# PUSH-PULL STRATEGY FOR INSECT PEST MANAGEMENT

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The 'push-pull' strategy, a novel tool for integrated pest management programs, uses a combination of behavior-modifying stimuli to manipulate the distribution and abundance of insect pests and/or natural enemies. In this strategy, the pests are repelled or deterred away from the main crop (push) by using stimuli that mask host apparency or are repellent or deterrent. The pests are simultaneously attracted (pull), using highly apparent and attractive stimuli, to other areas such as traps or trap crops where they are concentrated, facilitating their control.

The term 'push-pull' was first conceived as a strategy for insect pest management by Pyke, Rice, Sabine and Zaluki in Australia in1987. They investigated the use of repellent and attractive stimuli, deployed in tandem, to manipulate the distribution of *Heliocoverpa* spp. in cotton to reduce reliance on insecticides, to which the moths were becoming resistant. The concept was later formalized and refined by Miller and Cowles in the US in 1990, who termed the strategy 'stimulo-deterrent diversion' while developing alternatives to insecticides for control of the onion fly, *Delia antiqua*.

The development of a reliable, robust, and sustainable push-pull strategy requires a clear scientific understanding of the pest's biology and the behavioral/chemical ecology of the interactions with its hosts, conspecifics, and natural enemies. The specific combination of components differs in each strategy according to the pest to be controlled (its specificity, sensory abilities, and mobility) and the resource targeted for protection.

Among several push-pull strategies under development or used in practice for insect pest control, the most successful example of the push-pull strategy currently being used by farmers was developed in Africa for controlling stemborers on cereal crops. This strategy was developed using technologies appropriate to resource poor farmers and has shown a high adoption rate and spontaneous technology transfer by farmers, resulting in significant impact on food security by increased farm production in the region.

**Management of cereal stemborers in Africa through push-pull strategy**

Maize and sorghum are the principal food and cash crops for millions of the poorest people in the predominantly mixed crop-livestock farming systems of eastern Africa. Stemborers are one of the major constraints to increased maize production. At least four species of stem borers (*Chilo partellus*, *Eldana saccharina*, *Busseola fusca* and *Sesamia calamistis*) infest maize and sorghum crops in the region, causing reported yield losses of 30-40% 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. The main method of stemborer control, which is recommended to farmers by the Ministry of Agriculture in these countries, is use of chemical pesticides. However, chemical control of stemborers is uneconomical and impractical to many resource-poor, small-scale farmers. Therefore, reducing the losses caused by stemborers through improved management strategies is urgently needed which could significantly increase cereal production, and result in better nutrition and purchasing power for many maize and sorghum producers. To put stemborer control within the reach of African farmers, simple and relatively inexpensive measures need to be developed and tailored to the diversity of African farming systems. Several national and international agricultural research centers continue to devote increasingly scarce resources towards the development of technologies intended to increase farm production through stemborer management but with little impact.

A push-pull strategy for managing cereal stemborers in Africa was developed by scientists of the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya and Rothamsted Research in the United Kingdom, in collaboration with other research organizations in eastern Africa. The strategy involves combined use of intercrops and trap crops, using plants that are appropriate to the farmers. This 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 this push-pull strategy have the inherent ability of not allowing development of trapped stemborers, thus reducing the number of trapped insects. The strategy also attempts to fully exploit the natural enemies in the cereal farming system.

The push-pull strategy for cereal stemborers involves trapping stemborers on highly attractant trap plants (pull) while driving them away from the main crop using repellent intercrops (push). Plants that have been identified as effective in the push-pull tactics include Napier grass (*Pennisetum purpureum*), Sudan grass (*Sorghum vulgare sudanense*), molasses grass (*Melinis minutiflora*), and desmodium (*Desmodium uncinatum* and *Desmodium intortum*). Napier grass and Sudan grass are used as trap plants, whereas molasses grass and desmodium 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* (Fig. 2). All four plants are of economic importance to farmers in eastern Africa as livestock fodder and have shown great potential in stemborer and striga management in farmer participatory on-farm trials. These innovations have found ready acceptance among the resource-poor farmers in Africa. Although directed at resource-poor farmers, lessons can be learned and applied to organic or low-input agricultural systems. More than ten thousand farmers in eastern Africa are now using push-pull strategies to protect their maize and sorghum from cereal stemborers.

