Chapter 13
Push–Pull: A Novel IPM Strategy for the Green Revolution in Africa

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Abstract Africa faces serious challenges in feeding its population, mainly due to poor yields of cereals that serve as both staple and cash crops occasioned by insect pests, weeds, and poor soil fertility, and more recently effects of climate change. A novel IPM approach dubbed “push–pull” has been developed and implemented in eastern Africa, based on locally available companion plants, that effectively addresses these constraints resulting in substantial grain yield increases. The technology involves intercropping cereal crops with stemborer moth repellent crops
(push), the forage legume desmodium or molasses grass, and planting the attractive Napier grass (pull) as a border crop. Desmodium is very effective in suppressing striga weed while improving soil fertility through nitrogen fixation and improved organic matter content. The companion plants provide high-value animal fodder, facilitating milk production and diversifying farmers’ income sources. The technology, currently practiced by over 55,000 farmers in East Africa, has been adapted to dry conditions associated with climate change by identifying and incorporating drought-tolerant companion plants. The development of this technology, its benefits and subsequent efforts to expand its geographical suitability and effectiveness are described.

**Keywords** Food insecurity · Cereals · Push–pull · Semiochemicals · Stemborer · Striga

### 13.1 Introduction

Food insecurity and poverty are serious challenges in Africa resulting from poor crop yields, and complicated by high human population growth rates, environmental degradation, and climate change. Agriculture forms the backbone of the economy of most African countries. Indeed approximately 80% of the human population in sub-Saharan Africa (SSA) alone depends on agriculture for food, income, and employment. Increasing agricultural productivity therefore represents a significant opportunity for addressing food insecurity and poverty while allowing economic growth in the continent where human population tragically grows faster than the rate of agricultural production. Efficient production of staple cereal crops (including maize *Zea mays* L., and Sorghum *Sorghum bicolor* (L.) Moench) for millions of resource-constrained farmers on the continent, is central to this challenge. Unfortunately, grain yields of these cereals in Africa are the lowest in the world at around 1 ton(t)/ha (Jagtap and Abamu 2003) compared with 2.4 t/ha in South Asia, 3.2 t/ha in Latin America, and 4.5 t/ha in East Asia and Pacific (World Bank 2008). Agricultural growth in Africa is achievable by reducing major constraints to productivity that are mainly related to water stress, degraded soils, pests, diseases, and weeds. These constraints, already cause high levels of food insecurity, malnutrition, and poverty and are expected to increase as a result of climate change.

Insect pests are a major constraint to efficient production of cereals in Africa, with lepidopteran stemborers, such as the indigenous *Busseola fusca* (Fuller), and the invasive *Chilo partellus* (Swinhoe), being the most important in most parts of the continent. Attack by the stemborer pests results in yield losses ranging from 10 to 80% of the potential yield, depending on the pest population density and the phenological stage of the crop at infestation, among other factors. There is therefore a continued quest and significant interest among farmers to find better approaches for solving these pest problems.

Stemborers are difficult to control, largely because of the cryptic and nocturnal habits of the adult moths and the protection provided to immature stages by the stem
of the host crop (Ampofo et al. 1986; Kfir et al. 2002). Chemical pesticides are the main method of stemborer control recommended to farmers by the governments’ ministries of agriculture. However, these are not only environmentally unfriendly and unsustainable, but also uneconomical and impractical for most resource-poor farmers (Kfir et al. 2002), and a direct threat to beneficial arthropods. They are therefore not widely used by the majority of small-scale farmers in Africa (van den Berg and Nur 1998). Additionally, there is also near-absence of extension service providers to inform the farmers of the right pesticides and dosages to use, and absence of application equipment (Midega et al. 2012). Use of synthetic sex pheromones has also been attempted to monitor stemborer moth population levels. The number of male moths captured by pheromone-baited traps provides useful information on timing of insecticide application and is often employed by large-scale and commercial cereal farmers. These traps also provide information on the seasonal and annual flight patterns of the moths and can guide planning of application of pesticides. They can also be used to disrupt communication between male and female moths thereby disrupting mating. Indeed, some reduction in damage levels caused by B. fusca was observed in Kenya resulting from mating disruption between moths (Critchley et al. 1997). In addition to these, cultural and biological control methods have also been attempted, with variable results. Cultural control methods are often considered the first line of defense against pests, and include techniques such as intercropping, crop rotation, manipulation of sowing dates, and destroying of crop residues. Although most of these techniques are affordable, they are labor intensive. Indeed, effectiveness of some of these cultural methods is questionable (van den Berg et al. 1998), with the majority of smallholder farmers not attempting stemborer control, with devastating consequences (Chitere and Omolo 1993).

