iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: V Month of publication: May 2024

DOI: https://doi.org/10.22214/ijraset.2024.62302

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue V May 2024- Available at www.ijraset.com

Reviews on the Strategies Employed in Implementing the 'Push-Pull' Approach to Integrated Pest Management

Sameh Qasim Abdulqader
Agriculture Directorate of Nineveh/Al-Gwer Agriculture Division

Abstract: For small-holder maize farmers in Africa, the push-pull strategy is outlined as an alternate ecological management technique to traditional insecticide-based integrated pest management for the control of the spotted stem borer **Chilo partellus** ***and the autumn armyworm Spodoptera frugiperda. Push-Pull Technology (abbreviated PPT) is a unique integrated pest management method developed by the International Centre of Insect Physiology and Ecology (ICIPE) and its partners. This tactic involves influencing the behavior of natural enemies and insect pests by strategically deploying stimuli that make the resource under protection unappealing or inappropriate for the pests (the "push"). Additionally, the pests are drawn to an alluring source (the "pull"), from which they are then eliminated. The method entails intercropping a cereal crop with a repellent intercrop that prevents stem borer oviposition, like molasses grass (*****Melinis minutiflora*****) or a leguminous fodder crop like Desmodium (*****Desmodium uncinatum*****), while an attractant trap crop that is planted as a trap crop around the main crop is Sudan grass (*****Sorghum vulgare*** *Var sudanense*) ***or Napier grass (*****Pennisetum purpureum*****). Because they give cattle fodder, these companion plants are commercially beneficial to East African farmers. The method has been applied to improve soil fertility, decrease the parasitic Striga plant, and manage stem borers in cereal crops. By increasing crop yields, this environmentally friendly method has proven to be effective for resource-constrained farmers and has a high adoption rate. It may also provide a real challenge and substitute for the use of dangerous synthetic insecticides that are harmful to the environment and human health. As such, we believe it would be wise to elaborate on this crucial tactic in the future.***
Keywords: push-pull, Integrated Pest Management, armyworm, stem borer, Colorado potato beetle

I. INTRODUCTION

Numerous advanced studies and research have enabled the application and innovation of dynamic strategies for insect pest management, exemplified by the Push-Pull approach. This strategy centers on fundamental knowledge to develop and utilize the Push-Pull concept in insect control (1). In Australia, specifically in 1987, the term "Push-Pull" was coined as a method for Integrated Pest Management by Pyke et al. (2). The concept of "stimulus diversionary strategy" is one of the pest control strategies (3), also referred to as the Push-Pull strategy (4). The Push-Pull strategy is an innovative tool for Integrated Pest Management (5). This strategy was developed by scientists at the International Centre of Insect Physiology and Ecology (ICIPE), the Kenyan Agricultural Research Institute (KARI), and Rothamsted Research in the UK, in collaboration with other research organizations in East Africa (6). Techniques aimed at influencing pest behavior can serve as alternatives to insecticides in agricultural environments (7). The fall armyworm and spotted stem borer remain among the most problematic field pests in East Africa, owing to their severe economic ramifications on maize production, which is the primary food source in the region (8). The risk of invasion by the fall armyworm and the noxious Striga weed poses a threat to maize-producing farmers in the region (9). Furthermore, non-climatic conditions such as low crop prices and health adversities exacerbate the vulnerability of farmers in the region (10). Insecticides remain the predominant method for controlling the fall armyworm and stem borers; however, their continuous use has led to the emergence of insect resistance, in addition to detrimental human, animal, and environmental consequences (11, 12). Moreover, access to specialized pesticides and safety equipment for their application remains a challenge for resource-constrained farmers in the sub-Saharan region (13). The Push-Pull Technology (PPT) is recognized as an agro-ecological package and one of the most cost-effective agricultural approaches, aimed at mitigating the impact of Striga and stem borers on maize crops (14, 15). The Push-Pull Technology exemplifies another habitat manipulation technique applied in East Africa in 2014 by 68,800 farmers to control the maize stem borer *Chilo partellus*, as described by Tanda (16).

II. MATERIALS AND METHODS

The push-pull method is an ingenious incorporated insect administration (IPM) technique created by the International Centre of Insect Physiology and Ecology (ICIPE) and companions. It involves the concomitant use repellent (push) and trap (pull) plants to regulate insect bugs in crops like maize.

