CLIMATE-SMART PUSH-PULL TECHNOLOGY FOR FOOD SECURITY, SAFETY AND ENVIRONMENTAL SUSTAINABILITY

This policy brief explains the effectiveness and development impacts of a multi-functional push-pull technology in addressing constraints to sustainable intensification of smallholder agriculture in Africa such as fall armyworm, stemborers and striga, and identifies specific opportunities for policy recommendations that simultaneously address sustainable development goals (SDGs), food production and safety as well as building sustainable agro-ecosystems.

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1. Development challenges and climate change multiple effects

Biophysical factors, low capacities, institutional and policy bottlenecks remain major constraints for agricultural development in sub-Saharan Africa (SSA), while development assistance to agriculture has declined to only 4% of public expenditure[1,2]. The rural situation is marked by continuing stagnation and often deterioration, poor crop and livestock yields, low incomes and the rising vulnerability of poor people, with negative impacts on smallholder farming, the basic source of livelihood for millions of rural poor. Longer-term development challenges include dependence on a few primary commodities, poor human capacity, increasing migration to urban areas, low employment especially of the youth and women, and climate change[3].

Environmental degradation, low productivity, human population pressure on productive resources, food insecurity, undernutrition, poverty, high morbidity and human migrations are interrelated. Low productivity of smallholder agriculture in SSA and degradation of the natural resource bases remain major concerns, raising the need for sustainable intensification of production systems, driven further by significant increased demand for food as a result of population growth, urbanization and changing food consumption patterns.

Effects of climate change are expected to have greater impacts on sustainable development of SSA, withproduction constraints expected to increase during the next few decades as agriculture intensifies to meet the extra food demand from a growing population. The resource-constrained smallholder farmers living in the arid and semi-arid regions who practise mixed crop–livestock systems are particularly badly affected, with SSA being projected to have more than 500 million food insecure people by 2020.

1 World Bank 2008. World development report 2008: agriculture for development. Washington, DC: The World Bank

2 IFAD. 2011. Rural Poverty Report: New realities, new challenges: New opportunities for tomorrow's generation. IFAD, Rome

3 World Bank. 2007a.World Development Indicators. Washington, DC

2. Food insecurity and safety

Cereals are the major food and cash crops for the majority of poor smallholders in SSA, and together with livestock, provide the main source of nutrition and opportunities for income generation. Productivity of these crops is severely reduced by a complex of biotic constraints, such as stemborer pest complexes, fall armyworm and parasitic striga weeds, as well as abiotic factors, mainly water stress and degraded soils. In deed significant yield losses of over 80% have been reported as a result of ravages caused by stemborer pests[4] and up to 100% yield losses due to striga[5], resulting in losses of over US$ 14 billion annually. With the recent invasion of Africa by the fall armyworm, losses to maize and other crops over up to 100% due to this pest have been reported by smallholder farmers. Similarly, productivity of smallholder livestock farmers is constrained by the absence of sustainable sources of quality fodder, and a multitude of animal diseases. Cumulatively these result directly in high levels of food insecurity, malnutrition and poverty that are further complicated by high human population growth rates, environmental degradation and climate change, trapping approximately 300 million people below the poverty line in SSA.

Rural food security and livelihoods, as well as household nutritional security, are further threatened by the emergence of global, corporate-driven food systems and markets which exclude poor smallholder farmers, who now risk being bypassed by global investment in agricultural research and technological advancement. Moreover, with food scarcity, a large part of the population becomes malnourished due to imbalanced diets. Additionally, cases of **food contamination** by mycotoxins, especially aflatoxin, are rising and posing significant health risks to humans and animals, as stemborer and fall armyworm infestation intensifies maize ear rot, and *Aspergillus* and *Fusarium* fungi build up in the soils in farmers' fields.

