition of its role in fall armyworm management, push–pull was included in the second edition of *Fall Armyworm Identification, Monitoring, and Management Options for Maize in Kenya*, a Ministry of Agriculture, Livestock, Fisheries and Irrigation technical brief, which also credits brachiaria and Napier grass as effective 'pull' agents for this pest.

Typical symptoms in a maize field infested with fall armyworm in the Homa Bay County maize field of farmer Jackline Awino Juma.

Late-instar fall armyworm caterpillar feeding on maize cob, Bugiri District, Uganda.

Push–pull research benefits food safety

Studies have shown that maize in push–pull plots is less prone to ear rot (caused by the fungus *Fusarium verticillioides*) than monocropped maize. Microbiologist Nancy Njeru was awarded an *icipe*–DAAD doctoral scholarship to look into the role that push–pull plays in the management of ear rot and mycotoxins in maize. Having confirmed the reduction of ear rot in push–pull, she looked into the fungus's route into the maize plant. She found a strong correlation between stemborer and fall armyworm damage on maize cobs and the occurrence of ear rot. This indicates that the fungus enters the plant via insect damage.

Ear rot infection is also associated with toxins, so Nancy investigated aflatoxin and fumonisin in push–pull maize. She was able to identify the fungal producers of the toxins and showed that push–pull maize had less fungal infection and less toxin than monocropped maize. Push–pull significantly reduced fumonisin, which is a known problem in maize; however, aflatoxin is not a major toxin in maize. Such toxins can contaminate food and feed, so their control is a priority in food (and feed) safety.

Nancy also showed that root extract from desmodium slowed the growth of ear rot fungus. The identity of the chemical in root extracts that has this effect has still to be determined, as has the source of the fungus, which is not soil-borne. The latter information will aid management of ear rot by managing the source.

2. Uptake and impact: knowledge is the key

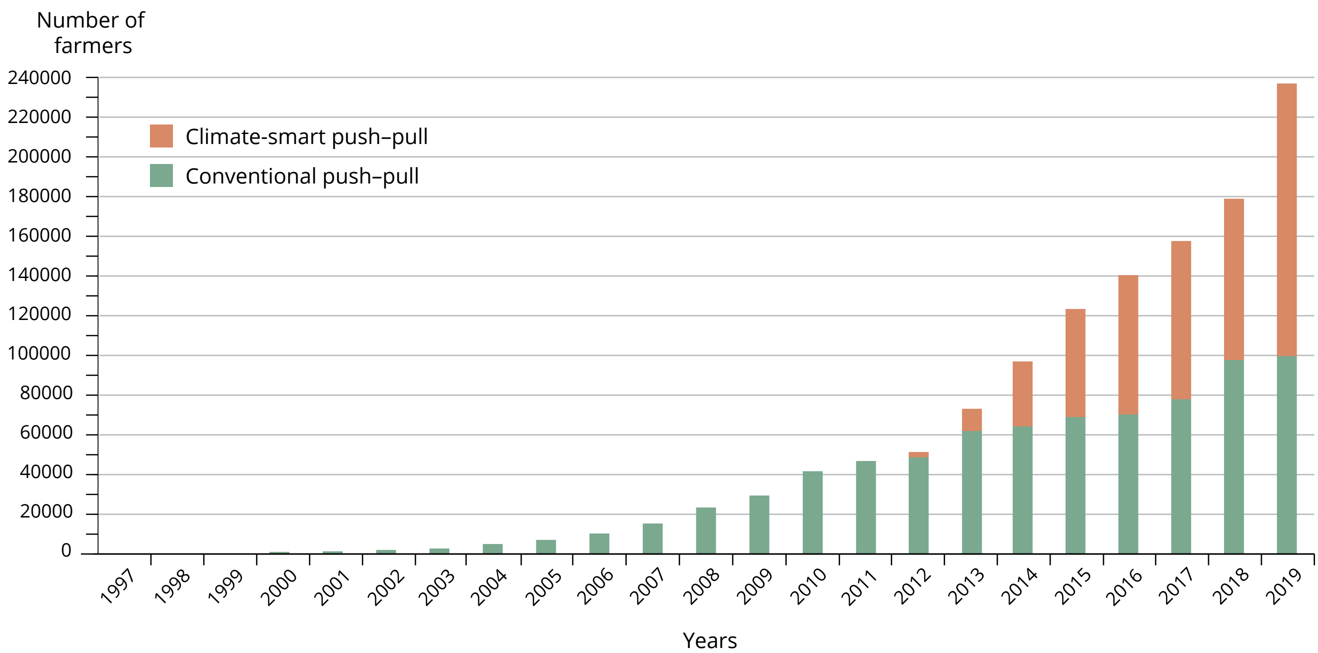
In early 1997, Khan and his colleagues began disseminating the push–pull or habitat management technology to farmers, aiming to transfer both the technology and the knowledge of how it worked. Training in scientific methods encouraged farmers to experiment further, gain ownership of the technology and 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 has established a mechanism for rapid adoption, which is the key to widespread impact. Some 236,000 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 (now KALRO) and government extension staff helped identify suitable areas for on-farm trials. The team chose two districts for the initial trials: Suba (now part of Homa Bay County), on the eastern shores of Lake Victoria, and Trans Nzoia (now Trans-Nzoia County), further north.