For the push part, a repellent intercrop such as molasses lawn (*Melinis minutiflora*) or the forage vegetable Desmodium (*Desmodium uncinatum*) is grown between the primary grain crop rows. These plants launch semiochemicals that fend off stem borer moths and draw in all-natural opponent bugs, discouraging oviposition on the main crop.

The pull element uses an attractant catch crop like Napier lawn (*Pennisetum purpureum*) or Sudan turf (*Sorghum vulgare* var sudanense) planted around the perimeter of the primary area. These grasses give off unpredictable cues highly appealing to stem borer moths, drawing them away from the main plant for oviposition. The trap plant serves as a repellent sink where eggs are laid but a lot of larvae cannot survive due to bad nutrition, sticky gum production entrapping them, and bountiful natural adversaries. The friend push and pull plants use additional benefits like nitrogen add, fertility enhancement, erosion control, and high-quality straw for animals' assimilation. Area experiments examine stem borer and parasite infestation levels, plant yields, and effect on soil wellness contrasting push-pull plots against monoculture controls. Semiochemical analysis defines the unstable accounts driving repellent and attractant effects.

III. RESULTS AND DISSCUTION

Why opt for this strategic approach? An elucidation of its paramount virtues and the salient instances of its efficacious implementation:

The principles of the push-pull strategy revolve around maximizing control efficacy and efficiency while minimizing adverse environmental ramifications (17). Integrated Pest Management (IPM) techniques, which eliminate the use of pesticides and harness natural processes, are deemed more appropriate and cost-effective than push-pull technologies (18). In this context, push-pull technology (PPT) is an ecological farming approach that endeavors to enhance the climate resilience of smallholder mixed crop-livestock farmers cultivating maize (19). The push-pull strategy has proven efficacious in suppressing the Colorado potato beetle, circumventing the historical failure of field control due to resistance development, and acknowledging the deleterious impacts of pesticides. In an effort to mitigate substantial crop losses associated with pests in sub-Saharan Africa, the International Centre of Insect Physiology and Ecology (ICIPE) and collaborating organizations developed the Push-Pull Technology (20). Researchers have also harnessed this strategy, employing concomitant repellent and attractant stimuli to manage the distribution and proliferation of the American bollworm (*Heliocoverpa* spp.) in cotton crops, reducing reliance on insecticides for managing this pesticide-resistant pest. Stem borers and the parasitic weed Striga posed formidable challenges to sustainable maize production in sub-Saharan Africa (21, 22, 23), causing up to 88% crop losses, while Striga infestations resulted in complete yield losses (24). Maize is a crop of paramount importance as a food and livestock feed in sub-Saharan Africa (25). Consequently, this strategy exhibited remarkable efficacy in controlling stem borers in cereal crops and garnered high acceptance among African farmers, significantly impacting food security through augmented agricultural yields in these regions (17). The technique has also been successfully employed in certain forestry systems (26). Furthermore, the push-pull technology has demonstrated unprecedented success in mitigating stem borer damage and even Striga infestations in cereal systems across sub-Saharan Africa (27). It has been cited as a promising method for controlling the fall armyworm in East Africa (28). A field study in western Kenya revealed a substantial increase in total nitrogen levels in intercropped maize fields with Desmodium compared to monoculture maize fields (29). Notwithstanding weed suppression, the forage crops (Desmodium, Napier, or Brachiaria) utilized in this technology offer supplementary benefits, including enhancing soil fertility through nitrogen fixation and organic matter contribution, mitigating soil erosion, and providing high-quality livestock feed, thereby increasing milk production. Collectively, these advantages augment the income of smallholder households with limited resources and potentially bolster food security (30). Evidence gleaned from East Africa indicates that the push-pull technology can potentially augment crop yield and cattle fodder up to threefold (31), (4), (22), (23), (32), and (33). This technique also mitigates crop loss in maize infested by the fall armyworm by 10–17%, thereby enhancing crop yield by 12–15%, rendering farmers more resilient against insect invasions (34). The Chinese citrus fly, *Bactrocera minax*, is a formidable citrus pest; its life stages conceal within infested host fruits or soil, necessitating the ingenious push-pull strategy for adult population suppression. An evaluation of three distinct lures in citrus orchards revealed a diminution in infested fruits from 95.0% to 75.4% for navel oranges and 89.6% to 72.4% for satsuma mandarins, respectively. Notably, in comparison to two commercial lures, an indigenously designed bait exhibited a superior reduction in pest infestation (35).

