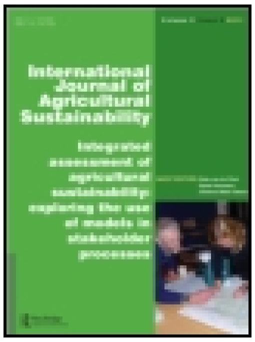
# Rothamsted Repository Download

**A - Papers appearing in refereed journals**

Khan, Z., Midega, C., Pittchar, J., Pickett, J. A. and Bruce, T. J. A. 2011. Push-pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa: UK government's Foresight Food and Farming Futures project. *International Journal of Agricultural Sustainability.* 9, pp. 162-170.



Taylor & Francis
Taylor & Francis Group

International Journal of Agricultural Sustainability

ISSN: 1473-5903 (Print) 1747-762X (Online) Journal homepage: http://www.tandfonline.com/loi/tags20

# Push—pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa

**Zeyaur Khan , Charles Midega , Jimmy Pittchar , John Pickett & Toby Bruce**

**To cite this article:** Zeyaur Khan , Charles Midega , Jimmy Pittchar , John Pickett & Toby Bruce (2011) Push—pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa, International Journal of Agricultural Sustainability, 9:1, 162-170

**To link to this article:** http://dx.doi.org/10.3763/ijas.2010.0558

Published online: 08 Jun 2011.

# Push–pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa

## UK government's Foresight Food and Farming Futures project

**Zeyaur Khan[1*], Charles Midega[1], Jimmy Pittchar[1], John Pickett[2] and Toby Bruce[2]**

[1] International Centre of Insect Physiology and Ecology, Nairobi, Kenya
[2] Rothamsted Research, Harpenden, Hertfordshire, UK

Push–pull technology (www.push-pull.net) is based on a novel cropping system developed by the International Centre of Insect Physiology and Ecology, Rothamsted Research (UK) and national partners for integrated pest, weed and soil management in cereal–livestock farming systems. Stemborers are attracted to Napier grass (*Pennisetum purpureum*), a trap plant (pull), and are repelled from the main cereal crop using a repellent legume intercrop (push), desmodium (*Desmodium* spp.). Desmodium root exudates effectively control the parasitic striga weed by causing abortive germination. Desmodium also improves soil fertility through nitrogen fixation, natural mulching, improved biomass and control of erosion. Both companion plants provide high value animal fodder, facilitating milk production and diversifying farmers' income sources. The technology is appropriate to smallholder mixed cropping systems in Africa. It effectively addresses major production constraints, increases maize yields from below 1 to 3.5t/ha, and is economical as it is based on locally available plants, not expensive external inputs. Adopted by over 30,000 farmers to date in East Africa, key factors in its further up-scaling include effective technology dissemination, adaptability of companion plants for climate resilience, capacity building and multi-stakeholder collaboration, integration with livestock husbandry, improvement in input accessibility and creation of a supportive policy framework.

*Keywords*: cereal–livestock integration; conservation agriculture; integrated pest and soil management; push–pull; soil fertility; stemborers; striga weed



## Process

### Who developed the technological or institutional innovation?

Push–pull technology (www.push-pull.net) is a novel cropping system developed by the International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with Rothamsted Research (UK) (www.rothamsted.ac.uk/), Kenyan Agricultural Research Institute (KARI) (www.kari.org) and other national partners for integrated pest, weed and soil management in cereal–livestock-based farming systems. It involves attracting stemborers with Napier grass (*Pennisetum purpureum*), planted on the border of the field as a trap plant (pull), while driving them away from the main crop using a repellent intercrop (push) such as desmodium forage legumes (*Desmodium* spp.). Chemicals released by desmodium roots cause abortive germination of the parasitic striga weed, providing effective

*Corresponding author. Email: zkhan@icipe.org


PAGES 162–170, doi:10.3763/ijas.2010.0558  ISSN: 1473-5903 (print), 1747-762X (online). www.earthscan.co.uk/journals/ijas

control of this noxious weed. The companion plants provide high-value animal fodder, facilitating milk production and diversifying farmers' income sources. Furthermore, soil fertility is improved and soil degradation prevented. The technology is appropriate to smallholder farmers as it effectively addresses the major production constraints, and is economical as it is based on locally available plants, not expensive external inputs. It also fits well with traditional mixed cropping systems in Africa.