Adoption of push–pull technology in eastern Africa, 1998–2019.



Map of Africa showing countries where farmers have adopted push–pull.

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.

The success of the dissemination tactics used 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 or brachiaria and desmodium, and extent of the stemborer, fall armyworm 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 programme by planting border rows of Napier or brachiaria, the programme will supply the initial seed required to establish the desmodium intercrop. In all areas, *icipe* and KALRO 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 push–pull farmers were to acquire sufficient knowledge to apply the technology correctly. The solution was to recruit some

Farmer–teachers spread the word

Peter Koinange is a respected elder in his village of Wamuini, 10 km southeast of Kitale in Trans Nzoia County, Kenya. Although there is no striga here, stemborers cause considerable damage and the soils are poor and lack nitrogen. Peter 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 fertiliser. 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.

Peter 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 results are 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, Peter 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 impact of farmer–teachers 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.

of the more experienced farmers as teachers to help their colleagues (see box). An internal review of the farmer–teacher system suggested that it works well, but needs close supervision from *icipe* or KALRO technicians to ensure the teachers visit their students regularly and give good advice. Some farmer–teachers already have long waiting lists of prospective students. Building on the success of farmer-to-farmer dissemination, the *icipe* team has 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 organising farmers into groups, a field school gives the group cohesiveness and they are much more attractive to other government organisations and non-government organisations (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 County. "When our eyes are opened to new knowledge, we start to see many more possibilities." The field schools also integrate many different aspects of production, helping farmers develop a strong business base for their farm enterprise.

Information and awareness

Every Saturday from one o'clock until half past two, more than seven million Kenyan farm households view *Shamba Shape-up* (Shape up your farm), a rural 'edu-tainment' programme broadcast on Citizen Television.

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.

The storyline introduces new ideas and technologies for improving agriculture. Push–pull technology features regularly and many farmers who have adopted the system heard about it through the programme. 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 Kakamega counties have written a push–pull play, which they perform for their peers, entertaining and educating them at the same time. Researchers hope to spread the idea to other counties.

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 KALRO field technicians, these channels include NGOs, community-based organisations, traders and fertiliser or seed sellers, particularly in the more remote areas. To ensure consistent and correct messages, KALRO 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. In addition, farmer-to-farmer communication tools such as participatory video, drama and mobile telephone are increasingly being used to disseminate push–pull technology.

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, p.12). Some farmers plant only border rows of Napier grass or brachiaria around their maize plot, utilising the 'pull' part of the technology. Those adopting both 'pull' and 'push' can choose to plant greenleaf or silverleaf 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 edible beans as an additional intercrop (see p.26). Smallholder farmers in Sub-Saharan Africa typically practise multiple cropping, where cereals are intercropped with food legumes. Therefore, the technology has been adapted to local farming systems by incorporating edible beans, planted either in the same hole with maize or in between maize plants within a row. This has increased the technology's appeal to farmers as it guarantees an additional protein source in the diet, resulting in higher adoption rates in the region. While this practice increases labour demand, it appears that yields of maize are not affected and the farmers benefit from being able to produce a source of protein without needing more land.

In Uganda, research has shown that edible legumes intercropped with maize provide 25–30% protection against fall armyworm compared with monocropped maize. While this is not even close to the protection provided by push–pull, "we are offering it as an additional component of integrated pest management," says Hailu, "particularly where desmodium seed and planting materials may not be available."

Meanwhile, Khan and his team have investigated and are now promoting the production of high-value vegetables – common bean and kale – within push–pull, either as intercrops or between maize seasons. "This is an intensification of push–pull," says Khan, "providing additional production for home consumption or sale."

The robustness and flexibility of the system is demonstrated by successful adoption in different agro-ecosystems. 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).

Common bean intercropped with maize in a conventional push–pull plot.

Food to eat, money to spend

Most farmers adopting push–pull have increased their maize yields by over 100% (see graph). The Were family

Meeting different needs

At first glance, the Gumo family farm in Kiminini (Trans-Nzoia County) has little in common with that of the Chapya family, who live in Ebukanga (Vihiga County). 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.

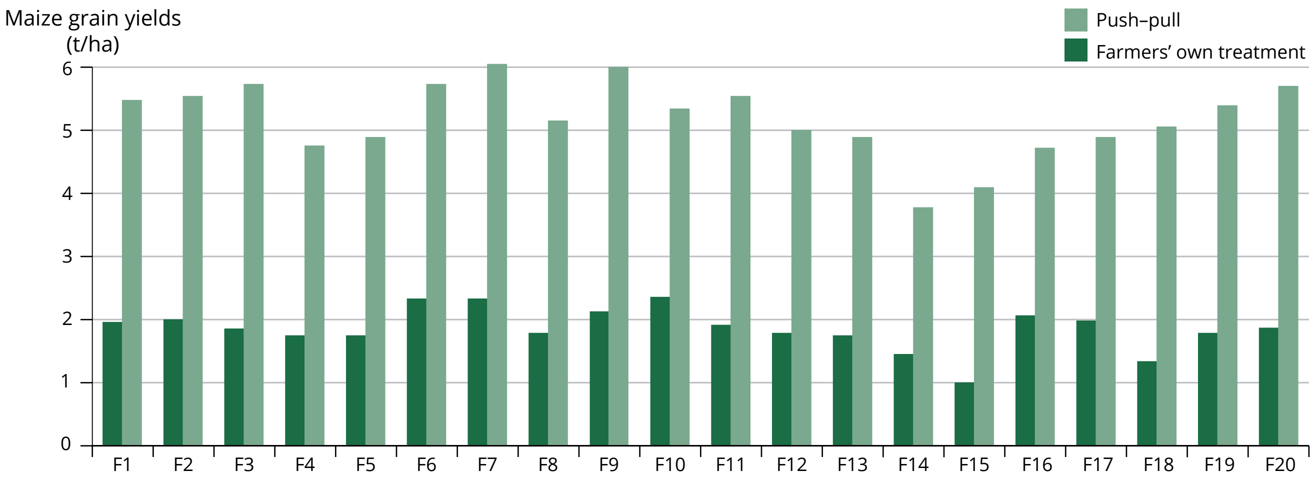
Both families, however, have adopted push–pull and have seen a dramatic increase in their farm output. Due to shortage of desmodium seed, Livingstone Chapya planted only a small plot (measuring 35 × 15 m) with the technology but was amazed at the result. "Before, the farm was purple with striga," he 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 with his zebu heifer. He now has sufficient forage to support a cross-breed animal.