Research conducted in Eastern Uganda explored the ramifications of push-pull technology adoption on household welfare concerning income, productivity, and individual food consumption status. Survey data encompassing 560 households across four districts (Busia, Tororo, Bugiri, and Pallisa) were collected in November and December 2014, employing the Global Positioning System (GPS) to ascertain adoption density (land area allocated to push-pull) and estimate the Dose-Response Function (DRF) linking adoption intensity to household welfare. Findings unveiled a poverty reduction concomitant with an augmented maize yield and consequential income escalation as push-pull adoption intensified. However, this effect varied with adoption level; with each increment in push-pull area from 0.025 to 1-acre, average maize production per unit area surged from 27 to 1400 kg, household income rose from $135 to $273, and per capita food consumption increased from $15 to $27. On average, the likelihood of impoverished households (below the rural poverty line of $12.71) diminished from 48% to 28%, underscoring the pivotal role of investment in push-pull technology for alleviating poverty among small-holder farmers in Uganda (30). In Western Kenya, Njeru et al. conducted a study to evaluate the impact of stemborer and fall armyworm management using the push-pull strategy on maize ear rot disease incidence and pre-harvest aflatoxin (fumonisin) contamination of maize grains. This experiment spanned three cropping seasons, comparing maize grown under push-pull and monoculture systems. Stemborer and fall armyworm damage was quantified as the percentage of infested plants, while ear rot disease incidence was assessed as the percentage of diseased ears exhibiting symptoms. Fungi associated with harvested maize grains were isolated, and the resulting mycotoxins (aflatoxin and fumonisin) were measured using an enzyme-linked immunosorbent assay. The push-pull system reduced stemborer and fall armyworm damage by 50% and substantially diminished *Fusarium verticillioides* and *Aspergillus flavus* incidence by 60% and 86%, respectively, translating to a 50% reduction in ear rot disease. Furthermore, fumonisin levels in push-pull maize declined by 39%, although aflatoxin levels remained unaffected. The study affirmed push-pull as an effective approach for managing ear rot disease and fumonisin mycotoxins, thereby potentially enhancing food safety among small-holder maize producers in the region (36).

An investigation utilizing the push-pull technique was conducted to combat the western flower thrips, *Frankliniella occidentalis*, infesting greenhouse-grown hot pepper. This approach employed repellent (push) and attractant (pull) semiochemicals, successfully reducing the pest's population density (37).

The push-pull strategy demonstrated high efficacy in diminishing the population density of the stable fly, *Stomoxys calcitrans* (L.), on cattle using a coconut oil formulation and traps (38). Furthermore, the push-pull tactic proved successful in repelling and attracting the tea green leafhopper, *Empoasca flavescens* F., through the repellent odors of *Tagetes erecta* and *Flemingia macrophylla* plants (39). An artificial semiochemical-based push-pull strategy was developed to control the European tarnished plant bug, *Lygus rugulipennis*, and mitigate subsequent fruit damage in UK strawberry crops, employing a series of small-plot field experiments on commercial strawberry cultivations (40). The push-pull approach effectively combatted leaf-cutting ants in poplar plantations, preserving Willow *Salix babylonica* tree growth by 60–80% at the end of the season (41). Additionally, this strategy contributed to the management of the sweet potato whitefly, *Bemisia tabaci*, in greenhouse-grown tomatoes by integrating push-pull tactics with colored insect traps, resulting in a threefold reduction in pest density compared to the control, with efficacy reaching 68.7% over time (42).

Table (I) Impact of Push-Pull Technology on Crop Yields and Household Welfare:

Adoption Level	Maize Yield (kg/acre)	Household Income (USD)	Per Capita Food Consumption (USD)	Likelihood of Poverty (below $12.71)
0.025 acre	27	135	15	48%
1 acre	1400	273	27	28%

Table (II) Impact of Push-Pull Technology on Pest and Disease Management:

Parameter %	Monoculture	Push-Pull	Reduction
Spotted Stemborer and Fall Armyworm Damage (infested plants)	-	50%	
Fusarium verticillioides Incidence (diseased ears)	-	60%	
Aspergillus flavus Incidence (diseased ears)	-	86%	
Ear Rot Disease Incidence (diseased ears)	-	50%	
Fumonisin Levels in Maize	-	39%	

Table (III) Effectiveness of Push-Pull Strategies for Various Pests:

Pest	Efficacy of Push-Pull
Colorado Potato Beetle	Highly Effective
American Bollworm (*Heliocoverpa* spp.)	Highly Effective
Stem Borers	Highly Effective
Striga (Parasitic Weed)	Highly Effective
Fall Armyworm (*Spodoptera frugiperda*)	Highly Effective
Chinese Citrus Fly (*Bactrocera minax*)	Effective
Western Flower Thrips (*Frankliniella occidentalis*)	Effective
Stable Fly (*Stomoxys calcitrans*)	Effective
Tea Green Leafhopper (*Empoasca flavescens*)	Effective
European Tarnished Plant Bug (*Lygus rugulipennis*)	Effective
Leaf-Cutting Ants	Effective
Sweet Potato Whitefly (*Bemisia tabaci*)	Effective

Table (IV) Benefits of Push-Pull Technology

Benefit	Description	Example
Pest Control	Reduces pest populations through repellency and attraction	Stem borers in maize - Fall armyworm - Colorado potato beetle
Increased Crop Yield	Enhances crop yield by minimizing pest damage	Up to 3-fold increase in crop yield
Improved Food Security	Contributes to food security through higher yields	Empowers smallholder farmers
Income Generation	Provides additional income through increased yields and livestock feed	Milk production increase
Soil Fertility Enhancement	Fixes nitrogen and adds organic matter to soil	Use of Desmodium, Napier, or Brachiaria forage crops
Erosion Control	Mitigates soil erosion	Forage crops provide ground cover
Livestock Feed	Offers high-quality feed for livestock	Desmodium, Napier, or Brachiaria forage crops

Table (V): Push-Pull Technology Applications:

Crop/System	Target Pest	Control Method	Result
Maize	Stem borers, Fall armyworm	Repellent intercrops (Desmodium) + attractant traps	Reduced pest damage, increased yield (12-15%)
Citrus Orchards	Chinese citrus fly	Attractant lures	Reduced fruit infestation (up to 20%)
Hot Pepper (Greenhouse)	Western flower thrips	Repellent and attractant semiochemicals	Decreased pest population density
Cattle	Stable fly	Repellent coconut oil formulation + traps	Lowered fly population
Tea	Green leafhopper	Repellent plants (Tagetes erecta, Flemingia macrophylla)	Reduced pest population
Strawberry (UK)	European tarnished plant bug	Artificial semiochemicals + traps	Mitigated fruit damage
Poplar Plantations	Leaf-cutting ants	Push-pull strategy	Preserved tree growth (60-80%)
Tomato (Greenhouse)	Sweet potato whitefly	Push-pull + colored insect traps	Decreased pest density (3-fold)

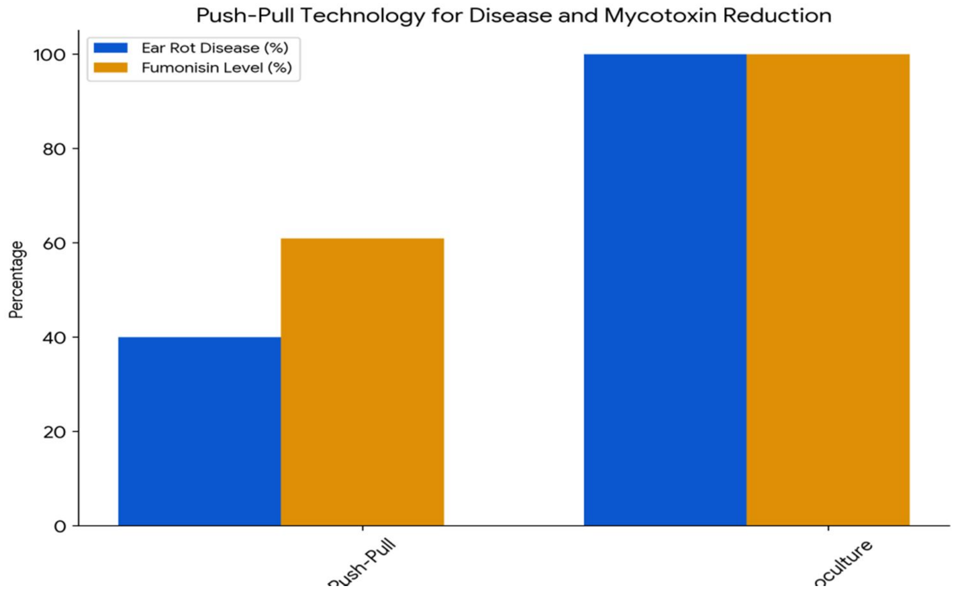

Chart (I) Push-Pull Technology for Disease and Mycotoxin Reduction

This chart can be a bar chart comparing the incidence of ear rot disease and mycotoxin contamination in maize. Categories on the X-axis can be: Maize with Push-Pull.
Categories on the X-axis can be:

- Maize with Push-Pull
- Maize without Push-Pull (monoculture)

The Y-axis can represent the percentage of:

- Ear rot disease incidence
- Fumonisin levels
- Aflatoxin levels (if applicable).