## What partnerships helped?

The research and development of the technology was done principally with funding from the Gatsby Charitable Foundation of the UK. Other donors included the Rockefeller Foundation, the UK's Department for International Development (DFID), UNEP's Global Environment Facility (GEF) and more recently Kilimo Trust East Africa and Biovision, Switzerland. The partnership between ICIPE and Rothamsted Research aided the identification and selection of companion plants, and allowed for elucidation of the science underlying the observed effects of these plants on pests, their natural enemies and weeds, particularly in terms of the active phytochemicals involved. Additionally, collaboration with the national agricultural research institutes (NARIs), national agricultural research and extension systems (NAREs) and other stakeholders allowed for dissemination of the technology to the smallholder farmers in the region. Partnerships with institutions of higher learning, non-governmental organizations (NGOs), donors and other national programmes were instrumental in resource mobilization, stakeholder training and technology dissemination in East Africa.



## To what extent was social capital development a part of the project?

As part of the research and development strategy, ICIPE directly involved thousands of smallholder farmers to test and experience the push–pull technology on their own farms, when mutual trust was developed and the communication process arising from this led to faster adoption of the technology. Farmers applied the technology in different configurations according to their unique farming systems; for example in Trans-Nzoia District, where striga is not a major threat, farmers used molasses grass instead of desmodium as the repellent plant, and also used different space intervals of the 'push' plant.

Push–pull is a knowledge-intensive technology. ICIPE, therefore, deployed a series of technology dissemination methods, namely field days, farmer teachers, mass media, public meetings, printed materials and farmer field schools (Khan *et al.*, 2008a; Amudavi *et al.*, 2009a, b). These approaches, particularly the farmer-to-farmer approaches, relied on trained farmer teachers who helped develop social networks as they disseminated and practically taught the technology. Most of the farmer teachers were later trained as farmer field school facilitators. The use of the farmer field school organizational structure and methodology additionally developed capabilities of farmers' groups to learn other agro-enterprises. This further catalysed the integration of push–pull with small-scale dairy livestock husbandry: partner NGOs, including Heifer International, saw the opportunity for sustainable fodder provision from push–pull and donated dairy goats and cows to push–pull farmers. The result is the creation of clusters of mutually supportive socio-economic networks of smallholder farmers deriving multiple benefits from the push–pull platform technology. These benefits include better linkages to support systems (the national extension networks, NGOs and technology providers), and with better income, employment and prospects to move whole communities from subsistence agriculture to a cash economy.

## What was the mix of agricultural innovations – new seeds and breeds, new agro-ecological or agroforestry innovations?

Push–pull technology involves the use of locally available plants as perennial intercrops and trap crops in a mixed cropping system. The system relies on an in-depth understanding of chemical ecology, agrobiodiversity, and plant–plant and insect–plant interactions (www.push-pull.net/publications.shtml). The main cereal crop is planted with an intercrop, desmodium, which repels stemborer moths (push) and also attracts their natural enemies (Khan *et al.*, 1997). An attractant trap plant, Napier grass (pull), is planted as a border crop around this intercrop. Gravid stemborer females are repelled from the main crop and are simultaneously attracted to the trap crop (Cook *et al.*, 2007). These companion crop plants release behaviour-modifying stimuli (semiochemicals) that manipulate the distribution and abundance of stemborers and beneficial insects for management of the pests (Hassanali *et al.*, 2008) (Figure 1).

The Napier grass trap crop produces significantly higher levels of green leaf volatile cues (chemicals), used by gravid stemborer females to locate host

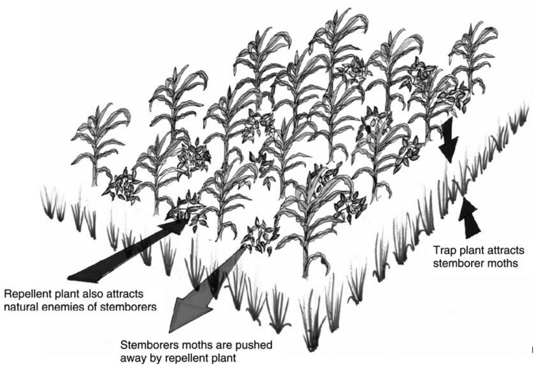



Figure 1 | How the push–pull technology works. Aerial responses are mediated by volatile organic compounds, where volatiles emitted by desmodium intercrop repel stemborer moths that are simultaneously attracted to the border Napier grass trap crop. The intercrop also attracts natural enemies, principally parasitic wasps. In the rhizosphere, chemicals secreted by desmodium roots inhibit the development of germinated striga to maize roots and cause rapid depletion of the striga seed bank in soil (modified from Khan *et al.*, 2006c)