Josephine Gumo is relieved she no longer needs to apply expensive fertiliser 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. Josephine has big plans for expansion and to become an employer 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.

Mean annual maize yields with and without push–pull, for 8 to 17 years, for a sample of 20 farmers in western Kenya.



now harvest two bags of maize (180 kg) from a push–pull plot of only 20 × 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. Some are even 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' below). 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).

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, Lillian 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 sufficient 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.

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

Lillian 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.

Napier grass being sold by traders on the roadside in Luanda, western Kenya.

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 0.3 litres per cow per day). This partly explains why, in most districts, milk demand far outstrips 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 such as Joseph Litunya (see Chapter 3) used income from push–pull to qualify to receive a dairy cow or goat as part of the Heifer International scheme; the NGO also promotes push–pull widely within its knowledge transfer mandate.

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 County, was experiencing diminishing maize yields due to the combined effects of stemborers, striga and declining soil fertility. When he heard about push–pull on the radio 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. At the time of interview, he hoped to build a bigger house and buy a crossbred cow. "Now every year gets better instead of worse," he said.

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 or brachiaria, stimulating faster growth and allowing more frequent harvesting. Improving soil fertility is especially important in Trans-Nzoia, where non-push–pull farmers have to use inorganic fertiliser and pesticides if they are to obtain a reasonable maize yield. Farmers such as the Wang'ombes and the Gumos have discovered that with push–pull they can get sizeable yields without using inorganic fertilisers 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 sole maize crops. Reducing the use of

Former 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 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, making 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.

pesticides and inorganic fertilisers 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.

Extending the benefits

The *icipe* team has linked up with national scientists to introduce the technology to other parts of Sub-Saharan Africa where striga is endemic. Since the farmer-to-farmer dissemination strategy used in Kenya proved so successful, researchers and partners in Ethiopia, Tanzania and Uganda adopted a similar approach. They focus on identifying farmers' needs and creating

Addressing the impacts of climate change

Climate models suggest the strong possibility of higher average growing-season temperatures in the majority of Africa's maize-growing regions, as well as progressively more unpredictable rainfall. Many resource-constrained smallholder farmers are modifying their farming systems, particularly by incorporating drought-tolerant plants and replacing cattle with small ruminants for dairy production. Climate-smart push–pull is a versatile tool for making these adjustments.

As well as addressing their soil fertility and productivity constraints, it gives farmers the opportunity to diversify their cropping system using a variety of drought-tolerant combinations. Among early push–pull adopters, it is not unusual to see several push–pull plots on different parts of the farm, each using a slightly different combination of cereals with either conventional or climate-smart push–pull to spread risk and increase resilience to negative climate events.

In addition to benefits for crops and soil, fodder from climate-smart push–pull has a positive impact on the health and productivity of dairy animals. Many farmers report that greenleaf desmodium increases milk production even more than silverleaf does.

Programme leader, Zeyaur Khan, examines healthy sorghum in a climate-smart push–pull plot in Kisumu County, Kenya.


Increasing numbers of maize farmers are now also cultivating sorghum using climate-smart push–pull (left). By diversifying both their crop mix and their agricultural biodiversity, they are helping make their farming systems more stable in the face of the changing climate. An added benefit of climate-smart push–pull is that greenleaf desmodium (right) is a very nutritious fodder, often having an even greater impact on milk yield than its silverleaf cousin.

awareness of the technology through demonstrations, field days and the media. On-farm field days are particularly important, increasing farmers' knowledge of the technology and giving them confidence to adopt. Practical training for farmers is carried out through structured groups and tutoring by farmer–teachers, and farmer feedback is sought and followed up.

As a result of these strategies, push–pull has successfully expanded, being adopted by 236,000 farmers in Sub-Saharan Africa – a number that is growing rapidly.

Different crops, increased resilience

Ensuring the continued appeal of push–pull for farmers has demanded continual adaptation of the technology to ensure its spread to new agro-ecosystems (farming environments) and its adaptability to changing climatic conditions.