**How push-pull strategy works**

The push-pull strategy undertakes a holistic approach in exploiting chemical ecology and agrobiodiversity. The plant chemistry responsible for stemborer control involves release of attractive volatiles from the trap plants and repellent volatiles from the intercrops. To understand the chemical ecology of the push-pull system, volatile chemicals from trap and repellent plants have been investigated using gas chromatography (GC) coupled-electroantennography on the antennae of stemborers and their natural enemies. GC peaks consistently associated with EAG activity were tentatively identified by GC coupled-mass spectrometry (GC-MS), and identity was confirmed using authentic samples (Fig. 1).

A general hypothesis developed during this work on insect pests is that non-host plants are recognized by colonizing insects through the release of repellent or masking semiochemicals, although it is almost inevitable that compounds also produced by hosts will be present (Fig. 2). 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 both members of the Poaceae family. For *M. minutiflora*, five new peaks with EAG activity were identified, in addition to the attractant compounds and others normally produced by members of the Poaceae. These are: (*E*)-ß-ocimene, α-terpinolene, ß-caryophyllene, humulene, and (*E*)-4,8-dimethyl-1,3,7-nonatriene. Ocimene and nonatriene had already been encountered as semiochemicals produced during damage to plants by herbivorous insects. It is likely that these compounds, being associated with a high level of stemborer colonization and, in some circumstances, acting as foraging cues for parasitoids, would be repellent to ovipositing stemborers. This was subsequently demonstrated in behavioral 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 α-cedrene.

Six host volatiles were found to be attractive to gravid stemborers: nonanal, napthelene, 4-allylanisole, eugenol and linalool. Recent studies have indicated that the differential preference of moths between maize and sorghum and Napier grass trap crops is related to a large burst of four electrophysiologically active green leaf volatiles released from the trap crop plants within the two hours of the scotophase, the time at which stemborers fly and most oviposition occurs. Although stemborers oviposit heavily on Napier grass, it produces a gummy substance which restricts larval development and only few survive to adulthood.

A trap crop of Sudan grass also increased efficiency of stemborer natural enemies. In a maize field surrounded by a border of Sudan grass, the parasitization of stemborers increased significantly relative to fields without grass borders.

**Benefits of push-pull strategy**

The principles of the push-pull strategy are to maximize control efficacy, efficiency, sustainability, and outputs, while minimizing negative environmental effects. Although each individual component of the strategy may not be as effective as a broad-spectrum insecticide at reducing pest numbers, the efficacy is increased through tandem deployment of push and pull components. The push and pull components are generally nontoxic and, therefore, the strategies are usually integrated with biological control.

The push-pull strategy developed for stemborers is a good example how basic research can be linked with technology transfer, with farmer participation leading to spontaneous technology transfer between farmers. The push-pull technology has the potential to improve the livelihoods of small-holder farmers and rural families, increase agricultural productivity and improve environmental sustainability. The push-pull strategy, now adopted by more than 10,000 households in 19 districts in Kenya, 5 districts in Uganda, and 2 districts in Tanzania has helped participating farmers to increase their maize yields by an average of 20% in areas where only stemborers are present and by more than 50% in areas where both stemborers and striga weed are problems. It constitutes an integrated system that addresses concurrently problems of stemborers, striga weed, soil fertility and soil moisture retention. It opens up significant opportunities for income generation by small-holder farmers and, represents a platform technology around which new income generation and human nutritional components, such as livestock keeping, can be added.

