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Exploiting Chemical Ecology in a 'Push-Pull' Strategy for Management of Cereal Stemborers in Africa*

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ABSTRACT

A 'push-pull' or stimulo-deterrent diversionary strategy for minimizing damage due to stemborers has been developed in maize-based farming systems for small- and medium-scale farmers of eastern Africa (www.push-pull.net). This strategy involved selection of plant species that could be employed as trap crops to attract stemborer colonization away from the cereal plants, or as intercrops to repel the pests. The two most successful trap crop plants Napier grass, *Pennisetum purpureum*, and Sudan grass, *Sorghum vulgare sudanensis* attracted greater oviposition by stemborers, than cultivated maize. The intercrops giving maximum repellent effect were molasses grass, *Melinis minutiflora* and two legumes, silverleaf, *Desmodium uncinatum* and greenleaf *Desmodium intortum*. 'Push-pull' trials, using the trap crops and repellent plants, significantly reduced stemborer attack and increased levels of parasitism of borers on protected plants, resulting in a significant increase in maize yield. The trap crop and intercrop plants also provide valuable forage for cattle, often reared in association with subsistence cereal production. There has been considerable take-up of the 'push-pull' system by farmers in eastern Africa and many farmers in different agro-ecologies in Kenya and Uganda have adopted this technology resulting in increased maize and milk production.

BACKGROUND

The widespread use of broad-spectrum pesticides has led to increased incidence of pest resistance and to long-term effects on environment and non-target organisms (Smart et al. 1994). Alternative strategies that incorporate several methods of pest control and that are likely to be more environmentally benign, have been under investigations for many years.

Pyke et al. (1987) described 'push-pull' strategy as a novel idea in management of *Heliothis* sp. in cotton. The pest was concentrated in a small area by the combined use of an attractant trap crop and a feeding deterrent. Later, Miller and Cowles (1990) devised the term 'stimulo-deterrent diversion' strategy for 'push-pull' and used the system for protection of onions from the onion fly. They proposed to attract gravid females to onion culls and to protect the main crop with a combination of a feeding deterrent and a toxin. Smart et al. (1994) described a 'push-pull' strategy for control of pea and bean weevil, *Sitona lineatus* L. The pest was diverted from the main crop by a feeding deterrent and was attracted to discard areas with an attractant pheromone.

‘PUSH-PULL’ STRATEGIES FOR CEREAL STEMBORER MANAGEMENT

At least four species of stem borers infest maize in eastern Africa, causing reported yield losses of 20-40% of potential output. Stemborers are difficult to control, largely because of the cryptic and nocturnal habits of the adult moths and the protection provided by the stem of the host crop for immature stages (Ampofo, 1986; Seshu Reddy and Sum, 1992). As part of our continuing efforts to manage cereal stemborers [*Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) and *Busseola fusca* Füller (Lepidoptera: Noctuidae)] in eastern Africa (Khan et al. 1997a, 1997b, 2000, 2001), alternative strategies that incorporate an understanding of chemical ecology of insect-pant interactions, have been under investigations for many years. The technology is based on novel strategies that combine a ‘push-pull’ tactic for controlling stemborers. Based on the information gathered on the interactions between stemborers and their host and non-host plants, we have developed a ‘push-pull’ strategy (Khan et al., 2000, 2001) to manage cereal stemborers by resource-poor farmers in maize-based farming systems in eastern Africa. The strategy involves a combined use of trap and repellent plants, whereby stemborers are repelled from the maize crop and are simultaneously attracted to a trap crop (Figure 1). Several plants have been identified which could be used as a trap or a repellent plant in a ‘push-pull’ strategy (Khan et al., 2000, 2001). Those that appear particularly promising are Napier grass (*Pennisetum purpureum* Schumach), Sudan grass (*Sorghum* *vulgare sudanense* Stapf.), molasses grass (*Melinis minutiflora* Beauv.), silver leaf desmodium (*Desmodium uncinatum* Jacq.) and greenleaf desmodium (*Desmodium intortum* Urb.). Napier grass and Sudan grass have shown potential for use as trap plants, whereas molasses grass and the two desmodium species repel ovipositing stemborers. Molasses grass, when intercropped with maize, not only reduced infestation of the maize by stemborers, but also increased stemborer parasitism by a natural enemy, *Cotesia sesamiae* (Khan et al. 1997b).