A research grant received from the European Union in 2010 not only supported the identification of the climate-smart push–pull plants greenleaf desmodium and brachiaria, but also led to the discovery that push–pull also benefits farming systems based on sorghum, millet and upland rice. These crops are more drought-tolerant than maize, but also susceptible to striga and stemborers. Trials have shown that using push–pull with these cereals reduces striga and stemborer damage as effectively as it does with maize. "This adaptation of the technology is proving particularly applicable for arid and semi-arid regions throughout Africa," says Khan.

As well as expanding push–pull to different regions, the applicability of the technology to different crops also increases its appeal to maize farmers who want to include other, more drought-tolerant cereals in their rotation as an insurance against low rainfall.

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 on p.17). 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 evaluated 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 or brachiaria 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 four to seven 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.

Impact on farmers: an independent assessment

An independent impact assessment by HELVETAS Swiss Intercooperation was carried out in Kenya and Uganda in 2013. It 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 to 4.2 t/ha) and milk (increased from 1.5 to 3.8 litres/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 among smallholder farmers adopting push–pull.

The study estimated the additional annual gross benefit generated by push–pull compared with a traditional maize crop in 2009 to be 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."

Most push–pull farmers report that some or all of the extra income they generate from push–pull goes to meet the cost of educating children, particularly to secondary level and beyond. These pupils are in a science lesson at the Gikasa Academy in Homa Bay County, a school that was constructed primarily for orphans with some of the income that local farmer Samuel Sana generated from selling maize and fodder from his push–pull plots. Of the 68 students in 2019, 15 were orphans, of which ten had their fees paid by the profits from Samuel's farm. Samuel also supplies fruit and vegetables to the school, and teaches climate-smart farming to the students.

Although push–pull plots had higher production costs for the first season, 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' compared to those of the two conventional systems, 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 fertiliser.

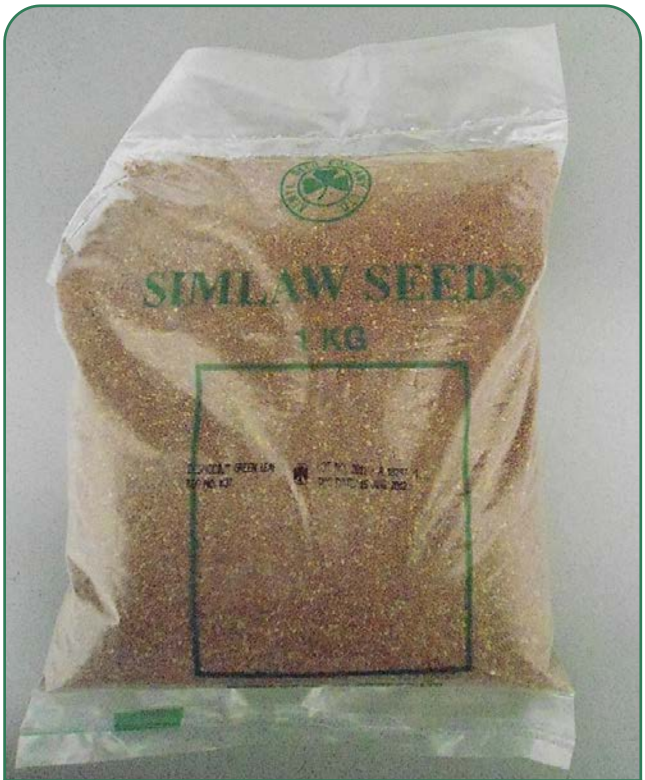
Rosemary Onduru and her husband Enos live near Onyatta village in Siaya County, where striga is a serious problem. Rosemary planted her first push–pull plot at the end of 2010 and, although it was hard work, she was encouraged when the yield more than tripled. In 2012, she planted a climate-smart push–pull plot with sorghum. The couple have no animals, but they harvest Napier grass, brachiaria and desmodium from the plots three times each year and sell it to neighbours who have dairy cows. This provides a steady income, which they use to pay school fees for their children and grandchildren. "The push–pull plots give, even when there is no rain," says Enos.

The results showed that push–pull with local maize and no fertiliser gave the best return. Adding fertiliser 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, brachiaria 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 fertiliser provided 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 fertiliser 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 fertiliser or IR maize.

3. Challenges and constraints: from seeds to policy

As they start to be adopted, new technologies often encounter unforeseen challenges. 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 smothered. 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. Labour shortages are relatively common, caused by both widespread abandonment of farming and high regional incidence of HIV/AIDS. Here too, farmer–teachers or farmer groups may be able to help by mobilising support within the local community.



Greenleaf desmodium seed. Greenleaf desmodium does not flower or set seed in equatorial or tropical Africa, creating an obstacle to the dissemination of climate-smart push–pull.

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 (KSC) was importing seed from Australia, the price was high and availability limited. To respond to this challenge, *icipe* began working in collaboration with KARI (now KALRO) to establish a farmer-based seed multiplication project, to test the farm conditions and management practices needed to establish desmodium bulking plots, and to harvest and process the resulting seed. As well as building capacity, this programme gave farmers the opportunity to develop an additional income stream. Initially, the programme was implemented by informal groups of farmers, who planted desmodium bulking plots primarily for the seed harvest. While the activity proved lucrative, with seeds fetching a high price, the quantities produced remained small. Large-scale dissemination of desmodium intercropping would depend on increasing the availability of seed on the open market.


