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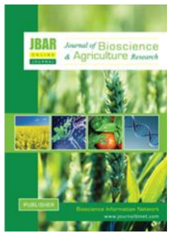

# Push-Pull Strategy: an integrated approach to manage insect-pest and weed infestation in cereal cropping systems

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***ABSTRACT***

*The "Push–Pull" strategy is an effective, efficient, and powerful tool in integrated pest management (IPM) that is combining several behaviour-modifying stimuli to control cereal stem borers and the noxious weed Striga in cereal-based farming systems in Africa. This technology involves driving away from the cereal stemborers from the main crop by using stimuli of repellent intercrops (push) that mask host apparency and simultaneously stemborers are attracted by highly apparent and attractive stimuli from trap plants (pull). The fodder legume, Desmodium (D. uncinatum and D. intortum), and Molasses grass (Melinis minutiflora) are used as the repellent intercrop, which is repugnant to stemborer moths. On the other hand, Napier grass (Pennisetum purpureum) and Sudangrass (sorghum vulgare sudanese) is planted as a border crop used as the trap plant (pull). Chemicals that are released by the roots of the Desmodium intercrop induce abortive germination of seeds of noxious Striga weeds, providing very effective control of this weed. Napier grass and Molasses grass also provide high-value animal fodder that facilities milk production, diversifying sources of farmers' income. Besides, this technology helps to improve soil fertility and prevent soil erosion that leads to increased grain yield in the future. Chemicals that are released by the roots of the Desmodium intercrop induce abortive germination of seeds of noxious Striga weeds, providing very effective control of this weed.*

***Key Words**: Push–Pull, Stemborers, Striga, Attractants, Repellent and Integrated Pest Management (IPM).*

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## I. Introduction

Cereals, mainly maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), finger millet (*Eleusine coracana* L.), and rice (*Oryza sativa* L.) are the most vital food and cash crops for the majority of the farmers of eastern Africa (Khan et al., 2010). Most of the farm families are fully dependent on earning their livelihood from cereal production. Despite the significance of cereal production in this region, grain



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yields have continued to decline due to insect pests and weeds infestation. Cereal stemborers and parasitic weeds in the genus *Striga* are the major constraints to the increased cereal production in Africa (Khan and Pickett, 2008). Either stemborers or Striga alone can destroy the total yield of cereal crops (Khan et al., 2001).

There is a complex of greater than 20 economically important Lepidopteran stem borers species were identified in cultivated grasses in Africa (Khan et al., 2010); however, four species are more harmful (*Chilo partellus*, *Busseola fusca, Eldana saccharina* and *Sesamia calamistis*) and cause up to 80% of yield losses in maize and sorghum (Khan and Pickett, 2008). The damage is caused by the larvae of stemborers by making a tunnel inside the stem tissues that destroy the growing point, interference with translocation of nutrients and metabolites, early leaf senescence, etc. Ultimately, results in the grain malformation, breakage of the stem, plant stunting, and lodging, and finally direct harm to ears (Kfir et al., 2002). Further, 23 species of the genus *Striga* (Family: Scrophulariaceae) are found in Africa, among them *Striga hermonthica* and *Striga asiatica* that are the most harmful for cereal cultivation and cause up to 100% of yield losses (Khan et al., 2006). In western Kenya, 76% of land cultivated to sorghum and maize is infested by *S. hermonthica* which causes annual losses of 40.8 million US dollars (Khan et al., 2008). This obligate root parasite *Striga* interferes with the normal growth of cereal crops through nutrients competition, weakening photosynthesis activities, and the release of phytotoxins during the attachment to its host (Khan et al., 2001). Moreover, *Striga* infested maize plants are more preferable egg-laying sites for stemborer moths than uninfected maize plants. To control the stemborers and *Striga* infestation, the farmers have to use insecticides and herbicides, which can alleviate these problems but complete control is rarely achieved. However, many resource-poor and small-scale farmers cannot afford the cost of these expensive insecticides and herbicides, therefore, the farmers could not manage stemborers or *Striga* infestation, resulting in high yield losses and food insecurity (Khan and Pickett, 2008).