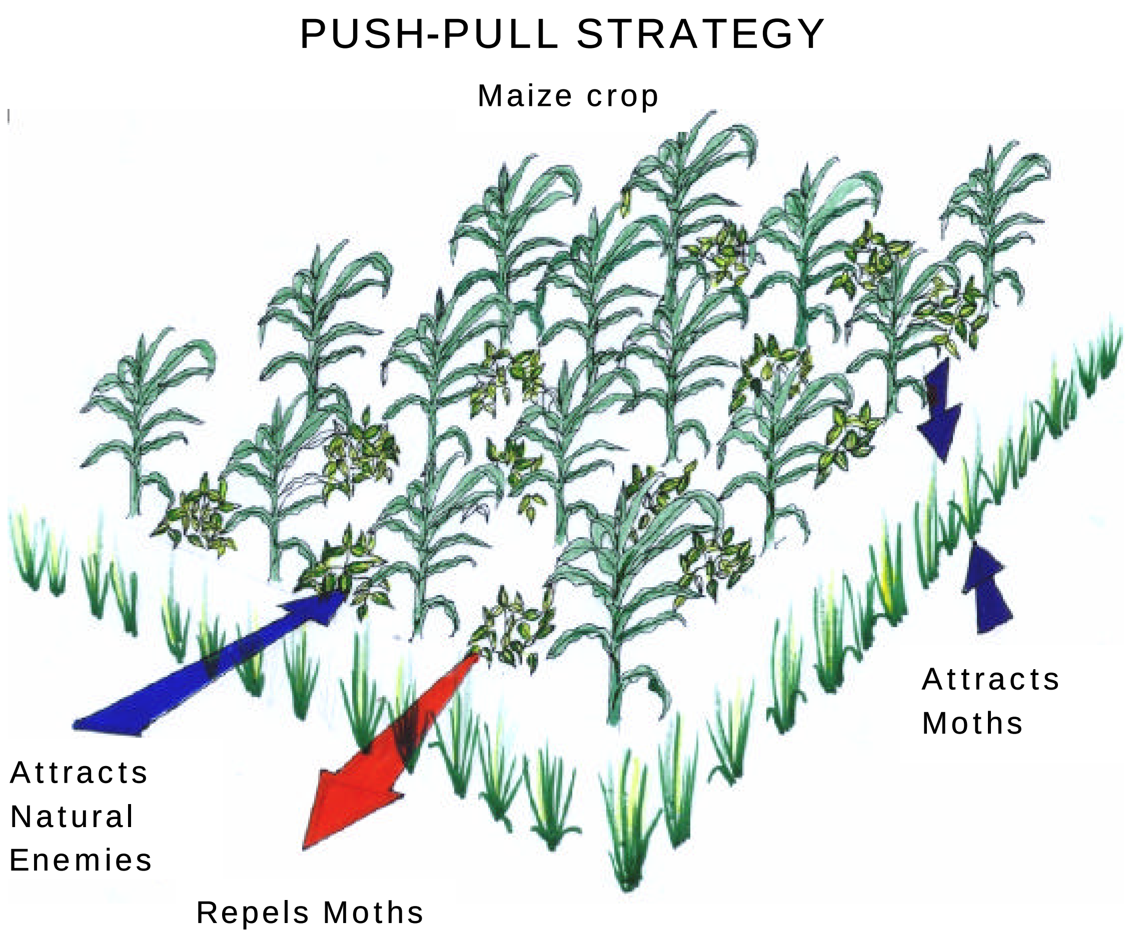

Figure 1

It has been our general principle that plants used to create 'push-pull' pest management strategies must themselves have value for the communities involved. In the work described here, the trap crops and intercrops can all be used as forage for livestock, Indeed, the luxuriant stands of Napier grass and Sudan grass have allowed the farmers to improve their cattle husbandry and many have increased the size of their herds. In the regions, where zero grazing is the usual method for cattle husbandry, such forage is extremely important.