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

To strengthen seed availability, particularly to expand existing commercial supplies of greenleaf desmodium,

Farmers are constantly thinking up new ideas and several have experimented with establishing new desmodium plants by means of vegetative propagation, planting desmodium vines or stems in the same way they propagate sweet potato. Propagation techniques are now included in *icipe*'s push–pull training.

icipe built relationships with two experienced international private seed companies, Seed Co. (Zimbabwe) and East African Seed Company and continued to promote seed production by local companies and community-based organisations. One advantage is that Ethiopia, Rwanda and Zimbabwe all have areas with sub- or even non-tropical climates, where greenleaf desmodium will grow and set seed. Similar relationships were build with Grupo Papalota (Mexico) and Tropical Seeds LLC (USA) to produce brachiaria seeds. Since the middle of the decade, several eastern and southern African seed companies have started producing brachiaria and/or desmodium seed, namely Advantage Crops Limited (Kenya), Alexis Business Limited (Rwanda), Barenbrug (South Africa), East African Seed Co. Ltd (Kenya), Funwe Farm Ltd (Malawi), Mukushi Seed Company (Zimbabwe) and Simlaw Seeds (Kenya); the Ethiopia Institute of Agricultural Research (EIAR), Institut de l'Environnement et Recherches Agricoles (Burkina Faso) and the Institut des Sciences Agronomiques du Burundi (ISABU) also produce seed.

Unfortunately, supply and availability of desmodium seed has remained a constraint to the adoption of push–pull in parts of the region. One small-scale solution has been to carry out vegetative propagation using desmodium vines or stems.

In the face of the seed and planting materials constraints for both desmodium and brachiaria, research has continued apace. *icipe* scientists have identified two

Recently established third-generation push–pull plot at *icipe*'s Thomas Odhiambo Campus at Mbita Point, Kenya.

species of drought-tolerant desmodium that readily flower and set seed in equatorial and tropical Africa: *Desmodium incanum* and *D. ramosissimum*. The two species were sourced by the *icipe* push–pull team via the gene bank of the International Center for Tropical Agriculture (CIAT), having originally been collected in Ethiopia and Sudan. The plan is to promote these two species as part of a third-generation push–pull, which will also include mite-resistant brachiaria (see below).

A few farmers have been given *D. incanum* to test on their farms, including Judith Owomo of Siaya County, Kenya. She reports that it is "not destroyed by termites" (unlike greenleaf desmodium), "but it does not grow very tall. It increases soil fertility and still works as a repellent [to insects], but it doesn't produce enough biomass [for use as fodder]. It is good in the climate." Khan indicates that Judith is reporting most "probably only first season [observations], but *incanum* does produce less biomass than greenleaf desmodium." This may present problems with dissemination to farmers primarily interested in producing fodder, but they can rest assured that the search for the best insect-repellent intercrop legume will continue.

Seeing red: spider mites in brachiaria

As climate-smart push–pull began to spread, a new problem arose: a red spider mite. *Oligonychus trichardti* has been recorded in Kenya and South Africa, and it has a taste for brachiaria. Unfortunately, brachiaria 'Mulato II' is particularly susceptible to this spider mite, which causes massive loss of biomass and consequent reduction of the grass's 'pull' effect. Scientists from *icipe* and North-West University (South Africa) evaluated 18 brachiaria lines for their resistance to spider mite and identified two cultivars – 'Piata' and 'Xaraes' – as superior and reliable in terms of spider mite resistance. These brachiaria cultivars are being promoted in spider mite-infested regions as part of the 'third-generation' push–pull.

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, the Ministry of Livestock and other NGOs to ensure the correct knowledge is passed on with the seeds.

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

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 were signed with both Heifer International and the Ministry of Agriculture's national agriculture and livestock programmes. Both organisations work with farmer groups to improve

The road to success

Joseph Litunya has come a long way in a short time. In 2011, he had recently qualified to receive a crossbred dairy cow from Heifer International, and was full of hope. Now that hope has been realized to an extent he probably never imagined possible before he adopted push–pull.

The cow Zawadi (meaning 'gift') calved nine times before Joseph sold her. Eight calves were bullocks and sold at an average of KSh 35,000 (about USD 350) each, having each consumed KSh 12,000 worth of their mother's milk.

Joseph had hoped that Zawadi would give over 6 litres of milk per day to provide the family with much-needed income. Her only daughter, Alpha, now gives 12 litres a day at peak lactation, and Passaka (bought around Passover with the proceeds from one of the bulls) provides 15 litres!

Alpha (left), first daughter of Joseph Litunya's original crossbred cow Zawadi (meaning 'gift'), and her stall-mate Passaka (from 'Passover').

Early on, Joseph helped establish the Busia Farmers' Group, which is now Butera/Munias Centre for Help Push–Pull Group. Registered with the Ministry of Social Services, the group runs a saving-and-loan scheme ('tabletop banking') and has a focus on livestock, including desmodium and Napier grass sales. He had to give up desmodium seed production when he moved to a small homestead. However, he did help create the Khwisaro Dairy Farmers Cooperative Society, which now has 200 farmer stakeholders (active and former dairy farmers) and sells 500 litres of milk a day at KSh 60 per litre.