plants than maize or sorghum (Birkett *et al.*, 2006). There is also an increase of approximately 100-fold in the amounts of these compounds produced in the first hour of nightfall (scotophase) by Napier grass (Chamberlain *et al.*, 2006), the period during which stemborer moths seek host plants for oviposition. Moths thus lay more eggs on the trap crop because it releases more attractive chemicals than the main cereal crop. However, once the eggs hatch, most of the stemborer larvae (about 80 per cent) do not survive (Khan *et al.*, 2006a) because Napier grass foliar tissue produces sticky sap (in response to their feeding), which traps and kills them. The intercrop of desmodium legumes (mainly either silverleaf, *Desmodium Uncinatum*, or greenleaf, *Desmodium intortum*), on the other hand, produces repellent volatile chemicals that push away the stemborer moths. These include (*E*)-$\beta$-ocimene and (*E*)-4,8-dimethyl-1,3,7-nonatriene, semiochemicals produced during damage to plants by herbivorous insects and responsible for the repellence by desmodium of stemborers (Khan *et al.*, 2000).

The desmodium intercrop releases root exudate allelochemicals that induce suicidal germination of striga seeds, thus dramatically reducing the striga seed bank and providing very effective control of this noxious weed. Secondary metabolites with striga seed germination stimulatory and post-germination inhibitory activities are present in the root exudates of *Desmodium incinatum*, which directly interferes with parasitism (Khan *et al.*, 2008c). This combination thus provides a novel means of *in situ* reduction of the striga seed bank in soil through efficient suicidal germination, even in the presence of cereal hosts in the vicinity (Tsanuo *et al.*, 2003; Khan *et al.*, 2008c; Hooper *et al.*, 2010). Other *Desmodium* spp. have also been evaluated and demonstrated similar effects on striga (Khan *et al.*, 2006a); these have been incorporated as intercrops in maize (Khan *et al.*, 2007), sorghum (Khan *et al.*, 2006b), millet (Midega *et al.*, 2010) and rice (Pickett *et al.*, 2010). The companion crops, Napier grass and desmodium, are valuable themselves as high-quality animal fodder.

## Outcomes

The technology is highly appropriate for smallholder farmers who do not purchase seasonal inputs, and has consequently been adopted by over 30,000 farmers in the East African region to date with relatively small resources expended on technology transfer so far. Maize and sorghum grain yields for these farmers have tremendously increased, from below 1t/ha to about 3.5 and 2t/ha, respectively (Khan *et al.*, 2006b, 2008b), achieved with minimal inputs, resulting from effective control of stemborers and striga, and improved soil fertility. Moreover, overall soil health has improved as a result of nitrogen fixation by desmodium (110kg N/ha), increased organic matter and soil moisture conservation. Ecologically, the technology has enhanced soil biodiversity, thereby further improving soil health and fertility. Additionally, because desmodium provides ground cover, it leads to reduced soil temperatures and, together with surrounding Napier grass, protects the soil against erosion. The farms under push–pull are therefore sustainable and resilient, with improved potential to mitigate the effects of climate change.

Both desmodium and Napier grass, grown perennially, continually provide valuable year-round quality animal fodder while the sale of desmodium seeds generates additional income for the farmers. Indeed these farmers have reported the benefits above in addition to increased milk production (Khan *et al.*, 2008a). These have resulted in significant improvements in economic returns to the farmers, with cost–benefit analyses showing significantly higher returns to both land and labour compared to conventional farmer practices (Khan *et al.*, 2008c). The push–pull technology has thus opened up significant opportunities for smallholder growth and represents a platform technology around which new income generation and human nutritional components, such as livestock keeping, can be added. It therefore affords the smallholder farmers an opportunity to enter into cash economy (Figure 2).

### Number of farmers adopting

To date the technology has been adopted by over 30,000 smallholder farmers in Kenya, Uganda and Tanzania. Figure 3 shows the number of farmers using the technology in western Kenya, where most adopters are found, and both stemborers and striga are serious limiting factors for maize production. About 24,000 farmers are in western Kenya, about 4,000 in central Kenya and another 4,000 in Uganda and Tanzania. The push–pull technology is likely to be adopted in the rest of sub-Saharan Africa (SSA) where striga, stemborers and low soil fertility are major constraints to cereal crop production.

### Number of hectares covered by new technologies or practices

Due to steady increases in human population in SSA, family landholdings are continually decreasing. Typically, about 1 acre is dedicated to cereal cultivation. To date the area covered by the push–pull technology in East Africa is about 15,000ha. This annually increases as more farmers adopt the technology and those who initially adopt it on smaller portions of land expand the acreage under the technology. After integration of edible beans in the push–pull system, its adoption increased rapidly during 2006–2009 (Khan *et al*., 2009).

### Predicted trends for both farmers and hectares into the future

It is expected that the observed trends of adoption will continue. Indeed, it is also envisaged that within the next five years approximately 50,000ha will be under push–pull technology, thereby lifting about 100,000 households out of food insecurity. Intensified use of technology transfer methods that have been tested and proven will enable the technology to spread to even more farmers.