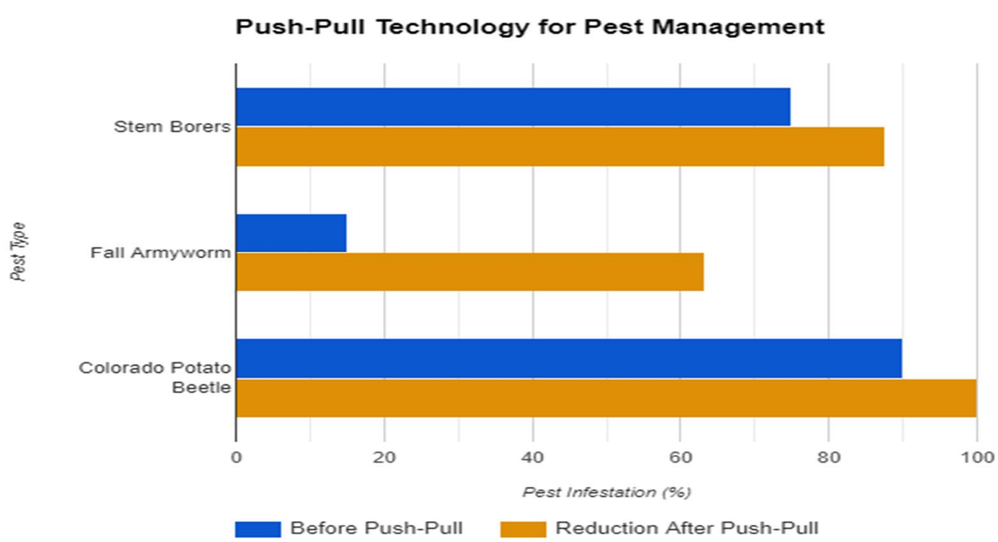

Chart (II) Push-Pull for Pest Management

These tables and analyses can assist in effectively conveying the main findings and impacts of the push-pull technology research to different stakeholders, such as researchers, policymakers, and smallholder farmers.

Push-Pull Technology Adoption Density Map: A map based on GIS that displays the adoption density of push-pull technology in various regions or districts. Dose-Response Function (DRF): A visual depiction showing the correlation between the level of adoption of push-pull technology and the outcomes related to household welfare such as maize yield, income, and food consumption. Diagram of the Integrated Pest Management (IPM) Approach: A visual depiction of using repellent and attractant stimuli together to control pests is known as push-pull technology within an IPM strategy. Diagram of Ecosystem Services: A visual representation showing different services offered by push-pull technology, including improving soil fertility, controlling erosion, and producing livestock feed.

IV. CONCLUSION

A. *How Does the Push-pull Strategy Function?*

The push-pull strategy employs a holistic approach to capitalize on agricultural biodiversity and the chemical environment. Plant chemistry is responsible for controlling stem borers in cereal crops, as attractive semiochemicals are released from trap plants, representing the "pull" component. This process involves the production of volatile chemicals from the trap plants, which attract female moths to lay eggs. Conversely, the volatile chemicals produced by the intercrop plants repel and deter the moths while attracting their natural enemies, constituting the "push" component (17). The push-pull strategy synergistically utilizes semi-attractive and repellent chemicals (43). In this technique, the targeted insect pest is deterred and diverted from the main crop during the harvesting period while simultaneously being lured towards the trap plants (4). The push-pull technology (PPT) necessitates the intercropping of maize with the forage legume Desmodium (*Desmodium uncinatum*) and planting Napier grass (*Pennisetum purpureum*) as a trap crop surrounding the main crop. The volatiles from the green leaves of Desmodium are repellent to stem borers (push), while those emitted from Napier grass are attractive to the pest (pull) (44, 31). As Napier grass is a preferred oviposition substrate for stem borer females over maize (45), the majority of eggs are laid on the trap plant, thereby protecting the maize crop. However, most of the resulting stem borer larvae fail to survive on the trap plants due to factors such as poor food quality, the production of sticky gums that entrap and kill the larvae, and the abundance of natural enemies associated with Napier grass (21, 46, 47, 45). Additionally, desmodium suppresses and eliminates the parasitic weed Striga through a multitude of mechanisms, including nitrogen fixation, the addition of organic matter to the soil, smothering due to its dense ground cover, and, most importantly, the exudation of allelopathic secondary metabolites into the rhizosphere (46).