Although efficient integrated pest management (IPM) has long been proposed as a sustainable crop protection approach, the concept requires new interventions devised through a thorough knowledge of biological interactions and information on the crop and on the surrounding environment. Some of the key components of IPM should include integrating cropping practices and genetic resistance to pests, and preservation and/or enhancement of the effectiveness of natural enemies. Here we describe a new multifaceted IPM approach, which is based on smallholder farmers’ own practice of companion cropping that has been developed for efficient management of stemborer pests in Africa and beyond.

13.2 The Push–Pull Technology

13.2.1 Discovery and Development

Scientists at the International Centre of Insect Physiology and Ecology (icipe) based in Kenya, in collaboration with various national and international partners, including Rothamsted Research of the United Kingdom, have developed and implemented
a technology for integrated pest, weed, and soil management through efficient use of natural resources to increase farm productivity. Dubbed “push–pull,” the technology exploits chemical ecology and diversity of local fauna and flora to deliver effective management of these pests. Cereal stemborers are polyphagous and their host plant range includes other members of the family Poaceae as well as the Cyperaceae and Typhaceae (Ingram 1958; Khan et al. 1997a; Polaszek and Khan 1998). The wild host plants are important not only in maintaining stemborer populations when the cultivated crops are out of season, but also for conservation of the pests’ natural enemies. The wild hosts often harbor food sources for many insect pest species and may encourage insect invasion and outbreaks in neighboring agroecosystems (van Emden 1990). 

icipe and partners from a series of surveys and bioassay studies identified the most attractive plant species as trap plants and repellent plants as intercrops. Among these, Napier grass, *Pennisetum purpureum* Schumach, was selected as the putative trap crop (pull) as it attracted considerably more oviposition by stemborer moths than maize (Khan et al. 2006a, 2007; Midega et al. 2011). However, it did not allow much survival of stemborer larvae, with over 80% of the young larvae dying within the first 15 days of larval feeding (Khan et al. 2006a, 2007). Mortality was caused by the gummy substance produced by Napier grass that immobilized the larvae as they tried to bore into the stem in addition to the poor nutritive value of the grass (Khan et al. 2007).

Similarly, through a series of field trials and bioassay experiments, Molasses grass, *Melinis minutiflora* P. Beauv, was selected as a putative repellent (push) plant as it neither attracted oviposition by stemborer moths nor supported survival of the young larvae (Khan et al. 2000). In subsequent studies, leguminous plants in the genus *Desmodium* were selected as the intercrop as they efficiently repelled ovipositing stemborer moths and at the same time suppressed emergence of the noxious and devastating parasitic weeds in the genus *Striga* (Khan et al. 2000, 2008a; Midega et al. 2013). The push–pull technology thus involves intercropping the main cereal crop with molasses grass or desmodium which are repellent to gravid stemborer moths (push) while Napier grass planted as a border crop around the main crop simultaneously attracts the stemborers and thus acts as a trap plant (pull; Cook et al. 2007; Hassanali et al. 2008; Khan et al. 2010; Fig. 13.1). The intercrop also attracts parasitic wasps, which are natural enemies of the stemborer (Khan et al. 1997b).

### 13.2.2 Semiochemistry of the Push–Pull Technology

Insects use specific semiochemicals (Dicke and Sabelis 1988) or specific ratios of semiochemicals (Bruce et al. 2005) from plants to detect exploitable hosts and to avoid unsuitable plants. Stemborer host plants produce attractive semiochemicals, notably octanal, nonanal, naphthalene, 4-allylanisole, eugenol, and linalool. It was discovered that Napier grass was preferred by stemborer moths because it produced significantly higher amounts of these attractive compounds relative to maize and...
sorghum. Furthermore, there was over 100-fold increased emission of these attractive semiochemicals during the first two hours of darkness (Birkett et al. 2006; Chamberlain et al. 2006). This coincided with the period during which stemborer moths were most actively seeking host plants (Päts 1991). The repellent intercrops, molasses grass and desmodium, on the other hand, were found to emit semiochemicals often associated with plants under herbivore attack, known as herbivore-induced plant volatiles (HIPVs), such as \((E)\)-ocimene and \((E)\)-4,8-dimethyl-1,3,7-nonatriene (DMNT; see review by Khan et al. 2008b). These HIPVs were subsequently shown to have dual functions: they repelled ovipositing moths and at the same time increased foraging behavior of the pests’ natural enemies, principally the parasitic wasp, *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae). The DMNT in particular was demonstrated to be responsible for the increased parasitoid foraging in the plots intercropped with molasses grass (Khan et al. 1997b). There were higher parasitism rates of the larvae in push–pull than maize monocrop fields in western Kenya (Khan et al. 1997a; Midega et al. 2009).