### Effects on food production or productivity (either yields or total production)

Maize grain yields have increased three- to four-fold, and sorghum yields have similarly increased two-fold. This has enabled a typical family of six to move from a situation of food insecurity to food sufficiency. Indeed, surpluses have been obtained that have stimulated grain market activities in the region. Farmers have also reported increases in fodder and milk

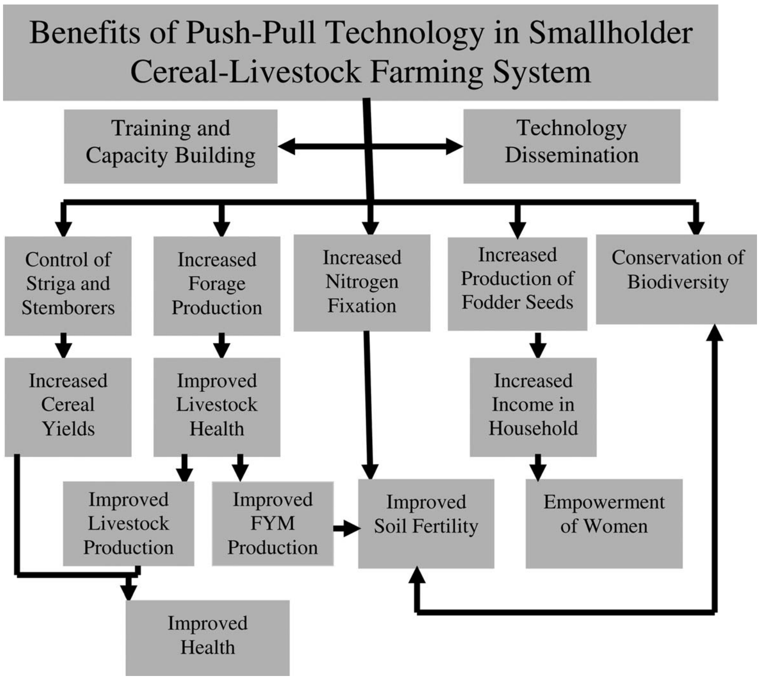



Figure 2 | Benefits of push–pull technology in smallholder farming systems
Source: Modified from Khan *et al*. (2006).

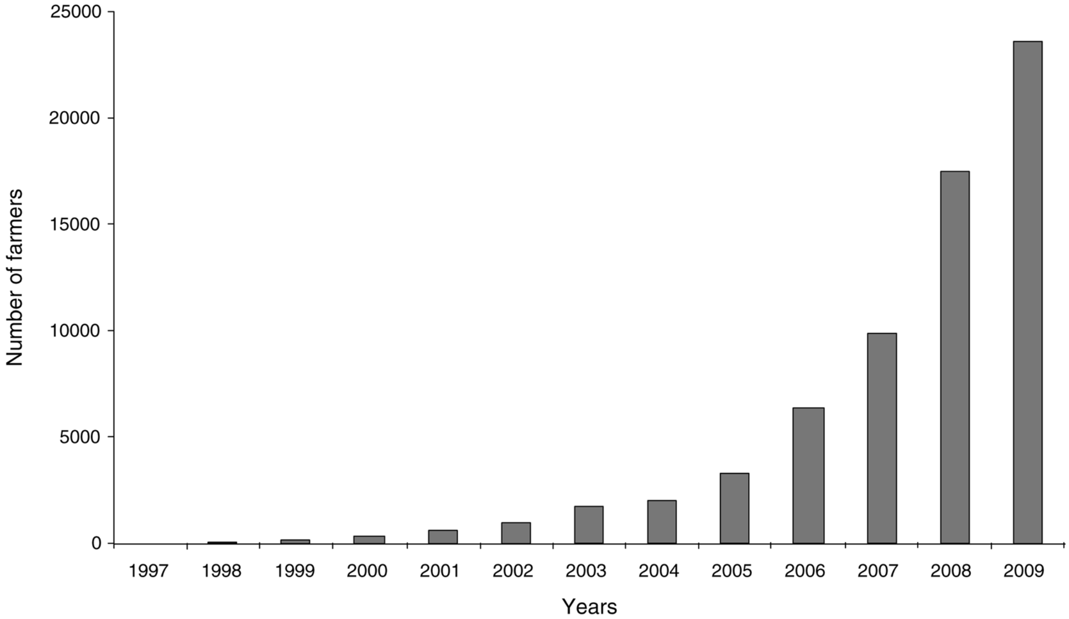



Figure 3 | Number of farmers using the push–pull system in western Kenya (1997–2009)



production. Soil fertility levels have similarly improved (Khan *et al*., 2006c).