The push–pull group has worked with a number of NGOs, which have helped them with cheaper inputs and built their capacities in livestock management and facilities. Joseph was particularly interested in pellet feed for cows as he was already using feeding supplements in the form of *Calliandra*, desmodium and *Sesbania*. Joseph is the group treasurer.

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

David Omurumba hosted a trial of Napier stunt disease-resistant Napier grass on his Butere farm. "Demand for stunt-resistant Napier is high," he says, and he has a knack for Napier management. "I had personal experience with traditional Napier. I train neighbours and buyers, but they tend to over-utilise it. Management of the resistant varieties is the same as for traditional Napier." He has sold resistant Napier plants to over 250 farmers, and one pickup truckload of Napier sells for KSh 6,000. He uses the cash to buy school books for his seven children.

livelihoods and both are now promoting the push–pull technology to their clients. Heifer International has worked with 4,300 farmers in Kenya, all of whom have received training in push–pull, while extension agents have learned about the technology and promoted it as a priority to all their clients.

"Push–pull fits well with our philosophy," says Titus Sagala, Kenya country director for Send A Cow. "We help farmers use their on-farm resources to become more productive in a sustainable way, by diversifying their livelihoods." Send A Cow operates in a very similar way to Heifer International, working with selected farmer groups to make them more food secure and resilient. The NGO provides training on farming systems, including appropriate livestock options such as dairying. Participating farmers have to ensure they have appropriate arrangements in place, including a reliable source of year-round fodder, before they engage in the programme, thereby ensuring optimum productivity. The farmers undertake to pass on the benefits, including skills and livestock, meaning success multiplies quickly. (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. Although this issue has deterred adoption, recent land reforms mean that local authorities are increasingly tackling the issue by enforcing trespass laws.

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. Working alongside national and international research institutions, *icipe* is developing the partnerships needed for an IPM approach to post-harvest pests and diseases.

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, Napier stunt disease (NSD) – which causes plants to become yellow and stunted – has spread rapidly across East Africa since the late 1990s, with dramatic negative effects on the smallholder dairy sector.

Determined to identify the cause of the disease, the *icipe* team and Rothamsted colleagues carried out DNA analysis of many thousands of plant and insect samples, eventually identifying the culprit as a phytoplasma bacterium transmitted from plant to plant by a tiny leafhopper, *Maiestas banda*. They then turned their attention to searching for varieties of Napier grass that would resist the phytoplasma, but not repel the leafhopper and force it to seek new hosts.

In partnership with KALRO and the International Livestock Research Institute, *icipe* scientists collected germplasm of 50 Napier grass cultivars, 70 new accessions and hundreds of varieties from farmers' fields. After two years of screening, two phytoplasma-resistant varieties were identified.

On-farm trials followed and, in September 2013, *icipe* received the go-ahead to multiply plants for distribution. Today, a small number of farmers are growing stunt-resistant varieties of Napier grass for distribution and sale to other farmers. David Omurumba of Kakamega County was identified early on as an ideal farmer to test and multiply Napier; today he grows four resistant varieties – 'Ouma 2', 'Phanice', 'South Africa' and 'Wanga'.

Ongoing research is essential. Many cereals and grasses – including maize, millet and rice – are potential hosts to *Maiestas banda*. Research has found several wild grasses are also host to the phytoplasma and the disease can be transmitted by the vector. Research into the epidemiology of the disease is ongoing to prevent it becoming a source of infection for valuable crops.

Investing in knowledge

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

In addition, the programme is investing in building the capacity of African scientists by helping them study for Masters and PhD degrees. Many scientists from across Africa have contributed to the development of push–pull and made key discoveries. For example, Dr Charles Midega, a Kenyan scientist, continued working in the push–pull programme at *icipe* after finishing his PhD. He is now a senior scientist and leads several research projects. Similarly, Amanuel Tamiru from Ethiopia, who was awarded a PhD for his work in the push-pull

Professor Khan and his colleagues, Dr Charles Midega and Jimmy Pittchar, have mentored 15 World Food Prize Borlaug–Ruan Interns since 2000, giving young scholars a grounding in the complex science behind push–pull. Here, Khan explains the allelopathic inhibition of striga germination by desmodium root exudates to 2011 intern Anthony Wenndt who, like two of his predecessors, went on to win the John Chrystal Award for his outstanding work.

programme on early herbivore alert, is now working for *icipe* on chemical ecology.

icipe also hosts the World Food Prize Summer Intern Programme. Fifteen young scientists have spent their summer break working at *icipe* in the push-pull programme, with Professor Khan, Dr Charles Midega and Jimmy Pittchar, with the aim of acquiring a 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 programme, 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 236,000 farmers as technology champions, who promote its benefits to others. Several high-profile Africans can be added to this number, including the Directors of KALRO, Send A Cow, Heifer International and a former Member of Parliament, and the Minister of Agriculture of Ethopia. 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, a push–pull farmer and former MP, lobbied to get push–pull accepted as part of Kenya's formal agriculture strategy; while he succeeded in raising awareness of the value of push–pull, it was not formally included in the strategy. It is, however, included in the latest strategy for combatting fall armyworm in Kenya. The Minister of Agriculture of Ethiopia has ensured the inclusion of push-pull in the country's formal agriculture strategy and the government is supporting farmer training and providing desmodium and brachiaria seed. 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 programme'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 KALRO research. Until 2000, such seed could only be distributed through Kenya Seed Company. The problem was that the seed was imported from Australia and became more expensive following the devaluation of the Kenya shilling. The policy change allowed the private sector to distribute KALRO-originated seed material in response to growing demand, and this has helped *icipe* explore different partnerships for broadening the seed supply base. (See also 'The need for seed' above.)