It was also discovered that fodder legumes in the genus *Desmodium* are effective repellents for stem borers (Khan et al. 2000), with the added benefit of fixing nitrogen in the soils as well as serving as a cover crop to prevent soil erosion (Khan et al. 2006b). From the studies on the mechanisms of striga suppression by *Desmodium* spp., Khan demonstrated that, in addition to the benefits derived from increased availability of nitrogen and soil shading, there was a strong allelopathic effect of the root exudates of the legume (Khan et al. 2002). These *Desmodium* spp. root

![Diagrammatic presentation of push–pull strategy for insect pest management. (Courtesy of Dr. Johnnie van den Berg, North West University, South Africa)](image-url)
exudates contain novel flavonoid and isoflavonoid compounds that interfere with striga parasitization of maize (a striga plant produces tens of thousands of seeds that can remain dormant in the soil for decades). Some of these compounds stimulate striga seed germination whereas others prevent attachment of the parasite’s roots to the maize roots (Khan et al. 2008a). This combination thus provides a novel means of in situ reduction of the striga seedbank in the soil through efficient suicidal germination even in the presence of graminaceous host plants.

13.2.3 Uptake and Impact of the Push–Pull Technology

During the last 15 years, on-farm implementation of the push–pull technology has been achieved through a number of technology dissemination pathways involving farmer-to-farmer approaches such as field days, farmer teachers, and farmer field schools (Khan et al. 2008c; Amudavi et al. 2009a, b; Murage et al. 2011). Other approaches have included use of mass media, print media, brochures and pamphlets, and more recently use of information and communications technology (ICT) approaches, principally mobile phones and participatory video. To date over 55,000 smallholder farmers in East Africa are practicing push–pull technology (Fig. 13.2). These farmers have realized effective control of stemborers and parasitic striga weed resulting in significant increases in grain yields from $<1$ t/ha to at least 3.5 t/ha for maize, (Khan et al. 2008c) (Fig. 13.3), from $<1$ t/ha to at least 2.5 t/ha for sorghum (Khan et al. 2008d) and from $<0.5$ t/ha to at least 1 t/ha for finger millet (Midega et al. 2010). These farmers have also achieved significant improvements in soil fertility (Khan et al. 2008d) because desmodium is an efficient nitrogen-fixing legume (Whitney 1966) and also improves soil organic matter content, in addition to preventing soil erosion (Midega et al. 2005). It also improves abundance and diversity of beneficial arthropods (Midega et al. 2008).
companion plants are valuable and nutritious fodder and therefore the technology allows cereal–livestock integration. Farmers have mentioned increases in fodder and milk production (Khan et al. 2008d), with an overall improvement in incomes and livelihoods (Khan et al. 2008e). Thus the push–pull technology opens up significant opportunities for smallholder growth and represents a platform technology around which new income generation and human nutritional components, such as keeping livestock, can be added.

### 13.2.4 Additional Benefits of Push–Pull Technology

**Soil Improvement** Push–pull technology improves soil health through nitrogen fixation with desmodium as an efficient N-fixing legume (Whitney 1966), 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. 2006b).
Increased Biodiversity The technology enhances arthropod abundance and diversity, part of which is important 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.

Mitigation of 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 monocropped plots. Farms under push–pull are therefore sustainable and resilient, with improved potential to mitigate the effects of climate change.

Improved 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.

13.2.5 Economics of the Push–Pull Technology

A number of studies have demonstrated that push–pull technology is more profitable than the farmers’ own practices, and some of the practices designed to improve soil fertility. Indeed Khan et al. (2001) reported significantly higher benefit–cost ratio with push–pull technology compared with maize monocrop and/or use of pesticides, posting a positive return on investment of over 2.2 compared with 0.8 obtained with the maize monocrop, and slightly less than 1.8 for pesticide use. Additionally, push–pull technology with no fertilizer had the best gross returns and less profit was registered with the use of fertilizer, implying it was economically propitious to invest in the push–pull technology. In a more detailed economic analysis utilizing data of over seven cropping seasons, returns to investment for the basic factors of production under push–pull technology were significantly higher compared to those from maize–bean intercropping and maize monocrop systems (Khan et al. 2008e). Positive total revenues ranged from $ 351/ha in low potential areas to $ 957/ha in the high potential areas, with general increases in subsequent years. The returns to labor that were recovered within the first year of establishment of the technology ranged from $ 0.5/person day in the low potential areas to $ 5.2/ person day in the higher potential areas under the push–pull technology, whereas in the maize monocrop, this was negligible or even negative. Furthermore, the net present value (NPV) from push–pull technology was positive and consistent over the years. More recently, a study by De Groote et al. (2010) that used discounted
partial budget and marginal analysis corroborated these findings and concluded that push–pull earned the highest revenue compared to other soil fertility management technologies, including green manure rotation.