Increased maize yields accompanied by the following additional features of the technology have contributed to the high farmer adoption rates of push-pull technology in eastern Africa:

*Reduced soil erosion and increased soil fertility*. Soil erosion and low fertility are very common problems in eastern Africa. The push-pull strategy has exploited 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 stemborer management. Similarly, desmodium, a nitrogen-fixing legume, already grown for improving soil fertility and for quality fodder, is also an effective stemborer repellent and striga weed suppressant. Intercropping desmodium with maize reduces the need for external mineral nitrogen inputs, which are costly and unaffordable by most small-holder rural people, and improves the use efficiency of other inputs. A long-term study in Kenya demonstrated a significant increase in total nitrogen (Fig. 3) on field plots under maize-desmodium intercropping for 3 years than those maize fields intercropped with other legumes.

*Striga weed control*. Witchweed or *Striga* (Scrophulariaceae) are obligate root parasites of cereal crops that inhibit host growth via two processes, competition for nutrients and impairment of photosynthesis. *Striga* infests 40% of Africa’s arable land and causes a loss of $7-11 billion to agricultural economy. Among the 23 species of striga prevalent in Africa, *Striga hermonthica* is the most socio-economically important. In western Kenya, it is estimated that 76% of land planted to maize and sorghum, *Sorghum bicolor* (L.) Moench, is infested with *S. hermonthica*, causing up to 100% yield losses equivalent to annual losses estimated at $40.8

million. *Striga hermonthica* infestation continues to extend to new areas in the region as farmers abandon heavily infested fields for new ones. The push-pull strategy provides significant suppression of striga through intercropping maize or sorghum with desmodium, a repellent plant for stemborers. The protection employed by desmodium in striga suppression has been established to involve a combination of mechanisms ranging from increased availability of nitrogen, soil shading, and an allelopathic root exudation. Exudates from desmodium roots possess striga seed germination stimulation and radical growth inhibition properties which diminish striga seeds through suicidal germination and a continual reduction of the soil seed bank. This combination provides a novel means of *in situ* reduction of striga seed bank in the soil. Additionally, because desmodium is a perennial crop, it is able to exert its striga control effect even when the host crop is out of season, an attribute that makes it a more superior trap crop than most of the other legumes that have been reported to give some limited level of striga control (Fig. 4).

*Enhanced biodiversity*. Biodiversity in agroecosystems has been reduced greatly in the last decades as a result of intensification of cereal agricultural systems, while empirical data show that agroecosystems with an enhanced overall biodiversity have relatively fewer pest problems. As a result of this observation it has often been stated that enhancement of biodiversity within agroecosystems can greatly contribute to the development of sustainable crop protection systems with a reduced reliance on pesticides. Biodiversity has an intricate role in the functioning of natural and agricultural ecosystems since it performs a variety of ecological services, mediating processes such as genetic introgession, natural control, nutrient cycling and decomposition. Farming practices that conserve such biodiversity as ground fauna and pests' natural enemies may be a practical alternative to manage pests in agricultural systems. Results from Kenya indicate that the push-pull strategy is associated with an overall enhancement of beneficial predator abundance (Fig. 4).

*Livestock production and human health*. Enhancing the production of fodder plants in local communities demonstrates clear beneficial impacts on health indices, especially for children. By promoting dairy cattle, human health is likely to improve because of high quality milk.

The research outputs have potential to contribute significantly to increased livestock production by providing quality fodder, especially on small farms where pressure for land is high. Dairy cows and dairy goats are emerging as important income alternatives in such situations. With the participation of such partners as Heifer International, more resource-constrained farmers are likely to benefit from dairy animals.

The Suba district of Kenya, a milk-deficit region on the shores of Lake Victoria which has mostly indigenous (zebu) livestock, produced only 7 million liters of milk, far short of the estimated annual demand of 13 million liters. A major constraint to keeping improved dairy cattle for milk production has been the unstable availability and seasonality of feed, which often is low quality. The push-pull strategy, which integrates crop and fodder production, has been adopted by more than 700 farmers in this district. This has resulted in enhanced livestock production and improved milk supply because there now is more and higher-quality feed available for cattle. The number of improved dairy cattle in the district has increased by 500, contributing to a 1 million liter increase in milk production.