A habitat management approach known as the "push–pull" strategy has been developed to control both *Striga* and stemborers in Africa. The "push-pull" strategy to control cereal stemborers and Striga, involves intercropping cereal crops (maize or sorghum) with stemborer repellent plants (push) and planting highly attractant trap plants (pull) around these intercrops (Figure, 01). The fodder legume, *Desmodium* (*D. uncinatum and D. intortum*) and Molasses grass (*Melinis minutiflora*), are used as the repellent intercrop, they produce semiochemicals, which is repugnant to stemborer moths. On the other hand, Napier grass (*Pennisetum purpureum*) and Sudangrass (*Sorghum vulgare sudanese*) are used as the trap plant that produces attractant volatiles (Khan and Pickett, 2008; Khan et al., 2010). All these plants have economic importance because they are high-value animal fodder crops, facilitating milk production, and finally diversify income sources of the farmers. Besides, these plants improve soil fertility and prevent degradation of soil (Khan and Pickett, 2008). Soil fertility and erosion control is crucial to maintain grain yield (Sultana et al., 2015; Siddique et al., 2017).

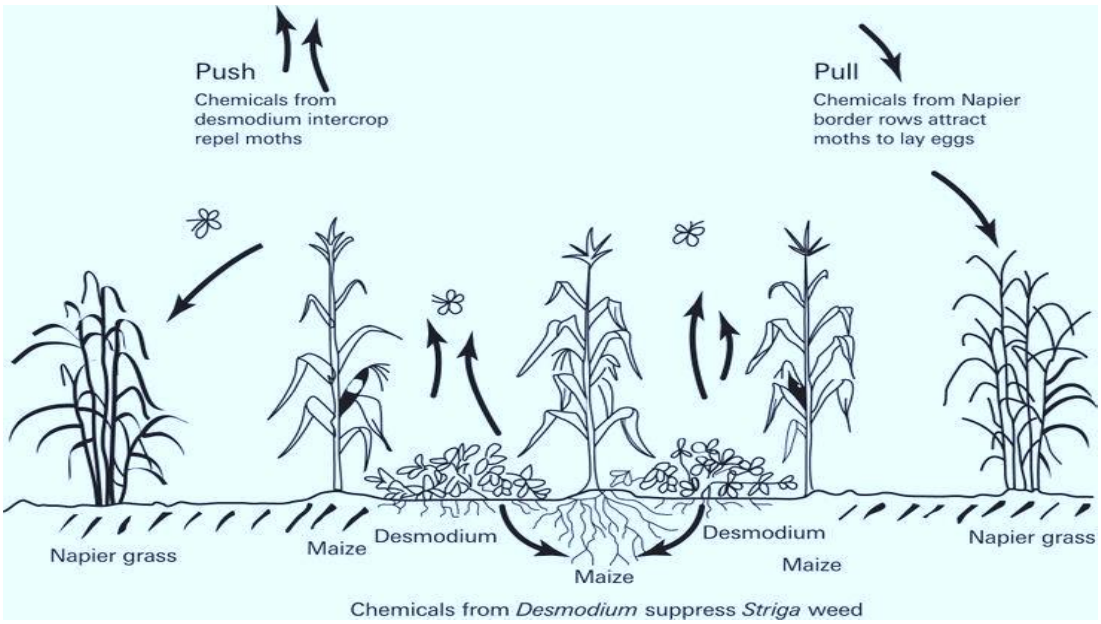


**Figure 01. Diagram of "push-pull" strategy for cereal stemborer (Khan and Pickett, 2008).**



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The "push-pull" strategy is an effective and powerful tool in integrated pest management (IPM) (Zhang et al., 2013). This may compile with different strategies of insect-pest management but mainly semiochemicals based (Cook et al., 2007), each of which, alone, will exert relatively weak pest control. However, the integrated effect must be robust and effective (Pickett et al., 2014). These semiochemicals are plant secondary metabolites, acting at a distance as attractants or repellents in the "push-pull" technology to control stem borers as well as *Striga*, whereas improves soil fertility status in Africa (Pickett et al., 2014). However, further studies are also needed based on the farming system on how to control *striga* weeds, considering the *striga* infested plants are more preferable egg-laying sites for stemborers. Thus, this innovation has created complete acceptance among the smallholder farmers in Africa and more than 10,000 farmers currently practice the push-pull strategies in their field to protect their cereal crops from stemborers and *Striga* (Khan et al., 2008).

A sustainable and reliable ''push-pull'' technology needs an understandable scientific knowledge about the biology of insect-pests and their tri-trophic interactions (Zhang et al., 2013). For this type of research, an important research question is how the push-pull technology can solve the stemborer problem as well as other limitations related to cereal production in Africa. Therefore, this review was conducted to identify the potential, principals, mechanisms including the advantages and disadvantages of ''push-pull'' technology for integrated pest management in African cropping systems.

## II. Literature Review

This section discussed various aspects of ''push-pull'' technology including the principals, components, and mechanisms involving the push-pull strategy. Literature searches were conducted to compile information mostly from published journal articles and books.