B. *Suggestion*

1) Research should be done over an extended period of time to establish the push-pull approach's long-term effectiveness in handling pests such stem borers and autumn armyworms. Check out whether the plants that act as a repellant and catch are durable, and whether insects might eventually come to be immune to the stimuli.
2) Extension to replace plants: Check out whether the push-pull strategy can be applied to substitute plants for maize. Examine its efficacy in controlling pests in various agricultural systems, including rice, cotton, and vegetable plants, in order to offer farmers access to a bigger range of sustainable pests monitoring remedies.
3) Take a look at the push-pull method's environmental results along with its results on insect monitoring. Check out just how it influences community services, soil health and wellness, and biodiversity. Analyse the method's overall environmental sustainability and how it influences useful microorganisms like pollinators and natural adversaries.
4) Socioeconomic evaluation: Conduct in-depth socioeconomic evaluations to evaluate the economic usefulness and adoption capacity of the push-pull technique. The costs of implementing the strategy are contrasted to those of using standard pests control methods. Analyse how sociocultural elements influence farmers' fostering options and make note of any type of potential barriers to broader adoption.
5) Participatory research study with farmers: To learn more about farmers' perspectives, troubles, and areas of lack of knowledge concerning the push-pull approach, conduct participatory research study with farmers. Together, co-design and assess push-pull systems with farmers to see to it the methods are applicable and workable.
6) Diffusion and scaling: Produce plans to increase small-holder farmers' approval of the push-pull method. Determine efficient expansion methods and knowledge-transfer networks to ensure that the strategy is commonly executed. Analyse the results of the push-pull technique's extensive fostering on resources, ecological sustainability, and food safety and security.

REFERENCES

[1] Alkema JT, Dicke M, Wertheim B. Context-dependence and the development of push-pull approaches for integrated Management of Drosophila suzukii. Insects 10 (12): 454. 2019.

[2] Pyke B, Rice M, Sabine B, Zalucki MP. The push-pull strategy-behavioural control of Heliothis. Australian Cotton Grower. 1987;9(1):7–9.

[3] Miller JR, Cowles RS. STIMULO-DETERRENT DIVERSION: A CONCEPT AND ITS POSSIBLE APPLICATION TO ONION MAGGOT CONTROL. Vol. 16, Journal of Chemical Ecology. 1990.

[4] Cook SM, Khan ZR, Pickett JA. The use of push-pull strategies in integrated pest management. Vol. 52, Annual Review of Entomology. 2007. p. 375–400.

[5] Khan ZR, Nairobi K, Pickett JA. PUSH-PULL STRATEGY FOR INSECT PEST MANAGEMENT.

[6] Khan Z, Midega C, Pittchar J, Pickett J, Bruce T. Push–pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa: UK Government's foresight food and farming futures project. In: Sustainable Intensification. Routledge; 2012. p. 162–70.

[7] Eigenbrode SD, Birch ANE, Lindzey S, Meadow R, Snyder WE. A mechanistic framework to improve understanding and applications of push-pull systems in pest management. Vol. 53, Journal of Applied Ecology. Blackwell Publishing Ltd; 2016. p. 202–12.

[8] Kumela T, Simiyu J, Sisay B, Likhayo P, Mendesil E, Gohole L, et al. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) in Ethiopia and Kenya. Int J Pest Manag. 2019 Jan 2;65(1):1–9.

[9] Skendžić S, Zovko M, Živković IP, Lešić V, Lemić D. The impact of climate change on agricultural insect pests. Vol. 12, Insects. MDPI AG; 2021.

[10] Molieleng L, Fourie P, Nwafor I. Adoption of climate smart agriculture by communal livestock farmers in South Africa. Vol. 13, Sustainability (Switzerland). MDPI; 2021.

[11] Nicolopoulou-Stamati P, Maipas S, Kotampasi C, Stamatis P, Hens L. Chemical Pesticides and Human Health: The Urgent Need for a New Concept in Agriculture. Vol. 4, Frontiers in Public Health. Frontiers Media S.A.; 2016.

[12] Sharma N, Singhvi R. Effects of Chemical Fertilizers and Pesticides on Human Health and Environment: A Review. International Journal of Agriculture, Environment and Biotechnology. 2017;10(6):675.