SEMIOCHEMISTRY OF 'PUSH' AND 'PULL' PLANTS

In terms of stemborer control, the plant chemistry responsible involves release of attractant semiochemicals from the trap plants and repellent semiochemicals from the intercrops. With M. minutiflora, parasitism of stemborers was also increased by certain chemical repellent to ovipositing adults. Samples of host-plant volatiles were investigated by gas chromatography coupled-electroantennography (GC-EAG) on the antennae of stemborers. GC peaks consistently associated with EAG activity were tentatively identified by GC coupled-mass spectrometry (GC-MS) and identity was confirmed using authentic samples (Figure 2). Six active compounds were identified (Khan et al. 2000): octanal (1), nonanal (2), naphthalene (3), 4-allylanisole (4), eugenol (5) and linalool (6). Behavioral tests, employing oviposition onto an artificial substrate treated with individual compounds, demonstrated positive activity for all these compounds.

The next step was to investigate the volatiles produced by the intercrop plants. Coupled GC-EAG with volatiles from *M minutiflora* showed a wide range of peaks associated with EAG activity. The specific objective here, however, was to identify active compounds in the host-plant volatiles. A general hypothesis that we have developed during our work on insect pests is that non-hosts are recognised as such by colonising insects through release of repellent or masking semiochemicals, although it is almost inevitable that compounds also produced by hosts will be present. In this case, the host cereal plants and the non-host *M minutiflora* would be expected to have a number of volatiles in common as they are all members of the Gramineae. For *M. minutiflora,* six new peaks with EAG activity were identified, in addition to the attractant compounds and others normally produced by members of the Gramineae (Figure 2) (Kimani et al. 2000; Khan et al. 2000). These comprised (E)- ß-ocimene (7), ?-terpinoliene (8), ß-caryophyllene, humulene (9), humulene (10), a-cedrene (11) and (E)-4, 8-dimethyl-1, 3, 7-nonatriene (12). The ocimene and nonatriene had already been encountered as semiochemicals produced during damage to plants by herbivorous insects (Turling et al. 1990, 1995).

It was considered likely that these compounds, being associated with a high level of stemborer colonisation and, in some circumstances, acting as foraging cues for parasitoids, would be repellent to ovipositing stemborers, and this was subsequently demonstrated in behavioural tests. Investigating the legume volatiles, it was shown that *D. uncinatum* also produced the ocimene and nonatriene, together with large amounts of other sesquiterpenes, including ?-cederene (Khan et al. 2000).