4 Kfir et al., 2002. Annu. Rev. Entomol. 47, 701–731.
5 Oswald A. 2005. Crop Prot. 24, 333–342

3. Rationale for sustainable agricultural intensification in SSA

The need for sustainable intensification in Africa is predicated on its populations' high dependence on agriculture. Smallholder agriculture remains the main source of household nutrition and incomes, and over half of total export earnings[6]. Cereals, including maize, sorghum, millets and rice, are the principal food and cash crops for millions of the poorest people in the predominantly mixed crop-livestock farming systems of the region[7]. The sustainable increase in agricultural productivity therefore represents a significant opportunity for addressing these challenges. Adaptable, resilient and sustainable agricultural systems are imperative against the risks and shocks associated with long-term climate variability in order to maintain food production into the future[8]. Climate-smart and resilient agricultural systems are needed to protect and enhance natural resources and ecosystem services in ways that mitigate future climate change. Sustainable agriculture in this context requires a more holistic approach, reflecting the multi-functionality of agriculture, using resource-conserving technologies and practices in managing weeds and pests, such as **Push-pull (www.push-pull.net),** with a strong focus on ecological resource management to enable sustainable agricultural intensification of agriculture[9].

4. Push–pull: a multifaceted agricultural intensification innovation

4.1 Holistic polycropping innovation

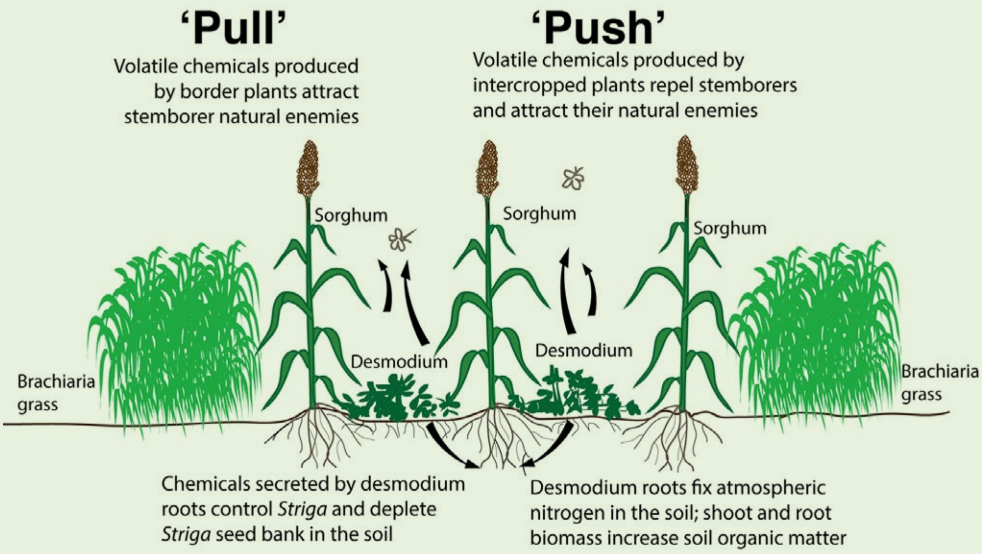
The push-pull technological innovation (www.push-pull.net), developed by the International Centre of Insect Physiology and Ecology (*icipe*) (http://www.icipe.org), Rothamsted Research (www.rothamsted.ac.uk) , and Kenya Agricultural Research Organisation (KALRO, www.kalro.org) addresses smallholder agricultural constraints, food insecurity, environmental degradation and loss of biodiversity[10]. Push–pull is a polycropping innovation that holistically provides integrated management of insect pests and soil fertility while making efficient use of natural resources to increase farm productivity by addressing most aspects of smallholders' constraints[11,12]. The technology involves intercropping cereal crops with legumes in the genus *Desmodium,* and planting forage grasses (Napier grass *Pennisetum purpureum* or Brachiaria cv MulatoII) around this intercrop. The conventional push-pull uses Napier grass as the border crop with silverleaf desmodium *Desmodium uncinatum* as the intercrop. The climate-adapted push-pull, however, uses drought tolerant companion plants, Brachiaria cv MulatoII and Greenleaf desmodium *Desmodium intortum*. This technology exploits the fact that adult female insect pests rely on chemical stimuli ('smell') emitted by plants to select those