### 13.2.6 Adaptation of the Push–Pull Technology to Climate Change

As there is evidence of increasingly hot and dry conditions associated with climate change, and to ensure that push–pull technology continues to affect food security positively in Africa over the longer term, new drought-tolerant trap (*Brachiaria* cv *mulato*) and intercrop (drought-tolerant species of *desmodium*, e.g., *D. intortum*) plants have been selected from research undertaken with funding from the European Union. The new companion plants also have the appropriate chemistry in terms of stemborer attractancy for the trap component and stemborer repellence and striga suppression, and ability to improve soil fertility and soil moisture retention for the intercrop component. In addition, they provide other ecosystem services such as biodiversity improvement and conservation and organic matter improvement. Currently over 4,000 smallholder farmers in drier parts of Kenya, Tanzania, and Ethiopia have taken up the adapted technology and have reported effective control of stemborers and striga weed resulting in significant increases in grain yields of both maize and sorghum (Khan et al. 2014). The work to isolate and purify all the active compounds in the desmodium root exudates and fully elucidate their effects on striga suppression is ongoing. Similarly, the full mechanism of stemborer control by the new companion plants is currently being elucidated, with the aim of providing both sustainability and quality assurance as more companion plants are selected for new agroecologies (Fig. 13.4).
13.3 Exploiting Early Herbivory Alert for a “Smarter” Push–Pull Technology

New opportunities for exploiting early herbivory in plant defense and elucidating the underlying mechanisms of plant–plant communication between companion plants and cereal crops are being explored with aim of selecting “smart” cereal and companion crops. Under natural conditions, plants have evolved direct and indirect defense strategies against attacking organisms. Directly, they produce toxins, digestion inhibitors, and HIPVs repellent to phytophagous insects (De Moraes et al. 2001; Kessler and Baldwin 2001); indirectly, they use HIPVs to attract natural enemies antagonistic to the herbivores (Turlings et al. 1990; De Moraes et al. 1998; Heil 2008). Stemborer larvae inflict substantial physical damage to cereal plants by their feeding, which induces qualitative and quantitative changes in the plant’s profile of volatiles (Tumlinson et al. 1993; Turlings et al. 1998; Ng-Song et al. 2000). Some of the key compounds in the HIPVs include (E)-ß-ocimene and (E)-4,8-dimethyl-1,3,7-nonatriene (Turlings et al. 1990). HIPVs are generally induced by elicitors in the herbivore saliva or oral secretions. These HIPVs provide parasitoids with early alert cues for plants colonized by their host and thus enhance their foraging efficacy. They are thus important in recruitment of these beneficial natural enemies thereby facilitating biological control. However, this pest control occurs following plant damage. Recruitment of natural enemies prior to plant damage would thus be more beneficial in preventing crop losses.

Many wild relatives and landraces of grass species from which crop plants and fodder crops have been selected continue to survive today. Some African poaceous plants have sophisticated responses to herbivory that involve multitrophic interactions with natural enemies. We discovered a trait in the African signal grass *Brachiaria brizantha* (Hochst. EX A. Rich.) where egg deposition by *C. partellus* moths induced qualitative changes in the volatile profile, making the plant attractive to the larval parasitoid *C. sesamiae* (Bruce et al. 2010). This trait would also be useful in cultivated cereal crops. Additionally, some reports had shown that egg laying on plants by herbivores could induce defense in host plants (Hilker et al. 2002). Our subsequent studies identified a similar trait in maize landraces and smallholder farmers’ own varieties where oviposition by *C. partellus* led to increased emission of HIPVs making these plants attractive to both egg and larval parasitic wasps, *Trichogramma bournieri* and *C. sesamiae*, respectively (Tamiru et al. 2011, 2012). Notably, this trait was absent in the elite maize hybrids, implying it must have been lost during the breeding processes as desirable qualities such as high yields are selected for.