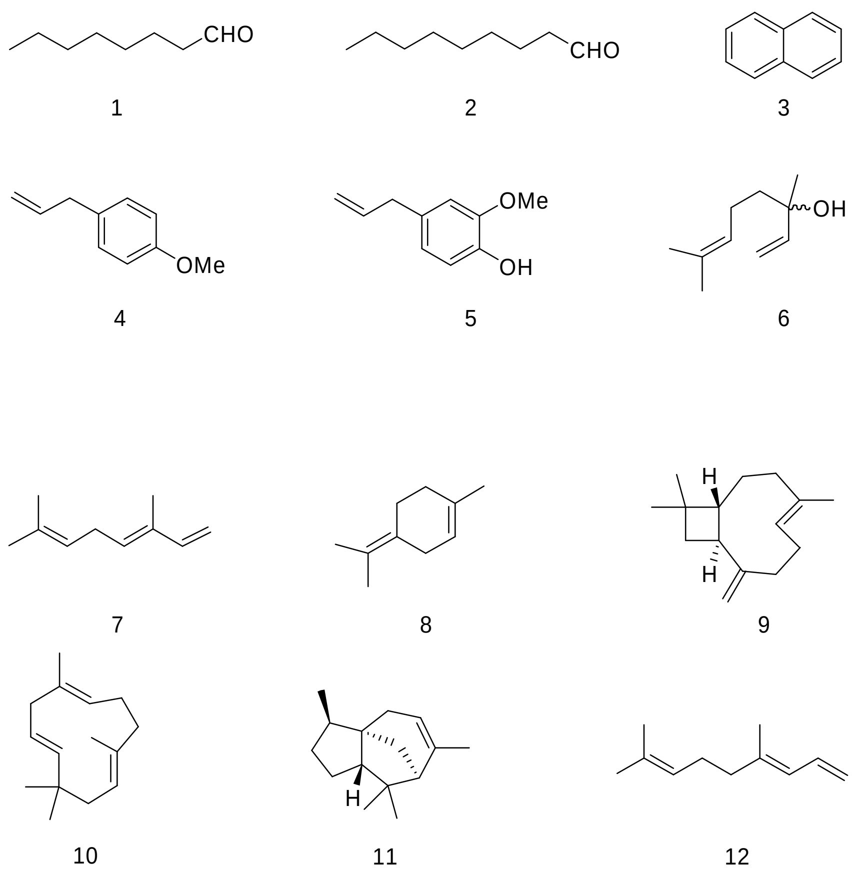

Figure 2. Volatile compounds having EAG activities from host plants (1-6) and from a repellent , *Melinis minutiflora* (6-12)

EXPLOITING NATURAL ENEMIES IN ‘PUSH-PULL’ SYSTEM

Throughout the development of the ‘push-pull’ strategies described above, exploitation of the natural enemies through trap plants has been attempted. We reported that planting grass around maize fields also significantly increased parasitisation of *C. partellus* and *B. fusca* (Khan et al. 1997a). As compared to the maize mono field where only 4.8% *C. partellus* and 0.5% *B. fusca* larvae were parasitised, 18.9 % *C. partellus* and 6.17% *B.*

fusca larvae were parasitised in Maize field surrounded by Sudan grass (Khan et al. 1997a).

However, in 1997, it was noted with great surprise that, although intercropping with *M. minutiflora* had reduced populations of stemborers in maize, there were never the less more parasitoids ovipositing in these plots than in the maize monocultures (parasitised in maize: monocrop 5.4%; intercropped with *M. minutiflora* 20.7%) (Khan et al. 1997b). Returning to the chemistry identified as reducing stemborer attack, it was realised that compounds such as the nonatriene might also be responsible for the increased parasitoid foraging. Indeed, when this compound was presented to parasitoid, *Cotesia sesamiae* in a Y-tube Olfactometer at a level similar to that found in the volatiles from *M minutiflora*, it accounted for most of the attractiveness of the natural sample. This discovery suggests that intact plants with an inherent ability to release such stimuli could be used in new crop protection strategies.

Although the nonatriene and ocemene were also released by the *D. uncinatum* and were responsible for their repellency to stemborers, there was no detectable increase in parasitism in the intercropped plots. It may be that other components produced by *D. uncinatum*, including the large amounts of ?-cedrene, are interfering with this effect. In the long term, this phenomenon may prove to be a useful discovery, as it is often necessary to repel parasitoids from situations where they could be harmed by other crop protection practices. For example, it could be valuable in deflecting ovipositing parasitoids from Napier grass, where the death of late-instar stemborer larvae could reduce developing populations of parasitoids. However, a new collection of *Desmodium* species has been established at the Mbita Point Field Station, and one cultivar of *D. uncinatum* has been found to produce enhanced amounts of the nonatriene and ocimene relative to other components such as ?-cedrene. This cultivar may prove a more useful intercrop in terms of stemborer control, but its discovery indicates opportunities for further plant breeding, whether conventional or aided by molecular genetics.