Photo Caption. *Alis perciam, offic tet excepre icaessus volorae debisit, veremquam et eum quam eius re veliaspis mincius quam etur, consequam sitis ipidi te verferi dolupta tiatem earum rerspe del id molorem ut que dita susanimo is sanitem quasimi, tet rectatet inctem as audipicilic to doloria ectempos re, sam et ad ut latem ut ullorerrum aute ventotatur modi cum quia asinvel imus.*

6 See footnote 1
7 Khan et al. 2014. Phil. Trans. R. Soc. B 369: 20120284.
8 Pretty et al., 2011. Int. J. Sust. Agric. 9, 5–24
9 IAASTD 2009. Agriculture at a Crossroads, IAASTD, Island Press, Washington, DC.

10 See footnote 7
11 Cook et al., 2007. Annu. Rev. Entomol. 52, 375–400.
12 Hassanali et al., 2008. Phil. Trans. R. Soc. B 363, 611–621.

Figure 1. *Push-pull technology: A stimulo-deterrent tactic uses aerial volatile organic compounds to mediate oviposition behaviour of gravid stemborers. In the rhizosphere, chemicals secreted by desmodium roots inhibit attachment of germinated striga to maize or sorghum roots and abort germination of striga seeds which are rapidly depleted in the soil[7].*



to utilize for egg laying. The desmodium intercrop emits cues that are repugnant to ovipositing female stemborer moths thus acting as a 'push', while a grass such as Napier grass emits attractive cues that 'pull' the moths towards itself. These companion plants release behaviour-modifying plant chemicals to manipulate the distribution and abundance of stemborers, fall armyworm and beneficial insects for management of the pests (**Figure 1**) in addition to other benefits (**Table 1**). While this strategy keeps the moths away from the cereal crops, it attracts beneficial organisms that attack the stemborer eggs, larvae and pupae. These include parasitoids such as *Cotesia sesamiae*, a wasp that parasitizes the damaging stages of the pest (larvae), and the generalist predators that are abundant in the push-pull plots.

4.2 Push-pull effectively controls cereal stemborers and fall armyworm: The technology effectively controls cereal stemborers and the invasive fall armyworm. The mechanism involves the diversionary 'push' and 'pull' tactics described above, complemented by activity of both parasitic wasps and the generalist predators such as ants, earwigs and spiders. Studies have shown that the damage caused by stemborers and fall armyworm is reduced by up to 100% with the technology, resulting in significant improvements in grain yields.

4.3 Push-pull effectively controls the parasitic striga weed and improves soil fertility: Striga (*Striga hermonthica* and *S. asiatica*) greatly reduces productivity of cereal crops such as maize and sorghum by attaching itself to the roots of the crop and robing it of nutrients. An individual striga plant produces thousands of tiny seeds that can remain viable in the soil for over 10 years. Striga is present in over 1 million hectares of land in East Africa alone, mainly in poor and degraded soils, causing up to total yield losses in maize. Push-pull technology effectively controls striga through three main mechanisms, mediated by desmodium intercrop: (i) improving soil fertility, desmodium being one of the most efficient nitrogen fixing legumes. It also improves soil organic matter content, conserves soil moisture and reduces soil temperature thereby improving activity of soil macro- and micro-organisms that breakdown plant materials into humus. (ii) It acts as a cover crop and thus smothers striga as well as other weeds. (iii) Allelopathy. Desmodium roots release exudates into the soil that contain a number of chemical compounds some of which induce striga seeds to germinate and others inhibit elongation of its roots thus preventing parasitisation of the crop. This is referred to as 'suicidal germination'. Because desmodium is a perennial