Figure 4 shows maize grain yields obtained from 20 farmers' fields per district in western Kenya during the long rainy season of 2006.

## Effects on environmental services (e.g. standing and soil carbon, biodiversity, water, soils)

*Soils*: Push–pull technology improves soil health through nitrogen fixation (desmodium being an efficient legume for this), increased soil organic matter content, conservation of soil moisture and reduced soil temperatures. Moreover, the companion plants prevent soil erosion, thereby protecting fragile soils (Khan *et al*., 2006c). Increased productivity ensures that the available land sufficiently meets the food needs of the households and thus removes the need to extend to protected areas such as forests.

*Biodiversity*: The technology enhances arthropod abundance and diversity, part of which is important

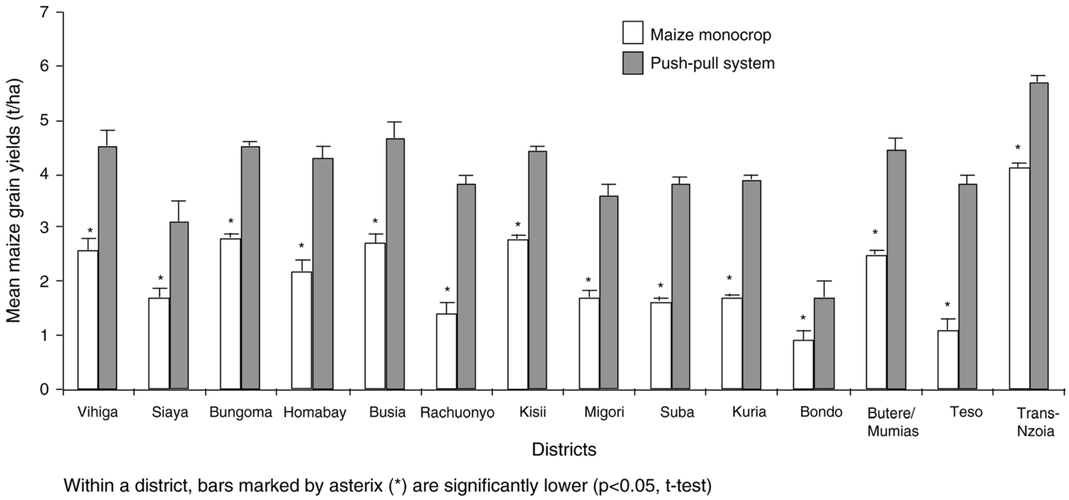



Figure 4 | Mean maize yields in different East African regions (adapted from Khan *et al*., 2008a) in soil regeneration processes, pest regulation (Midega *et al*., 2008) and stabilization of food webs, and thus the system ensures ecosystem stability. There is also a clear demonstration of the value of biodiversity because of the important roles played by companion crops and beneficial insects in the system.

*Climate change*: Desmodium provides live mulch and together with Napier grass lowers temperatures within the cropping system (Khan *et al*., 2002). By increasing organic matter content, the technology improves the soil's ability to sequester atmospheric carbon and thus mitigate the effects of climate change. Indeed preliminary data show that soil carbon is higher in push–pull plots than in the monocropped plots. Farms under push–pull are therefore sustainable and resilient, with improved potential to mitigate the effects of climate change.

*Environmental health*: In addition to improved biodiversity that is partly exploited for pest management, the technology eliminates the need for pesticides to be deployed in these cropping systems. This ensures that the environment and associated biodiversity are not harmed and no chemical residues drift into water bodies.

### Social outcomes –Who are the key beneficiaries? Who are the losers?

Beneficiaries are the subsistence resource-poor smallholder farmers in SSA producing cereals in mixed cropping systems with livestock. These directly benefit through improved cereal–livestock productivity, soils and incomes, ensuring their food and nutritional security. The increased income streams from the sale of grain surpluses, fodder and milk, and desmodium seeds enable these farmers to enter into cash economy (Khan *et al*., 2008c). Availability of smallholder disposable income is in turn injected into the local economy, thus ensuring improved livelihoods of the target communities. The push–pull technology was recently described as 'the single most effective and efficient low-cost technology for removing major constraints faced by the majority of smallholders in Eastern Africa resulting in an overall and significant improvement of their food security and livelihoods' (Fischler, 2010). Overall, stabilizing the abjectly poor rural community that can gradually move from subsistence to surplus without further migration to townships will have valuable socio-political value.

The losers are the chemical companies, both multinationals and associated subsidiaries, that provide seasonal inputs that are largely not sustainable. These include fertilizers, broad-spectrum eradicant chemical pesticides and seed material requiring such inputs.