POTENTIAL BENEFITS OF 'PUSH-PULL' STRATEGY

The 'push-pull' tactics, conducted in Kenya and Uganda, have helped more than 1,500 participating farmers to increase their maize yields by an average of 17% in high potential areas and by 25% in low potential areas. Increased maize yields accompanied by the following additional features of the technology have contributed in no small part to the high farmer adoption rates (Figure 3):

? **Dairy and Livestock Production**: The 'push-pull' tactics have contributed significantly to increased livestock production (milk and meat) by providing more fodder and different crop residues, especially on small farms where competition for land is quite high. For example, the Suba District of Kenya, a milk-deficit region on the shores of Lake Victoria, produces only 7 million liters of milk, far short of the estimated annual demand of 13 million liters, and has mostly indigenous livestock (zebu). In this district, a major constraint to keeping improved dairy cattle for milk production is the unstable availability and seasonality of feed, often of low quality. The habitat management strategy, adopted by 250 farmers in this district, are facilitating efforts by agricultural authorities there to promote livestock production and improve milk supply there by integrating crop and fodder production and more and quality feed available for cattle. Through the combined effort, the number of improved dairy cattle in the district has increased from 4 in 1997 to 390 in June 2003.

? **Soil Conservation and Fertility.** Soil erosion and low fertility are very common problems in eastern Africa. The habitat management strategy has placed some of the existing practices to address these problems in a multi-functional context. For example, the cultivation of Napier grass for livestock fodder and soil conservation, now assumes an additional rationale as a trap plant for stem-borer management. Similarly, *Desmodium*, a nitrogen-fixing legume, grown for improving soil fertility and for quality fodder, is also an effective striga weed suppressant.

? **Enhancing Biodiversity**: The innovation is contributing to the promotion and conservation of biodiversity. The habitat management approach embodies maintenance of species diversity. A recent study has demonstrated that the numbers of beneficial soil arthropods in maize-desmodium fields were significantly higher than the numbers in maize monocrops. The destruction of biodiversity is linked to the expansion of crop monoculture at the expense of diverse vegetation.

? **Protecting Fragile Environments:** Existing evidence indicates that higher crop yields and improved livestock production, resulting from habitat management strategies, has the potential of supporting many rural households under existing socio-economic and agro-ecological conditions. Thus, there will be less pressure for human migration to environments designated for protection. Moreover, farmers using such strategies have less motivation to use of pesticides.

? **Income generation and Gender empowerment:** The habitat management strategies have shown promise of not only significantly enhancing farm incomes but also gender empowerment through the sale of farm grain surpluses, fodder and *Desmodium* seed. In addition to targeting women farmer-groups, improved rural productivity and quality of life is expected to impact youth groups in the rural areas and help to stem rural-urban migration.