**Economics of push-pull**

The contribution of the push-pull strategies to food security cannot be over-emphasized. Intercropping or mixed cropping of maize, grasses and fodder legumes has enabled farmers in Kenya to increase crop yields, and thus improve their food security and gross benefits. This feature of the technology is suitable for mixed farming conditions, which are prevalent in eastern Africa. Using a semi-structured questionnaire, data were collected on crop performance, stemborer infestation, *Striga* infestation and yield of the different crops. Economic data on input and output amounts, and labor were collected. All crop management decisions were made by the farmers themselves, with technical backstopping from extension staff on management of the desmodium and Napier grass. In addition, baseline information was collected on the households detailing the household sizes and composition, off-farm activities, the farm sizes, the number of cattle, education level of different members of the households and labor availability. An analysis of expenses incurred and revenues accrued in a season was carried out on the push-pull technology and farmers' own practice. The yield of maize from the push-pull technology and the farmers' practice, the revenues generated from all the farm outputs in a season, the expenses incurred to generate that revenue and the gross benefits accruing to the farmers were investigated in the different districts in Kenya. The results showed that

Table 1. Economics of push-pull strategy as compared to farmer's practice in six districts in Kenya (from Khan et al., unpublished)

| Districts | Total Labor Cost ($)/ha | | Total Variable Cost ($)/ha | | Total Gross Revenue ($)/ha | | Gross Benefit ($)/ ha | |
|---|---|---|---|---|---|---|---|---|
| | Push-pull | Farmers' Practice | Push-pull | Farmers' Practice | Push-pull | Farmers' Practice | Push-pull | Farmers' Practice |
| Trans/ Nzoia[a] | 223 ± 1.2 | 128 ± 1.5 | 493 ± 1.6 | 374 ± 2.0 | 1290 ± 27.7 | 628 ± 32.4 | 797 ± 28.0 | 254 ± 31.0 |
| Suba[a] | 167 ± 1.6 | 134 ± 0.4 | 278 ± 1.1 | 250 ± 0.7 | 679 ± 10.2 | 329 ± 5.9 | 401 ± 9.9 | 79 ± 5.7 |
| Bungoma[b] | 247 ± 3.8 | 222 ± 2.3 | 331 ± 3.9 | 300 ± 2.8 | 867 ± 22.6 | 415 ± 8.6 | 536 ± 21.3 | 115 ± 9.9 |
| Busia[b] | 222 ± 1.7 | 118 ± 0.3 | 321 ± 1.9 | 243 ± 0.6 | 862 ± 11.9 | 418 ± 2.9 | 541 ± 12.7 | 175 ± 2.9 |
| Kisii[b] | 184 ± 1.8 | 140 ± 1.1 | 246 ± 2.1 | 210 ± 1.0 | 733 ± 6.4 | 334 ± 15.7 | 487 ± 5.3 | 134 ± 15.9 |
| Vihiga[c] | 227 ± 1.9 | 128 ± 1.0 | 359 ± 2.3 | 331 ± 1.5 | 785 ± 12 | 423.1 ± 7.1 | 426 ± 13.4 | 92 ± 7.0 |

a, b, c represent data averages for 7 years, 4 years and 3 years respectively. All the parameters studied were significantly lower in the farmers' practice than in the 'push-pull' technology in all the districts ($P<0.05$).

although total labor cost and total variable cost were lower in farmers' practice as compared to push-pull fields, total gross revenue and gross benefit of push-pull were significantly higher. As important, though less quantifiable, is the reduction in risk that push-pull strategy provides as the build-up of more fertile, water-retaining soil systems give added protection to crops in periods of water shortage and stress (Table 1).