## Options for spread, greater resilience and more productivity

The push–pull technology is effective under a range of different agro-ecologies and with a range of cereal crops, including the more drought-tolerant sorghum and millet. Thus, the technology, and associated benefits, is relevant to 300 million people in SSA. It effectively addresses all the major abiotic and biotic constraints affecting mixed cereal–livestock farming systems in SSA. However, the trap and intercrop components are rainfall and temperature limited. Therefore, to improve cereal and livestock productivity in dry areas and to ensure that the technology continues to positively impact food security in the region over the longer term, new drought-tolerant trap and intercrop plants are currently being identified for incorporation into the technology. These should have correct chemistry in terms of stemborer attractantion for the trap component and stemborer repellency and striga suppression, and ability to improve soil fertility and soil moisture retention, for the intercrop component. In addition, they should provide other ecosystem services such as biodiversity improvement conservation and organic matter improvement.

The science required to identify these new components and understand the underpinning mechanisms will not only help in providing a basis for feedback in case of changes in semiochemical production by the companion plants, but will also provide the underpinning science required for the next generation of high-yield but low-input crops detailed in the recent Royal Society report (http://royalsociety.org/Reapingthebenefits/), page 27 onwards.

Key factors in push–pull technology up-scaling are (1) deployment of a combination of dissemination pathways catering to different socio-cultural contexts and literacy levels of farmers, (2) multi-level collaboration with research institutions, national extension networks and NGOs, and farmer groups, and (3) extension efforts underpinned by a robust scientific base and continuous technical backstopping. Technology transfer was facilitated by a series of interventions (Khan *et al*., 2008b), including mass media, information bulletins (brochures, detailed practical manuals on how to plant push–pull), mass media (radio programmes in local languages and newspaper articles), farmer-to-farmer learning methods (such as field days, farmer teachers, farmer field schools and enactment of drama), training by specialized extension staff and public meetings. Access to clear information about a relevant agricultural technology and its demonstrated efficacy are some of the key factors determining technology uptake. Farmers reported that they were motivated to adopt the technology after obtaining information from a number of sources (Khan *et al*., 2008b), mainly early adopters, farmer teachers and field days, the mass media – through a national radio programme (*Tembea na majira*) – and through extension and NGO staff. This thus revealed the technology transfer methods that could be effectively employed in the different areas and on which incremental resources could be placed to disseminate the technology further in the target areas.

*Working with multiple stakeholders*: International research organizations, National Agricultural Research Systems (NARS), national extension networks, NGOs and farmers themselves disseminated push–pull technology and facilitated learning by farmers and development of their capacity and that of extension providers. National-level organizations and farmers were involved in (a) research and development and (b) on-farm testing of technology components and participatory trials. Collaboration with NGOs, including Heifer International, has facilitated the integration of livestock production with the 'push–pull' agronomic strategy.

The main constraints to technology up-scaling have been a lack of knowledge and the low financial and organizational capacity of target farmers and associated extension workers. Bottlenecks in the supply of seed and planting material were overcome by targeted training and capacity development. Availability of desmodium seed and other planting material was secured through collaboration with Western Seed Company, in conjunction with a community-based seed multiplication programme, where 600 smallholder farmers were contracted to produce and supply seed to the company, which in turn processed the seed, ensured its quality certification and distributed it through its private-sector network of agrodealers.

## How the technology can be spread to other agro-ecological zones in SSA

Technology spread to other agro-ecologies can be achieved by ensuring that, first, it is sustainable and fully adapted to the increasingly hot and dry conditions in arid and semi-arid zones, and sufficient attention is given to strategically important crops in drier agro-ecologies like sorghum and millet, capacity building of NARIs and NAREs, and multi-stakeholder collaboration with organizations, including NGOs, serving farmers in the target countries. Secondly, the current push–pull technology needs to be extended as widely as possible, while integrating with animal husbandry knowledge, in the target countries to a critical mass of adopters to allow its horizontal diffusion within and beyond the target sites through the use of the effective technology transfer pathways already developed for push–pull (Khan *et al*., 2008a, b; Amudavi *et al*., 2009a, b), and where necessary adapt and optimize them. Thirdly, input accessibility and availability should be ensured in the target areas by combining commercial production by seed companies, community-based seed production and distribution systems, and farmer groups trained on desmodium vegetative propagation using vines.