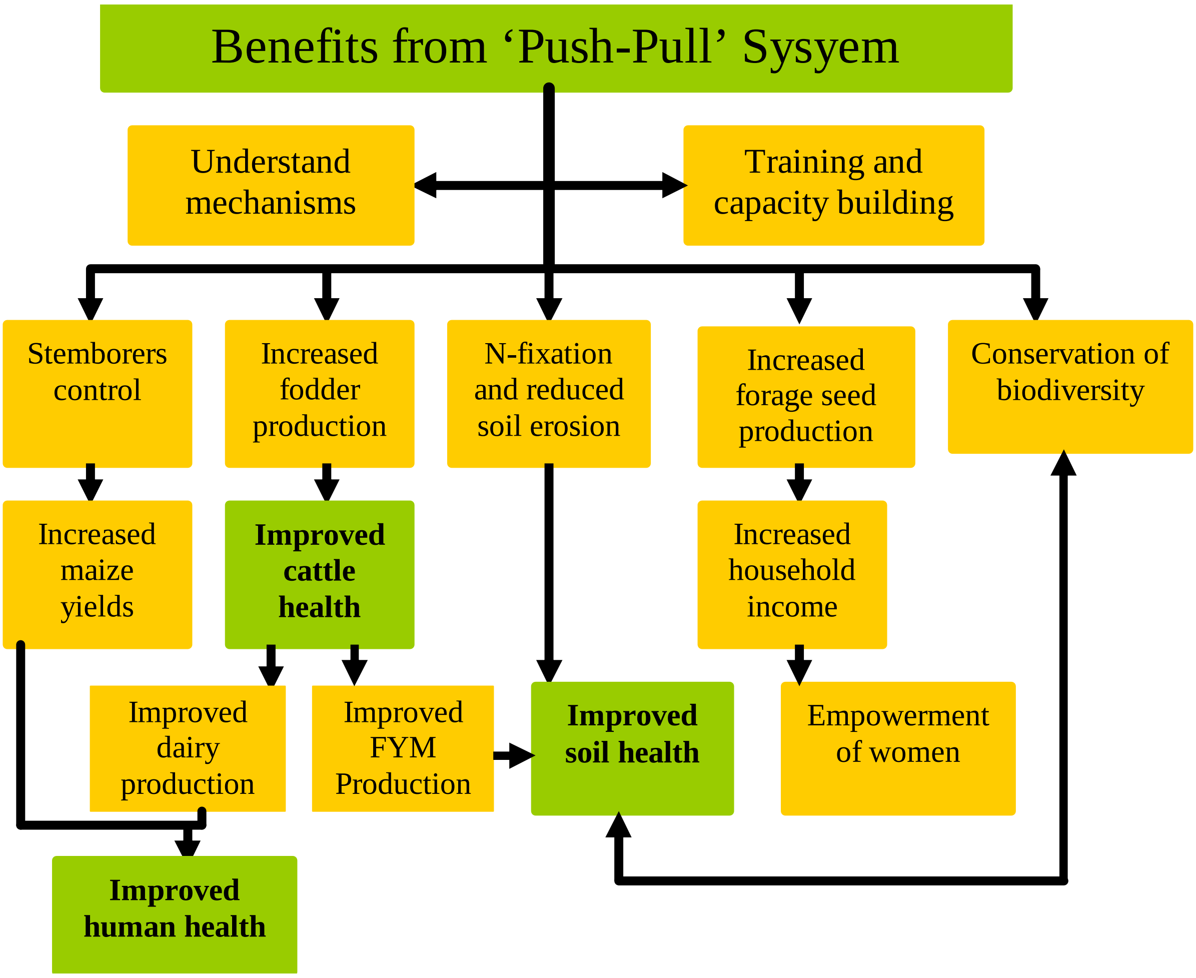

Figure 3. Benefits of 'push-pull' system in cereal farming systems

CONCLUSIONS:

Although information on the effect of habitat diversity on natural enemies and herbivores has increased greatly in the past 20 years, most studies do not attempt to explain why population densities differ in monoculture and polycultures. Thus these studies do not contribute to our understanding of the mechanisms involved. The present study has fully elucidated scientific understandings of insect-plant and pest-natural enemy interactions. Although the 'push-pull' strategy was originally described by Pyke et al. (1987) and Miller and Cowles (1990), in both cases no consideration to natural enemies was given and a chemical deterrent or toxin was used to repel or kill the pest. The resource poor farmers in Africa can not afford to apply chemicals to control stemborers on cereal crops. The present 'push-pull' strategy does not use any chemical deterrents or toxins, but uses repellent plants to deter the pest from the main crop. The trap plants, used in the present push-pull strategy, have inherent ability of not allowing development of trapped stemborers (Khan et al. 2000). The strategy also attempts to exploit the natural enemies in the farming system (Khan et al. 1997 a, b).

The present ‘push-pull’ strategy is quite unique in the way that it has developed from the basic science to technology transfer, to farmer take-up, and spontaneous technology transfer between farmers. The ‘push-pull’ approach described here will expand into Kenya, Uganda, Tanzania and Ethiopia. A pilot programme has been initiated in southern Africa, addressing stemborer control in the arid and semi-arid areas of the Northern Province of South Africa. However, each region has, in addition to varying climatic conditions and use of alternative cultivars, some differences in crops that must be taken into account. Whereas maize is the main crop in the farming systems in Kenya and Uganda, sorghum, pearl millet and maize are planted in southern Africa. Pest management options in this region are affected by low rainfall, the limited extent to which cattle are kept and the fact that the cattle are largely free-grazing. However, wherever these approaches are developed for the specific needs of local farming practices and communities, it is essential that the scientific basis of the modified systems should be completely elucidated. Every effort will be made to ensure that technology transfer follows the incorporation of these practices into other regions of Africa.

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