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 programme is working with private sector seed companies and the relevant regulatory agencies to help enable community-based seed production.

Funded by the Biovision Foundation of Switzerland, *icipe*'s Technology Transfer Unit was established in

Rachel Owino, *icipe* Technology Transfer Unit, pictured with Agnes Ambubi of Vihiga County, Kenya

2016. Over the past three years, it has been effectively disseminating push-pull throughout Sub-Saharan Africa. The present expansion of push-pull in eastern, central and West Africa is due to the efforts of the Unit.

icipe places great emphasis on ensuring effective transfer of technologies by instituting strategies to translate research into tangible products, building indigenous capacity to use and adapt these to local conditions, and working with public and private partners to create relevant and effective value chains. The Technology Transfer Unit is aligned with the Centre's vision and strategy for 2013–2020. It disseminates strategies and solutions developed by the Centre through a dedicated, appropriately skilled team led by Dr Saliou Niassy and assisted by Rachael Owino. The Unit presents a platform for synchronised, sustainable and visible technology dissemination. It has built on pilot technology dissemination projects by *icipe* and partners, to scale them out for enhanced impact. It has also strengthened cross-linkages between *icipe*, farmers, researchers, donors, enterprises and policymakers, facilitating better processes for providing information and advice, testing and improving technologies, capacity building, innovative project development and business incubation.

4. Across the spectrum: learning from experience

The story so far is one of success. More than 1.5 million people in 236,000 farm households have already benefitted from the push–pull system, which confers 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 21 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 *icipe* training officer 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 evaluated different combinations of ingredients and developed a mix that cost 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-ecosystems. Push–pull strategies can be developed and adapted for a range of cereal crops and farming systems. There is now a demand for the technology in Asia to control fall armyworm. 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 programme, 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 programme 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.

Margaret Oroko grows edible beans as an additional intercrop alongside the maize and desmodium on her farm in Homa Bay County. Farmers are continually experimenting and the *icipe* programme 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.

Dr Ephraim Mukisira, former director of KALRO, 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 programme provides 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.”

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

Programmes need ‘champions’

The importance of ‘champions’ – individuals who drive a project or programme forward by means of their own personal commitment and energy – is well-known. Push–pull programme leader, Zeyaur Khan, is just such an individual. He has spent more than 25 years working tirelessly to drive the programme. A committed and talented scientist, Khan has ensured the push–pull technology is based on sound science. He has also taken a key role in dissemination efforts. Known by programme farmers as ‘Dr Push–pull’, he is a vital part of the programme’s success, along with *icipe* social scientist Jimmy Pittchar.

Khan’s achievements have been widely recognised. In 2010, he received the designation of Fellow of the Entomological Society of America (ESA), as well as winning ESA’s Nan-Yao Su Award for Innovation and Creativity in Entomology and a Distinguished Scientist Award. In September 2012, his outstanding contribution to knowledge was further honoured when he received the 2011 The World Academy of Sciences (TWAS) Prize for Agriculture. He was also elected to the Council of the International Congress of Entomology, and designated a Fellow of the Royal Entomological Society, London. In 2013, he was elected Fellow of TWAS, Fellow of the African Academy of Sciences, and Extra-ordinary Professor, North-West University, South Africa. In 2015, Khan received the prestigious Louis Malassis International Prize for Food and Agriculture for his outstanding career in agriculture.

Zeyaur Khan was elected a Fellow of the World Academy of Sciences (TWAS) in 2013. The TWAS Fellowship is awarded to internationally renowned scientists who have made a remarkable contribution to the advancement of science and science-based sustainable development in the South. He is pictured receiving the TWAS prize from the President of the People’s Republic of China, Hu Jintao, in Tianjin, September 2012.

Charles Midega (left) being interviewed by Kenya Broadcasting Corporation about push-pull technology.

Dr Charles Midega, a senior scientist at *icipe* and a distinguished scholar at Cornel University (USA) has been working with the push-pull programme for more than15 years. Considered a ‘champion’ in his field, he coordinates a number of research activities within the programme, including ecological and system intensification of companion cropping; chemical ecology of plant-pest-natural enemy interactions and role in pest management; plant signalling; role of landscape architecture in pest dynamics and management; and management of invasive pests, weeds and diseases in African agriculture. He is also a capacity-building enthusiast and has a special focus on graduate scholars, farmers and national research and extension agencies.

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 and control of fall armyworm. The flexibility of the programme'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 programme's focus on farmer participation and training has sown the seeds of widespread and self-sustaining impact.

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.

Peter Waboya, chairman of Bungoma Umbrella Farmer Field School Network, sees his job as "to oversee and empower". Since 2006, his field school network has trained farmers from 248 farmer field schools 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 leadership positions (e.g. chiefs, assistant chiefs, village elders or field officers) in their communities.

Beryl Munika, a young disabled farmer from Maseno, western Kenya talks about the transformational impact of push–pull technology at an international symposium in Zurich, Switzerland. She has become a role model for other disabled farmers in Africa.