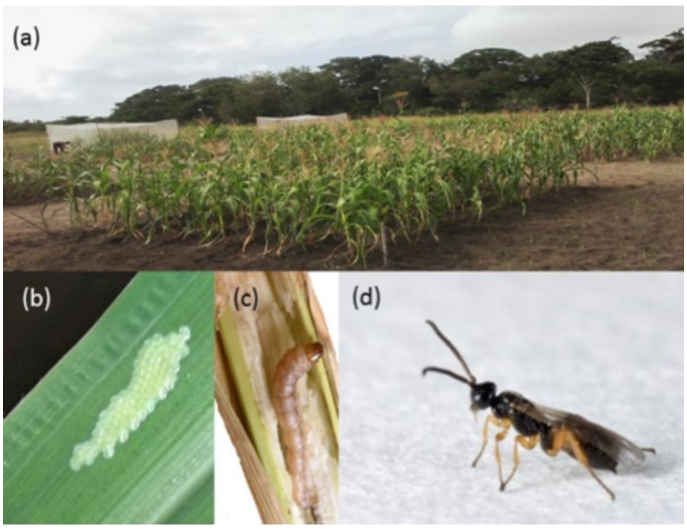


Table 1: Identified major constraints addressed by the Push-pull technology

Identified constraints	How Push-pull address the constraints
Parasitic striga weeds	Biological control of striga weeds by the intercrop, striga seed depletion
Stemborer pests	Effective stemborer control by companion plants, and natural enemies
Aflatoxin infestation	Effective control of aflatoxin and other mycotoxins by push-pull in cereals
Fall Army worm	Effective fall army worm control by companion plants, and natural enemies
Degraded land	Control soil erosion, increased organic matter, and soil physical properties
Moisture stress	Soil moisture conservation, improved water holding capacity by intercrops
Climate change effects	Push-pull technology has been adapted for climate resilience by incorporating drought-resilient companion crops
Low crop yields	Increased cereal yields (maize from 1 to 3.5t/ha; sorghum 0.8t to 2t/ha; millet 0.4t to 0.8t/ha)
Shortage of livestock fodder	All year round quality fodder from the trap and intercrop plants leading to improved milk production , and diversification of livestock production.
Loss of biodiversity	Increased abundance and diversity of beneficial organisms
Shortage of labour	Reduced labour requirement for land preparation and weed control

plant, it continually induces suicidal germination of striga seeds thereby over time cleaning the soil of striga seeds.

4.4 Push-pull effectively controls maize ear rots and mycotoxins, especially aflatoxin: Cases of food contamination by mycotoxins, especially aflatoxins- toxins produced by *Aspergillus flavus* and *Aspergillus parasiticus* fungi are on the rise. These toxins pose significant health risks to animals and humans in Africa, especially due to favorable climatic conditions for *Aspergillus*. Acute exposure can be lethal, while chronic exposure can lead to cancer among other serious medical conditions. These cases are projected to increase with climate change. Attack of maize cobs by cereal stemborer and fall armyworm larvae significantly predisposes these cobs and grains to ear rots and mycotoxins, especially aflatoxin. By controlling these pests, push-pull indirectly causes significant reductions in maize ear rots and mycotoxins, especially aflatoxin. Additionally, there are significant reductions in abundance of *Aspergillus* in the soil under push-pull.

4.5. Push-pull significant improves livestock productivity, nutrition and incomes: The companion crops used in the push-pull technology provide high quality fodder, with desmodium being an established source of protein and the grasses providing carbohydrates. These not only ensure year-round provision of fodder but ensure quality. Smallholder farmers are therefore able to integrate crop and livestock production, with results indicating significant improvements in quantities of fodder and milk production. With surplus grain production and increase in income streams from fodder and milk, smallholder households are able to realise improved nutrition and incomes, translating into overall improved livelihoods as surplus income sis ploughed into other aspects as housing and education for the children.

5. Complimentary synergistic effects and resilience

Push-pull relies on an in-depth understanding of chemical ecology, agro-biodiversity, plant-plant and insect-plant interactions[13] and is well suited to African socio-economic conditions as its efficacy is not based on high external inputs, but ecological management of local bio-resources using natural processes. It has been adopted by over 145,000 smallholder farmers in eastern Africa where maize yields have increased from about 1 t/ha to 3.5 t/ha, achieved with minimal inputs. The technology achieves higher factor productivity and economic returns which help reduce migration of youth to cities and help women to generate more income to educate children. The technology uses conservation agriculture principles of minimum tillage, moisture conservation through mulching and legume intercropping, and has been adapted to withstand drier and hotter conditions associated with climate change. The technology thuscontributes to the conservation and enhancement

13 See footnote 11

of the natural resource base, with continuous minimum mechanical soil disturbance, continuous soil cover, steady addition of organic matter, prevention of loss of top soil through soil erosion, improved water conservation, and other ecosystem services. Farmers integrate the technology into a crop–livestock production system, in which farmyard manure is added to the soil, increasing the fertility benefits already gained from the fixation of nitrogen by the desmodium intercrop.