[13] Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M, et al. Fall armyworm: Impacts and implications for Africa. Outlooks on Pest Management. 2017 Oct 1;28(5):196–201.

[14] Kopper RW, Ruelle ML. Is push-pull climate- and gender-smart for Ethiopia? A review. Vol. 46, Agroecology and Sustainable Food Systems. Taylor and Francis Ltd.; 2022. p. 23–55.

[15] Niassy S, Agbodzavu MK, Mudereri BT, Kamalongo D, Ligowe I, Hailu G, et al. Performance of Push–Pull Technology in Low-Fertility Soils under Conventional and Conservation Agriculture Farming Systems in Malawi. Sustainability (Switzerland). 2022 Feb 1;14(4).

[16] Tanda AS. Advances in Integrated Pest Management Technology: Innovative and Applied Aspects. Advances in Integrated Pest Management Technology: Innovative and Applied Aspects. Springer International Publishing; 2022. 1–482 p.

[17] Capinera JL. Encyclopedia of entomology. Springer Science & Business Media; 2008.

[18] Khan ZR, Pittchar JO, Midega CAO, Pickett JA. Push-pull farming system controls Fall armyworm: Lessons from Africa. Outlooks on Pest Management. 2018;29(5):220–4.

[19] Gugissa DA, Abro Z, Tefera T. Achieving a Climate-Change Resilient Farming System through Push–Pull Technology: Evidence from Maize Farming Systems in Ethiopia. Sustainability (Switzerland). 2022 Mar 1;14(5).

[20] Misango VG, Nzuma JM, Irungu P, Kassie M. Intensity of adoption of integrated pest management practices in Rwanda: A fractional logit approach. Heliyon. 2022 Jan 1;8(1).

[21] Khan ZR, Pickett JA. The 'push-pull'strategy for stemborer management: a case study in exploiting biodiversity and chemical ecology. Ecological engineering for pest management: Advances in habitat manipulation for arthropods. 2004;155–64.

[22] Khan ZR, Amudavi DM, Midega CAO, Wanyama JM, Pickett JA. Farmers' perceptions of a "push-pull" technology for control of cereal stemborers and Striga weed in western Kenya. Crop Protection. 2008 Jun;27(6):976–87.

[23] Khan ZR, Midega CAO, Amudavi DM, Hassanali A, Pickett JA. On-farm evaluation of the "push-pull" technology for the control of stemborers and striga weed on maize in western Kenya. Field Crops Res. 2008 Mar 20;106(3):224–33.

[24] Midega CAO, Bruce TJA, Pickett JA, Pittchar JO, Murage A, Khan ZR. Climate-adapted companion cropping increases agricultural productivity in East Africa. Field Crops Res. 2015 Aug 5;180:118–25.

[25] Matova PM, Kamutando CN, Magorokosho C, Kutywayo D, Gutsa F, Labuschagne M. Fall-armyworm invasion, control practices and resistance breeding in Sub-Saharan Africa. Crop Sci. 2020 Nov 1;60(6):2951–70.

[26] Borden JH, Birmingham AL, Burleigh JS. No. 4-THE FORESTRY CHRONICLE 579 The Forestry Chronicle Downloaded from pubs.cif-ifc.org by 212. Vol. 82.

[27] Hassanali A, Herren H, Khan ZR, Pickett JA, Woodcock CM. Integrated pest management: The push-pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry. Philosophical Transactions of the Royal Society B: Biological Sciences. 2008 Feb 12;363(1491):611–21.

[28] Njunie MN, Muthiani EN, Mzingirwa A, Pole NF, Muli BM. Fodder Crop Adoption through Push-Pull Technology (PPT) for Fall Armyworm (FAW) Control in Cereals Cropping Systems [Internet]. Available from: https://uknowledge.uky.edu/igc

[29] Khan ZR, Midega CAO, Hutter NJ, Wilkins RM, Wadhams LJ. Assessment of the potential of Napier grass (Pennisetum purpureum) varieties as trap plants for management of Chilo partellus. Entomol Exp Appl. 2006 Apr;119(1):15–22.

[30] Chepchirchir RT, Macharia I, Murage AW, Midega CAO, Khan ZR. Impact assessment of push-pull pest management on incomes, productivity and poverty among smallholder households in Eastern Uganda. Food Secur. 2017 Dec 1;9(6):1359–72.

[31] Khan ZR, Pickett JA, Wadhams L, Muyekho F. HABITAT MANAGEMENT STRATEGIES FOR THE CONTROL OF CEREAL STEMBORERS AND STRIGA IN MAIZE IN KENYA. Vol. 21, Insect Sci. Applic. 2001.