### Principles of ''push-pull'' strategy

In "push–pull" technology, various insect behavior-modifying stimuli are used to manipulate the abundance and distribution of target pest-insects and/or their natural enemies for successful pest management (Cook et al., 2007; Zhang et al., 2013). These strategies mainly apply to change the behaviour of targeted pest and reduce their abundance on the protected resource. When *Desmodium* used as a intercrop in cereal cultivation, volatiles, naturally emitted from *Desmodium*, repel the stemborer moths away from the main crop (push) and attracted by the released stimuli by the Napier grass (pull) (Amudavi et al., 2008).

However, the "push–pull" strategy changes the behaviour of herbivores and at the same times their natural enemies (Cook et al., 2007). When Molasses grass intercropped with cereal crop, not only reduced the abundance of stemborers, but also augmented natural enemy, *Cotesia sesamiae* of stemborer (Khan and Pickett, 2008). So, this technology manipulates the behaviour of stemborers as well as its natural enemies. Thus, the "push–pull" technology includes, direct movement, abundance and distribution of insect-pests and/or their natural enemies (Cook et al., 2007).

The technology comprising many features of different pest management approaches. The presence of different plant resources (trap and intercrop) and their visual and chemical stimuli, such as semiochemicals have been confirmed to be potentially useful in pest's management (Khan et al., 2008). Due to the secretion of visual or semiochemicals stimuli by Napier grass, the stemborer moths prefer Napier grass for oviposition than maize or sorghum. Thus, a large amount of the eggs of stemborer moths are trapped by the Napier grass and makes the main crop protected (Khan and Pickett, 2008). Therefore, trap crops can be used to convey attractive behaviour-modifying stimuli of pest insects. This "push-pull" strategy can be combined with IPM as a biological control weapon for control of pest population (Cook et al., 2007).

The principles of the ''push–pull'' technology are aimed at to maximize the controlling and manipulating efficiency, sustainability, efficacy, and output, with minimizing negative environmental impact. The ''push'' and ''pull'' constituents are usually harmless, and are safe and sound for organism as well as for environment (Cook et al., 2007; Zhang et al., 2013). Though, the effect of "push" or "pull" component is not equal as a broad spectrum pesticide to reduce the pest population density, but efficacy of this strategy will be improved through the proper development and use of "Push" or "pull" constituents. In general, the "push" and "pull" components may vary depending on target pest characteristics like, sensory abilities, biological characters and mobility (Cook et al., 2007; Zhang et al., 2013). By focusing on the target in an encoded place, the efficacy and efficiency of population-reducing methods could be maximized. This can be done by using renewable resources to encourage plants to produce semiochemicals (Cook et al., 2007). The main aim of this strategy is to lower the production cost for pest control as well as improve soil fertility.

**Mechanisms of ''push–pull'' strategy**

The ''push–pull'' strategy for cereal stemborers includes repellent intercrops, Green leaf *Desmodium* (*D. intortum*), silver leaf *Desmodium* (*D. uncinatum*) and Molasses grass (*M. minutiflora*) (push) that combined with attractant trap plants, Sudan grass (*Sorghum vulgare sudanese*) and Napier grass (*Pennisetum purpureum*) (pull) to control the population of targeted pest and their natural enemies (Zhang et al., 2013). *Desmodium* can produce DMNT and (E)-b-ocimene and large amounts of sesquiterpenes, together with α-cedrene when intercropped with maize or sorghum. These secondary metabolites that are released from *Desmodium* can suppress the development of parasitic weeds *Striga hermonthica.* On the other hand, green leaf volatiles (GLVs), (E)-ocimene, (E)-4,8-dimethyl1,3,7-nonatriene, humulene, b-caryophyllene, and a-terpinolene emitted by molasses grass when intercropped with maize, not only reduce oviposition of stemborer, but also attract parasitoid, *Cotesia sesamiae* (Khan et al., 2010).

Napier grass and Sudan grass were found to release six active compounds that are attractive to gravid stemborers: nonanal, octanal, 4-allylanisole, eugenol, naphthalene, and (*R*, *S*)-linalool. The preference of stemborers among maize and trap crops is associated to a huge amount of GLVs released from this trap crops during the time of oviposition of stemborer moths (Khan et al., 2010). Stemborers moths heavily prefer Napier grass for oviposition, but this plant produces a gummy material that restricts larval development of stemborer and very few to survive to adulthood. On the other hand, the effectiveness of parasitoid, *C. sesamiae* was increased by Sudan grass. Thus, the changes in stemborer populations are caused by interference of the top-down (natural enemies) and/or bottom-up (plant resources) forces that manipulate the distribution of stemborers (Zhang et al., 2013).