In addition to the pest control benefits, the perennial legume intercrop, *Desmodium* spp., improves system resilience and ecosystem services though impacts on soils and nutrient cycling while also reducing dependence on synthetic fertilizer and therefore greenhouse gas emissions, dramatically increases total soil Carbon and Nitrogen stocks, which builds soil health, drainage, and water holding capacity while also reducing erosion. Accrual of C and N is greatest in active soil organic matter fractions which play key roles in nutrient supply for crops and soil aggregation. The improvements in soil health are the basis for the increased drought tolerance observed in Push-pull system.

6. Push-pull and Sustainable Development Goals

The Push-pull technology effectively delivers Sustainable Development Goals (SDGs). The technology controls the main biotic constraints to cereal production in Africa, mainly parasitic striga weeds and insect pests (mainly stemborers and Fall armyworms), leading to three-fold increase in staple cereal yields, and significantly improved food security, nutrition and incomes. Secondly it increases quality fodder production and animal health which translates into higher milk production and production of farm yard manure for fertilizing soil. The two impact pathways directly address **SDG2 – Zero Hunger**, **SDG3-Good health and human wellbeing**, and **SDG1 – No poverty**. Increased household income from higher crop and livestock productivity is leading to significantly increase household incomes. Farm communities are investing the increase income into children's **quality education (SDG4)**. Increasing numbers of female children are being enrolled in school, while production of forage seeds, like Desmodium seeds, increase incomes of female farmers (**SDG 5- Gender Equality**). In another impact pathway the technology fixes atmospheric nitrogen into the soil, reduces soil erosion, conserves soil moisture, naturally improves soil carbon sequestration, biomass and soil biota, all of which improve soil health, the conservation of biodiversity and **life on land (SDG 15)**. The technology has been adapted to mitigate climate change effects which directly addresses **SDG 13 – Climate action**.

7. Sustainable, adaptable practices for the future

Sustainable intensification is based upon the assumption that agricultural production systems must produce significantly more food in the coming decades to feed a growing population on finite resource bases, particularly arable land, which cannot be expanded significantly, and that agricultural production must become more sustainable and resource-efficient to preserve its underlying natural capital. Agricultural production must therefore intensify, but in a manner that does not damage the environment. Push-pull is a low input technology alternative that not only facilitates intensification both of crops and livestock, but is also sustainable, as it includes interdependent dimensions, enabling adaptation as it uses locally available bio-resources and combines technical and social innovation, and perfectly fits smallholder farming systems in SSA. The technology is a perfect example of how understanding the science of plant-plant and plant-insect interactions can be fully applied and successfully extended for crop protection by smallholder farmers in SSA.

Additional reading

1. Publications on various aspects of the push-pull technology (http://www.push-pull.net/publications.shtml)

2. Khan ZR, Midega CAO, Bruce TJA, Hooper AM, Pickett JA. 2010. Exploiting phytochemicals for developing a 'push–pull' crop protection strategy for cereal farmers in Africa. Journal of Experimental Botany 61: 4185–4196.

3. Khan ZR, Midega CAO, Pittchar JO, Murage AW, Birkett MA, Bruce TJA, Pickett JA. 2014. Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. Phililosophical Transactions of the Royal Society B 369: 20120284.

4. Midega CAO, Bruce TJ, Pickett JA, Pittchar JO, Murage A, Khan ZR. 2015. Climate-adapted companion cropping increases agricultural productivity in East Africa. Field Crops Research 180: 118–125.

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