## Policy support for scaling up the impacts of the technology

Policy needs to support synergistic deployment of platform technologies like push–pull, which sustainably intensify productivity in all cereal systems (maize, sorghum, rice and millet) by addressing biotic and abiotic constraints, and soil fertility improvement, and ensuring economic viability. This requires targeted investments by both the public and the business sectors. Secondly, further development of smallholder production systems must be compatible with farming systems, and sound management of natural resources and the environment. Technology deployment must take into account other on-farm enterprises such as livestock keeping so that the novel technologies remain relevant to the farming systems. Thirdly, policy must support improvement in accessibility and efficiency of input and output markets, as well as value chain development of smallholder cereal, legume and livestock products. Fourthly, policy should support and encourage (a) further scientific innovation, (b) increased investment in agricultural technology, particularly by the private sector and farmers themselves, and (c) improvement of the value chains – from input supply through production to marketing.

Policy support needed to integrate research and up-scaling (and out-scaling) processes includes (1) promotion of cross-disciplinary research, development of innovation system approaches and multi-institutional collaboration; (2) capacity building for project teams (in mutual learning and knowledge sharing), farmers (in skills acquisition and organizational capacity) and scientists in national institutions (in adequate funding, real collaboration and action research orientation);

(3) development of information and knowledge management capacity, and wide dissemination of the findings of proven research work, underpinned by sound scientific bases; and (4) continuous learning by all involved stakeholders, participatory monitoring and evaluation, and a systemic approach to impact assessment, to track programme progress towards overall goals, precisely identify the needs for mid-course adjustments and document the returns on project/technology investment.

### What are the key elements of processes and actions that build system outputs and resilience?

The system involves the use of locally available natural resources to increase farm productivity while delivering other ecological and economic benefits to smallholder farmers. The practice of companion cropping is deeply embedded in the agricultural traditions of resource-poor farmers generally. As a polycultural system, it attracts higher arthropod abundance and diversity, including natural enemies of the pests. Stemborer and striga control is affected by plant natural chemistry, resulting in increased cereal grain yields, fodder and milk; surpluses are sold, thereby enabling farmers to generate income. Environmental benefits of the technology include soil and moisture conservation, improved soil health, enhanced biodiversity while eliminating pesticide usage, increased soil cover and organic matter rendering ecological services such as carbon sequestration. The perenniality of companion plants ensures continual striga seed bank depletion even when there is no cereal crop in the field.

Above all, push–pull technology delivers the objectives of national programmes, but the process of technology transfer and making seed or other planting material available needs external support until adoption is widely established.



## References


Amudavi, D. M., Khan, Z. R., Wanyama, J. M., Midega, C. A. O., Pittchar, J., Hassanali, A., Pickett, J. A., 2009a, 'Evaluation of farmers' field days as a dissemination tool for push–pull technology in Western Kenya', *Crop Protection* 28, 225–235.

Amudavi, D. M., Khan, Z. R., Wanyama, J. M., Midega, C. A. O., Pittchar, J., Nyangau, I. M., Hassanali, A., Pickett, J. A., 2009b, 'Assessment of technical efficiency of farmer teachers in the uptake and dissemination of push–pull technology in Western Kenya', *Crop Protection* 28, 987–996.

Birkett, M. A., Chamberlain, K., Khan, Z. R., Pickett, J. A., Toshova, T., Wadhams, L. J., Woodcock, C. M., 2006, 'Electrophysiological responses of the lepidopterous stemborers *Chilo partellus* and *Busseola fusca* to volatiles from wild and cultivated host plants', *Journal of Chemical Ecology* 32, 2475–2487.

Chamberlain, K., Khan, Z. R., Pickett, J. A., Toshova, T., Wadhams, L. J., 2006, 'Diel periodicity in the production of green leaf volatiles by wild and cultivated host plants of stemborer moths, *Chilo partellus* and *Busseola fusca*', *Journal of Chemical Ecology* 32, 565–577.

Cook, S. M., Khan, Z. R., Pickett, J. A., 2007, 'The use of "push–pull" strategies in integrated pest management', *Annals Review Entomology* 52, 375–400.

Fischler, M., 2010, 'Impact Assessment of Push Pull Technology in Eastern Africa', Intercooperation, Switzerland, ICIPE Science Press, Nairobi.

Hassanali, A., Herren, H., Khan, Z. R., Pickett, J. A., Woodcock, C. M., 2008, 'Integrated pest management: the push–pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry', *Philosophical Transactions of the Royal Society London Series B* 363, 611–621.

Hooper, A. M., Tsanuo, M. K., Chamberlain, K., Tittcomb, K., Scholes, J., Hassanali, A., Khan, Z. R., Pickett, J. A., 2010, 'Isoschaftoside, a *C*-glycosylflavonoid from *Desmodium uncinatum* root exudate, is an allelochemical against the development of *Striga*', *Phytochemistry* 71, 904–908.

Khan, Z. R., Ampong-Nyarko, K., Chilishwa, P., Hassanali, A., Kimani, S., Lwande, W., Overholt, W. A., Pickett, J. A., Smart, L. E., Wadhams, L. J., Woodcock, C. M., 1997, 'Intercropping increases parasitism of pests', *Nature (London)* 388, 631–632.