## III. Results and Discussion

**Advantages and disadvantages of Push-Pull Strategy**

The "push-pull" strategy to control stemborers is a nice example how a research work can be related with technology transfer, including farmer participation that leads to spontaneous transfer of technology between farmers. The "push-pull" strategy can improve the livelihoods of rural families and small-holder farmers, increase agricultural productivity and develop a sustainable environment for the future generation. Now, this "push-pull" technology is adopted by more than 10,000 farm families in Africa (Khan et al., 2008). The farmers have increased their maize production in 20% areas where previously infested with stemborer only and 50% areas infested with both stemborers and *Striga* in Kenya, Uganda, and Tanzania (Khan et al., 2001). The "push-pull" strategy builds up an integrated system to solve the problems of stemborers and *Striga* weed infestation, at the same time improve soil fertility and soil moisture holding capacity. It creates great opportunities to increase small-holder farmer's income by keeping livestock.

Low fertility and erosion of top soil are very ordinary problems in eastern Africa. The "push-pull" technology has exploited a number of the obtainable practices to tackle this problematic situation in a multi-functional context. For stemborer management, the cultivation of Napier grass as a trap plant, not only increase the fodder crop production but also reduce the soil erosions and conservation (Khan and Pickett, 2008). Correspondingly, *Desmodium* is a nitrogen-fixing legume, used as an effective stemborer repellent and suppressant of *Striga* weed in "push-pull" strategy that improves soil fertility and fodder quality (Koech et al., 2012). After cutting the arouses roots of *Desmodium* are incorporated in the soil, increased mineralization of nitrogen and decreases root development of *Desmodium* that reduce the nutrients competition with maize crop and finally increase maize yield (Koech et al., 2012). Thus, intercropping *Desmodium* in maize field reduces the demand for external nitrogenous fertilizer, which is expensive and sometime unaffordable by most of the rural people of Africa. A study in Kenya



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confirmed a significant increase of the amount of total nitrogen in maize field intercropped with *Desmodium* for 3 years than fields that are intercropped with other legumes (Khan et al., 2008).

Witch weed or *Striga* is an obligate root parasite of most of the cereal crops inhibiting growth of host plant by creating competition for nutrients and aggravation of photosynthesis. Among the 23 species of *Striga*, *S. hermonthica*is the most socio-economically important in Africa (Khan et al., 2006). In western Kenya, 100% yield losses were recorded in maize and sorghum field when infested by *Striga hermonthica,* which is equivalent to annual losses estimated at $40.8 million (Khan *et al.* 2008). The push-pull strategy strongly suppress *Striga* through intercropping sorghum or maize with desmodium, a highly repellent plant for stemborers. Desmodium inhibits the growth of *Striga* through effects on soil organic matter and nitrogen fixation and ground smothering and chemical allelopathy, which leading to frequent exhaustion of seed bank of *Striga* weed in the soil (Amudavi et al., 2008). This combination gives a novel means of *in situ* decline of *Striga* seed bank from the soil.

The biodiversity of agroecosystem has been reduced significantly in the last decades due to intensification of cereal production. Enhancement of overall biodiversity in an agroecosystem not only decreases the pest problem but also reduces reliance on pesticides. Biodiversity performs various ecological services, mediating processes (genetic introgression), nutrient cycling, natural control and decomposition in natural and agricultural ecosystems. Mixed farming systems that conserve such biodiversity, natural enemies could be a practical alternative to control insect pests in agricultural systems (Altieri, 2000). The "push-pull" strategy helps in overall enhancement of the beneficial predator abundance in Kenya (Khan et al., 2008).

Although, the push-pull technology for control stemborer and *Striga*, is expanding in most of the part Africa by small-holder farmers but it has faced a number of limitations, like adoption and technology dissemination in other countries of the world especially in Europe. It requires substantial research exertion to understand the chemical and behavioural ecology of the insect-pest and their host as well as interactions with natural enemies (Khan et al., 2008). However, insufficient knowledge about this push-pull technology, control may fall down, decreases robustness and reduces the reliability (Cook et al., 2007).

## IV. Conclusion

The "push–pull" technology is an intriguing cropping system and effective and powerful IPM tool to manage stemborers and *Striga* weed in cereal production systems in Africa. It improves soil fertility and prevents soil erosion. This technology also provides high value fodder by facilitating milk production, finally diversifying the sources of farmers' income. In addition, "push–pull" strategies explore a new plant defensive mechanism against pest attack. Although this technology is mainly used in cereal-based farming systems but it serves as a model to control other insect-pests in Africa and beyond. It may open a new window to minimize yield losses by insect-pest in different crop in an environmentally and economically sustainable way.

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