**Future directions**

The push-pull technology for stemborer control is expanding in eastern Africa via small-holder farmers and has significant impacts on food security and income generation for resource-poor maize farmers. On-station and on-farm trials have also demonstrated that push-pull strategies could also be used for control of stemborers in sorghum and millet, and further on-farm research and development is needed to understand the full potential of this strategy for sorghum and millet farmers in arid and semiarid parts of Africa. Pest management options in these regions are affected by low rainfall, the extent to which cattle are kept, and the fact that the cattle are largely free-grazing. However, wherever these approaches are adapted to the specific needs of local farming practices and communities, it is essential that the scientific basis for the modified systems should be clarified and explained by appropriate research.

The major constraint to widespread technology transfer of push-pull has been availability of desmodium seed. Several pathways have emerged, including involvement of a private seed company, community-based seed production, and vegetative propagation among farmers adopting push-pull technologies. The relative merits of these pathways in stimulating autonomous diffusion of the technologies are being analyzed and compared. In addition, the role of different reinforcing interventions such as mass media, information bulletins, field days, farmer teachers, farmer field schools, etc., are being evaluated and the most cost-effective ones will be identified. The relationship between household socio-economic status and land labor ratio in different areas, and the performance of different diffusion mechanisms are also being clarified.

For long-term sustainability of the push-pull system and its placement on a strong scientific foundation, there is also ongoing work on developing tools for quality control of the performance of new push and pull components, to enhance understanding of soil nutrient dynamics in long term push-pull fields, and to study and solve emerging problems of a previously unrecognized pest (a pollen beetle attacking desmodium), and a disease of the companion crops (phytoplasma disease of Napier grass). Current studies in these areas will be continued and tools that emerge will be optimized and incorporated into the push-pull dissemination activities. In addition, several new science-led maize production and protection technologies (such as Bt maize) have been developed by other research institutes, the effectiveness and sustainability of which need to be compared with push-pull strategies over a longer time scale. Questions relating to potential integration of these technologies or their complementarities have been raised and need to be evaluated in continued collaboration with other centers. Demonstration of the relative productivity of integrated approaches and their socio-economics, including the possibility of forward linkages, as well as collaborative undertakings with other institutions, will be important.

From the present example of the push-pull strategy it can be seen that understanding the interactions of plants with insects can yield new ways of exploiting plant defense. Basic science, and particularly understanding the chemical ecology of plant-insect interactions by combined analytical-chemical, neurophysiological and behavioral studies, can lead to practical developments to help resource-poor farmers.

Although the experience to date has been restricted to cereal-based farming systems, we believe that the general approach is applicable to a much wider range of pest problems in a variety of crops, and thus can serve as a model for other researchers in their efforts to minimize pest-induced yield losses in an economically and environmentally sustainable manner. This push-pull strategy for cereal stemborers lays the foundation for still wider application of these principles and serves as a model for the management of other pests in Africa and beyond.