Khan, Z. R., Pickett, J. A., Van den Berg, J., Wadhams, L. J., Woodcock, C. M., 2000, 'Exploiting chemical ecology and species diversity: stemborer and *Striga* control for maize and sorghum in Africa', *Pest Management Science* 56, 957–962.

Khan, Z. R., Hassanali, A., Khamis, T. M., Overholt, W. A., Hooper, A. M., Pickett, J. A., Wahams, L. J., Woodcock, C. M., 2002, 'Control of the witchweed, *Striga hermonthica*, by intercropping with *Desmodium* spp., and the mechanism defined as allelopathic', *Journal of Chemical Ecology* 28, 1871–1885.

Khan, Z. R., Midega, C. A. O., Hutter, N. J., Wilkins, R. M., Wadhams, L. J., 2006a, 'Assessment of the potential of Napier grass (*Pennisetum purpureum*) varieties as trap plants for management of *Chilo partellus*', *Entomology Experimental Application* 119, 15–22.

Khan, Z. R., Midega, C. A. O., Pickett, J. A., Wadhams, L. J., Hassanali, A., Wanjoya, A., 2006b, 'Management of witchweed, *Striga hermonthica*, and stemborers in sorghum, *Sorghum bicolor*, through intercropping with greenleaf desmodium, *Desmodium intortum*', *International Journal of Pest Management* 52, 297–302.

Khan, Z. R., Hassanali, A., Pickett, J. A., 2006c, 'Managing polycropping to enhance soil system productivity: a case study from Africa', in: N. Uphoff, A. S. Ball, C. Palm,

E. FernandesJ. Pretty, H. Herren, P. Sanchez, O. Husson, N. Sanginga, M. Laing, J. Thies (eds), *Biological Approaches to Sustainable Soil Systems*, CRC Press, Taylor and Francis, Boca Raton, FL, 575–586.

Khan, Z. R., Midega, C. A. O., Hassanali, A., Pickett, J. A., Wadhams, L. J., 2007, 'Assessment of different legumes for the control of *Striga hermonthica* in maize and sorghum', *Crop Science* 47, 730–734.

Khan, Z. R., Midega, C. A. O., Amudavi, D. M., Hassanali, A., Pickett, J. A., 2008a, 'On-farm evaluation of the "push-pull" technology for the control of stemborers and striga weed on maize in western Kenya', *Field Crops Research* 106, 224–233.

Khan, Z. R., Amudavi, D. M., Midega, C. A. O., Wanyama, J. M., Pickett, J. A., 2008b, 'Farmers' perceptions of a "push–pull" technology for control of cereal stemborers and striga weed in western Kenya', *Crop Protection* 27, 976–987.

Khan, Z. R., Midega, C. A. O., Njuguna, E. M., Amudavi, D. M., Wanyama, J. M., Pickett, J. A., 2008c, 'Economic performance of "push-pull" technology for stem borer and striga weed control in smallholder farming systems', *Crop Protection* 27, 1084–1097.

Khan, Z. R., Midega, C. A. O., Wanyama, J. M., Amudavi, D. M., Hassanali, A., Pittchar, J., Pickett, J. A., 2009, 'Integration of edible beans (*Phaseolus vulgaris* L.) into the push–pull technology developed for stemborer and striga control in maize-based cropping systems', *Crop Protection* 28, 997–1006.

Midega, C. A. O., Khan, Z. R., Van den Berg, J., Ogol, C. K. P. O., Dippenaar-Schoeman, A. S., Pickett, J. A., Wadhams, L. J., 2008, 'Response of ground-dwelling arthropods to a "push–pull" habitat management system: spiders as an indicator group', *Journal Application Entomology* 132, 248–254.

Midega, C. A. O., Khan, Z. R., Amudavi, D. A., Pittchar, J., Pickett, J. A., 2010, 'Integrated management of *Striga hermonthica* and cereal stemborers in finger millet *(Eleusine coracana* (L.) Gaertn.), through intercropping with *Desmodium intortum*', *International Journal of Pest Management* 56, 145–151.

Pickett, J. A., Hamilton, M. L., Hooper, A. M., Khan, Z. R., Midega, C. A. O., 2010, 'Companion cropping to manage parasitic plants', *Annual Review of Phytopathology* 48, 161–177.

Tsanuo, M. K., Hassanali, A., Hooper, A. M., Khan, Z. R., Kaberia, F., Pickett, J. A., Wadhams, L., 2003, 'Isoflavanones from the allelopathic aqueous root exudates of *Desmodium uncinatum*', *Phytochemistry* 64, 265–273.