[32] Murage AW, Midega CAO, Pittchar JO, Pickett JA, Khan ZR. Determinants of adoption of climate-smart push-pull technology for enhanced food security through integrated pest management in eastern Africa. Food Secur. 2015 Jun 1;7(3):709–24.

[33] Murage AW, Pittchar JO, Midega CAO, Onyango CO, Khan ZR. Gender specific perceptions and adoption of the climate-smart push-pull technology in eastern Africa. Crop Protection. 2015 Oct 1;76:83–91.
[34] Fetene GM, Balew S, Abro Z, Kassie M, Tefera T. Push-Pull Technology as a Climate-Smart Integrated Pest Management Strategy in Southern Ethiopia. 2021.
[35] Cui Z, Si P, Liu L, Chen S, Wang Y, Li X, et al. Push-pull strategy for integrated control of Bactrocera minax (Diptera, Tephritidae) based on olfaction and vision. Journal of Applied Entomology. 2022;146(10):1243–51.
[36] Njeru NK, Midega CAO, Muthomi JW, Wagacha JM, Khan ZR. Impact of push–pull cropping system on pest management and occurrence of ear rots and mycotoxin contamination of maize in western Kenya. Plant Pathol. 2020 Dec 1;69(9):1644–54.
[37] Kim CY, Khan F, Kim Y. A push-pull strategy to control the western flower thrips, Frankliniella occidentalis, using alarm and aggregation pheromones. PLoS One. 2023;18(2):e0279646.
[38] Lehmann AT, Brewer GJ, Boxler DJ, Zhu JJ, Hanford K, Taylor D, et al. A push–pull strategy to suppress stable fly (Diptera: Muscidae) attacks on pasture cattle via a coconut oil fatty acid repellent formulation and traps with m-cresol lures. Pest Manag Sci. 2023;79(9):3050–7.
[39] Niu Y, Han S, Wu Z, Pan C, Wang M, Tang Y, et al. A push–pull strategy for controlling the tea green leafhopper (Empoasca flavescens F.) using semiochemicals from Tagetes erecta and Flemingia macrophylla. Pest Manag Sci. 2022;78(6):2161–72.
[40] Fountain MT, Deakin G, Farman D, Hall D, Jay C, Shaw B, et al. An effective ‘push–pull’control strategy for European tarnished plant bug, Lygus rugulipennis (Heteroptera: Miridae), in strawberry using synthetic semiochemicals. Pest Manag Sci. 2021;77(6):2747–55.
[41] Perri D V, Gorosito NB, Schilman PE, Casaubón EA, Dávila C, Fernández PC. Push-pull to manage leaf-cutting ants: an effective strategy in forestry plantations. Pest Manag Sci. 2021;77(1):432–9.
[42] Lee YS, Lee HA, Lee HJ, Choi JY, Lee SW, Hong SS, et al. Push-pull strategy for control of sweet-potato whitefly, Bemisia tabaci (Hemiptera: Aleyrodidae) in a tomato greenhouse. Korean journal of applied entomology. 2019;58(3):209–18.
[43] Hume JB, Luhring TM, Wagner CM. Push, pull, or push–pull? An alarm cue better guides sea lamprey towards capture devices than a mating pheromone during the reproductive migration. Biol Invasions. 2020;22:2129–42.
[44] Khan ZR, Pickett JA, Van Den Berg J, Wadhams LJ, Woodcock CM. Exploiting chemical ecology and species diversity: Stem borer and striga control for maize and sorghum in Africa. In: Pest Management Science. 2000. p. 957–62.
[45] Van Den Berg J. Oviposition preference and larval survival of Chilo partellus (Lepidoptera: Pyralidae) on Napier grass (Pennisetum purpureum) trap crops. Int J Pest Manag. 2006 Jan 1;52(1):39–44.
[46] Khan ZR, Midega CAO, Hutter NJ, Wilkins RM, Wadhams LJ. Assessment of the potential of Napier grass (Pennisetum purpureum) varieties as trap plants for management of Chilo partellus. Entomol Exp Appl. 2006;119(1):15–22.
[47] Midega CAO, Khan ZR, Van Den Berg J, Ogol CKPO, Pickett JA, Wadhams LJ. Maize stemborer predator activity under ‘push – pull’ system and Bt-maize: A potential component in managing Bt resistance. Int J Pest Manag. 2006 Jan 1;52(1):1–10.