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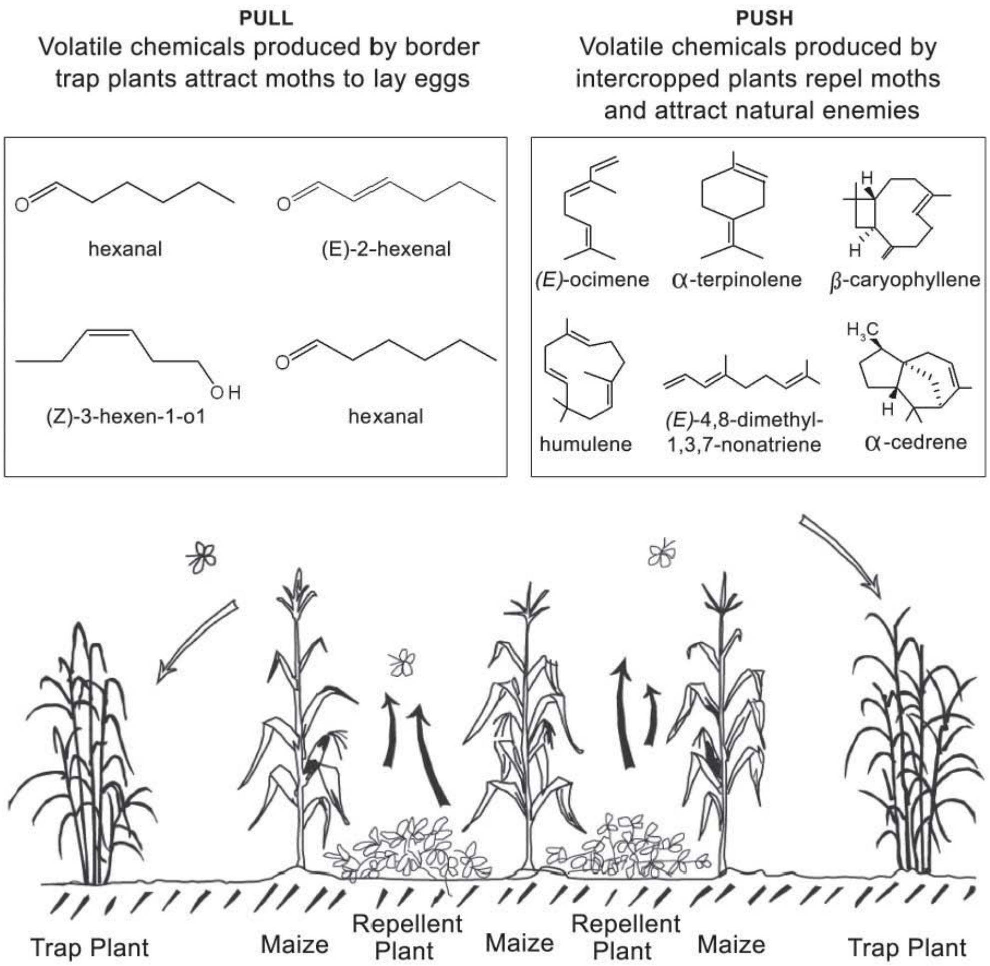


Figure 1. A diagrammatic presentation on how push-pull strategy works for cereal stemborers.