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* and national scientists. Indeed, Pickett believes the programme 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 grass, 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 research and development 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.

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 fertiliser, 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 additional 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.

The *icipe*–Rothamsted collaboration worked well, due mainly to good communication. They do not compete for funds and neither organisation considers itself the leader, rather 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 has succeeded in involving a wide range of stakeholders. They have conducted workshops at Mbita Point for government extension officers, farmers, teachers and community opinion leaders such as chiefs and church ministers. They also work closely with staff from Heifer International, Send A Cow, Catholic Relief Services and other NGOs through joint field days, farmer field schools and other dissemination activities.

The programme 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 project countries (Benin, Burkina Faso, Burundi, Ethiopia, Ghana, Kenya, Malawi, Mozambique, Republic of Congo, Rwanda, Senegal, Tanzania, Togo, Uganda, Zambia and Zimbabwe), 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 was given a boost in 2014 when the Ethiopian government fully endorsed push–pull technology in line with its 'green' agriculture policy.

Push–pull programme 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. More than one million people have benefitted from push–pull.

'Transformational' technology

The experience of the push–pull programme 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.

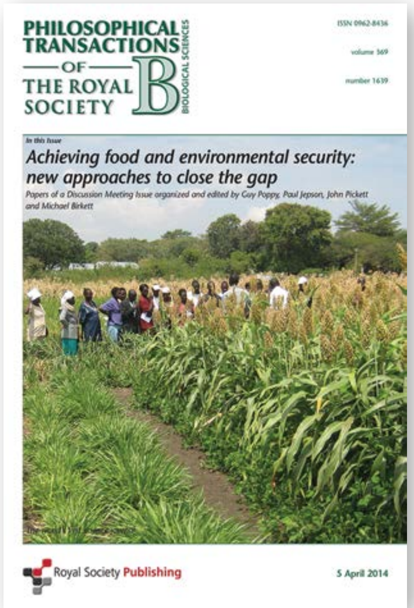
That is not to say that the technology will continue to spread unchecked. Issues such as a continuing under-investment in national agricultural research and development, the lack of agricultural credit for small-scale farmers and the frailty of public sector seed supply systems could well frustrate widespread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

If these problems can be tackled, push–pull technology will make a substantial contribution to the 'uniquely African green revolution' called for by Kofi Annan, former United Nations Secretary-General. United Nations special rapporteur on the right to food, Olivier De Chutter, also highlighted the benefits and dissemination methods of push–pull in reports to the Human Rights Council in 2010 and the General Assembly in 2015.

icipe is scaling up conventional, climate-smart and 'third-generation' push–pull technology – and various combinations of their components – across the continent. It will continue to work through strategic partnerships with a range of institutions in its target areas, including national and NGO extension systems, and farmer group networks. It will build on already established partnerships with international NGOs such as Heifer International and Send A Cow to ensure the integration of cereal cropping with livestock husbandry.

Establishment and implementation of target-specific and cost-effective dissemination pathways with a view to creating nuclei of adopting farmers to allow horizontal transfer and uptake of the technology in the target areas remains a high priority. This is being supported by technology demonstration and research on up-scaling and farmer-to-farmer knowledge transfer approaches. As the technology spreads to new areas and countries, there is a need for local adaptation, and building of technology support systems for ownership, quality control and backstopping following the channels described above. Availability of inputs, particularly desmodium and brachiaria seeds, needs to be ensured for large-scale technology uptake.

Push–pull is a readily available technology that could do much to achieve the massive increase in food



A push–pull field featured on the cover of one of the most prestigious scientific journals published by the UK's Royal Society. The volume included an article by *icipe* and Rothamsted Research scientists entitled 'Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020'.

production required by 2050 to meet Africa's food demands without damaging the environment and without bringing additional land into cultivation. 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.

As push–pull continues to spread and achieve a positive, long-term impact, it is playing a vital part in helping African countries support their progress on the path towards reducing poverty and hunger, and achieving international targets on health, education and nutrition.

The International Centre of Insect Physiology and Ecology (*icipe*) was established in Kenya in 1970, founded by renowned Kenyan entomologist Thomas Odhiambo.

Its mission is to help alleviate poverty, ensure food security and improve the overall health status of people in the tropics by developing and extending management tools and strategies for harmful and useful insects, while preserving the natural resource base through research and capacity building.

Why work with insects? Because in the tropics, insects are a fact of life to be reckoned with. They pose a great risk to food production, often causing the loss of entire crops and destroying about half of all harvested food in storage. Livestock succumb in their millions to insect- and tick-borne diseases, resulting in loss of milk, meat and traction power.

The Centre's main objective is to research and develop alternative and environmentally friendly pest and vector management strategies that are effective, selective, non-polluting, non-resistance inducing, and which are affordable to resource-limited rural and urban communities.

Push–pull is one such strategy. It is an effective, low-cost and environmentally friendly intercrop technology for the control of stemborers, fall armyworm and striga, which are among the major pests of maize throughout Africa. For the farmers who successfully adopt 'climate-smart' push–pull, it can bring about an overall improvement in both farming systems and livelihoods.

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***icipe*—International Centre of Insect Physiology and Ecology**
P.O. Box 30772-00100, Nairobi, Kenya
Tel: +254 (20) 8632000 • **Fax:** +254 (20) 8632001/8632002 • **E-mail:** icipe@icipe.org