Plants that are able to produce HIPVs in response to egg deposition have the advantage of defending themselves early on, before hatching larvae can damage the plant. The HIPV emission following oviposition enables egg parasitoids to distinguish odors of plants colonized by hosts. Moreover, the attraction of larval parasitoids in response to oviposition indicates that their recruitment occurs in anticipation of larval hatching and before they damage the plant. Although it is of adaptive value to the plant to emit HIPVs, there is also selection pressure on the parasitoids to respond to
such signals, as it enhances their foraging efficiency and thus improves their ecological fitness. In the short term we have selected maize varieties with the early herbivory trait that have now been incorporated in the push–pull technology with the added benefit of initiating biological control of stemborers at oviposition, the earliest stage of attack. In the medium to long term we are studying the molecular basis of this egg-induced semiochemical production with a view to developing molecular markers that will allow advanced selection of crop varieties and introgression of these traits into mainstream commercial hybrid maize varieties that will provide novel and ecologically sound approaches to the control of these destructive stemborer pests.

13.4 Exploiting Plant–Plant Signaling for Stemborer Management

Evidence is accumulating indicating that some plants respond to HIPVs produced by damaged neighbors even when they themselves have not been attacked (Baldwin and Schultz 1983; Bruin et al. 1992; Karban et al. 2000). For example, wild tobacco, *Nicotiana attenuata*, plants grown with clipped sagebrush, *Artemisia tridentate*, neighbors had increased levels of the putative defensive oxidative enzyme, polyphenol oxidase, relative to control tobacco plants with unclipped sagebrush neighbors. Tobacco plants near clipped sagebrush experienced greatly reduced levels of leaf damage by grasshoppers and cutworms (Karban et al. 2000). Also, cotton plants growing next to those that are attacked by herbivorous mites experience reduced oviposition of these herbivores, and are attractive to predatory mites (Bruin et al. 1992). Our previous studies had shown that intact molasses and desmodium plants produced similar semiochemicals as those produced by maize under attack by stemborer pests (Khan et al. 1997b, 2000). Subsequently, we have recently observed that maize growing next to *B. brizantha* with oviposition becomes less attractive to *C. partellus* for oviposition but becomes attractive for the parasitic wasp, *C. sesamiae* (C.A.O. Midega et al., unpublished data). In addition, maize plants growing next to molasses grass produce similar semiochemicals as those under attack by stemborer larvae (Z. R. Khan et al., unpublished data). This suggests that semiochemicals emitted by molasses grass act as airborne signals that induce resistance in the neighboring, undamaged maize plants. Our preliminary results also show that these neighboring maize plants are “primed” to respond more quickly or aggressively to future attack by stemborers. Efforts are underway to identify the key compounds within the HIPVs that induce and/or prime these responses in a variety of plants. In cotton as well as other plants, cis-jasmone has been identified as one of the key compounds mediating these responses, causing dramatic induction of direct and indirect defense compounds, such as (E, E)-4,8,12-trimethyltridecaca-1,3,7,11-tetraene (TMTT). These then lead to a reduction in colonization by sucking insects (Birkett et al. 2000). Understanding these processes will enable their full exploitation in crop protection and in the development of future push–pull strategies with these traits. We are currently identifying companion plants with the ability to induce
defense against insect attack in cereal crop varieties for possible incorporation in the push–pull technology, or for development of other companion cropping-based approaches, a common feature in smallholder cropping systems in Africa, to enhance natural plant defense.

13.5 Conclusions

The push–pull system effectively addresses the constraints to production faced by the farmers and is an appropriate system because it uses locally available companion plants rather than expensive imported inputs. Although the technology was originally devised to control insect pests it has multiple benefits in controlling striga weeds, improving soil fertility, and providing livestock fodder in a truly integrated system. It is thus a novel IPM approach that was developed with full participation of the target farmers and is modeled alongside their practice of multiple cropping thereby enhancing its acceptance. It is currently used by over 55,000 smallholder farmers in eastern Africa and has been adapted for drier areas vulnerable to climate change by identifying and incorporating drought-tolerant trap and repellent plants. This has made the technology more resilient in the face of climate change as rainfall becomes increasingly unpredictable. Moreover, the technology is being made “smarter” through identification and incorporation of cereal crops with defense systems against stemborer pests that are inducible by egg deposition by the pests. Companion plants that are able to signal defense systems of the neighboring smart cereals are also being identified. Accompanying these are efforts to elucidate full mechanisms of these responses. Science-based IPM solutions, which are environmentally sustainable and low cost, like push–pull, are urgently needed to address the real and increasing dangers of food insecurity, and for a real Green Revolution in Africa without causing any ecological and social harm.

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References


13推-拉：一种新颖的IPM策略用于非洲绿色革命