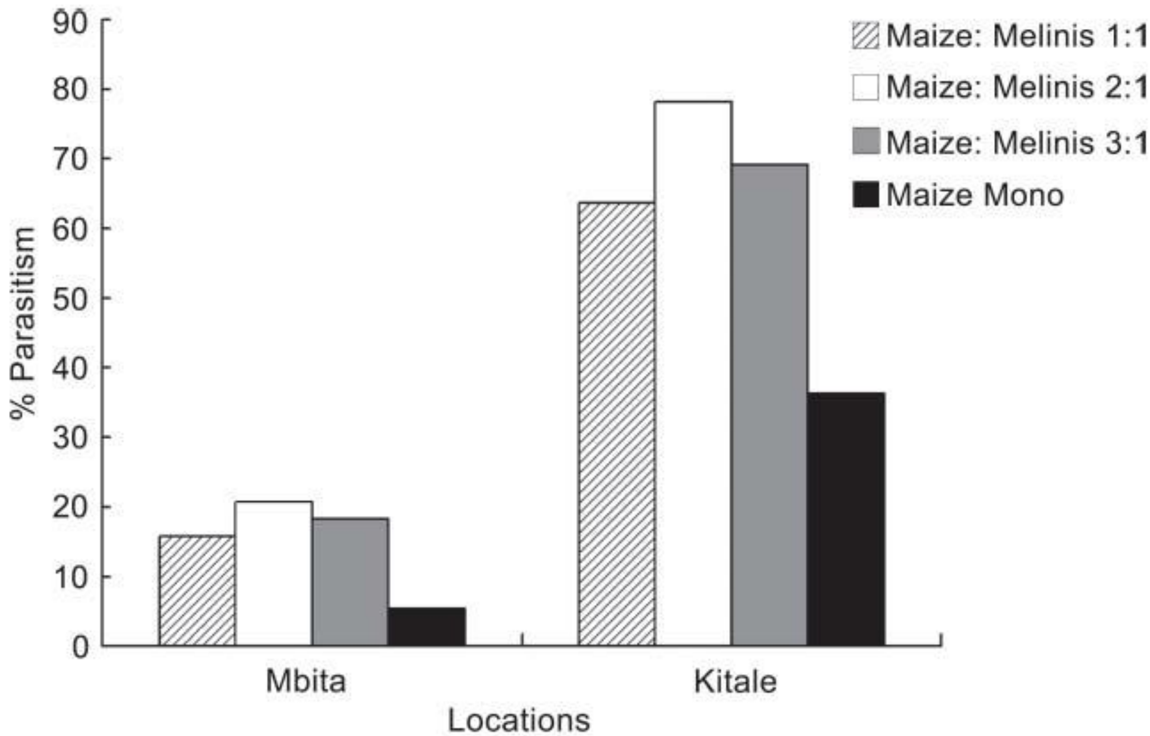


Figure 2. Parasitism of stemborer larvae by *Cotesia sesameae* in maize-*M. minutiflora* intercrops planted in various ratios.

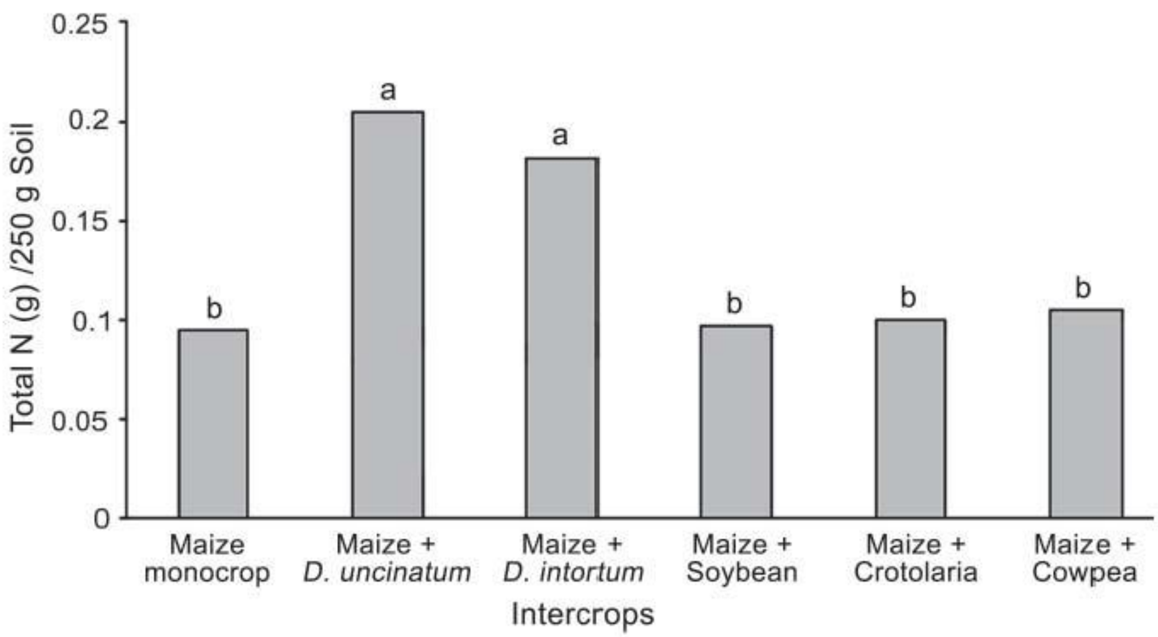


Figure 3. Total nitrogen (N) levels in the soil under different intercrops in western Kenya (after Khan et al., 2006).

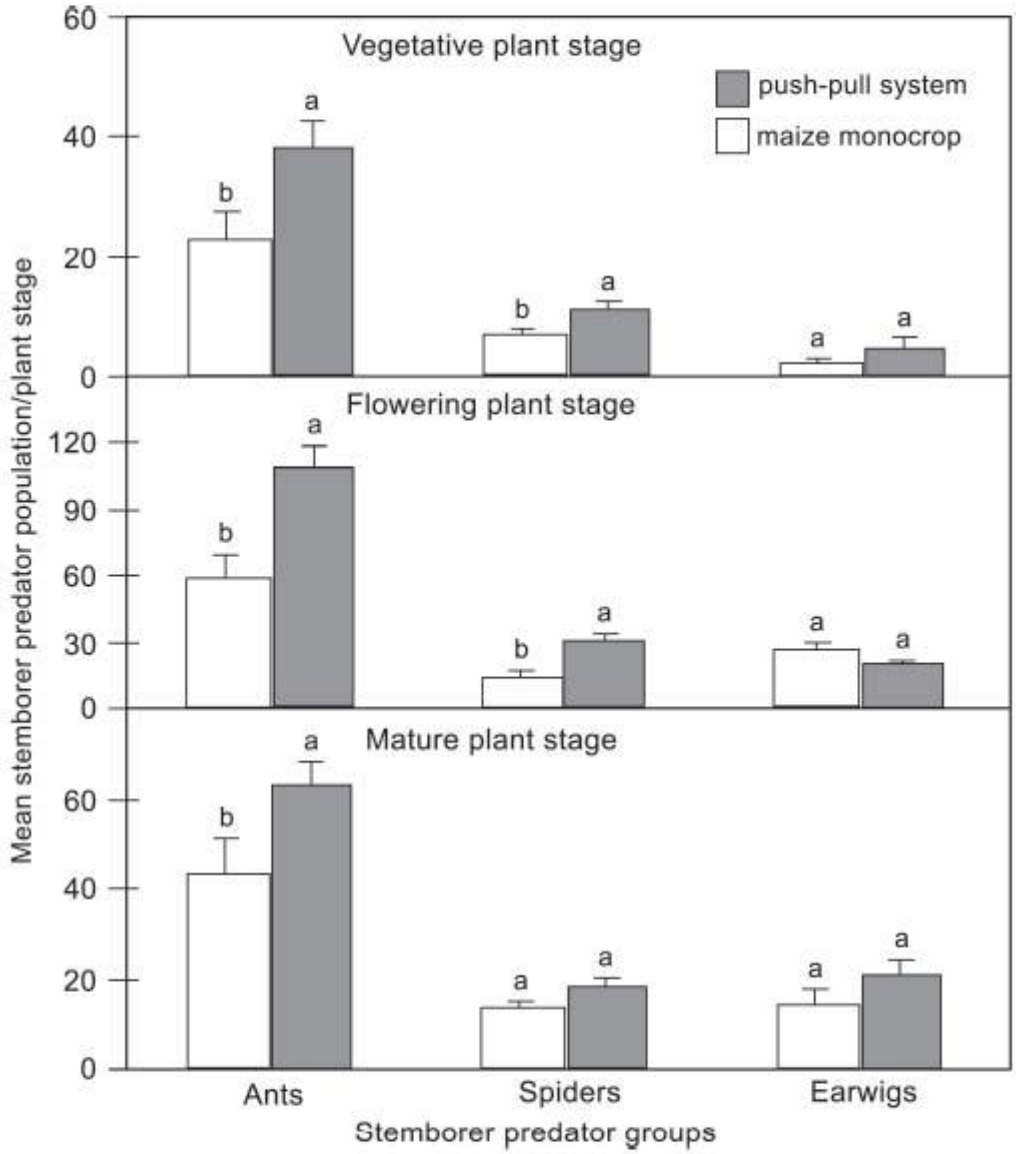


Figure 4. Stemborer predator populations at the vegetative, flowering and mature stages of maize plants in Lambwe, Kenya (after Midega and Khan, 2003. *Insect Science and its Application* 23: 301-308).